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SKRIPSI

PENGGUNAAN LIMBAH BOTOL PLASTIK (PET) SEBAGAI CAMPURAN BETON UNTUK MENINGKATKAN KAPASITAS TARIK BELAH DAN GESER

Disusun Untuk Melengkapi Salah Satu Syarat Kelulusan Program Sarjana Teknik Sipil Fakultas Teknik Universitas Indonesia

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UNIVERSITAS INDONESIA

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Saya menyatakan dengan sesungguhnya bahwa skripsi dengan judul :

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Jakarta, 8 Juli 2008

Bambang Mahendya
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PENGESAHAN

Skripsi dengan judul :

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Dibuat untuk melengkapi sebagian persyaratan menjadi Sarjana Teknik pada program Studi Teknik Sipil Departemen Teknik Sipil Fakultas Teknik Universitas Indonesia. Skripsi ini telah diujikan pada tanggal 8 Juli 2008 dan dinyatakan memenuhi syarat/sah sebagai skripsi pada Departemen Teknik Sipil Fakultas Teknik Universitas Indonesia.

Depok, 8 Juli 2008

Dosen Pembimbing I	Dosen Pembimbing II
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KATA PENGANTAR

Puji syukur kehadirat Allah SWT atas rahmat dan berkat-Nya, penulis dapat menyelesaikan tugas penulisan skripsi dengan tema "*Penggunaan Limbah Botol Plastik (PET) Sebagai Campuran Beton Untuk Meningkatkan Kapasitas Tarik Belah Dan Geser*".

Penulis menyadari bahwa penulisan skripsi ini tidak akan selesai tanpa bantuan dan bimbingan dari berbagai pihak. Oleh karena itu pada kesempatan ini penulis mengucapkan terima kasih kepada :

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Depok, Juli 2008

Penyusun

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PENGGUNAAN LIMBAH BOTOL PLASTIK (PET) SEBAGAI CAMPURAN BETON UNTUK MENINGKATKAN KAPASITAS TARIK BELAH DAN GESER

ABSTRAK

Polyethylene terephthalate (PET) merupakan bahan poliester termoplastik yang diproduksi secara komersial melalui produk kondensasi. PET adalah bahan dasar dari botol plastik dan akan mengeras bila dipanaskan.

Berdasarkan karakteristik fisik dari PET, dalam skripsi ini telah dilakukan penelitian limbah botol plastik PET sebagai bahan tambah dalam campuran beton dan menggunakannya dalam campuran beton normal (*fc'*=25 MPa).

Bahan tambah limbah botol plastik PET tersebut berupa cacahan-cacahan yang sebelumnya telah dipotong dengan mesin yang khusus untuk memotong limbah botol plastik dengan mudah. Cacahan-cacahan botol plastik PET tersebut dalam dimensi yang beragam dan bervariasi.

Kadar *Polyethylene terephthalate* (PET) yang ditambahkan pada beton mutu normal dalam volume fraksi adalah 0,10, 0,20, 0,30, 0,50, 0,70 dan 1,00%. Dengan persentase yang berbeda maka akan diketahui pengaruh penambahan limbah botol plastik (PET) terhadap beton tanpa penambahan limbah botol plastik (PET).

Sifat fisik botol plastik PET didapat dari literatur, sedangkan yang diuji hanya berat jenisnya saja yaitu dari hasil percobaan yang dilakukan diperoleh nilai

sebesar 1,35 gr/cm^3.

Percobaan pembebanan yang dilakukan meliputi kuat tarik belah dan kuat geser. Benda uji berbentuk silinder dengan diameter 15 cm dan tinggi 30 cm digunakan untuk pengujian kuat tarik belah dan benda uji double L berukuran 20x30x7.5 cm^3 untuk pengujian kuat geser.

Dari hasil penelitian beton normal terhadap beton segar, dapat disimpulkan bahwa dengan bertambahnya kadar cacahan botol plastik PET yang dicampur dalam campuran beton, maka akan cenderung terjadi penurunan pada nilai slump.

Dari hasil pengujian terhadap beton yang telah mengeras didapatkan hasil dengan penambahan cacahan botol plastik PET optimum sebesar 0,5% terjadi peningkatan kuat tarik belah sebesar 25,44% pada umur 7 hari, sedangkan pada umur 28 hari peningkatan optimum pada 0,7% yaitu sebesar 19,39%. Pada kuat geser peningkatan optimum terjadi pada 0,5% yaitu sebesar 37,19%.

Kata kunci : *Polyethylene Terephtalate* (PET), Botol Plastik, Bahan Tambah, Beton Normal

Bambang Mahendya Lestariono NPM 043210118 Civil Engineering Department	Counsellor **Dr.-Ing Josia Irwan Rastandi** **Mulia Orientilize, ST. M.Eng**

APPLICATION OF PLASTIC BOTTLE WASTE (PET) IN CONCRETE MIX TO INCREASE TENSILE AND SHEAR CAPACITY

ABSTRACT

Polyethylene terephthalate (PET) is classified as thermoplastic polyester material that is commercially produced by condensation product. PET is the basic raw material from plastic bottle and will ossify when heated.

Based on physical characteristic of PET, in this study has been conducted by research of plastic bottle waste PET as admixture which add in concrete mixture and use it in normal concrete mixture (*fc'*=25 MPa).

Substance of these plastic bottle waste PET in the form of cutting that has been cut by special machine to cut plastic bottle waste easily. Cutting of these plastic bottle PET mentioned in immeasurable dimension and vary.

Rate of *Polyethylene terephthalate* (PET) that added on normal concrete in fraction volume is 0,10; 0,20; 0,30; 0,50; 0,70 and 1,00%. With the different percentage hence will be known the influence of addition plastic bottle waste (PET) to concrete without addition plastic bottle waste.

Nature of physical of plastic bottle PET got from literature, while examine only specific gravity and from attempt result conducted to be obtained value equal to 1.35 gr/cm^3.

The loading attempt conducted cover tensile and shear strength. Object test in the form of cylinder with 15 cm on diameter and 30 cm high is used for tensile

strength test and double L samples with size 20x30x7,5 cm^3 is used for shear test.

From normal concrete research result to fresh concrete, inferential that by increasing rate of cutting plastic bottle PET in concrete mixture, hence will tend to occured the degradation of the slump value.

From examination result to concrete ossified got by result with the addition of cutting plastic bottle PET optimum equal to 0,5% will increasing tensile strength 25,44% at 7 day, while at age 28 day optimum increasing optimum occured at 0,7% that is equal to 19,39%. For the shear strength the optimum improvement occured at 0,5% that is equal to 37,19%.

Keywords : *Polyethylene Terephtalate* (PET), plastic bottle, admixture, normal concrete

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BAB I
PENDAHULUAN

1.1. LATAR BELAKANG

Beton merupakan bahan yang paling banyak pemakaiannya di seluruh dunia dan digunakan secara luas di dunia sebagai bahan kontruksi selain baja dan kayu. Beton digunakan dihampir semua jenis konstruksi, seperti di atas tanah (gedung dan jembatan), di bawah tanah (pondasi, terowongan) dan di dasar laut (pipa minyak, anjungan lepas pantai). Hal ini antara lain disebabkan oleh mudahnya dalam memperoleh bahan penyusun beton dan kesederhanaan dalam pembuatan beton. Selain itu beton juga dapat dibuat dengan berbagai mutu dan dapat disesuaikan dengan kebutuhan konstruksi.[1]

Namun beton juga dikenal sebagai material yang getas (*brittle*) dan lemah terhadap tarik dibandingkan dengan baja. Daktilitas beton yang rendah dicerminkan oleh kurva load/tegangan-regangannya yang mempunyai penurunan kekuatan tekan yang cepat pada daerah pasta puncak sehingga menyebabkan keruntuhan yang terjadi relatif secara tiba-tiba pada elemen beton.

Seiring dengan pertumbuhan teknologi beton yang semakin berkembang, berbagai penelitian telah banyak dilakukan baik oleh kalangan praktisi maupun dari kalangan peneliti. Berbagai jenis teknologi beton telah diperkenalkan dan digunakan kini secara umum seperti penggunaan serat baja dan serat *polyetylene terephtalate* (PET) sebagai bahan tambah beton.

Seperti yang kita ketahui bahwa sampah merupakan salah satu masalah yang cukup kompleks, terutama di daerah perumahan, perkantoran dan perniagaan seiring dengan pertumbuhan industri dan bertambahnya jumlah penduduk. Di samping akan menyebabkan berbagai macam penyakit, sampah juga dapat menyebabkan pencemaran terhadap lingkungan disekitarnya. Selain itu sampah yang menumpuk dapat

[1] V.N.Vazirani, S.P. Chandola, *" Concise handbook of Civil Engineering"*, New Delhi : S.Chand & Company Ltd : 1993

menimbulkan kesan yang negatif dan terlihat kumuh. Berbagai upaya telah dilakukan untuk mengatasi permasalahan sampah ini, diantaranya yaitu dengan membuat Tempat Pembuangan Akhir (TPA) baru dan membakar sampah di ruang terbuka, namun hal tersebut menimbulkan masalah baru seperti pertentangan dari lingkungan sekitarnya dan polusi udara yang cukup mengganggu.

Berdasarkan komposisinya, sampah dibedakan menjadi dua jenis, yaitu jenis organik dan jenis anorganik. Sampah jenis organik dapat diolah dengan mudah menjadi pupuk kompos, namun untuk sampah jenis anorganik seperti plastik wadah pembungkus makanan, kertas, plastik mainan, botol dan gelas minuman, kaleng, kayu, dan sebagainya sulit untuk dapat diuraikan kembali.

Plastik merupakan salah satu jenis sampah anorganik yang mana tidak semua dari material jenis ini dapat didaur ulang. Botol plastik bekas / *polyetylene terephtalate* (PET) merupakan salah satu jenis plastik yang dapat didaur ulang dengan mudah. Penggunaanya sebagai bahan tambah beton merupakan salah satu alternatif untuk menanggulangi limbah/sampah plastik yang ada. Pemanfaatan limbah botol plastik bekas / *polyetylene terephtalate* (PET) dalam teknologi beton di samping dapat menambah kekuatan pada beton juga dapat mengurangi limbah / sampah plastik.

Tujuan dari penelitian ini adalah untuk mempelajari potensi akan penggunaan cacahan botol plastik bekas / *polyetylene terephtalate* (PET) sebagai bahan tambah campuran pada beton normal (f_c'=25 MPa) terhadap kuat tarik dan kuat geser pada beton.

Kadar cacahan botol plastik bekas / *polyetylene terephtalate* (PET) yang ditambahkan pada beton adalah sebesar 0.00 %; 0.10 %; 0.20 %; 0.30 %; 0.50 %; 0.70 % dan 1.00 %. Hal ini dimaksudkan untuk mengetahui pengaruh cacahan botol plastik bekas tersebut terhadap beton. Benda uji yang digunakan untuk percobaan kuat geser adalah dengan menggunakan double L dengan dimensi 30 x 20 x 7,5 cm, sedangkan untuk percobaan kuat tarik adalah dengan menggunakan silinder dengan diameter 15 cm dan tinggi 30 cm.

Seperti yang kita ketahui bahwa penggunaan beton serat saat ini telah banyak digunakan, yang mana dalam campuran beton tersebut ditambahkan dengan serat. Serat ini umumnya berupa batang-batang dengan dengan ukuran 5-500 μm, dengan panjang

sekitar 25 mm. Bahan seratnya dapat berupa serat asbestos, serat plastik, atau potongan kawat baja.

Beberapa jenis bahan serat yang dapat digunakan untuk memperbaiki sifat-sifat pada beton telah dilaporkan oleh ACI Committee 544-1984. Bahan serat tersebut pada dasarnya terbagi atas serat baja, plastik, kaca, dan serat alami. Masing-masing serat (*fiber*) tersebut memiliki sifat dan kekuatan yang berbeda-beda, seperti yang dapat dilihat dalam tabel 1.1. Serat tersebut dicampur ke dalam adukan beton dengan persentase penambahan serat yang bervariasi. Dengan penambahan serat tersebut diharapkan dapat memberikan perbaikan terhadap kinerja kekuatan geser serta sifat-sifat lain pada beton yang menguntungkan.[2]

Tabel 1.1. Sifat dan Kekuatan Pada Serat

Jenis Serat	Kuat tarik (Ksi)	Modulus Young (10 Ksi)	Batas Ulur (%)	Berat Jenis
Acrylic	30 – 60	0,3	25 – 45	1,1
Asbes (Asbestos)	80 – 140	12 – 20	~ 0,6	3,2
Cotton	60 – 100	0,7	3 – 10	1,5
Kaca (Glass)	150 – 550	10	1,5 – 3,5	2,5
Nylon	110 – 120	0,6	16 – 20	1,1
Polyester	**105 – 125**	**1,2**	**11 – 13**	**1,4**
Polyethylene	~ 100	0,02 – 0,06	~ 10	0,95
Polypropylene	80 – 100	0,5	~ 25	0,90
Rayon	60 – 90	1,0	10 – 25	1,5
Rock Wool	70 – 110	10 – 17	~ 0,6	2,7
Baja (Steel)	40 – 400	29	0,5 – 35	7,8

Sumber : ACI Committee 544-1984

Pada penelitian ini bahan tambah PET yang dicampur ke dalam adukan beton tidaklah berupa serat, namun berupa cacahan – cacahan botol plastik PET, yang mana penelitian seperti ini belum pernah dilakukan sebelumnya. Penelitian yang pernah

[2] Tri Mulyono, "*Teknologi Beton*", Yogyakarta: Andi, 2003

dilakukan sebelumnya yaitu dengan menggunakan botol plastik PET sebagai agregat dalam beton, dengan sebelumnya melelehkan terlebih dahulu botol plastik PET tersebut dan memecahkan gumpalan lelehan botol plastik PET yang telah menyatu menjadi agregat dengan beragam gradasi. Selanjutnya agregat tersebut digunakan dalam campuran beton.

1.2. PERUMUSAN MASALAH

Dari latar belakang di atas dapat dirumuskan masalah sebagai berikut :

- Kemungkinan akan penggunaan cacahan limbah botol plastik / *polyetylene terephtalate* (PET) sebagai bahan tambah campuran beton normal
- Seberapa besar pengaruh cacahan limbah botol plastik / *polyetylene terephtalate* (PET) tersebut sebagai bahan tambah campuran beton normal terhadap kuat tarik belah dan kuat geser pada beton.

1.3. BATASAN MASALAH

Lingkup dari penelitian ini hanya terbatas pada penelitian terhadap karakteristik material pembentuk beton normal dan beton normal itu sendiri, terutama terhadap sifat-sifat mekaniknya. Pengamatan terhadap sifat-sifat mekanik sendiri hanya pada pengujian kuat tarik dan kuat geser yang mengacu pada ASTM, dalam hal ini membandingkan antara 0 % bahan campuran dengan % campuran yang lainnya.

1.4. TUJUAN PENELITIAN

Tujuan dari penelitian ini adalah untuk mempelajari pengaruh dan efektifitas akan penggunaan cacahan limbah botol plastik / *polyetylene terephtalate* (PET) sebagai bahan tambah campuran beton normal terhadap sifat-sifat mekanik beton normal.

Selain itu dari penelitian ini diharapkan juga dapat diperoleh suatu gambaran tentang kuat tarik dan kuat geser dari beton normal dengan cara membandingkan beton normal yang menggunakan bahan tambah berupa cacahan limbah botol plastik / *polyetylene terephtalate* (PET) dengan yang tidak menggunakan bahan tambah tersebut.

1.5. METODE PENULISAN

Tahap awal dari penulisan ini yaitu dengan penelurusan literatur yang ada untuk memahami karakteristik *polyetylene terephtalate* (PET), karakteristik beton beserta klasifikasinya dan metode rancang campur (*mix design*) yang tepat untuk digunakan dalam merancang campuran beton normal. Tahap selanjutnya yaitu dengan melakukan percobaan dilaboratorium untuk mendapatkan kualitas bahan-bahan penelitian, merancang campuran beton (*mix design*), pembuatan benda uji untuk kuat tarik dan kuat geser pada beton dan melakukan pengujian terhadap beton yang telah dihasilkan yaitu baik pada beton segar maupun pada beton yang telah mengeras. Dari pengujian yang telah dilakukan maka dapat dilakukan analisa baik pada kuat gesernya maupun kuat tarik pada beton tersebut.

1.6. SISTEMATIKA PENULISAN

Adapun sistematika penulisan pada penelitian ini mencakup :

BAB I PENDAHULUAN

Berisikan tentang latar belakang, perumusan masalah, batasan masalah, tujuan penelitian, metode penulisan dan sistematika penulisan yang berhubungan dengan permasalahan yang akan dibahas.

BAB II DASAR TEORI

Berisikan tentang karakteristik dan klasifikasi beton, material pembuat beton, bahan tambah beton, karakteristik dari *polyethylene terephtalate* (PET), proses pembuatan bahan tambah PET dan metode rancangan campuran ACI.

BAB III METODE PENELITIAN

Berisikan tentang prosedur pengujian dan pemeriksaan agregat halus maupun kasar, spesifikasi bahan baku penelitian, prosedur campuran beton dengan metode ACI, prosedur percobaan beton yang meliputi

pembuatan benda uji beton dan pengujian beton segar maupun beton yang telah mengeras.

BAB IV HASIL DAN ANALISA DATA PENELITIAN

Menyajikan hasil dan analisa yang meliputi analisa hasil pengujian material dasar pembentuk beton, beton segar dan beton setelah mengeras serta analisa mengenai kuat tarik belah dan kuat geser pada beton yang mendapat bahan tambahan cacahan botol plastik dengan persentase yang berbeda.

BAB V KESIMPULAN DAN SARAN

Berisikan kesimpulan serta saran-saran mengenai penelitian yang telah dilakukan

BAB II
DASAR TEORI

2.1. PENGERTIAN BETON

Beton merupakan campuran antara semen, air, pasir dan kerikil dengan perbandingan tertentu yang mengeras menyerupai batu. Air dan semen membentuk pasta yang akan mengisi rongga-rongga di antara butir-butir pasir dan kerikil.[3] Dalam melakukan campuran beton, dapat dilakukan pemilihan material yang layak komposisinya sehingga akan didapatkan beton yang efisien, memenuhi kekuatan batas yang disyaratkan dan memenuhi persyaratan *serviceability* yang dapat diartikan sebagai pelayanan yang handal dengan memenuhi kriteria ekonomi. Bahan tambah lain juga sering digunakan dalam campuran beton untuk menghasilkan beton dengan karakteristik tertentu.[4]

Untuk dapat memahami perilaku beton maka diperlukan pengetahuan tentang karakteristik dari masing-masing komponen penyusun beton tersebut. Dengan memahami perilaku dari beton maka kita akan dapat membuat beton dengan karakteristik yang kita diinginkan sesuai dengan perencanaan.

Adapun parameter-parameter yang paling berpengaruh dalam kekuatan beton adalah :

a. Kualitas semen yang digunakan
b. Proporsi semen terhadap campuran
c. Kekuatan dan kebersihan agregat
d. Interaksi antara pasta semen dengan agregat
e. Pencampuran yang cukup dari bahan-bahan pembentuk beton
f. Penempatan, penyelesaian dan pemadatan beton yang benar
g. Perawatan beton
h. Kandungan klorida tidak melebihi 0,15% dalam beton yang diekspos dan 1% bagi beton yang tidak diekspos

[3] L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, Jakarta : Gramedia, 1999
[4] Tri Mulyono, "*Teknologi Beton*", Yogyakarta: Andi, 2003

i. Kualitas pelaksanaannya

Pada umumnya keuntungan dan kerugian dalam menggunakan beton diantaranya, yaitu :[5]

Keuntungan :

1. Ekonomi : merupakan pertimbangan yang sangat penting, meliputi : material, kemudahan dalam pelaksanaan, waktu untuk konstruksi, pemeliharaan struktur, daktilitas, dan sebagainya.
2. Keserasian beton untuk memenuhi kepentingan struktur dan arsitektur. Beton dicor ketika masih cair dan menahan beban ketika telah mengeras. Hal ini sangat bermanfaat, karena dapat membuat berbagai bentuk.
3. Tahan api (sekitar 1 hingga 3 jam tanpa bahan kedap api tambahan), sementara kayu dan baja memerlukan bahan kedap api khusus untuk mencapai tingkat seperti ini.
4. Rigiditas tinggi
5. Biaya pemeliharaan (maintenance) rendah.
6. Penyediaan materialnya yang cukup mudah

Kerugian :

1. Kekuatan tariknya rendah (sekitar 10% dari kekuatan tekan), sehingga mudah retak.
2. Memerlukan biaya untuk bekisting, perancah (untuk beton cor di tempat) yang tidak sedikit jumlahnya.
3. Berat
4. Bentuk yang sulit diubah bila beton telah mengeras
5. Daya pantul yang dihasilkan cukup besar
6. Beton mengalami rangkak jangka panjang dan susut

[5] L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, Jakarta : Gramedia, 1999

2.2. KLASIFIKASI BETON

Klasifikasi beton terdiri dari beberapa jenis, diantaranya yaitu berdasarkan berat volume betonnya, berdasarkan material pembentuknya dan kegunaan dari strukturnya. Pada umumnya bahan agregat yang digunakan dalam campuran beton mempengaruhi beton yang akan dihasilkan.[6]

Terminologi ASTM C.125 mendefinisikan bahwa agregat ringan adalah agregat yang digunakan untuk menghasilkan beton ringan. Agregat berat didefinisikan sebagai agregat yang mampu menghasilkan beton dengan kepadatan tinggi. Sedangkan agregat normal adalah agregat yang mampu menghasilkan beton normal.

Berikut akan dijelaskan klasifikasi beton menurut berat volumenya, yaitu :

1. Beton Ringan

Merupakan beton yang diproduksi dengan menggunakan agregat ringan. Biasanya beton jenis ini digunakan atas pertimbangan ekonomis dan struktural. Berat jenis agregat ringannya sekitar 1900 kg/m^3 atau berdasarkan kepentingan penggunaan strukturnya yang berkisar antara 1440 – 1850 kg/m^3, dengan kekuatan tekan umur 28 hari lebih besar dari 17,2 MPa (ACI-318). SNI memberikan batasan kriteria beton ringan sebesar 1900 kg/m^3. Agregat yang biasanya digunakan untuk menghasilkan beton ringan yaitu meliputi batu apung, scoria, vulkanik, cinder, tuff, diatomite, atau hasil pembakaran lempung, shale, slte atau batubara dan hasil residu pembakarannya.

2. Beton Normal

Merupakan beton yang diproduksi dengan menggunakan agregat normal. Beton jenis ini memiliki berat isi sebesar 2200 - 2500 kg/m^3. Beton normal pada umumnya sering digunakan pada industri konstruksi. Contohnya yaitu dalam pembuatan gedung-gedung, jalan (jenis perkerasan beton), bendungan, saluran air dan lainnya.

Agregat normal dihasilkan dari pemecah batuan di industri quarry dengan ukuran butirannya sebesar 5 – 40 mm atau didapatkan langsung dari sumber alam. Agregat ini biasanya berasal dari granit, basalt, kuarsa, dan sebagainya. Berat jenis agregat normal ini rata-ratanya adalah sebesar 2.5 - 2.7 atau tidak boleh kurang dari 1.2 kg/dm^3. Beton

[6] Tri Mulyono, "*Teknologi Beton*", Yogyakarta: Andi, 2003

normal yang dihasilkan mempunyai berat sebesar 2.200-2.500 kg/m^3 dan kuat tekan sebesar 15-40 MPa (150-400 kg/cm^3).

3. Beton Berat

Beton berat adalah beton yang dihasilkan dari agregat yang mempunyai berat ini lebih besar dari beton normal atau lebih dari 2400 kg/m^3. Beton jenis ini biasanya digunakan untuk kepentingan tertentu seperti menahan radiasi, menahan benturan dan lainnya. ASTM C.638 memberikan suatu deskripsi mengenai pertimbangan penggunaan agregat untuk kepentingan beton yang menahan radiasi.

Beton jenis ini digunakan bila masalah ruang tidak menjadi masalah. Agregat yang digunakan biasanya besarnya lebih dari 4.0. Contohnya seperti barium sulfat, barite, magnetite, limonite, besi atau bijih besi. Adapun penggunaan bijih besi sebagai agregat dapat mencapai 3000 – 3900 kg/m^3.[7]

2.3.KARAKTERISTIK BETON NORMAL

2.3.1. Kuat Tekan Beton

Salah satu cara untuk mengendalikan mutu beton adalah dengan menguji sampel atau benda uji. Dimana nilai uji yang diperoleh dari setiap benda uji akan berbeda, karena beton merupakan material heterogen, yang kekuatannya dipengaruhi oleh proporsi campuran, bentuk, ukuran, kecepatan pembebanan dan oleh kondisi lingkungan pada saat pengujian.

Oleh karena itu, metode statistik diperlukan untuk menentukan kekuatan tekan karakteristik beton f_c', yang didefinisikan sebagai kekuatan tekan beton yang dilampaui oleh paling sedikit 95% dari benda uji. Nilai f_c' merupakan kekuatan tekan benda uji silinder berdiameter 150 mm dan panjangnya 300 mm sebagaimana ditetapkan dalam SNI T-15-1991. Pengujian standarnya didasarkan atas kekuatan beton umur 28 hari.[8]

Berdasarkan percobaan tekan beton dapat dibuat suatu bentuk kurva yang menyatakan nilai tegangan yang bersesuaian dengan nilai regangan betonnya. Dari berbagai macam mutu beton akan dihasilkan suatu bentuk kurva seperti gambar 2.1.

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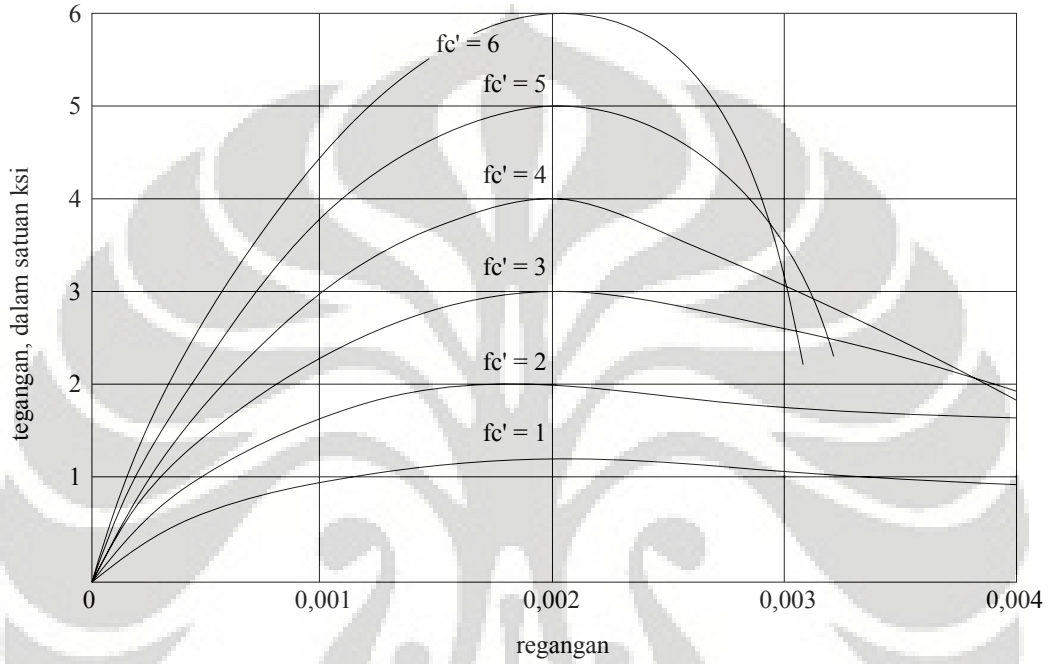
[7] Neville, A.M., "*Properties of Concrete*", 3rd Edition, London: Pitman Books Ltd, 1981
[8] L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, Jakarta : Gramedia, 1999

Bagian pertama dari kurva tersebut berbentuk parabola yang dapat diidealisasi menjadi garis lurus yang nilai tegangan dan regangan beton dapat dianggap proporsional. Selanjutnya kurva akan mencapai titik maksimum pada nilai tegangan karakteristik beton, f_c'.



Gbr.2.1. Kurva tegangan-regangan beton silinder dengan pembebanan uniaksial

Sumber : L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, 1999

Untuk beton normal tegangan tekan f_c' ini kira-kira terletak pada nilai regangan 0,002 hingga 0,003 in/in, sedangkan untuk beton ringan berkisar antara 0,003 sampai 0,0035. Setelah titik maksimum dilampaui, kurva tersebut akan menurun lagi hingga benda uji beton hancur. Dapat dilihat bahwa beton mutu rendah akan memiliki puncak kurva yang agak panjang dan datar, sedangkan kurva beton mutu tinggi lebih tajam.

2.3.2. Perbandingan Poisson

Bila suatu benda ditekan secara uniaksial (dalam satu arah), selain benda tersebut akan memendek, juga akan mengembang ke arah lateral/tegak lurus. Gejala ini secara ekstrem dapat dilihat pada suatu kubus karet yang ditekan searah dari atas dan bawah. Perubahan dimensi atau regangan lateral yang terjadi pada beton tidaklah terlalu

terlihat. Perbandingan regangan lateral terhadap regangan memanjang ini dinyatakan dalam perbandingan poisson (koefisien konstraksi), yang untuk material beton berkisar antara 0,15 hingga 0,20.[9]

2.3.3. Rangkak (*creep*)

Rangkak didefinisikan sebagai penambahan regangan terhadap waktu akibat adanya beban yang bekerja[10]. Deformasi awal akibat pembebanan disebut sebagai regangan elastis, sedangkan regangan tambahan akibat beban yang sama disebut regangan rangkak. Rangkak timbul dengan intensitas yang semakin berkurang setelah selang waktu tertentu dan kemungkinan berakhir setelah beberapa tahun.

Pada umumnya, rangkak tidak mengakibatkan dampak langsung terhadap kekuatan struktur tetapi akan mengakibatkan timbulnya redistribusi tegangan pada beban yang bekerja dan kemudian mengakibatkan terjadinya peningkatan lendutan.

Besar kecilnya rangkak ini tergantung baik pada kondisi material, misalnya rasio air-semen, jenis semen, jenis agregat, maupun pada kelembaban lingkungan, dimensi atau ukuran beton dan ada tidaknya aditif. Dalam kondisi lembab, dimana kehilangan air dalam beton rendah, maka nilai rangkak juga rendah.

2.3.4. Susut (*shrinkage*)

Susut didefinisikan sebagai perubahan volume yang tidak berhubungan dengan beban. Pada waktu proses hidrasi berlangsung, beton melepaskan panas dan air, yang dapat diamati dengan naiknya suhu beton tersebut, yang menyebabkan terjadinya susut. Susut dapat menyebabkan retak bila tidak dikendalikan dengan baik.

Faktor utama yang menentukan besarnya susut adalah kandungan air dalam adukan beton. Sedangkan faktor-faktor lain (misalnya butir agregat, faktor air-semen, ukuran elemen beton, kondisi lingkungan, tipe semen, serta ada tidaknya aditif) kurang menentukan.

Beberapa pedoman yang dapat diambil, yaitu :

1. Susut akan rendah bila nilai slump betonnya rendah

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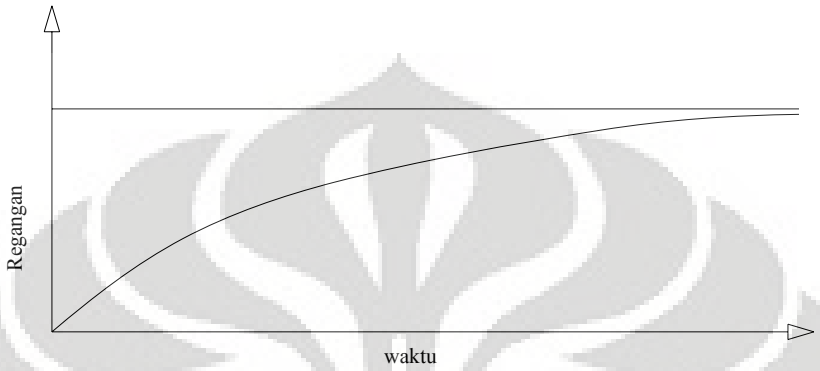
[9] L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, Jakarta : Gramedia, 1999

[10] Nawy, Edward. G., "*Reinforced Concrete a Fundamental Approach-Terjemahan*", Cetakan Pertama, Bandung: PT. Eresco, 1990

2. Susut yang terjadi akan berkurang dengan meningkatnya kelembapan udara lingkungan
3. Susut akan berkurang bila tebal elemen beton bertambah



Gbr. 2.2. Kurva susut tipikal untuk beton

Sumber : Nawy, Edward. G., "*Reinforced Concrete a Fundamental Approach":*1990

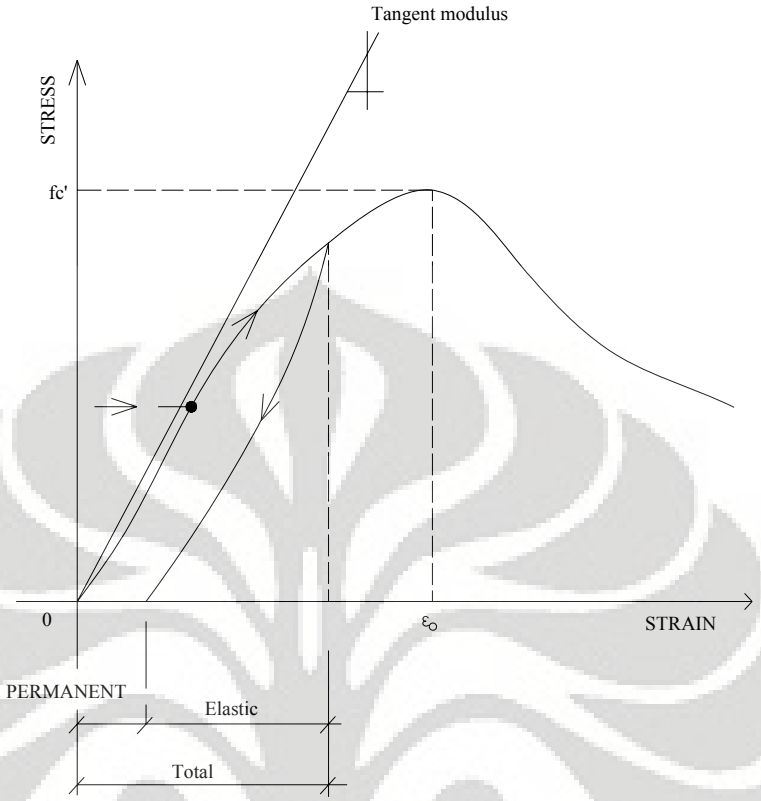
2.3.5. Modulus Elastisitas

Beton tidak memiliki nilai modulus elastisitas yang pasti. Nilainya bervariasi tergantung dari kekuatan beton, umur beton, jenis pembebanan, karakteristik dan perbandingan antara semen dan agregat.

Kemiringan garis singgung pada segmen pertama garis parabola didefinisikan sebagai modulus tangen, yang sering dianggap sebagai modulus elastisitas beton, E_c. Sedangkan kemiringan garis yang melalui titik $0{,}5f_c'$ adalah modulus sekan (*secant modulus*), yang lebih umum diambil sebagai modulus elastisitas beton, E_c. SNI menetapkan nilai modulus E_c sebagai nilai variabel dan tergantung dari mutu beton, dan dirumuskan sebagai :

$$\boxed{E_c = 4700\sqrt{f_c'}} \quad \text{(dalam MPa)}$$

Berdasarkan rumus di atas, dengan percepatan gravitasi g = 10 m/s^2, besarnya nilai modulus elastisitas dari beberapa mutu beton dapat disusun seperti dalam tabel 2.1.



Gbr 2.3. Modulus tangen dan modulus sekan

Sumber : L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, 1999

Tabel 2.1. Nilai Modulus Elastisitas Beton Normal

f_c'		E_c
kg/cm^2	MPa	MPa
175	17,17	19 500
200	19,62	20 800
225	22,07	22 100
250	24,52	23 300
275	26,98	24 400
300	29,43	25 500
325	31,88	26 500
350	34,33	27 500
400	39,24	29 400
450	44,14	31 200

Sumber : L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, 1999

Sebagai perbandingan, ACI menetapkan beberapa rumus untuk menghitung modulus elastisitas dari beton normal dengan berat 2320 kg/m^3 sebagai :

$$E_c = 57000\sqrt{f_c'} \qquad (f_c\text{' dalam psi})$$

Atau

$$E_c = 15100\sqrt{f_c'} \qquad (f_c\text{' dalam kg/cm}^2)$$

2.3.6. Kuat Tarik Belah

Kekuatan tarik beton sering kali diukur berdasarkan modulus tarik yaitu tegangan tarik lentur dari beton silinder 6 inchi. Nilai yang didapatkan sedikit lebih besar dibandingkan kekuatan tarik sesungguhnya. Kuat tarik beton lebih bervariasi dibandingkan dengan kuat tekannya, dimana besarnya berkisar antara 10% - 15% dari kuat tekan. Tetapi saat ini lebih sering ditentukan oleh kekuatan belah silinder beton. ACI menetapkan nilai modulus tarik sebagai :[11]

$$f_r = 7,5\sqrt{fc'} \qquad \text{(untuk beton normal)}$$

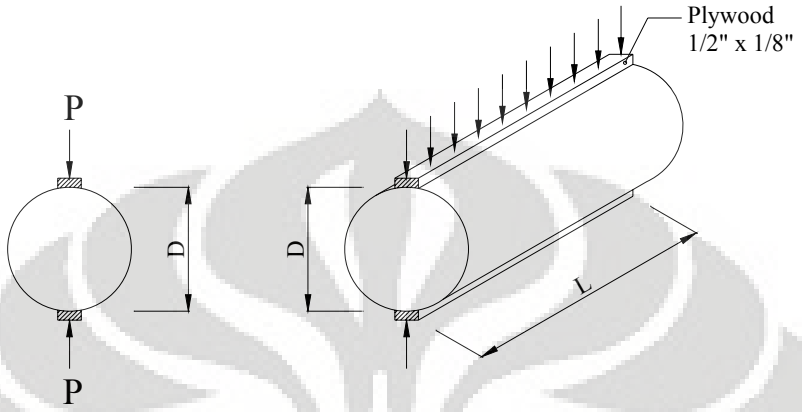
Dimana f_r dalam psi bila f_c' dalam psi. Sedangkan dalam SNI T-15-1991-03 pasal 3.2.5 ditetapkan bahwa besarnya modulus tarik sebagai berikut :

$$f_r = 0,70\sqrt{fc'} \qquad \text{(untuk beton normal)}$$

Dengan f_r dan f_c' dinyatakan dalam MPa. Dari berbagai percobaan yang telah dilakukan terlihat bahwa kekuatan tarik beton sangat kecil dibandingkan kekuatan tekannya, sehingga dalam analisis atau desain kekuatan tarik beton diabaikan dan beton dianggap hanya menahan gaya tekan saja. Pada umumnya untuk meninjau besarnya

[11] L. Wahyudi, Syahril A. Rahim, *"Struktur Beton Bertulang"*, Jakarta : Gramedia, 1999

kuat tarik pada beton dilakukan uji tarik tak langsung, yaitu metode dari Fernando Carneiro (kebangsaan Brazil) yang umumnya dikenal sebagai "Brazilian Test" atau "Splitting Test".



Gbr 2.4. Splitting Test untuk uji kuat tarik beton

2.3.7. Kuat Geser

Kekuatan geser pada beton jarang ditemukan pada struktur beton. Hal ini disebabkan karena sulitnya dalam mengisolasi beban geser murni terhadap pembebanan yang lainnya. Dalam percobaan dan pengujian beton di laboratorium didapatkan hasil yang sangat bervariasi yaitu antara 20% s/d 85%. Gaya yang bekerja pada benda uji, bersifat kolinear terhadap bidang gesernya, sehingga terjadi retak dan selip di sepanjang permukaan bidang geser tersebut. Untuk itu harus diterapkan kosep gesekan geser di dalam transfer geser.[12]

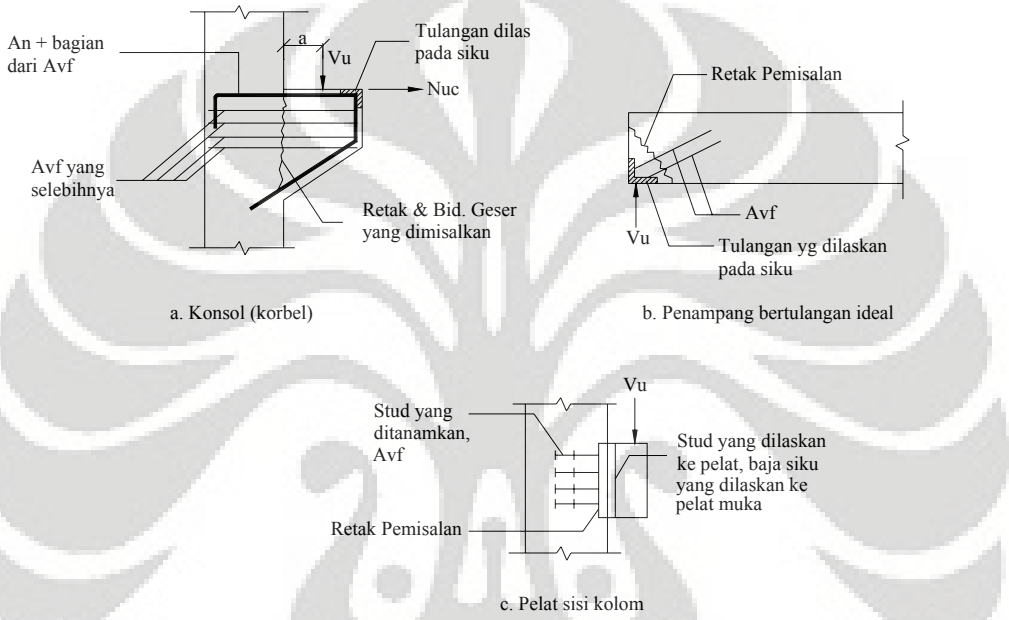
Menurut SK SNI T-15-1991-03 pasal 3;4;7 tentang geser friksi, dinyatakan bahwa dipandang perlu untuk meninjau penyaluran geser melalui suatu bidang tertentu, misalnya pada retakan atau daerah yang mempunyai potensi retak, bidang kontak antara bahan-bahan yang berlainan, atau bidang kontak antara dua beton yang dicor pada waktu yang berbeda. Pada benda uji double L ini, dianggap memiliki potensi retak, sehingga perlu diterapkan konsep geser friksi.

Pada kasus di lapangan, mekanisme untuk transfer geser dapat ditemui dalam keadaan seperti :

- Pada bidang permukaan antara beton yang dicor dalam waktu yang berlainan

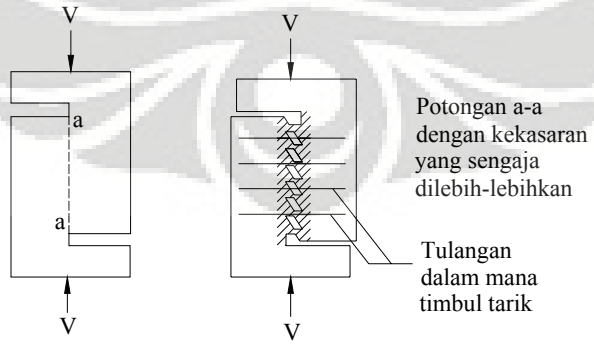
[12] Wang, Chu-Kia; Salmon, Charles G, *"Desain Beton Bertulang-Terjemahan"*, PT. Erlangga, 1986

- Pada sambungan antar korbel (braket) dengan kolom, seperti yang dapat dilihat pada gambar 2.5.a.
- Pada hubungan antara unsur dari konstruksi pracetak, seperti gambar 2.5.b.
- Pada permukaan antara baja dan beton, seperti perletakan dari braket baja dengan kolom beton seperti gambar 2.5.c.



Gbr. 2.5. Penggunaan dari konsep gesekan geser

Sumber : Wang ,90



Gbr. 2.6. Idealisasi dari konsep gesekan geser

Sumber : Wang ,92

2.4. MATERIAL DASAR PEMBENTUK BETON

Beton pada umumnya tersusun dari tiga bahan penyusun utama, yaitu semen, agregat dan air. Bilamana diperlukan, bahan tambah dapat ditambahkan untuk mengubah sifat-sifat tertentu dari beton. Berikut akan dijelaskan mengenai ketiga bahan penyusun utama beton tersebut, maupun bahan tambahnya yang saat ini sering digunakan.[13]

2.4.1. Semen

Semen merupakan bahan hidrolis yang dapat bereaksi secara kimia dengan air, disebut dengan hidrasi, sehingga dapat membentuk material batu padat. Pada umumnya semen untuk bahan bagunan adalah tipe semen Portland. Semen ini dibuat dengan cara menghaluskan silikat-silikat kalsium yang bersifat hidrolis dan dicampur dengan bahan gips.

Fungsi utama semen adalah mengikat butir-butir agregat sehingga membentuk massa padat dan mengisi rongga-rongga udara di antara butir-butir agregat. Walaupun komposisi semen dalam beton hanya sekitar 10%, namun karena fungsinya sebagai bahan pengikat maka peranan semen menjadi penting.

Bahan baku untuk pembuatan semen terdiri atas :

- Kapur (CaI)
- Silika (SiO_2)
- Alumina (Al_2O_3)
- Fe_2O_3

Keempatnya bereaksi satu sama lain di dalam kiln membentuk klinker (setelah dipanaskan pada temperatue 1400^o C. Klinker tersebut mengandung 4 senyawa kompleks, yaitu :

- *Tricalcium Silicate* (C_3S)
- *Dicalcium Silicate* (C_2S)
- *Tricalcium Silicate* (C_3A)
- *Tetra Calcium Aluminate* (C_4AF)

[13] Gunawan.T, Margaret. S, *"Diktat Konstruksi Beton"*, Jakarta: Delta, 2005

C_3S dan C_2S merupakan senyawa yang sangat penting, karena kekuatan beton tergantung pada kedua senyawa tersebut. Untuk membuat semen, harus lakukan pengawasan yang ketat terhadap prosentase oksida di dalam bahan mentah. Jika % kapur melebihi dari yang seharusnya, maka akan sulit untuk bereaksi dengan bahan lain, sehingga kapur bebas akan tertinggal (tidak beraksi) di dalam klinker, yang akan menyebabkan kehalusan semen tidak merata. Akhirnya dapat menyebabkan kerusakan dan ekspansi pada beton. Semen yang mengandung % alumina dan oksida besi yang tinggi akan menghasilkan kekuatan awal yang tinggi. Semen yang mengandung % C_3A yang lebih sedikit akan mempunyai kekuatan tekan yang tinggi pada umur awal dan tidak ada retak-retak yang terjadi.

Beberapa semen yang diproduksi di Indonesia, antara lain semen Portland tipe I, II, III dan V. Jenis struktur, cuaca dan kondisi lainnya merupakan faktor-faktor yang akan menentukan dalam memilih jenis semen yang akan dipakai.

Semen Portland tipe I merupakan semen yang paling banyak dimanfaatkan untuk konstruksi karena tidak memerlukan persyaratan-persyaratan khusus sebagimana jenis semen lainnya.

Semen portland tipe II merupakan modifikasi semen portland tipe I dengan maksud untuk meningkatkan ketahanan terhadap sulfat dan dapat menghasilkan panas hidrasi yang lebih rendah. Semen jenis ini umumnya dimanfaatkan untuk konstruksi yang terletak di daerah dengan tanah yang memiliki kadar sulfat yang rendah.

Semen Portland tipe III merupakan jenis semen yang cepat mengeras. Beton yang dibuat dengan semen tipe ini akan mengeras cukup cepat dan kekuatan yang dihasilkannya dalam 24 jam akan sama dengan kekuatan beton dari semen biasa dalam 7 hari. Sehingga hanya sekitar 3 hari kekuatan tekannya akan setara dengan kekuatan tekan umur 28 hari beton dari semen biasa.

Semen tipe V umumnya digunakan untuk memberikan perlindungan terhadap bahaya korosi akibat pengaruh air laut, air danau, air tambang, maupun pengaruh garam sulfat yang banyak terdapat di dalam air tanah. Semen tipe ini memiliki daya resistensi terhadap sulfat yang lebih baik dibandingkan dengan semen tipe II. Persentase komposisi semen portland dapat dilihat pada tabel 2.2.

Tabel 2.2. Persentase Komposisi Semen Portland

Jenis Semen	Komponen (%)							Karakteristik Umum
	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	CaO	MgO	
Normal, I	49	25	12	8	2,9	0,8	2,4	Semen untuk semua tujuan
Modifikasi, II	46	29	6	12	2,8	0,6	3,0	Relatif sedikit pelepasan panas; digunakan untuk struktur besar
Kekuatan awal tinggi, III	56	15	12	8	3,9	1,4	2,6	Mencapai kekuatan tinggi pada umur 3 hari
Pemanasan rendah, IV	30	46	5	13	2,9	0,3	2,7	Dipakai pada bendungan beton
Tahan sulfat, V	43	36	4	12	2,7	0,4	1,6	Dipakai pada saluran dan struktur yang diekspos terhadap sulfat

Sumber : Nawy, Edward. G, 1990

Jenis semen lainnya yaitu semen portland pozzolan yang banyak digunakan untuk konstruksi beton masif seperti bendungan karena dapat menghasilkan panas hidrasi yang rendah, dan karena jenis semen ini juga tahan terhadap sulfat sehingga sering dimanfaatkan untuk konstruksi bangunan limbah.

Dalam prakteknya, material yang dipakai disyaratkan harus melewati pengujian terhadap spesifikasi yang berlaku. Pengujian ini berdasarkan Standar Industri Indonesia (SII) atau *American Standard for Testing Material* (ASTM) atau standar lain yang setara, misalnya *Japanese Industrial Standard* (JIS).

Dalam penelitian ini jenis semen yang digunakan adalah semen tipe I (normal) yaitu tipe semen yang digunakan untuk semua tujuan.

2.4.2. Air

Air digunakan pada campuran beton agar terjadi reaksi kimiawi dengan semen untuk membasahi agregat dan untuk melumas campuran agar mudah dalam pengerjaanya. Air yang mengandung senyawa-senyawa yang berbahaya, yang tercemar garam, minyak, gula, atau bahan-bahan kimia lain, bila dipakai untuk campuran beton akan dapat menurunkan kekukatan beton dan juga dapat mengubah sifat-sifat beton yang dihasilkan.

Air yang digunakan dapat berupa air tawar (dari sungai, dananu, kolam, dan lainnya) air laut maupun air limbah yang memenuhi syarat mutu yang telah ditetapkan. Air tawar yang dapat diminum umumnya dapat digunakan dalam campuran beton. Air laut tidak boleh digunakan dalam bahan campuran beton pra-tegang atau beton bertulang karena resiko terhadap karat lebih besar. Air buangan industri yang mengandung asam alkali juga tidak boleh digunakan.

Menurut ACI 318-89:2-2 mengenai syarat air dalam beton yaitu air yang digunakan untuk campuran beton harus bersih, tidak boleh mengandung minyak, asam, alkali, zat organis atau bahan lainnya yang dapat merusak beton atau tulangan. Air yang digunakan dalam pembuatan beton pra-tekan dan beton yang akan ditanami logam almunium tidak boleh mengandung ion klorida dalam jumlah yang membahayakan.

Proporsi air yang sedikit akan memberikan kekuatan yang tinggi pada beton, tetapi kelemasan beton atau daya kerjanya menjadi berkurang. Sedangkan proporsi air yang agak besar dapat memberikan kemudahan pada waktu pelaksanaannya, tetapi kekuatan hancur beton akan menjadi rendah. Proporsi air ini dinyatakan dalam rasio air semen, yaitu angka yang menyatakan perbandingan antara berat air (kg) dibagi dengan berat semen (kg) dalam adukan beton tersebut.

Beton untuk konstruksi gedung biasanya memiliki nilai rasio semen sebesar 0,45 hingga 0,65. Dengan rasio tersebut dapat dihasilkan beton yang kedap air, namun mutu beton tetap dipengaruhi cara pemadatan dan daya kerjanya. Bilamana daya kerja beton rendah, maka diperlukan bahan aditif, sehingga daya kerja beton menjadi lebih baik, tanpa mempengaruhi kekuatan atau rasio air semen.

2.4.3. Agregat

Menurut SNI T-15-1991-03 agregat didefinisikan sebagai material granular, misalnya pasir, kerikil, batu pecah dan kerak tungku besi yang dipakai bersama-sama dengan suatu media pengikat untuk membentuk semen hidrolik atau adukan.

Kandungan agregat dalam campuran beton biasanya sangat tinggi, komposisinya berkisar 60% - 70% dari berat campuran beton. Walaupun fungsinya hanya sebagai pengisi, namun karena komposisinya yang cukup besar, maka agregat menjadi penting.

Berdasarkan ukurannya, agregat ini dapat dibedakan menjadi :

1. Agregat halus merupakan agregat yang semua butirannya menembus ayakan berlubang 4,8 mm (SII.0052,1980) atau 4,75 mm (ASTM C33,1982) yang biasanya disebut pasir. Jenis agregat ini dapat dibedakan lagi menjadi :
    a. Pasir halus : ∅ 0 -1 mm
    b. Pasir kasar : ∅ 1-5 mm
2. Agregat kasar merupakan agregat yang semua butirannya tertinggal di atas ayakan 4,8 mm (SII.0052, 1980) atau 4,75 mm (ASTM C33, 1982), yang biasanya disebut kerikil. Material ini merupakan hasil disintegrasi alami batuan atau hasil dari industri pemecah batu.

Agregat untuk beton harus memenuhi ketentuan dari mutu dan cara uji agregat beton dalam SII 0052-80 ataupun persyaratan dari ASTM C330 tentang *specification for concrete agregate*.

Ukuran nominal butir agregat terbesar menurut PB,1989:9 dan ACI 318,1989:2-1 tidak boleh melebihi nilai berikut ini, yaitu :

1. Seperlima jarak terkecil antara bidang-bidang samping cetakan
2. Seperlima tebal pelat
3. Tiga perempat jarak bersih minimum antar batang tulangan, berkas batang tulangan, ataupun kabel prategang atau tendon prategang.

Kekuatan beton dipengaruhi oleh kualitas agregat, proporsi campuran, serta kebersihan air dan agregatnya. Oleh karena itu, selain harus memiliki kekuatan dan daya tahan yang baik, butir agregat disyaratkan harus bersih dari lumpur atau material organis lainnya yang dapat mengurangi kekuatan beton.

Hal-hal yang perlu diperhatikan berkaitan dengan penggunaan agregat dalam campuran beton, yaitu:[14]

1. Volume udara

[14]Landgren, Robert, "Unit Weight, Specific Gravity, Absorption and Surface Moisture, Significance of Test and Properties of Concrete and Concrete-Materials", Philadelphia, 1978

Udara yang terdapat dalam campuran beton akan mempengaruhi proses pembuatan beton, terutama setelah terbentuknya pasta semen.

2. Volume padat

   Kepadatan volume agregat akan mempengaruhi berat isi dari beton jadi

3. Berat jenis agregat

   Berat jenis agregat akan mempengaruhi proporsi campuran dalam berat sebagai kontrol.

4. Penyerapan

   Penyerapan berpengaruh pada berat jenis

5. Kadar air permukaan agregat

   Kadar air permukaan agregat berpengaruh pada penggunaan air pada saat pencampuran.

Tabel 2.3. Persyaratan Gradasi Untuk Agregat Pada Beton Berbobot Normal (ASTM C – 33)

Ukuran saringan standar Amerika	Persen Lewat				
	Agregat Kasar				Agregat Halus
	No.4 – 2 in.	No.4 – 1½ in.	No.4 – 1 in.	No.4 – ¾ in.	
2 in.	95 – 100	100	-	-	-
1 ½ in.	-	95 – 100	100	-	-
1 in.	25 – 70	-	95 – 100	100	-
¾ in.	-	35 – 70	-	90 – 100	-
½ in.	10 – 30	-	25 – 60	-	-
3/8 in.	-	10 – 30	-	20 – 55	100
No. 4	0 – 5	0 – 5	0 – 10	0 – 10	95 – 100
No. 8	0	0	0 – 5	0 – 5	80 – 100
No. 16	0	0	0	0	50 – 85
No. 30	0	0	0	0	25 – 60
No. 50	0	0	0	0	10 – 30
No. 100	0	0	0	0	2 – 10

Sumber : ASTM, "*Concrete and Aggregates*", 2002

2.4.4. Bahan Tambah (*Admixtures*)

Bahan tambah (*admixtures*) adalah bahan-bahan yang ditambahkan ke dalam campuran beton pada saat atau selama pencampuran berlangsung. Fungsi dari bahan tambah ini adalah untuk mengubah sifat-sifat dari beton agar menjadi sesuai untuk pekerjaan tertentu, atau untuk menghemat biaya.[15]

Penambahan bahan tambah dalam campuran beton tidak mengubah komposisi yang besar dari bahan yang lainnya, karena penggunaan bahan tambah ini cenderung merupakan pengganti dari dalam campuran beton itu sendiri. Karena tujuannya memperbaiki atau mengubah sifat dan karakteristik tertentu dari beton yang akan dihasilkan, maka kecenderungan perubahan komposisi dalam berat volume tidak terasa secara langsung dibandingkan dengan kompoisi awal beton tanpa bahan tambah.

Di Indonesia bahan tambah telah banyak digunakan. Manfaat dari penggunaan bahan tambah ini perlu dibuktikan dengan menggunakan bahan agregat dan jenis semen yang sama dengan bahan yang akan digunakan di lapangan.

Beberapa hal yang perlu diperhatikan dalam menggunakan bahan tambah, yaitu :

1. Tipe semen yang akan digunakan
2. Petunjuk umum dalam menggunakan bahan tambah
3. Banyaknya bahan tambah yang digunakan dalam campuran
4. Efek dari penggunaan bahan tambah

Beberapa tujuan yang penting dari penggunaan bahan tambah ini menurut *manual of concrete practice* dalam admixture and concrete (ACI.212.1R, Revised 1986, antara lain :

a. Memodifikasi beton segar, mortar dan grouting
   - Menambah sifat kemudahan pekerjaan tanpa menambah kandungan air atau mengurangi kandungan air dengan sifat pengerjaan yang sama.
   - Menghambat atau mempercepat waktu pengikatan awal dari campuran beton
   - Mengurangi atau mencegah secara preventif penurunan atau perubahan volume beton
   - Mengurangi segregasi

[15] Tri Mulyono, "*Teknologi Beton*", Yogyakarta: Andi, 2003

- Mengembangkan dan meningkatkan sifat penetrasi dan pemompaan beton segar
- Mengurangi kehilangan nilai slump

b. Memodifikasi beton keras, mortar dan grouting
   - Menghambat atau mengurangi ekolusi panas selama pengerasan awal (beton muda).
   - Mempercepat laju pengembangan kekuatan beton pada umur muda
   - Menambah kekuatan beton (kuat tekan, lentur dan geser dari beton)
   - Menambah sifat keawetan beton atau ketahanan dari gangguan luar termasuk serangan garam-garam sulfat.
   - Mengurangi kapilaritas dari air
   - Mengurangi sifat permeabilitas
   - Mengontrol pengembangan yang disebabkan oleh reaksi dari alkali termasuk alkali dalam agregat
   - Menghasilkan struktur beton yang baik
   - Menambah kekuatan ikatan beton bertulang
   - Mengembangkan ketahanan gaya impact (berulang) dan ketahanan abrasi
   - Mencegah korosi yang terjadi pada baja
   - Menghasilkan warna tertentu pada beton atau mortar

Secara umum bahan tambah yang digunakan dalam beton dapat dibedakan menjadi dua jenis, yaitu bahan tambah yang bersifat kimiawi dan bahan tambah yang bersifat mineral. Selain itu terdapat juga bahan tambah jenis lainnya yang sering digunakan dalam campuran beton. Bahan tambah jenis kimia ditambahkan pada saat pengadukan dan atau saat pelaksanaan pengecoran sedangkan bahan tambah jenis mineral ditambahkan pada saat pengadukan dilaksanakan.

Bahan tambah jenis kimia lebih banyak digunakan untuk memperbaiki kinerja pelaksanaan, sedangkan yang berjenis mineral lebih banyak digunakan untuk perbaikan kinerja kekuatannya.

Berikut akan dijelaskan mengenai kedua jenis bahan tambah itu maupun bahan tambah jenis lainnya, yaitu :

2.4.4.1.Bahan Tambah Kimia

Menurut ASTM C494 (1995:254) jenis bahan tambah kimia dibedakan menjadi tujuh macam, yaitu :

- Tipe A yaitu *water reducing admixtures*

  Merupakan bahan tambah yang berfungsi untuk mengurangi pemakaian air pencampur yang diperlukan pada beton. Digunakan antara lain untuk dengan tidak mengurangi kadar semen dan nilai slump untuk memproduksi beton dengan nilai perbandingan atau rasio faktor air semen yang rendah. Atau dengan tidak mengubah kadar semen yang digunakan dengan faktor air semen yang tetap maka nilai slump yang dihasilkan dapat lebih tinggi.

  Bahan tambah ini dapat berasal dari bahan organik ataupun campuran anorganik untuk beton tanpa udara atau dengan udara dalam hal mengurangi kandungan air campuran. Bahan tambah ini juga dapat digunakan untuk memodifikasi waktu pengikatan beton sebagai dampak perubahan atas faktor air semen.

  Komposisi dari campuran bahan tambah jenis ini dibagi atas 5 jenis, yaitu :

  a. Asam lignosulfonic dari kandungan garam-garam
  b. Modifikasi dan turunan asam lignosulfonic dan kandungan garam-garam
  c. *Hydroxylated carboxylic acids* dan kandungan garamnya.
  d. Modifikasi *Hydroxylated carboxylic acids* dan kandungan garamnya.
  e. Material lainnya, seperti :
     - Material inorganik seperti seng, garam-garam, posfat, klorida
     - Asam amino dan turunannya
     - Karbohidrat, polisakarin dan gula asam
     - Campuran polimer, seperti eter, turunan melamic, naptan, silikon, hidrokarbon-sulfat.

  Hal-hal yang perlu diperhatikan dalam penggunaan bahan tambah jenis ini, yaitu :

  - Air yang dibutuhkan

- Kandungan air
- Konsistensi
- Bleeding
- Kehilangan air pada saat beton segar
- Susut pada saat pengeringan
- Ketahanan terhadap perubahan volume

- Tipe B yaitu *retarding admixtures*

  Merupakan bahan tambah yang berfungsi untuk memperpanjang waktu pengikatan awal beton. Penggunaannya untuk menunda waktu pengikatan beton misalnya karena kondisi cuaca yang panas, atau untuk memperpanjang waktu pemadatan untuk menghindari *cold joints* dan juga untuk menghindari dampak penurunan pada saat beton segar dilakukan pengecoran.

- Tipe C yaitu *accelerating admixtures*

  Merupakan bahan tambah yang berfungsi untuk mempercepat waktu pengikatan dan pengembangan kekuatan awal beton. Bahan ini digunakan untuk mengurangi lamanya waktu pengeringan dan mempercepat pencapaian kekuatan pada beton.

  Penggunaan bahan tambah jenis ini harus didasarkan atas pertimbangan ekonomi dengan membandingkan pada pennggunaan bahan tambah lain seperti penggunaan semen yang lebih banyak, penggunaan metode perawatan dan proteksi yang berbeda, penggunaan bahan air dan agregat yang panas. Pada umumnya kelompok jenis bahan tambah ini terbagi menjadi tiga, yaitu :

  1. Larutan garam organik
  2. Larutan campuran organik
  3. Material *miscellaneous*

- Tipe D yaitu *water reducing and retarding admixtures*

  Merupakan bahan tambah yang berfungsi ganda yaitu untuk mengurangi air dan sekaligus juga untuk memperlambat waktu pengikatan awal beton. Bahan tambah jenis ini digunakan untuk menambah kekuatan beton dan juga akan mengurangi

kandungan semen yang sebanding dengan pengurangan kandungan air. Perbandingan antara mortar dengan agregat kasat tidak boleh berubah, sehingga bila terjadi perubahan pada kandungan air, atau udara maupun semen, harus diatasi dengan perubahan kandungan agregat halus sehingga volume tidak berubah.

- Tipe E yaitu *water reducing and accelerating admixtures*

  Merupakan bahan tambah yang berfungsi untuk mengurangi pemakaian air sekaligus untuk mempercepat waktu pengikatan awal beton. Bahan ini juga digunakan untuk menambah kekuatan beton. Kondisi yang dikehendaki dari bahan tambah ini adalah kuat tekan beton yang tinggi namun kecepatan pengikatan yang diinginkan dapat lebih tinggi.

- Tipe F yaitu *Water Reducing, High Range Admixtures*

Merupakan bahan tambah yang berfungsi untuk mengurangi jumlah air pencampur yang diperlukan untuk dapat menghasilkan beton dengan konsistensi tertentu, sebanyak 12% atau lebih.

Kadar pengurangan air dalam bahan tambah ini lebih tinggi sehingga diharapkan kekuatan beton yang dihasilkan lebih tinggi dengan air yang sedikit, namun tingkat kemudahan pekerjaan juga lebih tinggi. Dosis yang disarankan adalah 1% sampai 2% dari berat semen. Dosis yang berlebihan akan menyebabkan menurunnya kekuatan tekan beton. Jenis bahan tambah ini dapat berupa *superplasticizer*. Tiga jenis *plasticizer* yang dikenal adalah :

1. Kondensi sulfonat melamin formaldehid dengan kandungan klorida sebesar 0.005%
2. Sulfonat nafthalin formaldehid dengan kandungan klorida yang dapat diabaikan
3. Modifikasi lignosulfonat tanpa kandungan klorida

- Tipe G yaitu *water reducing, high range retarding admixtures*

Merupakan bahan tambah yang berfungsi untuk mengurangi jumlah air pencampur yang diperlukan untuk menghasilkan beton dengan konsistensi tertentu, sebanyak 12% atau lebih dan juga berfungsi untuk menghambat pengikatan beton. Bahan tambah ini

digunakan biasanya untuk kondisi pekerjaan yang sempit karena sedikitnya sumber daya yang mengelola beton karena terbatasnya sumber daya.

2.4.4.2.Bahan Tambah Mineral (additive)

Bahan tambah jenis ini merupakan bahan tambah yang dimaksudkan untuk memperbaiki kinerja beton. Namun saat ini bahan tambah jenis ini lebih banyak digunakan untuk memperbaiki kinerja tekan beton.

Beberapa keuntungan penggunaan bahan tambah mineral diantaranya, yaitu :[16]

- Memperbaiki kinerja workability
- Mengurangi panas hidrasi
- Mengurangi biaya pekerjaan beton
- Mempertinggi daya tahan terhadap serangan sulfat
- Mempertinggi daya tahan terhadap serangan alkali-silika
- Mempertinggi usia beton
- Mempertinggi kekuatan tekanbeton
- Mempertinggi keawetan beton
- Mengurangi penyusutan
- Mengurangi porositas dan daya serap air dalam beton

Adapun beberapa jenis yang termasuk dalam bahan tambah jenis ini, yaitu :

1. Abu terbang batu bara

   Menurut ASTM C.618 (ASTM, 1995:304) abu terbang (*fly ash*) didefinisikan sebagai butiran halus hasil residu pembakaran batu bara atau bubuk batu bara. Abu terbang dapat dibedakan menjadi dua, yaitu abu terbang yang normal yang dihasilkan dari pembakaran batu bara antrasit atau batu bara bitomius dan abu terbang kelas C yang dihasilkan dari batu bara jenis lignite atau subbitumeus. Kandungan kimia yang dibutuhkan dalam abu terbang dapat dilihat dalam tabel di bawah ini.

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[16] Cain, Craig J, *"Mineral Admixture, Significance of Test And Properties of Concrete and Concrete-Making Material-STP 169 C"*, Philadelphia, 1994

Tabel 2.4. Kandungan Kimia Abu Terbang

Senyawa Kimia	Jenis F	Jenis C
Oksida Silika (SiO_2) + Oksida Alumina (Al_2O_3) + Oksida Besi (Fe_2O_3), minimum %	70.0	50.0
Trioksida Sulfur (SO_3), maksimum %	5.0	5.0
Kadar Air, maksimum %	3.0	3.0
Kehilangan Panas, maksimum %	6.0	6.0

Sumber : ASTM C.618-95:305

2. Slag

Menurut ASTM C.989 (ASTM, 1995:494) slag didefinisikan sebagai produk non-metal yang merupakan material berbentuk halus, granular hasil pembakaran yang kemudian didinginkan, misalnya dengan mencelupkannya dalam air.

Adapun beberapa keuntungan penggunaan slag dalam campuran beton adalah :[17]

- Mempertinggi kekuatan tekan beton karena kecenderungan melambatnya kenaikan kekuatan tekan
- Menaikkan ratio antara kelenturan dan kuat tekan beton
- Mengurangi variasi kekuatan tekan beton
- Mempertinggi ketahanan terhadap sulfat dalam air laut
- Mengurangi serangan alkali-silika
- Mengurangi panas hidrasi dan menurunkan suhu
- Memperbaiki keawetan karena pengaruh perubahan volume
- Mengurangi porositas dan serangan klorida

3. Silika fume

Menurut ASTM.C.1240, 1995:637-642) *silica fume* adalah material pozzolan yang halus, dimana komposisi silica lebih banyak yang dihasilkan dari tanur tinggi atau sisa produksi besi silikon.

Penggunaan bahan tambah ini dalam campuran beton dimaksudkan untuk menghasilkan beton dengan kekuatan tekan yang tinggi. Misalnya untuk struktur

[17] Tri Mulyono, "*Teknologi Beton*", Yogyakarta: Andi, 2003

kolom, dinding geser, beton prategang dan lainnya. Penggunaannya berkisar antara 0 – 30% untuk memperbaiki karakteristik kekuatan dan keawetan beton dengan faktor air semen sebesar 0.34 dan 0.28 dengan atau tanpa bahan *superplasticizer* dan nilai slump 50 mm.

Tabel 2.5. Komposisi kimia silica fume

Kimia	Berat dalam persen
SiO_2	92 -94
Karbon	3 - 5
Fe_2O_3	0.10 – 0.50
CaO	0.10 – 0.15
Al_2O_3	0.20 – 0.30
MgO	0.10 – 0.20
MnO	0.008
K_2O	0.10
Na_2O	0.10
Fisika	Berat dalam persen
Berat Jenis	2.02
Rata-rata ukuran partikel, um	0.1
Lolos ayakan no.325 dalam %	99.00
Keasaman pH (10% air dalam slurry)	7.3

Sumber : Yogendran, ACI Material Journal, Maret/April,1987

4. Penghalus Gradasi

Bahan ini berupa mineral yang digunakan untuk memperhalus perbedaan pada campuran beton dengan memberikan ukuran yang tidak ada atau kurang dalam agregat. Selain itu juga dapat digunakan untuk menaikkan mutu beton dan mengurangi permeabilitas maupun biaya produksi beton.

2.4.4.3.Bahan Tambah Lainnya

a. Air entraining

Merupakan bahan tambah yang membentuk gelembung-gelembung udara berdiameter 1 mm atau lebih kecil di dalam beton selama pencampuran. Hal ini dimaksudkan untuk mempermudah pengerjaan beton pada saat pengecoran dan dapat menambah ketahanan awal pada beton.

Banyaknya bahan tambah jenis ini tergantung pada bentuk dan gradasi agregat yang digunakan. Semakin halus ukuran agregat maka semakin besar persentase bahan tambah yang diperlukan. Penambahan bahan jenis ini dapat mengurangi kekuatan udara, tetapi dengan mempertahankan kandungan semen dan kemudahan kerja, pengurangan kekuatan ini dapat dicegah karena faktor air semennya yang berkurang.

b. Beton tanpa slump

Beton tanpa slump didefinisikan sebagai beton yang mempunyai slump sebesar 1 inchi (25.4 mm) atau kurang, sesaat setelah pencampuran. Pemilihan bahan tambah ini tergantung pada sifat-sifat beton yang diinginkan.

c. Polimer

Merupakan bahan tambah yang dapat menghasilkan kekuatan tekan beton yang tinggi sekitar 15.000 psi atau lebih dan kekuatan tariknya sekitar 1500 Psi atau lebih. Beton yang ditambah bahan jenis ini diproduksi dengan cara :

- Memodifikasi sifat beton dengan mengurangi air di lapangan
- Menjenuhkan dan memancarkannya pada temperatur yang sangat tinggi di laboratorium

d. Bahan pembantu untuk mengeraskan permukaan beton (*hardener concrete*)

Merupakan bahan tambah yang berfungsi untuk memperkeras permukaan beton sehingga mengurangi pengausan pada permukaan beton. Contohnya penggunaan pada lantai untuk bengkel alat-alat berat.

Terdapat dua jenis bahan ini, yaitu :

- Agregat beton yang terbuat dari bahan kimia
- Agregat metalik yang terdiri dari butiran-butiran halus

e. Bahan pembantu kedap air (*water proofing*)

Merupakan bahan tambah yang berfungsi untuk mengurangi permeabilitas air. Jenis bahan tambah ini mempunyai partikel-partikel halus dan gradasi yang menerus dalam campuran beton.

f. Bahan tambah pemberi warna

Merupakan bahan tambah yang memberikan keindahan pada beton, sehingga tidak diperlukan pengecatan lagi pada beton. Bahan tambah ini biasanya dicampurkan dalam suatu adukan yang mutunya terjamin baik.

g. Bahan tambah untuk memperkuat ikatan beton lama dengan beton baru

Biasanya bahan tambah ini disebut dengan bonding agent yang merupakan larutan polimer. Berfungsi untuk memperkuat ikatan beton lama dengan yang baru.

2.5. POLYETHYLENE TEREPHTHALATE (PET)

Polyethylene terephthalate (PET) merupakan polyester termoplastik yang diproduksi secara komersial melalui produk kondensasi yang dikarakterisasi dengan banyaknya ikatan ester yang didistribusikan sepanjang rantai utama polimer. *Polyethylene terephthalate* (PET) merupakan bahan dasar dari botol minuman plastik, dengan nama IUPAC-nya *Polioksi etilen neooksitereftaoil*.

Proses pembuatan PET memerlukan suhu yang sangat tinggi di atas 100°C untuk produk yang secara komersial memiliki kemampuan kristalisasi cepat. Material ini memiliki sifat mekanik yang baik, ketahanan terhadap pelarut yang bagus, dan stabilitas hidrolitiknya yang baik.[18]

PET dan polyester lain pada umumnya bebas dari hasil pembakaran berbahaya selain CO_2. Titik leleh PET murni di atas 280°C untuk sampel yang di "annealing" secara lengkap. Sedangkan produk komersialnya meleleh pada suhu 255°C-265°C,

[18] Ehrig, R.J. (editor), "*Plastic Recycling*", New York: Oxford University Press, 1993

karena hasil kristalisasi berkurang dengan adanya pengotor pada rantai utamanya. Pengotor yang ada dalam PET mengakibatkan kekuatan produk akan berkurang, baik sebagai produk film atau serat. Titik transisi gelas bervariasi dalam interval yang luas tergantung pada kemurnian polimernya.[19]

Poliethylene terephthalate (PET) secara komersial disintesa dari *etilen glikol* (EG) dan *dimethyl terephthalate* (DMT) melalui esterifikasi langsung dengan *asam terephalate* (TPA), dan memiliki lebih banyak gugus dietilen glikol daripada PET yang dibuat dengan proses trans esterifikasi. Polimerisasi terjadi melalui 2 tahap, yaitu pertukaran ester dan tahap polimerisasi. Secara umum tahap pembuatan PET adalah sebagai berikut :[20]

Tahap pertama, melibatkan reaksi pertukaran ester untuk memproduksi bis (2-hidroksietil) terephthalat dengan jumlah kecil. Selanjutnya bereaksi secara terus menerus antara *dimethyl terephthalate* (DMT) atau asam terephalate (TPA) dengan etilen glikol, akan menghasilkan oligomer dengan massa molekul yang relatif lebih banyak. Reaktan dipanaskan secara bertingkat dari 150°C-210°C dan methanol didestilasi secara terus menerus sampai hilang pada temperature tersebut.

Tahap kedua, merupakan tahap polimerisasi, suhu dinaikkan hingga 270°C-280°C dan polimerisasi berlangsung untuk mengeluarkan air dengan cara mengurangi tekanan menjadi 0.5-1.0 torr (66-133 Pa). Pada tahap ini merupakan polimerisasi lelehan karena reaksi terjadi pada titik leleh kristalin polimer.

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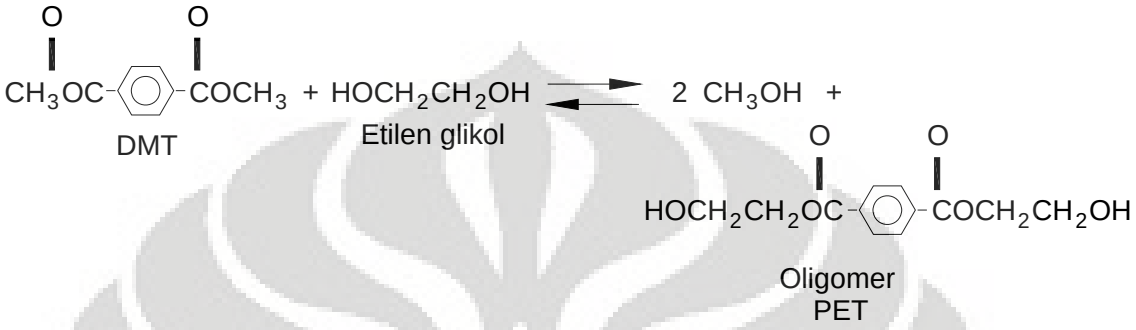
[19] Young J.F., Mindess, S., Bentur, A. (editor), "*The Science and Technology of Civil Engineering Material*", Prentice Hall, 1993

[20] Juwono, H., Harmani, Kurniawan, F., "*Studi Pengkajian Limbah Botol Minuman*/*Polietilen Terephtalate* (*PET*) *Sebagai Bahan Campur Tambah* (*Admixture*) *Dalam Pembuatan Beton Polimer*", Laporan Penelitian, Surabaya: 1999

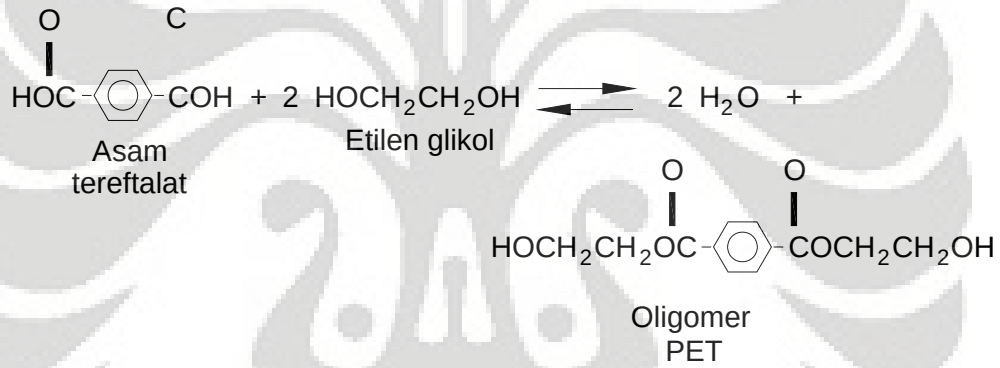
Secara singkat reaksi pembuatan PET dapat dilihat di bawah ini :

Tahap I :

- Pertukaran ester trans – esterifikasi

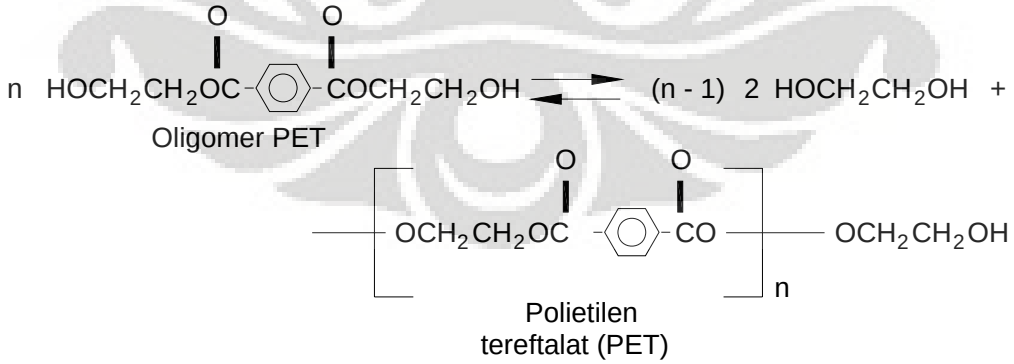


- Esterifikasi



Tahap II :

- Reaksi Polikondensasi



Pembentukan oligomer pada tahap ini merupakan reaksi katalisa pertukaran ester yang dikatalisa oleh garam-garam dari Mg, Co, Mn, Zn, atau Ca, pada temperatur dan tekanan tinggi dapat mempercepat reaksi. Dan tahap kedua dikatalis oleh *antimoni*.

Poliethylene terephthalate dapat larut dalam m-cresol panas, asam trifluoro asetat, oklorofenol, memiliki titik leleh kristalin yang cukup tinggi yaitu sekitar 270°C dan sifat mekanik yang baik, tahan terhadap perlakuan kimia, hidrolitik, dan pelarut. PET digunakan juga dalam teknik pemlastik sebagai pengganti baja, alumunium dalam pembuatan bahan elektronik.

Adapun sifat fisik maupun sifat mekanik dari *Poliethylene terephthalate* (PET) adalah sebagai berikut :[21]

Sifat – sifat fisik dari *Poliethylene terephthalate* (PET) :

a. *Density* : 1.35 gr/cm^3

b. *Konduktivitas thermal* : 0.15 W/m-K

c. *Ekspansi thermal* : 117×10^{-6} (°C)$^{-1}$

d. *Specific Heat* : 1170 J/Kg-K

e. *Electrical Resistivity* : 10^{12} Ohm-m

Sifat-sifat mekanik dari *Poliethylene terephthalate* (PET) :

a. Kuat tarik (*tensile strength*) : (48.3-72.4) MPa

b. Kuat tekan (*compressive strength*) : -59.3 MPa

c. Modulus elastisitas (*modulus of elasticity*) : (0.40-0.60) x 10^6 psi

d. Ketahanan retak (*fracture Toughness*) : 7-12 MPa m$^{0.5}$

2.6. PROSES PEMBUATAN BAHAN TAMBAH PET

Proses pembuatan bahan tambah PET yang berupa cacahan-cacahan botol plastik ini cukup mudah dan cepat untuk dilakukan, karena dalam proses pencacahan botol plastik itu dilakukan dengan bantuan mesin pencacah. Berbagai jenis botol plastik dapat digunakan untuk penelitian ini, karena pada umumnya botol plastik terbuat dari bahan *Poliethylene terephthalate* (PET). Keterangan bahan botol plastik yang mengindikasikan bahwa botol plastik tersebut terbuat dari PET, biasanya dapat dilihat pada lapisan bawah botol plastik.

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[21] William .D. Callister, "*Material Science and Engineering an Introduction*"

Gbr. 2.7. Botol Plastik PET

Adapun proses pembuatan bahan tambah ini, yaitu :

1. Botol plastik dibersihkan terlebih dahulu dari sisa-sisa cairan ataupun kandungan lainnya dengan menggunakan air bersih.
2. Kemudian leher botol plastik dipotong, dan plastik merk dari botol plastik tersebut juga turut dibuang.
3. Botol plastik tersebut dipotong menjadi tiga atau empat bagian, yang kemudian dimasukkan ke dalam mesin pencacah. Mesin dinyalakan dan potongan botol plastik yang telah dimasukkan tadi akan menjadi bentuk cacahan – cacahan dengan beragam ukuran.

Gbr. 2.8. Mesin pencacah botol plastik PET

4. Cacahan-cacahan botol plastik tersebut selanjutnya dicuci kembali dengan soda api hingga bersih.
5. Setelah PET yang telah dicuci telah mengering, maka bahan tambah PET yang berupa cacahan-cacahan ini siap untuk digunakan dalam campuran beton sebagai bahan tambah

Gbr. 2.10. Cacahan botol plastik PET

2.7. METODE RANCANGAN CAMPURAN BETON ACI

Perancangan campuran beton dimaksudkan untuk mengetahui komposisi atau proporsi bahan-bahan penyusun beton. Proporsi campuran dari bahan-bahan penyusun beton ini ditentukan melalui sebuah perancangan campuran beton (*mix design*). Hal ini dilakukan agar proporsi campuran dapat memenuhi syarat teknis serta ekonomis.

Kriteria dasar dalam merancang campuran beton adalah kekuatan tekan dan hubungannya dengan faktor air semen yang digunakan. Kriteria lain yang harus diperhatikan adalah kemudahan pengerjaannya. Selain dua kriteria di atas, yang perlu diperhatikan adalah keawetan dan permeabilitas beton itu sendiri.

Banyak metode yang dapat digunakan dalam melakukan perancangan campuran beton, yaitu : metode ACI, *Portland Cement Association*, Road note no.4, BS, Departemen Pekerjaan Umum, dan dengan cara coba-coba. Untuk penelitian ini hanya akan digunakan metode *American Concrete Institute* (ACI).

Metode *American Concrete Institute* (ACI) ini mensyaratkan suatu campuran perancangan beton dengan mempertimbangkan sisi ekonomisnya dengan memperhatikan ketersediaan akan bahan-bahan yang akan digunakan dilapangan,

kemudahan pengerjaan, keawetan dan kekuatan pekerjaan beton. Metode ini melihat bahwa dengan ukuran agregat tertentu, jumlah air per kubik akan menentukan tingkat konsistensi dari campuran beton yang akhirnya akan mempengaruhi pelaksanaan pekerjaan (*workability*).

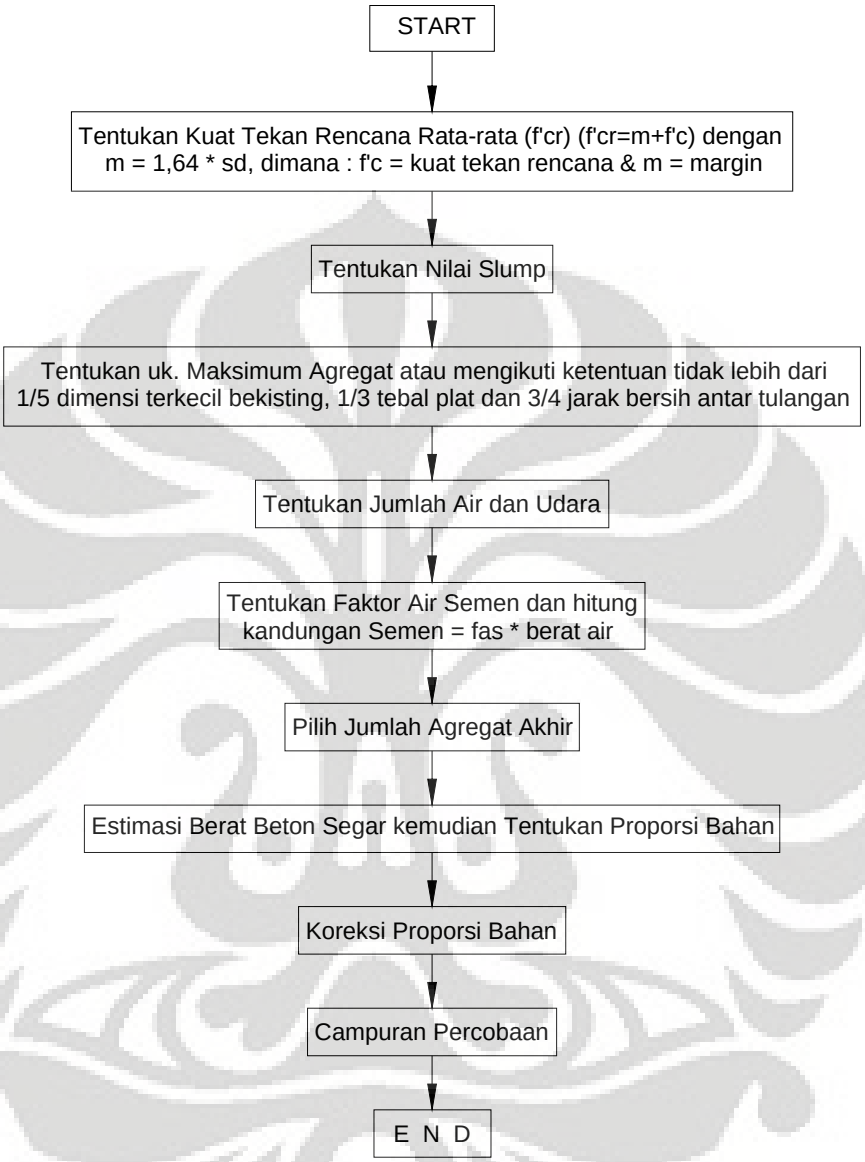
Yang perlu diperhatikan dalam menggunakan metode *American Concrete Institute* (ACI) ini, yaitu :

- Metode ini merupakan cara coba-coba (eksperimental) untuk memperoleh proporsi bahan yang menghasilkan konsistensi. Bilamana digunakan agregat yang berbeda maka akan menyebabkan konsistensi yang berbeda juga.

- Nilai Modulus Halus Butir (MHB) kurang menggambarkan gradasi agregat yang tepat, maka untuk agregat dengan berat jenis yang berbeda perlu dilakukan koreksi lagi.

Langkah pengerjaan untuk merancang campuran beton dengan metode *American Concrete Institute* (ACI) ini dapat dilihat pada bagan alir pada gambar 2.10.[22]

[22] Tri Mulyono, "*Teknologi Beton*", Yogyakarta: Andi, 2003



Gbr.2.11. Bagan Alir mix design metode ACI

BAB III
METODE PENELITIAN

3.1. PENDAHULUAN

Dalam penelitian ini akan dipelajari pengaruh pemakaian cacahan limbah botol plastik (PET) sebagai bahan tambah (*admixtures*) terhadap beton normal (f_c' = 25 MPa) dengan persentase campuran yang berbeda. Dalam penelitian ini hanya akan melakukan pengujian terhadap kuat tarik belah dan kuat geser pada beton. Sebelumnya terlebih dahulu akan dilakukan pengujian terhadap material dasar penyusun beton diantaranya agregat kasar dan halus terhadap mutu dan syarat dengan berdasarkan pada standar yang telah ditetapkan.

Setelah diketahui karakteristik dari agregat kasar dan halus, maka proses dilanjutkan dengan membuat rancang campuran beton normal menurut standar ACI. Proses pembuatan benda uji dilakukan setelah hasil rancangan beton didapatkan. Benda uji yang digunakan adalah berupa double L ukuran 20 x 30 x 7,5 cm untuk pengujian kuat geser sebanyak 21 buah dan benda uji berupa silinder 15 x 30 cm sebanyak 42 buah untuk pengujian kuat tarik belah. Prosedur pembuatan benda uji dan pengujian terhadap agregat kasar dan halus maupun beton yang dihasilkan berdasarkan pada standar ASTM *(American Society For Testing Materials)*.

3.2. PENELITIAN TERHADAP BAHAN BAKU

Pada penelitian ini dilakukan pengujian terhadap agregat halus normal yaitu pasir alam dan agregat kasar normal yaitu batu pecah, sedangkan untuk semen dan air maupun bahan tambah tidak dilakukan pengujian. Sifat – sifat semen diambil dari standar pabrik, bahan tambah yang berupa cacahan botol plastik (PET) melihat dari literatur mengenai sifat-sifat fisik & mekanik *polyetylene terephtalate* (PET), sedangkan air yang digunakan telah memenuhi standar air baku. Sebagai standar dalam pemeriksaan dan pengujian ini berdasarkan pada ASTM *(American Society For Testing Materials).*

3.2.1. Bahan Baku Penelitian

a. Semen

- Jenis : Semen type I (PCC)
- Merk : Semen Tiga Roda
- Sumber : PT. INDOCEMENT

b. Agregat Halus

- Jenis : Pasir Alam
- Asal : Cimangkok, Jawa Barat

c. Agregat Kasar

- Jenis : batu pecah (*split*) dari batu kali
- Asal : -

d. Air

- Jenis : Air PAM
- Sumber : Laboratorium Beton FT-UI Depok

e. Bahan Tambah

- Jenis : *Polyetylene Terephtalate* (PET)
- Asal : Cacahan Limbah Botol Plastik (PET)

3.3. PENGUJIAN AGREGAT

Agregat yang digunakan dalam campuran beton normal dalam penelitian ini adalah agregat kasar yang berupa batu pecah dan agregat halus normal yang berupa pasir alam. Maka pengujian agregat dilakukan terhadap kedua jenis agregat tersebut.

3.3.1. Metode Standar Pengujian Agregat

Pengujian yang dilakukan terhadap agregat halus & kasar berdasarkan pada standar ASTM C.33-02A, *"Standard for Concrete Aggregates"*. Dimana pada standar ASTM C.33-02A terdapat pengujian agregat halus dan kasar yang biasa dilakukan, diantaranya, yaitu :

ASTM C.29	Metode standar untuk menentukan berat isi agregat halus dan kasar.

ASTM C.40 Metode standar untuk pemeriksaan kotoran organik dalam agregat halus.

ASTM C.117 Metode standar untuk pemeriksaan bahan yang lolos saringan No.200.

ASTM C.127 Metode standar untuk menentukan spesific gravity dan absorbsi agregat kasar.

ASTM C.128 Metode standar untuk menentukan spesific gravity dan absorbsi agregat halus

ASTM C.136 Metode standar untuk analisa saringan agregat kasar dan halus.

3.3.2. Jenis Pengujian Agregat

3.3.2.1. Pengujian Berat Isi Agregat Halus dan Agregat Kasar

Jenis pengujian ini berdasarkan pada metode ASTM C.29, yaitu metode standar untuk menentukan berat isi agregat halus dan kasar. Pengujian ini dilakukan untuk mengetahui besarnya berat isi pada agregat halus dan kasar yang akan digunakan pada campuran. Pengujian berat isi dan rongga udara dalam agregat dapat dilakukan dalam dua kondisi, yaitu kondisi padat dan kondisi gembur. Pada penelitian ini hanya dilakukan pengujian pada kondisi padat, yaitu dengan cara ditusuk.

Prosedur pengujian :

1. Isi penakar 1/3 dari volume penuh dan ratakan dengan batang perata.
2. Tusuk lapisan agregat dengan 25 kali tusukan batang penusuk.
3. Isi lagi sampai volume menjadi 2/3 penuh kemudian ratakan dan tusuk sebanyak 25 kali dengan batang penusuk.
4. Isi penakar sampai berlebih dan tusuk lagi.
5. Ratakan permukaan agregat dengan batang perata.
6. Tentukan berat penakar dan isinya (G) dan berat penakar itu sendiri (T).
7. Catat beratnya sampai ketelitian 0.05 kg.
8. Hitung berat isi agregat : $M = \frac{(G - T)}{V}$

Dimana :

M = Berat isi agregat dalam kondisi kering oven, kg/m^3.

G = Berat agregat dan penakar, kg.

T = Berat penakar, kg.

V = Volume penakar, kg.

9. Hitung kadar rongga udara : $\text{Rongga Udara} = \frac{[(s \times w) - M]}{(s \times w)} \times 100\%$

Dimana :

M = Berat isi agregat dalam kondisi kering oven, kg/m^3.

s = Berat jenis agregat dalam kering oven.

w = Kerapatan air. 998 kg/m^3.

3.3.2.2. Pemeriksaan Kotoran Organik Dalam Agregat Halus

Jenis pengujian ini berdasarkan pada metode ASTM C.40, yaitu metode standar untuk pemeriksaan kotoran organik dalam agregat halus. Pemeriksaan ini dilakukan untuk mengetahui adanya kandungan bahan organik dalam pasir alam yang akan digunakan sebagai bahan campuran mortar atau beton. Kotoran organik merupakan bahan-bahan organik yang terdapat di dalam pasir dan dapat menimbulkan efek yang merugikan terhadap mutu mortar beton yang dihasilkan.

Prosedur pengujian :

1. Masukkan benda uji ke dalam botol gelas sampai mencapai garis skala 130 ml
2. Tambahkan larutan (3 % NaOH + 97 % air) dan dikocok sampai volumenya mencapai 200 ml.
3. Tutup botol, dikocok lagi kuat – kuat, kemudian didiamkan selama 24 jam
4. Setelah 24 jam, bandingkan warna cairan yang terlihat dengan warna standar yang menggunakan larutan standar atau *organic plate* No.3
5. Jika warna larutan benda uji lebih gelap dari warna larutan standar, lebih besar dari no.3, maka kemungkinan agregat halus ini mengandung bahan organik yang tidak diizinkan untuk bahan campuran beton.

3.3.2.3. Pemeriksaan Jumlah Bahan Dalam Agregat Yang Lolos Saringan No. 200 (0,075 mm)

Jenis pengujian ini berdasarkan pada metode ASTM C.117, yaitu metode standar untuk pemeriksaan bahan yang lolos saringan No.200. Pemeriksaan ini dilakukan untuk memperoleh besarnya persentase jumlah dalam bahan agregat yang lolos saringan No. 200 (0,075 mm) dengan cara pencucian. Jumlah bahan dalam agregat yang lolos saringan No. 200 (0,075 mm) merupakan banyaknya bahan yang lolos saringan No. 200 (0,075 mm) sesudah agregat tersebut dicuci sampai air cucian tersebut menjadi jernih.

Prosedur pengujian :

1. Timbang wadah tanpa benda uji
2. Timbang benda uji dan masukkan ke dalam wadah
3. Masukkan air pencuci yang sudah berisi sejumlah bahan pembersih ke dalam wadah, sehingga benda uji terendam
4. Aduk benda uji dalam wadah sehingga menghasilkan pemisahan yang sempurna antara butir-butir kasar dan bahan halus yang lolos saringan No.200 (0,075 mm). Usahakan bahan halus tersebut menjadi melayang di dalam larutan pencuci sehingga mempermudah dalam pemisahannya.
5. Tuangkan air pencuci dengan segera di atas saringan No. 16 (1,18 mm) yang di bawahnya dipasang saringan No.200 (0,075 mm) pada waktu menuangkan air pencuci harus hati-hati supaya bahan yang kasar tidak ikut tertuang.
6. Ulangi proses pengujian 3,4 dan 5, sehingga tuangan air pencuci terlihat jernih.
7. Kembalikan semua benda uji yang tertahan saringan No. 16 (1,18 mm) dan No. 200 (0,075 mm) ke dalam wadah lalu keringkan dalam oven dengan suhu (110±5)°C, sampai mencapai berat tetap, dan timbang sampai ketelitian maksimum 0,1 % dari berat contoh
8. Hitung persen bahan yang lolos saringan No.200 (0,075 mm) :
   - Berat kering benda uji awal

     $w_3 = w_1 - w_2$
   - Berat kering benda uji sesudah pencucian

$$w_5 = w_4 - w_2$$

- Bahan lolos saringan No. 200 (0,075 mm)

$$w_6 = \frac{w_3 - w_5}{w_3} \times 100\%$$

Dimana :

w_1 = berat kering benda uji + wadah (gram)

w_2 = berat wadah (gram)

w_3 = berat kering benda uji awal (gram)

w_4 = berat kering benda uji setelah pencucian + wadah (gram)

w_5 = berat kering benda uji sesudah pencucian (gram)

w_6 = % bahan lolos saringan No. 200 $(0{,}075 \text{ mm})$

3.3.2.4. Pengujian Berat Jenis dan Penyerapan Air Terhadap Agregat Kasar

Jenis pengujian ini berdasarkan pada metode ASTM C.127, yaitu metode standar untuk menentukan spesific gravity dan absorbsi agregat kasar. Pengujian ini dilakukan untuk mengetahui besarnya berat jenis dan persentase air yang dapat diserap oleh agregat kasar yang akan digunakan dalam campuran beton.

Prosedur pengujian :

1. Benda uji direndam dalam air pada suhu kamar 25°C selama 24 jam.
2. Setelah 24 jam keluarkan benda uji dari air, lap dengan kain penyerap sampai selaput air pada permukaan hilang (jenuh permukaan kering), untuk butir yang besar pengeringan harus dilakukan satu persatu.
3. Timbang benda uji dalam keadaan jenuh permukaan kering (B).
4. Letakkan benda uji di dalam keranjang, goncangkan batunya untuk mengeluarkan gelembung udara yang tersekap dan tentukan beratnya di dalam air (C). Ukur suhu air untuk penyesuaian perhitungan pada suhu kamar 25°C.
5. Masukkan benda uji ke dalam oven pada suhu (110 ± 5)°C sampai berat tetap.
6. Dinginkan benda uji pada suhu kamar selama satu jam sampai tiga jam, kemudian ditimbang dengan ketelitian 0.5 gram (A).

7. Perhitungan :

- Berat Jenis $= \frac{A}{A-C}$

- Berat Jenis SSD $= \frac{B}{B-C}$

- Penyerapan Air $= \frac{B-A}{A} \times 100\%$

3.3.2.5. Pengujian Berat Jenis dan Penyerapan Air Terhadap Agregat Halus

Jenis pengujian ini berdasarkan pada metode ASTM C.128, yaitu metode standar untuk menentukan spesific gravity dan absorbsi agregat halus. Pengujian ini dilakukan untuk mengetahui besarnya berat jenis dan persentase air yang dapat diserap oleh agregat halus yang akan digunakan dalam campuran beton.

Prosedur pengujian :

1. 1000 gram agregat halus yang diperoleh dari alat pemisah contoh atau cara perempat, dikeringkan sampai didapatkan keadaan yang kering merata dari kondisi jenuh air. Agregat halus tersebut disebut kering merata bila telah dapat tercurah.
2. Setelah kondisi tersebut didapat, sebagian dari benda uji dimasukkan pada metal sand cone mold. Benda uji yang telah dimasukkan tadi, dipadatkan dengan tongkat pemadat sampai 25 kali tumbukan. Kondisi yang diinginkan adalah kondisi SSD (*surface dry* condition) yaitu bila cetakan diangkat, maka agregat halus tersebut akan longsor atau runtuh.
3. Sebanyak 500 gram agregat halus yang telah mencapai kondisi SSD, dimasukkan dalam piknometer dan diisi sampai dengan 90% kapasitasnya. Gelembung-gelembung udara dibebaskan dengan cara menggoyang-goyangkan piknometer.
4. Rendam selama 1 hari. Tentukan berat piknometer, benda uji dan air.
5. Pisahkan benda uji dari piknometer dan dikeringkan dalam oven pada suhu (110 ± 5)°C selama 1 hari.
6. Dinginkan benda uji pada suhu kamar selama satu jam sampai tiga jam, kemudian timbang dengan ketelitian 0.5 gram.

7. Tentukan berat piknometer yang telah berisi air sesuai kapasitas kalibrasi
8. Perhitungan :

- Berat Jenis $= \frac{A}{B + A - C}$

- Berat Jenis SSD $= \frac{500}{B + 500 - C}$

- Penyerapan Air $= \frac{500 - A}{A} \times 100\%$

3.3.2.6. Pengujian Analisa Ayakan

Jenis pengujian ini berdasarkan pada metode ASTM C.136, yaitu metode standar untuk analisa saringan agregat kasar dan halus. Pengujian ini dimaksudkan untuk menentukan pembagian butiran (gradasi) agregat kasar dan halus dengan menggunakan saringan.

Prosedur pengujian :

1. Benda uji dikeringkan dalam oven dengan suhu (110 ± 5)°C, sampai berat tetap.
2. Saring benda uji lewat susunan saringan dengan ukuran saringan paling besar ditempatkan paling atas. Saringan digoncang dengan tangan atau mesin penggoncang selama 15 menit.
3. Timbang berat agregat kasar yang terdapat pada masing-masing ayakan.
4. Hitung persentase berat benda uji yang tertahan di atas masing-masing saringan terhadap berat total benda uji.

3.4. RENCANA CAMPURAN BETON

Pada penelitian ini, perhitungan campuran beton dengan menggunakan bahan tambah berupa cacahan limbah botol plastik mengacu pada standar ACI. Sebelum melakukan perancangan campuran, data-data yang dibutuhkan harus dicari terlebih dahulu. Jika data-data yang dibutuhkan tidak ada, maka data tersebut dapat diambil dari tabel-tabel yang telah dibuat untuk menyelesaikan metode perancangan cara ACI.

Pada metode ini, input data perancangan meliputi data standar deviasi hasil pengujian yang berlaku untuk pekerjaan yang sejenis dengan karakteristik yang sama. Data yang digunakan untuk merancang campuran beton dalam metode ini, meliputi data tentang kuat tekan rencana, data butir nominal yang akan digunakan, data slump, berat jenis agregat serta karakteristik lingkungan yang diinginkan.

Prosedur pencampuran :

1. Hitung kuat tekan rata-rata beton, berdasarkan kuat tekan rencana dan margin,
   $f'_{cr} = m + f_c'$
   a. m = 1.64* Sd, standar deviasi diambil berdasarkan data yang lalu, bila tidak ada data, maka dapat diambil dari tabel 3.1 berdasarkan mutu pelaksanaan yang diinginkan.
   b. Kuat tekan rencana (f_c') ditentukan berdasarkan rencana atau dari hasil uji sebelumnya.

Tabel 3.1. Nilai Standar Deviasi

Volume Pekerjaan	Mutu Pelaksanaan (MPa)		
	Baik Sekali	Baik	Cukup
Kecil (<1000 m^3)	4.5 < sd ≤ 5.5	5.5 < sd ≤ 6.5	6.5 < sd ≤ 8.5
Sedang (1000-3000 m^3)	3.5 < sd ≤ 4.5	4.5 < sd ≤ 5.5	5.5 < sd ≤ 7.5
Besar (>3000 m^3)	2.5 < sd ≤ 3.5	3.5 < sd ≤ 4.5	4.5 < sd ≤ 6.5

Sumber : Tri Mulyono, "*Teknologi Beton*", 2003

2. Tetapkan nilai slump, dan butir maksimum agregat
   a. Slump ditentukan. Jika tidak didapat, maka data dapat diambil dari tabel 3.2
   b. Ukuran maksimum agregat dihitung dari 1/3 tebal plat dan atau ¾ jarak bersih antar baja tulangan, tendon, bundle bar, atau ducting dan atau 1/5 jarak terkecil bidang bekisting ambil yang terkecil, jika tidak maka dapat diambil dari tabel 3.3

Tabel 3.2. Nilai Slump yang di Syaratkan untuk Berbagai Konstruksi Menurut ACI

Jenis Konstruksi	Slump (mm)	
	Maksimum*	Minimum
Dinding Penahan dan Pondasi	76.2	25.4
Pondasi sederhana, sumuran dan dinding sub struktur	76.2	25.4
Balok dan dinding beton	101.6	25.4
Kolom struktural	101.6	25.4
Perkerasan dan slab	76.2	25.4
Beton massal	50.8	25.4

Sumber : ACI 318-89

*)dapat ditambahkan sebesar 25.4 mm untuk pekerjaan beton yang tidak menggunakan birator, tetapi mengunakan metode konsolidasi.

Tabel 3.3. Ukuran Maksimum Agregat

Dimensi Minimum (mm)	Balok/kolom (mm)	Plat (mm)
62.5	12.5	20
150	40	40
300	40	80
750	80	80

Sumber : ACI 318-89

3. Tetapkan jumlah air yang dibutuhkan berdasarkan ukuran maksimum agregat dan nilai slump dari tabel 3.4

Tabel 3.4. Perkiraan Air Campuran dan Persyaratan Kandungan Udara untuk Berbagai Slump dan Ukuran Nominal Agregat Maksimum

Dimensi (mm)	Air (lt/m^3)							
	9.5 mm[a)]	12.7 mm[a)]	19.1 mm[a)]	25.4 mm[a)]	38.1 mm[a)]	50.8 mm[ab)]	76.2 mm[bc)]	152.4 mm[bc)]
25.4 s/d 50.8	210	201	189	180	165	156	132	114
76.2 s/d 127	231	219	204	195	180	171	147	126
152.4 s/d 177.8	246	231	216	204	189	180	162	-
Mendekati jumlah kandungan Udara dalam beton air-Entrained (%)	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2
25.4 s/d 50.8	183	177	168	162	150	144	123	108
76.2 s/d 127	204	195	183	177	165	159	135	120
152.4 s/d 177.8	219	207	195	186	174	168	156	-
Kandungan udara total rata-Rata yang disetujui[d)] (%)								
Diekspose sedikit	4.5	4.0	3.5	3.0	2.5	2.0	1.5[ef)]	1.0[ef)]
Diekspose menengah	6.0	5.5	5.0	4.5	4.5	4.0	3.5[ef)]	3.0[ef)]
Sangat ekspose	7.5	7.0	6.0	6.0	5.5	5.0	4.5[ef)]	4.0[ef)]

Sumber : ACI 318-89

Keterangan:

a. Banyaknya air campuran disini dipakai untuk menghitung faktor air semen untuk suatu campuran percobaan (*trial batch*). Harga-harga ini adalah maksimal butirnya 1.5 in (40 mm), untuk suatu agregat kasar bentuk dan gradasinya cukup baik dan dalam batas yang diterima oleh spesifikasi.

b. Nilai slump untuk beton yang mengandung agregat dengan ukuran maksimum 1.5 in (38.1 mm atau 40 mm) ini adalah berdasarkan percobaan-percobaan yang dibuat setelah membuang partikel agregat yang lebih besar dari 38 atau 40 mm

c. Banyaknya air campuran disini dipakai untuk menghitung faktor air semen untuk suatu campuran percobaan (*trial batch*). Jika digunakan butiran maksimum agregat 3 in (76.2 mm) atau 6 in (152.4 mm). Harga-harga ini adalah maksimal untuk suatu agregat kasar bentuk dan gradasinya cukup baik dari halus sampai kasar.

d. Rekomendasi lainnya tentang kandungan air dan toleransi yang diperlukan untuk kontrol dilapangan tercantum dalam sejumlah dokumen ACI, seperti ACI 201, 345, 318, 301, dan 302. Batas-batas kandungan air dalam beton juga diberikan oleh ASTM C-94 untuk beton ready mix. Persyaratan-persyaratan ini bisa saja tidak sama untuk masing-masing peraturan, sehingga perancangan beton perlu ditinjau lebih lanjut dalam menentukan kandungan air yang memenuhi syarat untuk pekerjaan yang juga memenuhi syarat peraturan.

e. Untuk beton yang menggunakan agregat yang lebih besar dari 1.5 in (40 mm) dan tertahan di atasnya, prosentase udara yang diharapkan pada 1.5 in, dikurangi material ditabelkan di kolom 38.1. Akan tetapi, dalam perhitungan komposisi awal seharusnya kandungan udara juga ada sebagai suatu persen keseluruhan.

f. Jika menggunakan agregat besar pada beton dengan FAS besar, gelembung udara yang ada bisa saja tidak mengurangi kekuatan. Dalam banyak hal, persyaratan air campuran akan berkurang jika FAS bertambah, artinya pengaruh reduksi kekuatan akibat air entrained akan berkurang.

g. Harga-harga ini berdasarkan kriteria 9% udara diperlukan pada fase mortar sangat berbeda dengan yang ditentukan dalam rekomendasi praktis ini, besarnya dapat dihitung dengan mengambil 9% dari volume mortar sesungguhnya.

4. Tetapkan nilai faktor air semen dari tabel 3.5, untuk nilai kuat tekan dalam MPa yang berada diantara nilai yang diberikan, maka dapat dilakukan interpolasi.

Tabel 3.5. Nilai Faktor Air Semen

Kekuatan Tekan 28 hari *(MPa)**	FAS	
	Beton Non Air-entrained	Beton Air-entrained
41.4	0.41	-
34.5	0.48	0.4
27.6	0.57	0.48
20.7	0.68	0.59
13.8	0.62	0.74

Sumber : ACI 318-89

*) Untuk harga FAS yang konstan, kekuatan tekan beton akan berkurang jika kandungan udara bertambah. Kekuatan ini berdasarkan beton yang kelembabannya dijaga (curing) pada temperatur 23±1.7^{o}C, sesuai dengan ASTM C-31 ”membuat dan merawat benda uji tekan dan lentur di lapangan” dengan uji silinder diameter 150 mm, tinggi 300 mm.

5. Hitung semen yang diperlukan dari langkah (3) dan (4), yaitu jumlah air dibagi dengan faktor air semen.
6. Tetapkan volume agregat kasar berdasarkan agregat maksimum dan modulus halus butir (MHB) agregat halusnya sehingga didapatkan persen agregat kasar (tabel 3.6). Jika nilai modulus halus butirnya berada diantaranya, maka dapat dilakukan interpolasi. Volume agregat kasar = persen agregat kasar dikalikan dengan berat kering agregat kasar.
7. Estimasikan berat beton segar berdasarkan tabel 3.7, kemudian hitung agregat halus, yaitu berat beton segar – (berat air + berat semen +berat agregat kasar)
8. Hitung proporsi bahan, semen, air, agregat kasar dan agregat halus, kemudian koreksi berdasarkan nilai daya serap air pada agregat
   a. Semen didapat dari langkah (5)
   b. Air didapat dari langkah (3)
   c. Agregat kasar didapat dari langkah (6)
   d. Agregat halus didapat dari langkah (7), dikurang langkah [(3) + (5) + (6)]
9. Koreksi proporsi campurannya

Tabel 3.6. Volume Agregat Kasar Per Satuan Volume Beton

Ukuran Agregat Maks (mm)	Volume Agregat kasar kering * per satuan volume untuk berbagai modulus halus butir			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.7	0.59	0.57	0.55	0.53
19.1	0.66	0.64	0.62	0.60
25.4	0.71	0.69	0.67	0.65
38.1	0.75	0.73	0.71	0.69
50.8	0.78	0.76	0.74	0.72
76.2	0.82	0.80	0.78	0.76
152.4	0.87	0.85	0.83	0.81

Sumber : ACI 318-89

*) Volume ini disarankan atas agregat kasar kondisi kering oven (*dry-rodded*) sesuai dengan ASTM C-29, ”Satuan Berat Agregat”. Volume ini dihasilkan dari hubungan empiris yang menghasilkan beton dengan tingkat kemudahan pengerjaan yang tinggi, cocok untuk beton biasa. Untuk beton yang kurang mudah dikerjakan dalam syarat konstruksi maka nilai ini dapat dinaikan sekitar 40%. Untuk beton yang lebih mudah dikerjakan kandungan agregat kasarnya dapat dikurangi sekitar 10%, apabila nilai slump dan FAS telah dipenuhi.

Tabel 3.7. Estimasi Berat Awal Beton Segar* (kg/m^3)

Ukuran Agregat Maks (mm)	Beton Non Air-entrained	Beton Air-entrained
9.5	2,304	2,214
12.7	2,334	2,256
19.1	2,376	2,304
25.4	2,406	2,340
38.1	2,442	2,376
50.8	2,472	2,400
76.2	2,496	2,424
152.4	2,538	2,472

Sumber : ACI 318-89

*) Harga-harga yang dicantumkan adalah untuk beton dengan semen sedang (Bj 3.14) dan agregat sedang (Bj 2.7). Persyaratan air campuran dengan slump 3-4 in atau 76.2 mm – 12.5 mm, dari tabel 5.5.2, ASTM C.143

3.5. PEMBUATAN BENDA UJI BETON NORMAL

Pada penelitian ini akan dibuat 7 tipe campuran beton normal yang menggunakan bahan tambah dari cacahan limbah botol plastik (PET) dengan persentase yang berbeda-beda. Banyaknya bahan tambah yang digunakan dan benda uji yang dibuat dapat lebih jelas dilihat pada tabel 3.8.

Tabel 3.8. Benda Uji Beton Normal

Kode Benda Uji	Persentase Bahan Tambah PET	Bentuk Benda Uji	Jenis Pengujian	Umur Beton (hari)	Jumlah Benda Uji (buah)
BN_{00} – KTR	0 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{10} – KTR	0.10 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{20} – KTR	0.20 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{30} – KTR	0.30 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{50} – KTR	0.50 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{70} – KTR	0.70 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{100} – KTR	1.00 %	Silinder (15 x 30 cm)	Kuat Tarik Belah	7 & 28	3 + 3 = 6
BN_{00} – KG	0 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
BN_{10} – KG	0.10 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
BN_{20} – KG	0.20 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
BN_{30} – KG	0.30 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
BN_{50} – KG	0.50 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
BN_{70} – KG	0.70 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
BN_{100} – KG	1.00 %	Double L (20 x 30 x 7,5 cm)	Kuat Geser	28	3
JUMLAH TOTAL BENDA UJI					63

Prosedur dalam membuat benda uji beton normal, baik dalam membuat benda uji berbentuk double L maupun benda uji yang berbentuk silinder, mengacu kepada standar ASTM. Prosedur tersebut dapat diuraikan menjadi 3 tahapan, yaitu :

1. Pengadukan

1. Bahan baku disiapkan dan ditimbang sesuai proporsi berat yang telah ditentukan.
2. Agregat kasar dan halus bersama dengan bahan tambah yang berupa cacahan limbah botol plastik (PET) dimasukkan seluruhnya ke dalam mesin pengaduk, kemudian nyalakan mesin. Kedua jenis agregat bersama dengan bahan tambah tersebut diaduk hingga merata.
3. Mesin dimatikan, lalu dimasukkan semen dan 2/3 dari bagian air dan mesin dinyalakan kembali.
4. Setelah 2 menit, mesin dimatikan dan material yang berada didasar mesin serta yang belum teraduk, diaduk kembali dengan menggunakan sendok semen.

5. Setelah itu, mesin dijalankan kembali selama 2 menit sambil menuangkan sisa air.
6. Setelah semua material campuran dimasukkan ke dalam mesin, aduklah beton selama 3 menit. Hentikan mesin, tutup mesin dan proses pengadukan telah selesai.

2. Pencetakan Benda Uji

1. Cetakan disiapkan, sebelumnya diberi pelumas terlebih dahulu pada bagian dinding dalam cetakan agar memudahkan pada waktu melepas benda uji dari cetakan.
2. Adukan beton dimasukkan ke cetakan dalam 3 lapisan.
3. Dilakukan pemadatan dengan cara penusukan yang menggunakan tongkat pemadat sebanyak 25 kali untuk tiap lapisan dan digetarkan.
4. Pada lapisan akhir ditambahkan adukan beton sampai melebihi permukaan agar tidak perlu penambahan kembali setelah beton dipadatkan.
5. Kemudian permukaan beton diratakan dan didiamkan pada udara terbuka selama 24 jam hingga beton mengeras, dan menghindari adanya hubungan langsung dengan air.

3. Perawatan (*curing*)

1. Perawatan dilakukan dengan cara merendam benda uji yang telah mengeras dalam bak air selama batas umur beton yang ditentukan untuk dilakukan pengujian.
2. Pada benda uji diberi kode sesuai dengan persentase bahan tambah dan jenis pengujian maupun tanggal. Hal ini dimaksudkan untuk memudahkan identifikasi, sehingga tidak akan menyulitkan pada waktu akan dilakukan pengujian.
3. Suhu air rata-rata pada bak perendaman benda uji tersebut harus berkisar antara 25-27°C.

3.6. PENGUJIAN BETON

Pengujian beton normal yang dilakukan pada penelitian ini, meliputi pengujian terhadap beton segar yang berupa pengujian slump. Sedangkan pengujian terhadap beton yang telah mengeras meliputi pengujian kuat tarik belah dan kuat geser beton normal.

3.6.1. Metode Standar Pengujian Beton

Pengujian terhadap beton normal berdasarkan pada standar ASTM C.330-00, "*Standard Spesification for Lightweight for Structural Concrete*". Dimana pada standar ASTM C.330-00 terdapat beberapa macam pengujian yang biasa dilakukan terhadap beton normal, diantaranya, yaitu :

ASTM C-496	Metode standar untuk test kuat tarik belah dari silinder beton.
ASTM C-143	Metode standar untuk pengukuran slump dari beton semen portland
ASTM C-192	Metode standar untuk pembuatan benda uji dan pemeliharaan

3.6.2. Pengujian Beton Segar

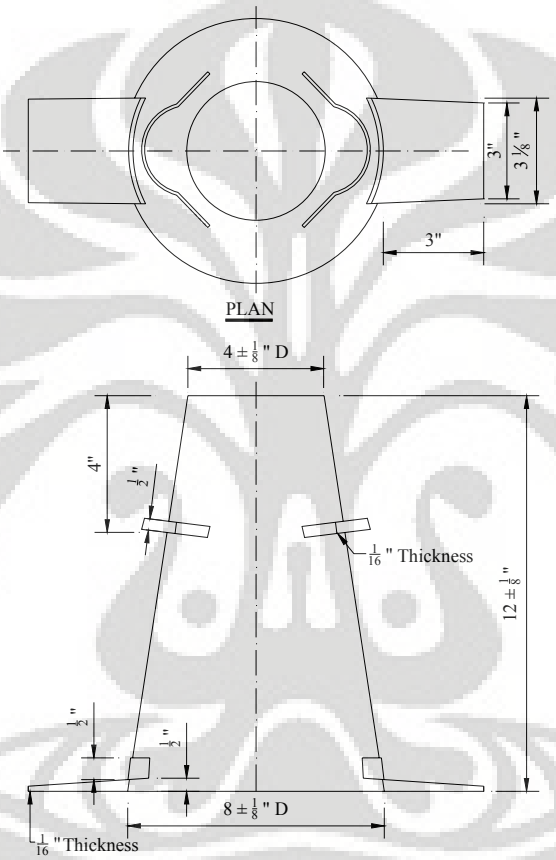
3.6.2.1. Pengujian Slump

Jenis pengujian ini berdasarkan pada metode ASTM C-143, yaitu metode standar untuk pengukuran slump dari beton semen portland. Pengujian ini dimaksudkan untuk mengukur kekentalan adukan beton yang dihasilkan pada setiap proses pengadukan. Kekentalan beton berpengaruh pada kemudahan pengerjaan (*workability*) dari beton. Adukan ini diambil langsung dari mesin pengaduk.

Prosedur pengujian :

1. Sebelumnya alat-alat yang akan digunakan pada pengujian ini, dibasahi permukaannya. Hal ini dimaksudkan untuk menghindari adanya penyerapan air dari campuran beton.
2. Kerucut Abrams diletakkan di atas bidang alas yang rata sambil ditekan ke bawah pada penyokongnya.

3. Adukan beton dimasukkan ke dalam kerucut dalam 3 lapis yang sama dan setiap lapis ditusuk-tusuk sebanyak 25 kali dengan tongkat baja.
4. Setelah selesai, permukaan atasnya diratakan dan dibiarkan selama 30 detik.
5. Kemudian kerucut ditarik vertikal ke atas dengan hati-hati.
6. Segera setelah penurunan kerucut terhadap tinggi semula diukur.
7. Hasil pengukuran tersebut disebut nilai slump.



Dimensional Units									
in.	1/16	1/8	1/2	1	3	3 1/2	4	8	12
mm	[2]	[3]	[13]	[25]	[75]	[88]	[100]	[200]	[300]

Gbr. 3.1. Kerucut Abrams
Sumber : ASTM C-143

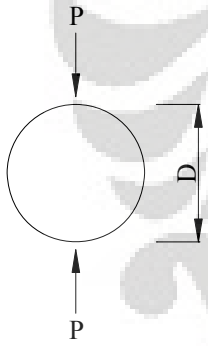
3.6.3. Pengujian Beton Yang Telah Mengeras

Pengujian yang akan dilakukan pada beton yang telah mengeras adalah untuk mengetahui besarnya kekuatan tarik belah dan kuat geser beton untuk masing-masing persentase kadar penambahan PET pada benda uji.

3.6.3.1.Pengujian Kuat Tarik Belah

Jenis pengujian ini berdasarkan pada metode ASTM C-496, yaitu metode standar untuk test kuat tarik belah dari silinder beton. Bentuk benda uji yang digunakan pada pengujian ini bentuknya sama dengan benda uji pada pengujian kuat tekan yaitu berupa silinder ukuran 15 x 30 cm. Pada penelitian ini pengujian hanya dilakukan pada umur beton 7 dan 28 hari. Untuk masing-masing tipe percobaan akan digunakan 6 buah benda uji, dimana 3 buah untuk umur beton 7 hari dan 3 buah lagi untuk umur beton 28 hari.

Langkah-langkah pengujiannya sama seperti pengujian pada kuat tekan. Yang membedakannya adalah pada pengujian ini mesin tekan ditambahkan dengan suatu lempengan pelat besi, yang berfungsi agar dapat membagi beban merata pada panjang silinder. Sebatang kayu lapis sepanjang 25 mm dan tebal 3 mm disisipkan diantara silinder dengan muka atas dan bawah landasan mesin tekan. Besarnya beban maksimum dicatat. Besarnya tegangan tarik belah beton dapat dihitung sebagai berikut :



$$f_{tr} = \frac{2P}{\pi DL}$$

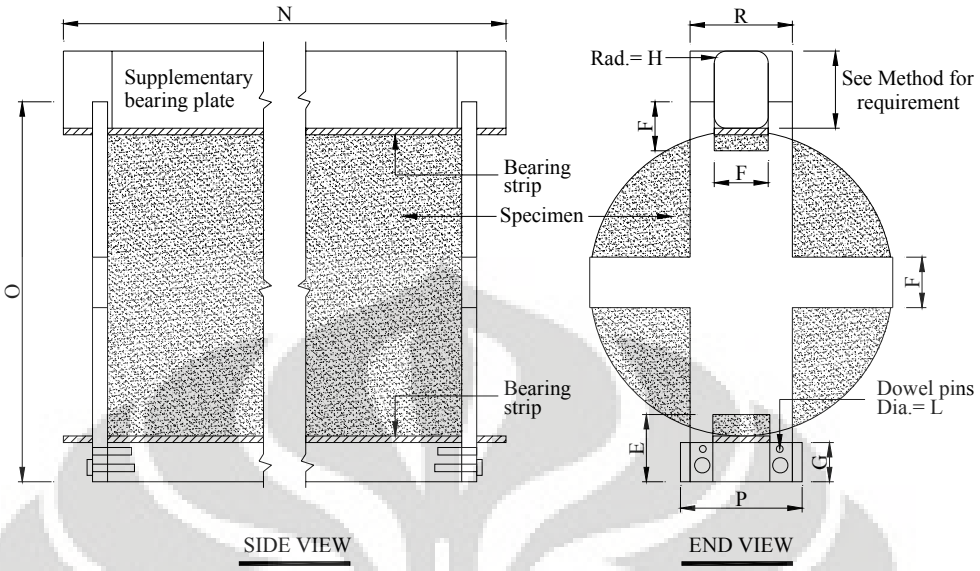
Dimana :

f_{tr} = tegangan tarik belah (kg/cm^2 ; MPa)

P = beban maksimum yang diberikan (kg ; kN)

L = panjang silinder beton (cm ; mm)

D = dimeter silinder beton (cm ; mm)



N	O	P	R	E	F	G	H	L
15 in.	7 1/2 in.	2 1/2 in.	2 in.	1 1/4 in.	1 in.	3/4 in.	1/2 in.	1/8 in.
375 mm	190 mm	65 mm	50 mm	32 mm	25 mm	20 mm	13 mm	3 mm

Gbr. 3.2. Detail jig pada benda uji
Sumber : ASTM C-496

3.6.3.2.Pengujian Kuat Geser

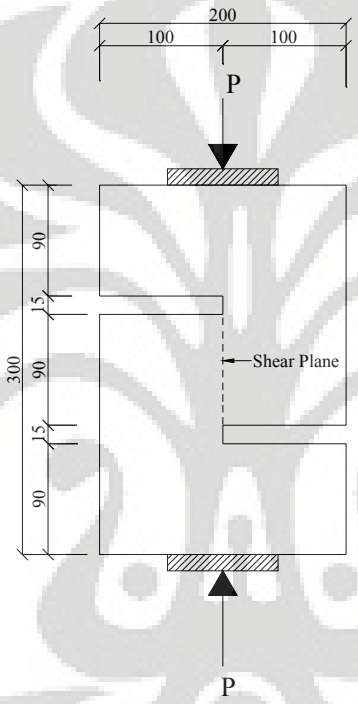
Benda uji yang digunakan adalah berupa double L, yang mana di dalamnya telah diberi tulangan sebagai reinforcement. Tulangan ini dimaksudkan untuk memperkuat sisi benda uji double L yang tidak diharapkan untuk hancur, sehingga kehancuran yang terjadi hanya terletak pada daerah lemah benda uji double L, yaitu pada garis sentris di tengah benda uji. Tulangan yang digunakan yaitu berupa baja ∅ 8 mm dan sengkangnya menggunakan baja ∅ 6 mm.

Pada penelitian ini pengujian terhadap kuat geser dilakukan dengan menggunakan alat tekan standar yang biasa digunakan pada pengujian kuat tekan. Pengujian hanya dilakukan pada umur beton 28 hari dan untuk masing-masing tipe percobaan akan digunakan tiga buah benda uji.

Adapun prosedur dalam melakukan pengujian kuat geser, yaitu :

- Benda uji double L yang akan diuji diambil dari tempat perawatan satu hari sebelum pengujian akan dilaksanakan.
- Permukaan atas dan bawah benda uji sebelumnya dibersihkan terlebih dahulu dari kotoran dengan amplas halus.

- Setelah proses pembersihan permukaan benda uji telah selesai, maka dapat dilakukan pengujian. Benda uji berbentuk double L tersebut kemudian diletakkan pada mesin tekan dan berada pada posisi sentris.
- Mesin tekan kemudian dijalankan dengan penambahan beban yang tetap.
- Pembebanan dilakukan sampai benda uji double L menjadi hancur dan dicatat besarnya beban maksimum (*P*).



Gbr. 3.3. Pembebanan pada benda uji double L

BAB IV
HASIL DAN ANALISA DATA PENELITIAN

Dalam penelitian ini dilakukan pengujian terhadap bahan baku pembentuk beton, pengujian beton segar dan pengujian beton yang telah mengeras. Dari hasil pengujian yang telah dilakukan, selanjutnya data yang telah diperoleh akan dianalisa terhadap kuat tarik belah benda uji dan kuat geser benda uji dengan variasi campuran cacahan-cahan botol plastik (PET) yang berbeda-beda. Bahan baku pembentuk beton hanya akan dibahas secara umum, berupa rangkuman hasil pengujian dan spesifikasi yang telah ditetapkan.

4.1. Analisa Bahan Baku Pembentuk Beton

Pengujian bahan baku pembentuk beton hanya dilakukan terhadap agregat halus dan agregat kasar, sedangkan untuk semen, air dan bahan tambahan yang berupa cacahan-cacahan botol plastik (PET) tidak dilakukan. Dilakukannya pengujian terhadap agregat kasar dan halus disebabkan karena kedua jenis bahan baku pembentuk beton tersebut didapatkan tanpa ada spesifikasinya, sehingga ada kemungkinan tercampur dengan bahan-bahan tertentu yang dapat mempengaruhi kekuatan beton. Semen diperoleh dari pabrik, sedangkan air yang berasal dari PAM sudah memenuhi standar yang diberikan. Pengujian terhadap bahan tambah dilakukan hanya untuk mengetahui berat jenis material tersebut, sedangkan besarnya parameter nilai lainnya didapatkan dari literatur yang ada. Hasil pengujian terhadap agregat halus dan kasar yang telah dilakukan dapat dilihat pada lampiran dan kedua jenis material tersebut telah memenuhi standar spesifikasi dari ASTM.

4.2. Analisa Hasil Pengujian Beton Segar

Pengujian beton segar dilakukan melalui pengujian slump yang dilakukan untuk menunjukkan tingkat konsistensi adukan beton dari tiap-tiap tipe percobaan. Dengan melakukan pengujian ini maka akan dapat dilihat pengaruh penambahan bahan tambah yang berupa cacahan botol plastik (PET) dalam adukan beton terhadap kemudahan

dalam pekerjaan. Dari pengujian yang telah dilakukan diketahui bahwa penambahan cacahan botol plastik (PET) dalam adukan beton akan cenderung menurun dalam nilai slump dengan semakin meningkatnya persentase bahan tambah cacahan botol plastik (PET). Dengan semakin menurunnya nilai slump menunjukkan bahwa bilamana bahan tambah ini dicampur dalam adukan beton dengan persentase bahan tambah yang meningkat, maka akan semakin menyulitkan dalam pekerjaan. Besarnya nilai slump yang semakin menurun dapat dilihat pada tabel. 4.1.

Tabel 4.1. Slump vs cacahan PET

Cacahan PET (%)	Slump (cm)
0	9
	8
	10
0,1	8,5
	8,5
	8,5
0,2	8
	8
	8
0,3	10
	8,5
	10,5
0,5	9
	8
	8,5
0,7	7,5
	6
	7
1,0	5,5
	8
	5

4.3. Analisa Hasil Pengujian Beton Yang Telah Mengeras

Pada beton yang telah mengeras, dalam hal ini beton tersebut sudah berumur 7 hari dan 28 hari untuk benda uji yang berbentuk silinder, dilakukan pengujian kuat tarik belah. Sedangkan untuk pengujian kuat geser pada benda uji berbentuk double L dilakukan untuk umur 28 hari. Data yang diperoleh dari kedua jenis pengujian

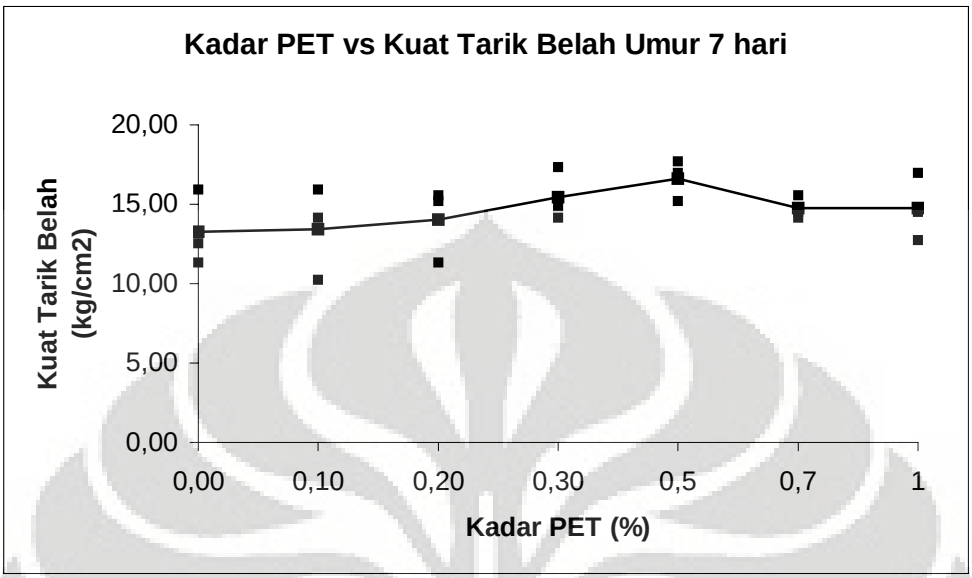
kemudian dibuat grafik dan dianalisa sehingga didapatkan pengaruh penambahan cacahan botol plastik (PET) dengan variasi campuran yang berbeda-beda.

4.3.1. Kuat Tarik Belah

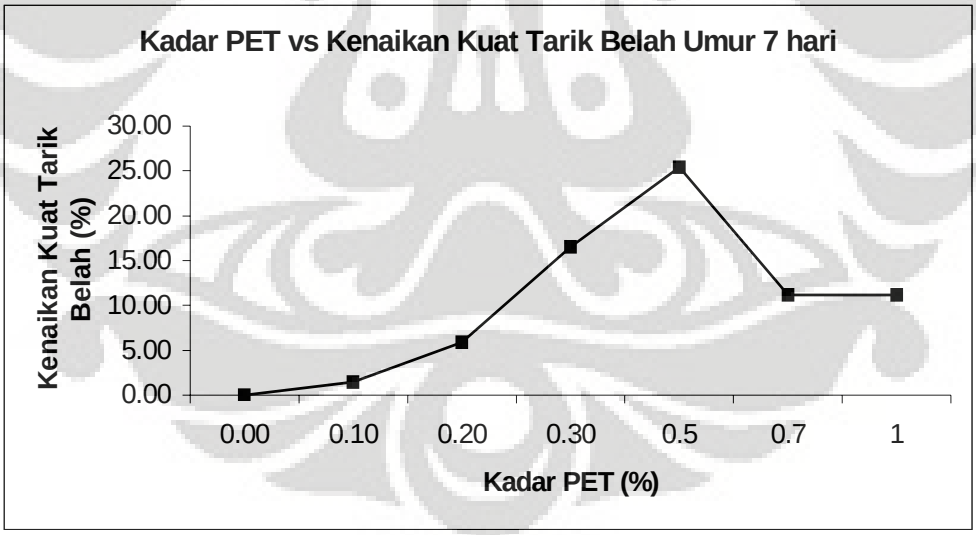
Dari pengujian kuat tarik belah terhadap 7 (tujuh) tipe campuran bahan tambah yang berupa cacahan botol plastik (PET) yang telah dilakukan, dapat dilihat bahwa dengan semakin bertambahnya bahan tambah yang dicampur dalam adukan beton sampai kadar volume sebesar 0,7% terdapat penambahan kekuatan, namun dengan kadar volume sebesar 1% terjadi penurunan. Data dan hasil pengujian serta persentase kenaikan yang terjadi pada pengujian kuat tarik belah pada umur 7 hari maupun 28 hari selengkapnya dapat dilihat pada tabel.4.2 dan 4.3.

Tabel 4.2. Hasil Pengujian Kuat Tarik Belah Umur 7 Hari

Kadar PET (%)	Beban (kg)	Kuat Tarik Belah (kg/cm^2)	Kuat Tarik Belah Rata-rata (kg/cm^2)	Kenaikan (%)
0,00	8.850	12,53	13,26	-
	11.250	15,92		
	8.000	11,32		
0,10	7.250	10,26	13,45	1,42
	10.000	14,15		
	11.250	15,92		
0,20	11.000	15,57	14,04	5,87
	10.750	15,22		
	8.000	11,32		
0,30	10.500	14,86	15,45	16,55
	12.250	17,34		
	10.000	14,15		
0,50	10.750	15,22	16,63	25,44
	12.000	16,99		
	12.500	17,69		
0,70	10.000	14,15	14,74	11,21
	11.000	15,57		
	10.250	14,51		
1,00	10.250	14,51	14,74	11,21
	9.000	12,74		
	12.000	16,99		



Gbr 4.1. Grafik Kadar PET vs Kuat Tarik Belah umur 7 hari

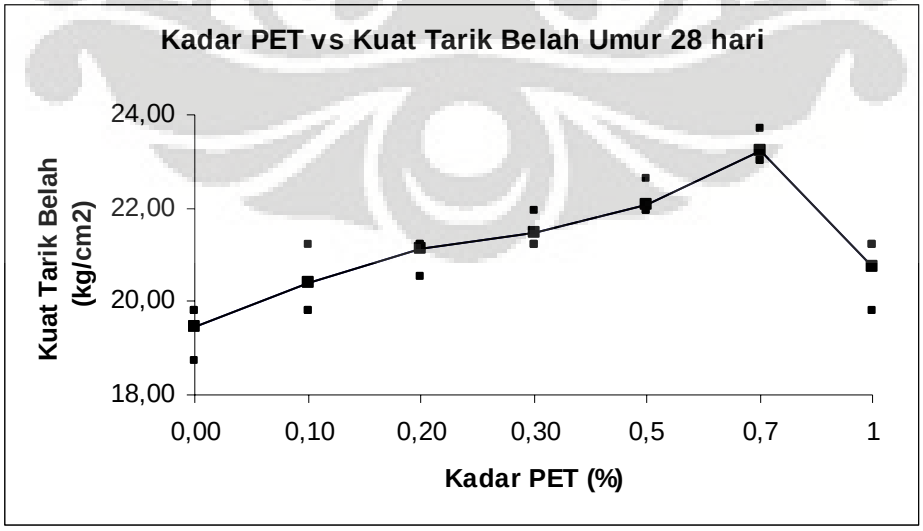


Gbr 4.2. Grafik Kadar PET vs Kenaikan Kuat Tarik Belah Umur 7 hari

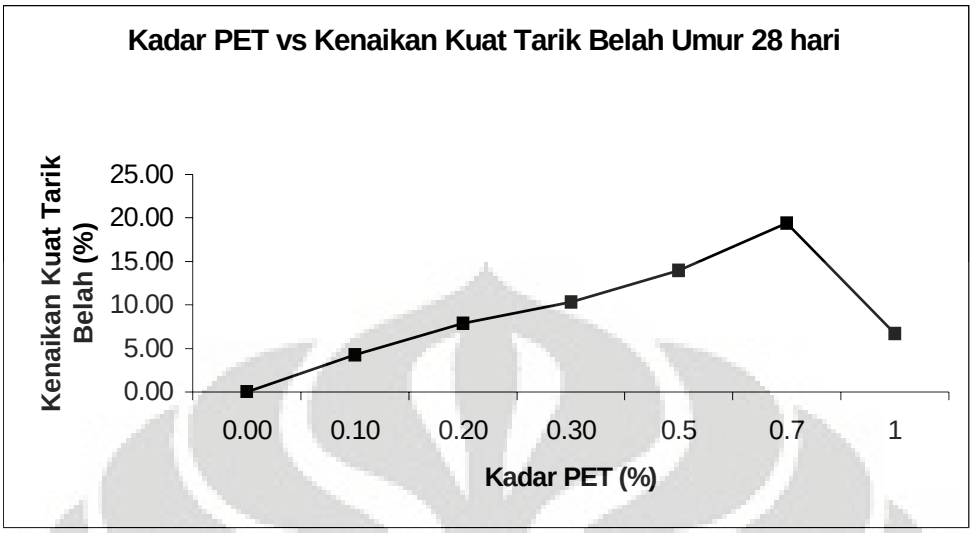
Pola retak yang terjadi dapat dilihat pada lampiran D1 – D10, keretakan terjadi pada bidang yang diharapkan dan dari lampiran tersebut terlihat bahwa PET menyatu dengan campuran beton.

Tabel 4.3. Hasil Pengujian Kuat Tarik Belah Umur 28 Hari

Kadar PET (%)	Beban (kg)	Kuat Tarik Belah (kg/cm^2)	Kuat Tarik Belah Rata-rata (kg/cm^2)	Kenaikan (%)
0,00	14.000	19,82	19,46	-
	13.250	18,75		
	14.000	19,82		
0,10	14.250	20,17	20,41	4,85
	15.000	21,23		
	14.000	19,82		
0,20	15.000	21,23	21,11	8,48
	15.250	21,59		
	14.500	20,52		
0,30	14.750	20,88	21,47	10,30
	15.500	21,94		
	15.250	21,59		
0,50	15.250	21,59	22,06	13,33
	16.000	22,65		
	15.500	21,94		
0,70	16.750	23,71	23,24	19,39
	16.250	23,00		
	16.250	23,00		
1,00	15.000	21,23	20,76	6,67
	15.000	21,23		
	14.000	19,82		



Gbr 4.3. Grafik Kadar PET vs Kuat Tarik Belah umur 28 hari

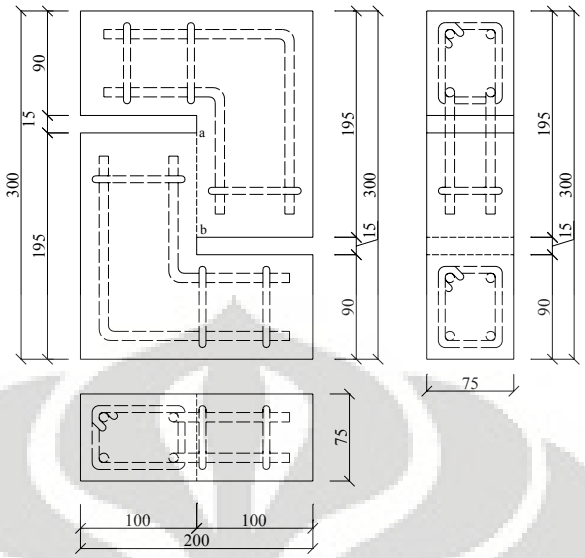


Gbr 4.4. Grafik Kadar PET vs Kenaikan Kuat Tarik Belah Umur 28 hari

4.3.2. Kuat Geser

Dari pengujian geser terhadap 7 (tujuh) tipe campuran bahan tambah yang berupa cacahan botol plastik (PET) yang telah dilakukan, dapat dilihat bahwa dengan semakin bertambahnya bahan tambah PET yang dicampur dalam adukan beton sampai kadar volume sebesar 0,5% terdapat penambahan kekuatan, namun dengan kadar volume sebesar 0,7% - 1% terjadi penurunan. Data dan hasil pengujian serta persentase kenaikan yang terjadi pada pengujian kuat tarik belah pada umur 28 hari selengkapnya dapat dilihat pada tabel 4.3.

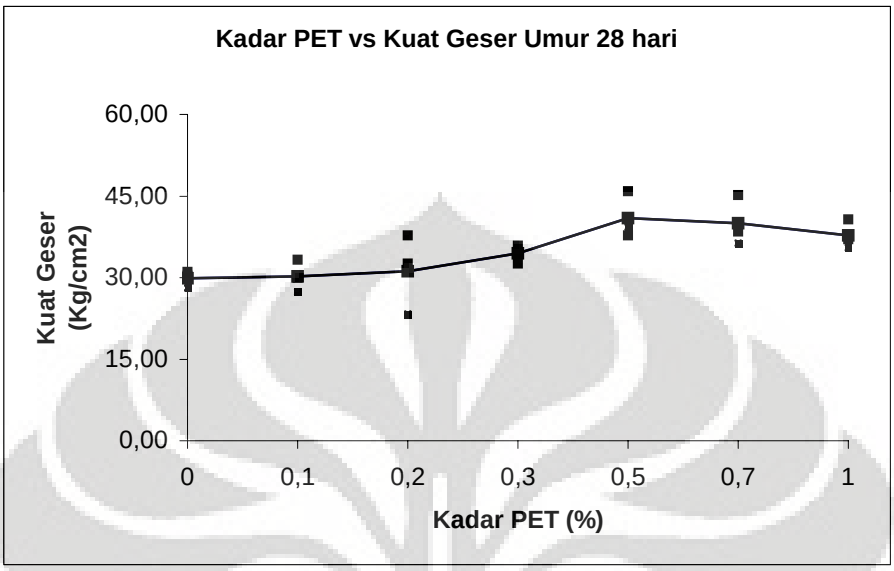
Gambar benda uji double L dapat dilihat pada gambar 4.5. dimana terdapat tulangan sebagai reinforcement pada sisi yang berbeda. Keretakan diharapkan terjadi pada bidang a-b, yaitu bidang yang tidak terdapat tulangannya. Tulangan yang digunakan yaitu ϕ8 mm sebagai tulangan utama dan ϕ6 mm yang berfungsi sebagai sengkang.



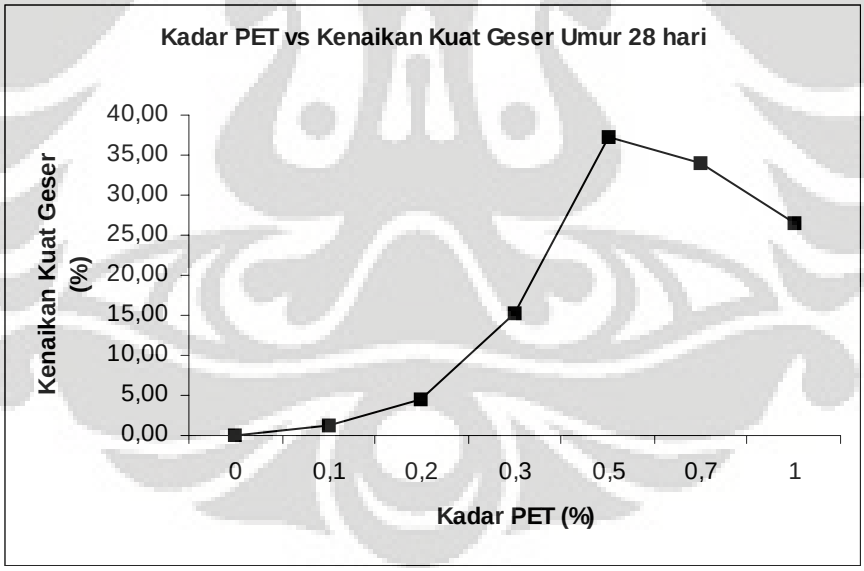
Gbr 4.5. Gambar Benda Uji Double L

Tabel 4.4. Hasil Pengujian Kuat Geser Umur 28 Hari

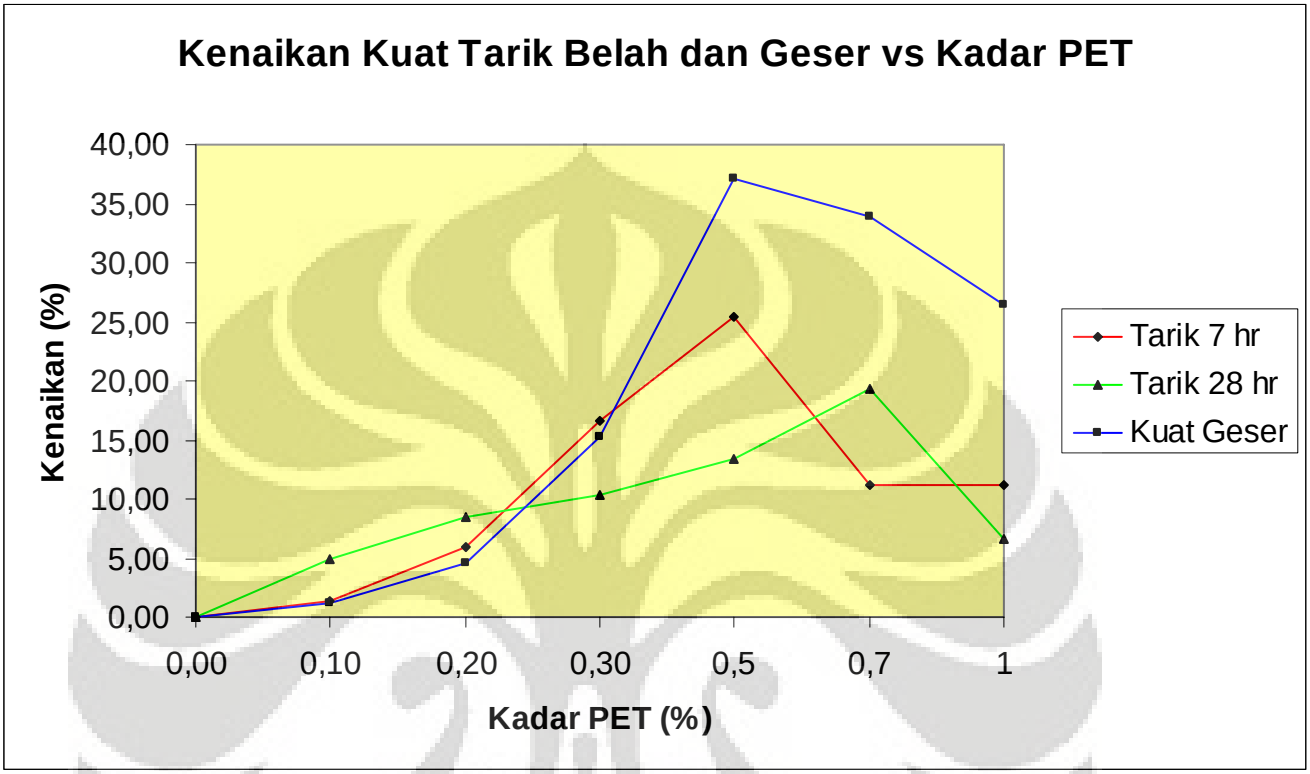
Kadar PET (%)	Beban (kg)	Kuat Geser (kg/cm^2)	Kuat Geser Rata-rata (kg/cm^2)	Kenaikan (%)
0,00	1.900	28,15	29,88	-
	2.050	30,37		
	2.100	31,11		
0,10	1.850	27,41	30,25	1,24
	2.025	30,00		
	2.250	33,33		
0,20	1.575	23,33	31,23	4,55
	2.200	32,59		
	2.550	37,78		
0,30	2.350	34,81	34,44	15,29
	2.425	35,93		
	2.200	32,59		
0,50	2.650	39,26	40,99	37,19
	3.100	45,93		
	2.550	37,78		
0,70	2.450	36,30	40,00	33,88
	2.600	38,52		
	3.050	45,19		
1,00	2.400	35,56	37,78	26,45
	2.500	37,04		
	2.750	40,74		



Gbr 4.6. Grafik Kadar PET vs Kuat Geser Umur 28 hari



Gbr 4.7. Grafik Kadar PET vs Kenaikan Kuat Geser Umur 28 hari



Gbr 4.8. Grafik Kadar PET vs Kenaikan Kuat Tarik Belah dan Kuat Geser

4.3.2.1 Pola Retak Kuat Geser Pada Benda Uji Double L

Pola retak pada benda uji double L dapat dilihat pada gambar di bawah ini. Dari hasil keseluruhan pengujian pada benda uji, keretakan yang terjadi pada bidang yang diharapkan yaitu pada bagian yang tidak diberi tulangan, walaupun terjadi sedikit penyimpangan. Sebaiknya sebelum dilakukan pengujian, diberikan coakan pada bidang yang diharapkan terjadi retak supaya keretakan terjadi dengan baik.

Gbr 4.9. Pola Retak Pada Benda Uji Kadar PET 0,1%

Gbr 4.10. Pola Retak Pada Benda Uji Kadar PET 0,2%

Gbr 4.11. Pola Retak Pada Benda Uji Kadar PET 0,3%

Gbr 4.12. Pola Retak Pada Benda Uji Kadar PET 0,5%

Gbr 4.13. Pola Retak Pada Benda Uji Kadar PET 1,0%

BAB V
KESIMPULAN DAN SARAN

5.1. Kesimpulan

Dari hasil penelitian dilaboratorium mengenai pengaruh pencampuran cacahan botol plastik (PET) dalam campuran beton terhadap kuat tarik belah dan kuat geser, maka dapat disimpulkan hal-hal sebagai berikut :

1. Penambahan kadar PET dalam adukan beton sampai kadar optimum 0,5% dari volume fraksi pada umur 7 hari, akan meningkatkan kekuatan tarik belah pada beton maksimum sebesar 25,44%, sedangkan pada umur 28 hari penambahan kadar PET sampai dengan kadar optimum 0,7% akan meningkatkan kekuatan tarik belah pada beton maksimum sebesar 19,39%.
2. Penambahan kadar PET dalam adukan beton sampai kadar optimum 0,5% dari volume fraksi pada umur 28 hari, akan meningkatkan kekuatan geser pada beton maksimum sebesar 37,19%.
3. Dengan penambahan kadar PET yang semakin meningkat, akan mengakibatkan penurunan pada nilai slump. Hal ini akan mengakibatkan beton dengan penambahan kadar PET yang besar akan sulit dilakukan dilapangan.
4. Dengan terbukti bahwa pemakaian cacahan-cacahan botol plastik (PET) dalam campuran beton dapat meningkatkan kekuatan pada beton normal, maka bahan tambah jenis ini dapat digunakan pada lapangan sesuai dengan kebutuhan konstruksinya. Dengan menggunakan cacahan-cacahan botol plastik (PET) pada campuran beton, maka selain dapat meningkatkan kekuatan pada beton juga dapat mengurangi limbah plastik yang ada.

4.2. Saran-saran

Dari hasil penelitian tentang studi penambahan cacahan-cacahan botol plastik (PET) dalam campuran beton, dapat dikemukakan saran-saran untuk penelitian lebih lanjut, yaitu :

1. Melakukan penelitian untuk beton mutu tinggi dengan penambahan kadar PET yang sama dalam volume fraksi. Dengan melakukan penelitian terhadap beton mutu tinggi tersebut diharapkan dapat diketahui pengaruh penambahan cacahan botol plastik (PET) terhadap beton mutu tinggi.
2. Hal yang sama dapat diterapkan pada beton ringan dengan penambahan kadar PET yang sama dalam volume fraksi. Walaupun penggunaan PET sebagai agregat pernah dilakukan, namun pemakaiannya sebagai bahan tambah belum pernah dilakukan, sehingga dapat diketahui apakah pemakaiannya juga dapat meningkatkan kekuatan pada beton seperti pemakaian PET sebagai agregat.
3. Dengan melakukan penelitian yang sama, dapat pula dilakukan terhadap botol plastik bekas pelumas kendaraan bermotor. Botol pelumas kendaraan bermotor merupakan salah satu produk polymer yang sering kita jumpai, polymer ini masuk dalam kategori HDPE (*high density polyethylene*).
4. Menggunakan pengaduk beton/molen dengan kapasitas yang lebih besar untuk penelitian selanjutnya, agar kadar PET yang berbeda dapat dilakukan dalam satu adukan sehingga homogenitas menjadi lebih baik.
5. Menggunakan admixture dalam penelitian selanjutnya, sehingga penambahan kadar PET dapat dilakukan untuk kadar persentase yang lebih besar.
6. Menggunakan botol plastik PET yang permukaannya dibuat menjadi kasar terlebih dahulu dan potongan botol yang digunakan lebih panjang dan seragam (2 – 5 cm). Dengan ini diharapkan hasilnya mungkin akan lebih baik dan lebih homogen.
7. Melakukan penelitian terhadap properti material botol plastik berbahan dasar PET, baik terhadap sifat fisik maupun mekaniknya, seperti kuat leleh, kuat tarik, dan lainnya, sehingga didapatkan data yang lengkap dan hasil yang didapatkan akan menjadi lebih baik lagi.

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LABORATORIUM : KONSTRUKSI BETON & BAJA

TEST OF SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

Sample : Pasir
Source : Cimangkok
Date tested : 16 November 2008

	I	II
A) Weight of oven - dry specimen in air (gr)	450	452
B) Weight of pycnometer Filled with water (gr)	670	663
C) Weight of pycnometer with specimen and water to Calibration mark (gr)	957	951
Bulk Specific Gravity $= \frac{A}{B+500-C}$	2,113	2,132
Average of above	2,122	
Bulk Specific Gravity (Saturated Surface Dry Basis) $= \frac{500}{B+500-C}$	2,347	2,358
Average of above	2,353	
Apparent Specific Gravity $= \frac{A}{B+A-C}$	2,761	2,756
Average of above	2,758	
Absorption (%) $= \frac{500-A}{A} \times 100\%$	11,111	10,619
Average of above (%)	10,865	

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LABORATORIUM : KONSTRUKSI BETON & BAJA

TEST FOR UNIT WEIGHT AND VOIDS IN AGGREGATE

Sample : Pasir
Source : Cimangkok
Date tested : Maret 2008

		I	II
a) Weight of Measure	(kg)	1,055	1,055
b) Weight of Measure + Water	(kg)	3,055	3,055
c) Weight of Measure and Sample	(kg)	3,698	3,640
d) Weight of Sample	(kg)	2,643	2,585
e) Volume of Measure	(liter)	2	2
f) Unit weight of aggregate	(kg/liter)	1,322	1,293
B) Average of above	(kg/liter)	1,307	
A) Bulk Spesific Gravity of Aggregate		2,122	
W) Unit Weight of Water	(kg/liter)	0,998	
Average	(%)	38,295	
$d = c - a$ $e = b - a$ $f = \frac{d}{e}$		Void (%) $\frac{(A \times W) - B}{(A \times W)} \times 100\%$	

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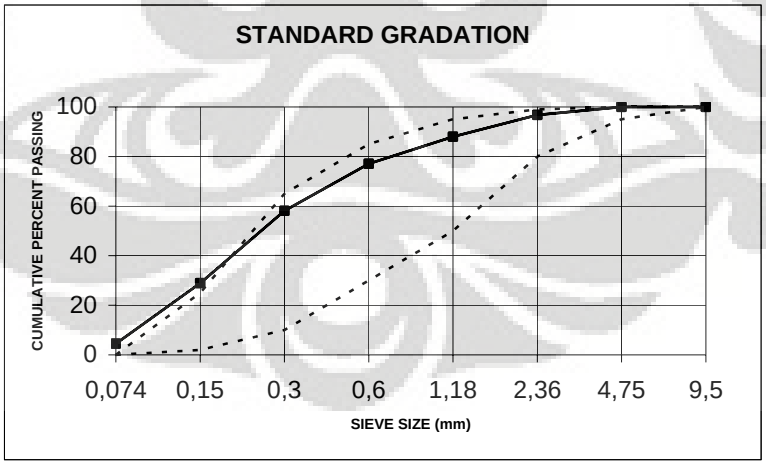
LABORATORIUM : KONSTRUKSI BETON & BAJA

SIEVE ANALYSIS OF FINE AGGREGATE

Sample : Pasir Alam
Source : Cimangkok
Date tested : 16 November 2006

Sieve Size (mm)	Sample No.1			Sample No.2			Average		
	Weight Ret Grams	Ind % Ret	Cum % Ret	Weight Ret Grams	Ind % Ret	Cum % Ret	Ind % Ret	Cum % Ret	Average Passing %
4,75	-	-	-	-	-	-	-	-	100
2,36	18,0	3,6	3,6	14,0	2,8	2,8	3,2	3,2	96,8
1,18	42,0	8,4	12,0	46,0	9,2	12,0	8,8	12,0	88,0
0,60	55,0	11,0	23,0	54,0	10,8	22,8	10,9	22,9	77,1
0,30	95,0	19,0	42,0	95,0	19,0	41,8	19,0	41,9	58,1
0,15	147,0	29,4	71,4	145,0	29,0	70,8	29,2	71,1	28,9
0,074	121,0	24,2	95,6	123,0	24,6	95,4	24,4	95,5	4,5
PAN	22,0	4,4	100,0	23,0	4,6	100,0	4,5	100,0	0,0
FM	2,476			2,428			2,466		



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LABORATORIUM : KONSTRUKSI BETON & BAJA

TEST FOR ORGANIC IMPURITIES IN FINE AGGREGATE

(ASTM C 40-92)

Sample : Pasir
Source : Cimangkok
Date tested : Maret 2008

Nearest Colour of the liquid of the test sample	Organic plate Number
Lighter / Equal / Darker Colour to	1
	(2)
	3 (Standard)
	4
	5

Determination of Colour Value :

Lighter / Equal / Darker Colour to that the reference standard (No.3)

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LABORATORIUM : KONSTRUKSI BETON & BAJA

TEST FOR MATERIALS FINER THAN NO. 200 SIEVE IN MINERAL AGGREGATE BY WASHING

Sample : Pasir Alam
Source : Cimangkok
Date tested : Maret 2008

		I	II
B) Original dry weight of sample	(gr)	500	500
C) Dry weight of sample, after washing	(gr)	492	493
A) Percentage of material finer than a No. 200 sieve, by washing	(%)	1,600	1,400
Average above	(%)	1,500	

$$A = \frac{B - C}{B} \times 100\%$$

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LABORATORIUM : KONSTRUKSI BETON & BAJA

TEST OF SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE

Sample : Agregat Kasar
Source : -
Date tested : November 2007

	I	II
A) Weight of oven - dry specimen in air (gr)	4816	4865
B) Weight of ssd specimen in air (gr)	5000	5000
C) Weight of saturated specimen in water (gr)	3046	3074
Bulk Specific Gravity $= \frac{B}{B-C}$	2,559	2,596
Average of above	2,578	
Apparent Specific Gravity $= \frac{A}{A-C}$	2,721	2,716
Average of above	2,719	
Absorption (%) $= \frac{B-A}{A} \times 100\%$	3,821	2,775
Average of above (%)	3,295	

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LABORATORIUM : KONSTRUKSI BETON & BAJA

TEST FOR UNIT WEIGHT AND VOIDS IN AGGREGATE

Sample : Agregat Kasar
Source : -
Date tested : November 2006

		I	II
a) Weight of Measure	(kg)	5,089	5,089
b) Weight of Measure + Water	(kg)	14,361	14,361
c) Weight of Measure and Sample	(kg)	19,65	19,56
d) Weight of Sample	(kg)	14,561	14,471
e) Volume of Measure	(liter)	9,272	9,272
f) Unit weight of aggregate	(kg/liter)	1,570	1,561
B) Average of above	(kg/liter)	1,566	
A) Bulk Spesific Gravity of Aggregate		2,578	
W) Unit Weight of Water	(kg/liter)	0,998	
Voids	(%)	39,17	
$d = c - a$ $e = b - a$ $f = \frac{d}{e}$		Void (%) $\frac{(A \times W) - B}{(A \times W)} \times 100\%$	

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MIX DESAIN

Mix desain dibuat berdasarkan kriteria sebagai berikut:

- Volume pekerjaan kurang dari 1000 m^3
- Untuk konstruksi balok ataupun pelat dan kolom, dengan mutu 25 MPa
- Mutu Pelaksanaannya baik sekali
- Butir maksimal agregat kasar sebesar 20 mm, dan data material pada lampiran A.

1. Menghitung kuat tekan rata-rata, berdasarkan kuat tekan rencana dan margin

   Data-data yang diperoleh dari tabel 3.1.

   Volume pekerjaan < 1000 m^3

   Pengawasan mutu pelaksanaan baik sekali

   Standar deviasi 4.5< sd ≤ 5.5 diambil 4.5

Tabel 3.1. Nilai Standar Deviasi

Volume Pekerjaan	Mutu Pelaksanaan (MPa)		
	Baik Sekali	Baik	Cukup
Kecil (<1000 m^3)	4.5 < sd ≤ 5.5	5.5 < sd ≤ 6.5	6.5 < sd ≤ 8.5
Sedang (1000-3000 m^3)	3.5 < sd ≤ 4.5	4.5 < sd ≤ 5.5	5.5 < sd ≤ 7.5
Besar (>3000 m^3)	2.5 < sd ≤ 3.5	3.5 < sd ≤ 4.5	4.5 < sd ≤ 6.5

Sumber : Tri Mulyono, "*Teknologi Beton*", 2003

Sehingga diperoleh nilai *f'cr* :

$f'cr = fc' + m$ ➔ $m = 1{,}64 \times s = 1{,}64 \times 4{,}5 = 7{,}38$ MPa

$= 25 + 8{,}2 = 32{,}38$ MPa

2. Menentukan nilai slump dan agregat maksimum

   Dari tabel 3.2 untuk konstruksi balok, ataupun kolom, nilai slump diambil sebesar 100 mm dan ukuran agregat maksimum ditentukan 20 mm.

Tabel 3.2. Nilai Slump yang di Syaratkan untuk Berbagai Konstruksi Menurut ACI

Jenis Konstruksi	Slump (mm)	
	Maksimum*	Minimum
Dinding Penahan dan Pondasi	76.2	25.4
Pondasi sederhana, sumuran dan dinding sub struktur	76.2	25.4
Balok dan dinding beton	101.6	25.4
Kolom struktural	101.6	25.4
Perkerasan dan slab	76.2	25.4
Beton massal	50.8	25.4

Sumber : ACI 318-89

3. Jumlah air yang dibutuhkan dalam campuran beton tercantum dalam tabel 3.4, berdasarkan nilai slump dan agregat maksimum, didapatkan air sebesar 205 lt/m^3

Tabel 3.4. Perkiraan Air Campuran dan Persyaratan Kandungan Udara untuk Berbagai Slump dan Ukuran Nominal Agregat Maksimum

Dimensi (mm)	Air (lt/m^3)							
	9.5 mm[a)]	12.7 mm[a)]	19.1 mm[a)]	25.4 mm[a)]	38.1 mm[a)]	50.8 mm[ab)]	76.2 mm[bc)]	152.4 mm[bc)]
25.4 s/d 50.8	210	201	189	180	165	156	132	114
76.2 s/d 127	231	219	204	195	180	171	147	126
152.4 s/d 177.8	246	231	216	204	189	180	162	-
Mendekati jumlah kandungan Udara dalam beton air-Entrained (%)	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2
25.4 s/d 50.8	183	177	168	162	150	144	123	108
76.2 s/d 127	204	195	183	177	165	159	135	120
152.4 s/d 177.8	219	207	195	186	174	168	156	-
Kandungan udara total rata-Rata yang disetujui[d)] (%)								
Diekspose sedikit	4.5	4.0	3.5	3.0	2.5	2.0	1.5[ef)]	1.0[ef)]
Diekspose menengah	6.0	5.5	5.0	4.5	4.5	4.0	3.5[ef)]	3.0[ef)]
Sangat ekspose	7.5	7.0	6.0	6.0	5.5	5.0	4.5[ef)]	4.0[ef)]

Sumber : ACI 318-89

4. FAS yang dibutuhkan berdasarkan nilai kekuatan tekan estimasi beton umur 28 hari untuk non air-entrained dengan *f'cr* 32,38 MPa dalam tabel 3.5 adalah 0,507

Tabel 3.5. Nilai Faktor Air Semen

Kekuatan Tekan 28 hari *(MPa)**	FAS	
	Beton Non Air-entrained	Beton Air-entrained
41.4	0.41	-
34.5	0.48	0.4
27.6	0.57	0.48
20.7	0.68	0.59
13.8	0.62	0.74

5. Sehingga semen yang di butuhkan = 205/0,507 = 404,44 ~ 404 kg

6. Volume agregat kasar berdasarkan Fm/MHB agregat halus dan ukuran maksimum agregat tabel 3.6. MHB = 2,47 dan ukuran maksimum 20 mm didapat nilai 0,653.

Tabel 3.6. Volume Agregat Kasar Per Satuan Volume Beton

Ukuran Agregat Maks (mm)	Volume Agregat kasar kering * per satuan volume untuk berbagai modulus halus butir			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.7	0.59	0.57	0.55	0.53
19.1	0.66	0.64	0.62	0.60
25.4	0.71	0.69	0.67	0.65
38.1	0.75	0.73	0.71	0.69
50.8	0.78	0.76	0.74	0.72
76.2	0.82	0.80	0.78	0.76
152.4	0.87	0.85	0.83	0.81

Sumber : ACI 318-89

Berat agregat kasar = 0,653 x 1566 kg/m^3 = 1022.5 ~ 1023 kg/m^3

7. Estimasi berat beton segar berdasarkan ukuran maksimum agregat 20 mm beton non air-entrained tabel 3.7, di dapat 2376 kg/m^3.
   Berat agregat halus = 2376 – (404+ 205 + 1023) = 744 kg/m^3

Tabel 3.7. Estimasi Berat Awal Beton Segar* (kg/m^3)

Ukuran Agregat Maks (mm)	Beton Non Air-entrained	Beton Air-entrained
9.5	2,304	2,214
12.7	2,334	2,256
19.1	2,376	2,304
25.4	2,406	2,340
38.1	2,442	2,376
50.8	2,472	2,400
76.2	2,496	2,424
152.4	2,538	2,472

Sumber : ACI 318-89

8. Sehingga Proporsi campuran beton per meter kubik
   Semen = 404 kg
   Air = 205 liter
   Agregat kasar = 1023 kg
   Agregat halus = 744 kg

9. Koreksi proporsi campuran
   Agregat kasar (absorbsi 3,295%) ➔ 1023 x 1,03295 = 1056,71 ~ 1057 kg
   Agregat halus (absorbsi 3,095%) ➔ 744 x 1,03095 = 767,0 ~ 767 kg
   Air ➔ 205 – {(0,03095 x 744) + (0,03295 x 1023) = 148,3 ~ 148 liter
   Sehingga untuk permeter kubik beton dibutuhkan
   Semen = 404 kg
   Air = 148 liter

Agregat kasar = 1057 kg
Agregat halus = 767 kg
Jumlah = 2346 kg

Hasil mix desain di atas kemudian ditrial. Dengan benda uji sebanyak 3 buah silinder ukuran d = 15 cm, t = 30 cm.
Selain mix desain di atas, kami juga membuat mix desain dengan *f'cr* = 25 MPa

1. *f'cr* = 25 MPa
2. Menentukan nilai slump dan agregat maksimum
   Dari tabel 3.2 untuk konstruksi balok, ataupun kolom, slump diambil 100 mm, agregat maksimum ditentukan 20 mm
3. Jumlah air yang dibutuhkan tercantum dalam tabel 3.4, berdasarkan nilai slump dan agregat maksimum, didapat 205 lt/m^3
4. FAS yang dibutuhkan berdasarkan nilai kekuatan tekan estimasi beton umur 28 hari untuk non air-entrained dengan *f'cr* 25 MPa dalam tabel 3.5 adalah 0,611
5. Semen yang dibutuhkan = 205/0,611 = 335,5 ~ 336 kg
6. Volume agregat kasar berdasarkan Fm/MHB agregat halus dan ukuran maksimum agregat tabel 3.6. MHB = 2,47 dan ukuran maksimum 20 mm (19,1 mm by ASTM), didapat nilai 0,653.
   Berat agregat kasar = 0,653 x 1566 kg/m^3 = 1022.5 ~ 1023 kg/m^3
7. Estimasi berat beton segar berdasarkan ukuran maksimum agregat 20 mm (19,1 mm), beton non air-entrained tabel 3.7, di dapat 2376 kg/m^3.
   Berat agregat halus = 2376 – (336+ 205 + 1023) = 812 kg/m^3
8. Sehingga Proporsi campuran beton per meter kubik
   Semen = 336 kg
   Air = 205 liter
   Agregat kasar = 1023 kg
   Agregat halus = 812 kg
9. Koreksi proporsi campuran
   Agregat kasar (absorbsi 3,295%) ➔ 1023 x 1,03295 = 1056,71 ~ 1057 kg

Agregat halus (absorbsi 3,095%) ➔ 812 x 1,03095 = 837,13 ~ 837 kg

Air ➔ 205 – {(0,03095 x 812) + (0,03295 x 1023) = 139,6 ~ 140 liter

Sehingga untuk permeter kubik beton dibutuhkan

Semen	= 404 kg
Air	= 148 liter
Agregat kasar	= 1057 kg
Agregat halus	= 837 kg
Jumlah	= 2376 kg

Dari trial dengan *f'cr* = 32,38 MPa menghasilkan kuat tekan 29,3 ; Fas 0,507

Dari trial dengan *f'cr* = 25 MPa menghasilkan kuat tekan 23,74, Fas 0,611

Direncanakan hasilnya 27 MPa, dengan interpolasi didapat Fas = 0,55

maka dengan FAS 0,55 dibuat sebagai acuan mix desain yang baru.

1. FAS yang dipakai 0,55
2. Semen yang di butuhkan = 205/0,55 = 372,7 ~ 373 kg
3. Volume agregat kasar berdasarkan Fm/MHB agregat halus dan ukuran maksimum agregat tabel 3.6. MHB = 2,47 dan ukuran maksimum 20 mm (19,1 mm by ASTM), didapat nilai 0,653.

   Berat agregat kasar = 0,653 x 1566 kg/m^3 = 1022.5 ~ 1023 kg/m^3
4. Estimasi berat beton segar berdasarkan ukuran maksimum agregat 20 mm (19,1 mm), beton non air-entrained tabel 3.7, didapat 2376 kg/m^3.

   Berat agregat halus = 2376 – (373 + 205 + 1023) = 775 kg/m^3
5. Sehingga Proporsi campuran beton per meter kubik

Semen	= 373 kg
Air	= 205 liter
Agregat kasar	= 1023 kg
Agregat halus	= 775 kg
6. Koreksi proporsi campuran

   Agregat kasar (absorbsi 3,295%) ➔ 1023 x 1,03295 = 1056,71 ~ 1057 kg

   Agregat halus (absorbsi 3,095%) ➔ 775 x 1,03095 = 798,98 ~ 799 kg

   Air ➔ 205 – {(0,03095 x 775) + (0,03295 x 1023) = 147,3 ~ 147 liter

Sehingga untuk permeter kubik beton dibutuhkan

Semen	= 373 kg
Air	= 147 liter
Agregat kasar	= 1057 kg
Agregat halus	= 799 kg
Jumlah	= 2376 kg

C1.1. Benda uji Silinder

C1.2. Cacahan Botol Plastik PET

C2.1. Alat Pencetak Double L

C2.2. Benda Uji Bentuk Double L

C3.1. Botol Plastik PET

C3.2. Mesin Pencacah Botol Plastik PET

C4.1. Mesin Pengaduk Beton

C4.2. Mesin Tekan

C5.1. Alat Pencetak Benda Uji Silinder

C5.2. Hasil Pengadukan Beton Dengan Kadar PET 0%

C6.1. Pengukuran Slump Dengan Kadar PET 0%

C6.2. Hasil Pengadukan Beton Dengan Kadar PET 0,3%

C7.1. Pengukuran Slump Dengan Kadar PET 0,3%

C7.2. Hasil Pengadukan Beton Dengan Kadar PET 0,5%

C8.1. Pengukuran Slump Dengan Kadar PET 0,5%

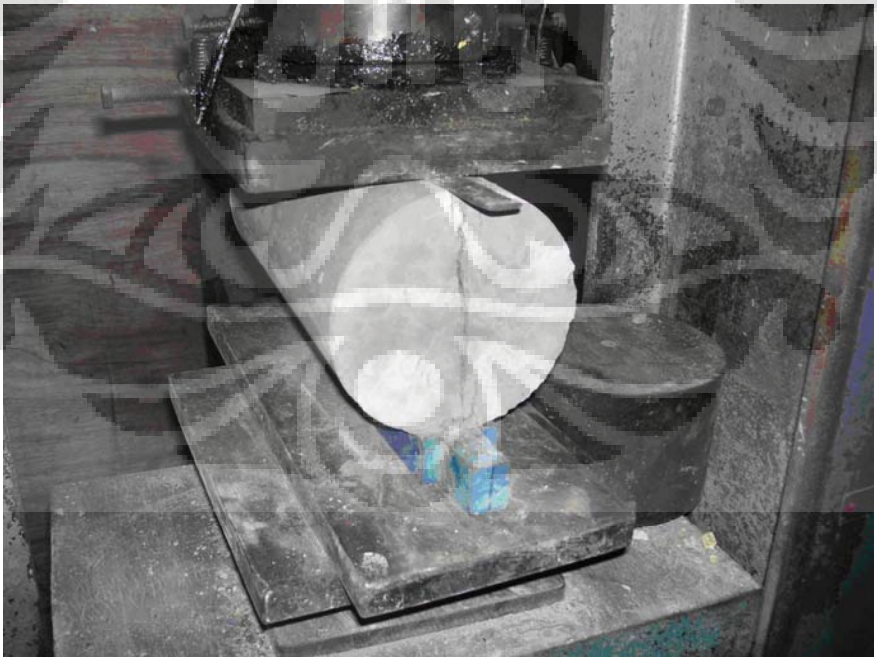
C8.2. Hasil Pengadukan Beton Dengan Kadar PET 0,7%

C9.1. Pengukuran Slump Dengan Kadar PET 0,7%

C9.2. Hasil Pengadukan Beton Dengan Kadar PET 1,0%

C10.1. Pengukuran Slump Dengan Kadar PET 1,0%

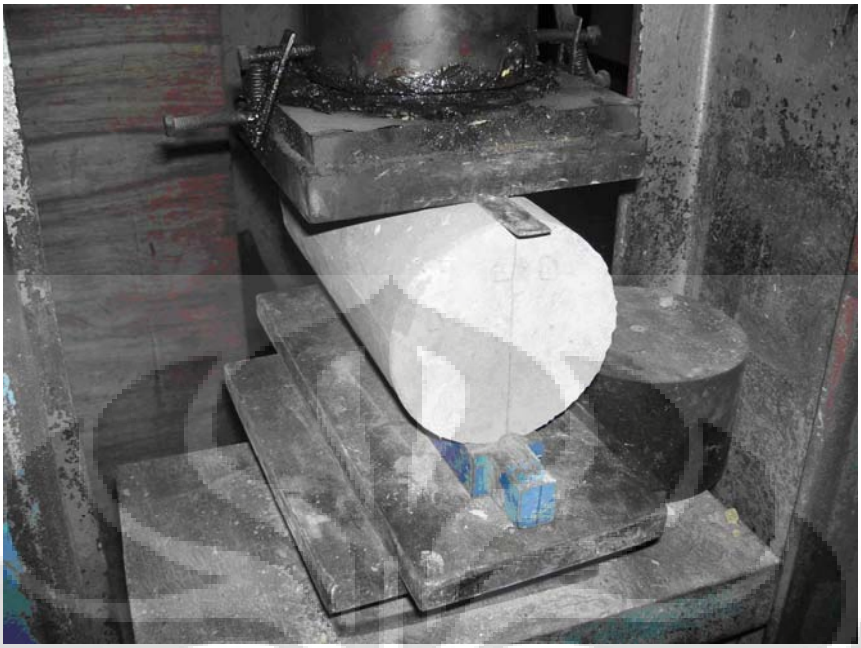
D1.1. Pengujian Kuat Tarik Belah Kadar PET 0%



D1.1. Hasil Pengujian Kuat Tarik Belah Kadar PET 0%

D2.1. Pola Retak Silinder Dengan Kadar PET 0,0%

D2.2. Silinder Yang Terbelah Dengan Kadar PET 0,0%



D3.1. Pengujian Kuat Tarik Belah Kadar PET 0,3%

D3.2. Hasil Pengujian Kuat Tarik Belah Kadar PET 0,3%

D4.1. Pola Retak Silinder Dengan Kadar PET 0,3%

D4.2. Silinder Yang Terbelah Dengan Kadar PET 0,3%

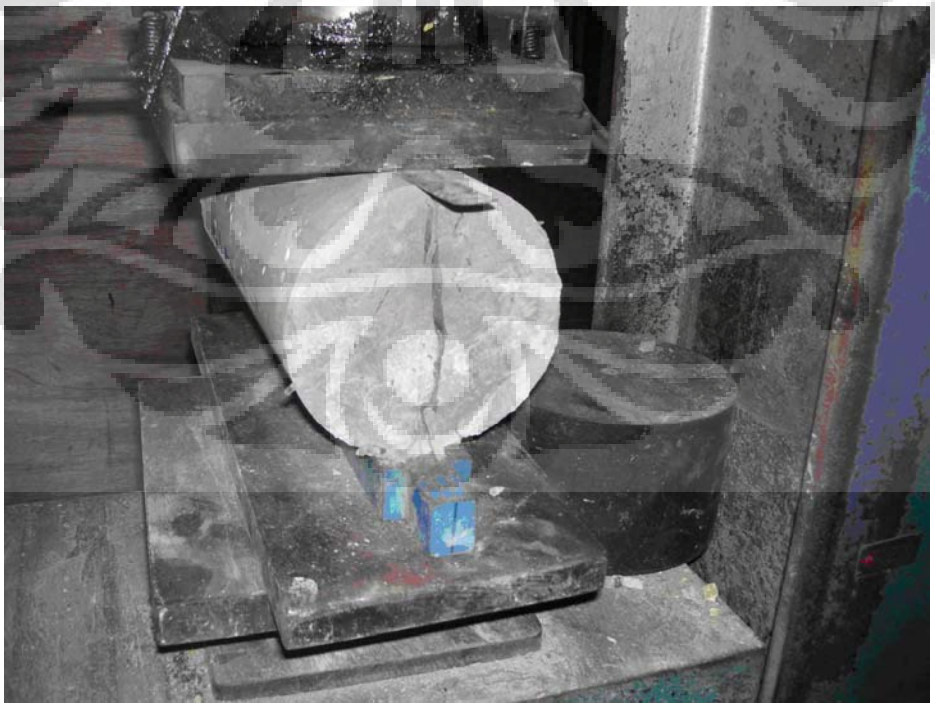
D5.1. Pengujian Kuat Tarik Belah Kadar PET 0,5%

D5.2. Hasil Pengujian Kuat Tarik Belah Kadar PET 0,5%

D6.1. Pola Retak Silinder Dengan Kadar PET 0,5%

D6.2. Silinder Yang Terbelah Dengan Kadar PET 0,5%

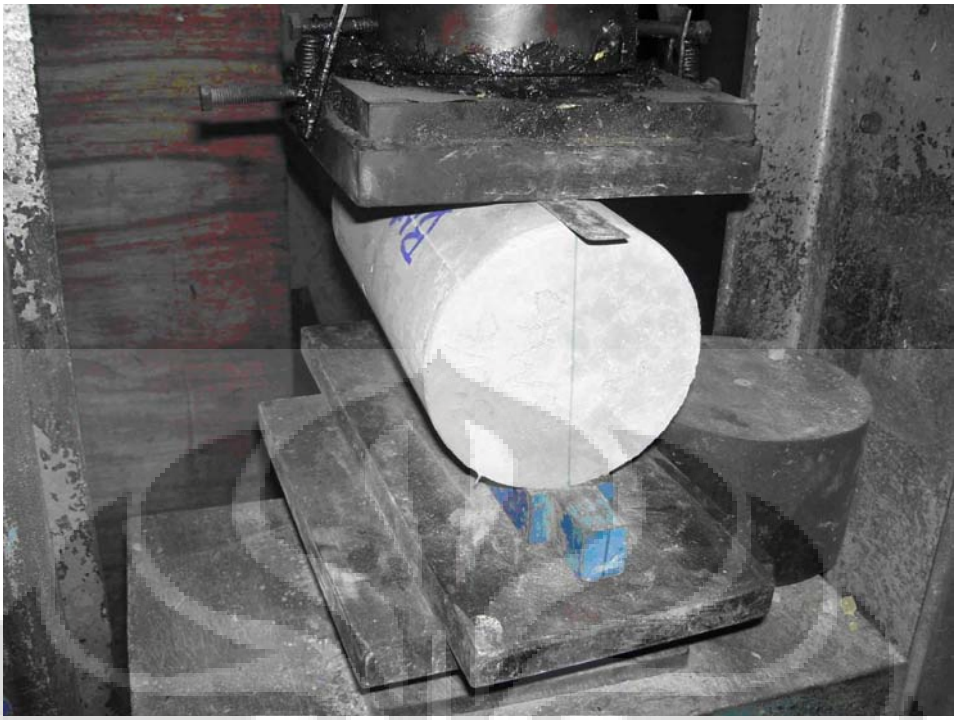
D7.1. Pengujian Kuat Tarik Belah Kadar PET 0,7%



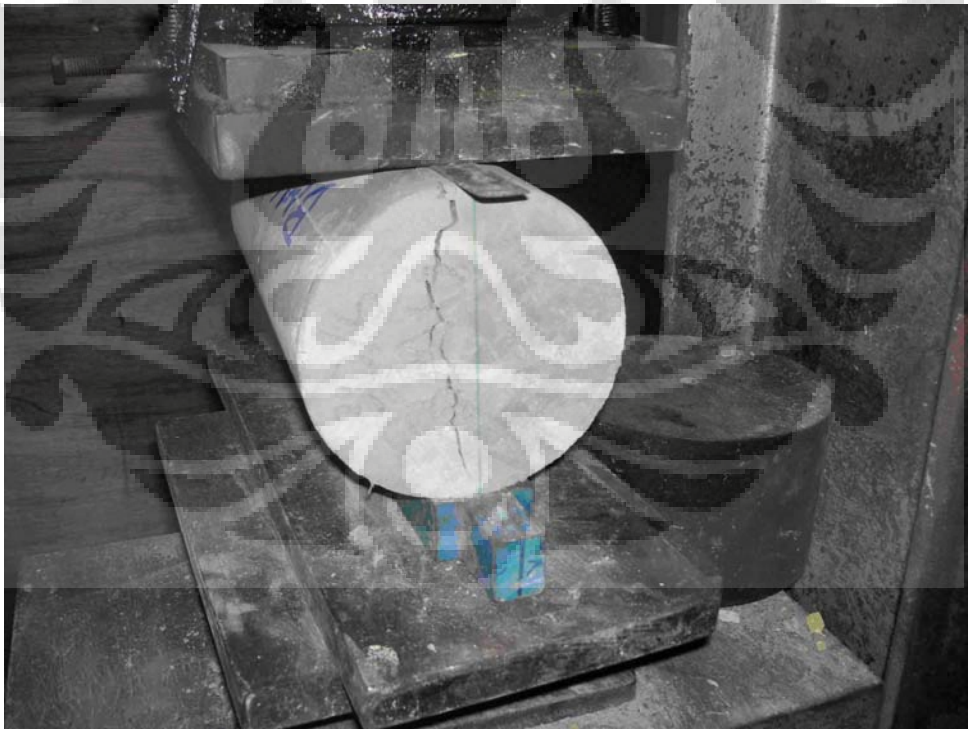
D7.2. Hasil Pengujian Kuat Tarik Belah Kadar PET 0,7%

D8.1. Pola Retak Silinder Dengan Kadar PET 0,7%

D8.2. Silinder Yang Terbelah Dengan Kadar PET 0,7%



D9.1. Pengujian Kuat Tarik Belah Kadar PET 1,0%



D9.2. Hasil Pengujian Kuat Tarik Belah Kadar PET 1,0%

D10.1. Pola Retak Silinder Dengan Kadar PET 1,0%

D10.2. Silinder Yang Terbelah Dengan Kadar PET 1,0%

D11.1.Benda Uji Silinder Yang Telah Diuji

D11.2. Cacahan Botol Plastik PET Yang Menyatu Dengan Beton

D12.1. Pengujian Kuat Geser

D12.2. Hasil Pengujian Kuat Geser

Designation: C 29/C 29M – 97 (Reapproved 2003)

American Association of State
Highway and Transportation Officials Standard
AASHTO No.: T19/T19M

Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[1]

This standard is issued under the fixed designation C 29/C 29M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of bulk density ("unit weight") of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination. This test method is applicable to aggregates not exceeding 5 in. [125 mm] in nominal maximum size.

NOTE 1—Unit weight is the traditional terminology used to describe the property determined by this test method, which is weight per unit volume (more correctly, mass per unit volume or density).

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as standard, as appropriate for a specification with which this test method is used. An exception is with regard to sieve sizes and nominal size of aggregate, in which the SI values are the standard as stated in Specification E 11. Within the text, SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore each system must be used independently of the other, without combining values in any way.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate[2]

C 128 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate[2]

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 123 Terminology Relating to Textiles[4]

E 11 Specification for Wire Cloth and Sieves for Testing Purposes[5]

2.2 *AASHTO Standard:*

T19/T19M Method of Test for Unit Weight and Voids in Aggregate[6]

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology C 125 unless otherwise indicated.

3.1.1 *bulk density, n—of aggregate*, the mass of a unit volume of bulk aggregate material, in which the volume includes the volume of the individual particles and the volume of the voids between the particles. Expressed in lb/ft^3 [kg/m^3].

3.1.2 *unit weight, n*—weight (mass) per unit volume. (Deprecated term used–preferred term **bulk density**.)

3.1.2.1 *Discussion*—Weight is equal to the mass of the body multiplied by the acceleration due to gravity. Weight may be expressed in absolute units (newtons, poundals) or in gravitational units (kgf, lbf), for example: on the surface of the earth, a body with a mass of 1 kg has a weight of 1 kgf (approximately 9.81 N), or a body with a mass of 1 lb has a weight of 1 lbf (approximately 4.45 N or 32.2 poundals). Since weight is equal to mass times the acceleration due to gravity, the weight of a body will vary with the location where the weight is determined, while the mass of the body remains constant. On the surface of the earth, the force of gravity imparts to a body that is free to fall an acceleration of approximately 9.81 m/s^2 (32.2 ft/s^2). **D 123.**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *voids, n—in unit volume of aggregate*, the space between particles in an aggregate mass not occupied by solid mineral matter.

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[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved July 10, 1997. Published September 1997. Originally approved in 1920. Last previous edition approved in 1991 as C 29/C 29M – 91a.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 07.01.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

[6] Available from American Association of State Highway and Transportation Officials, 444 N. Capitol St. NW, Suite 225, Washington, DC 20001.

3.2.1.1 *Discussion*—Voids within particles, either permeable or impermeable, are not included in voids as determined by this test method.

4. Significance and Use

4.1 This test method is often used to determine bulk density values that are necessary for use for many methods of selecting proportions for concrete mixtures.

4.2 The bulk density also may be used for determining mass/volume relationships for conversions in purchase agreements. However, the relationship between degree of compaction of aggregates in a hauling unit or stockpile and that achieved in this test method is unknown. Further, aggregates in hauling units and stockpiles usually contain absorbed and surface moisture (the latter affecting bulking), while this test method determines the bulk density on a dry basis.

4.3 A procedure is included for computing the percentage of voids between the aggregate particles based on the bulk density determined by this test method.

5. Apparatus

5.1 *Balance*—A balance or scale accurate within 0.1 % of the test load at any point within the range of use, graduated to at least 0.1 lb [0.05 kg]. The range of use shall be considered to extend from the mass of the measure empty to the mass of the measure plus its contents at 120 lb/ft^3 [1920 kg/m^3].

5.2 *Tamping Rod*—A round, straight steel rod, ⅝ in. [16 mm] in diameter and approximately 24 in. [600 mm] in length, having the tamping end, or both ends, rounded to a hemispherical tip, the diameter of which is ⅝ in. (16 mm).

5.3 *Measure*—A cylindrical metal measure, preferably provided with handles. It shall be watertight, with the top and bottom true and even, and sufficiently rigid to retain its form under rough usage. The measure shall have a height approximately equal to the diameter, but in no case shall the height be less than 80 % nor more than 150 % of the diameter. The capacity of the measure shall conform to the limits in Table 1

TABLE 1 Capacity of Measures

Nominal Maximum Size of Aggregate		Capacity of Measure[A]	
in.	mm	ft^3	L (m^3)
½	12.5	1/10	2.8 (0.0028)
1	25.0	⅓	9.3 (0.0093)
1½	37.5	½	14 (0.014)
3	75	1	28 (0.028)
4	100	2½	70 (0.070)
5	125	3½	100 (0.100)

[A] The indicated size of measure shall be used to test aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 % of the nominal volume listed.

for the aggregate size to be tested. The thickness of metal in the measure shall be as described in Table 2. The top rim shall be smooth and plane within 0.01 in. [0.25 mm] and shall be parallel to the bottom within 0.5° (Note 2). The interior wall of the measure shall be a smooth and continuous surface.

NOTE 2—The top rim is satisfactorily plane if a 0.01-in. [0.25-mm] feeler gage cannot be inserted between the rim and a piece of ¼-in. [6-mm] or thicker plate glass laid over the measure. The top and bottom are satisfactorily parallel if the slope between pieces of plate glass in contact with the top and bottom does not exceed 0.87 % in any direction.

TABLE 2 Requirements for Measures

Capacity of Measure	Thickness of Metal, min		
	Bottom	Upper 1½ in. or 38 mm of wall[A]	Remainder of wall
Less than 0.4 ft^3	0.20 in.	0.10 in.	0.10 in.
0.4 ft^3 to 1.5 ft^3, incl	0.20 in.	0.20 in.	0.12 in.
over 1.5 to 2.8 ft^3, incl	0.40 in.	0.25 in.	0.15 in.
over 2.8 to 4.0 ft^3, incl	0.50 in.	0.30 in.	0.20 in.
Less than 11 L	5.0 mm	2.5 mm	2.5 mm
11 to 42 L, incl	5.0 mm	5.0 mm	3.0 mm
over 42 to 80 L, incl	10.0 mm	6.4 mm	3.8 mm
over 80 to 133 L, incl	13.0 mm	7.6 mm	5.0 mm

[A] The added thickness in the upper portion of the wall may be obtained by placing a reinforcing band around the top of the measure.

5.3.1 If the measure is to also be used for testing for bulk density of freshly-mixed concrete according to Test Method C 138, the measure shall be made of steel or other suitable metal not readily subject to attack by cement paste. Reactive materials, such as aluminum alloys are permitted, where as a consequence of an initial reaction, a surface film is formed which protects the metal against further corrosion.

5.3.2 Measures larger than nominal 1 ft^3 (28 L) capacity shall be made of steel for rigidity, or the minimum thicknesses of metal listed in Table 2 shall be suitably increased.

5.4 *Shovel or Scoop*—A shovel or scoop of convenient size for filling the measure with aggregate.

5.5 *Calibration Equipment*—A piece of plate glass, preferably at least ¼ in. [6 mm] thick and at least 1 in. [25 mm] larger than the diameter of the measure to be calibrated. A supply of water-pump or chassis grease that can be placed on the rim of the container to prevent leakage.

6. Sampling

6.1 Obtain the sample in accordance with Practice D 75, and reduce to test sample size in accordance with Practice C 702.

7. Test Sample

7.1 The size of the sample shall be approximately 125 to 200 % of the quantity required to fill the measure, and shall be handled in a manner to avoid segregation. Dry the aggregate sample to essentially constant mass, preferably in an oven at 230 ± 9°F [110 ± 5°C].

8. Calibration of Measure

8.1 Fill the measure with water at room temperature and cover with a piece of plate glass in such a way as to eliminate bubbles and excess water.

8.2 Determine the mass of the water in the measure using the balance described in 5.1.

8.3 Measure the temperature of the water and determine its density from Table 3, interpolating if necessary.

8.4 Calculate the volume, *V*, of the measure by dividing the mass of the water required to fill the measure by its density. Alternatively, calculate the factor for the measure (1/*V*) by dividing the density of the water by the mass required to fill the measure.

TABLE 3 Density of Water

Temperature		lb/ft³	kg/m³
°F	°C		
60	15.6	62.366	999.01
65	18.3	62.336	998.54
70	21.1	62.301	997.97
73.4	23.0	62.274	997.54
75	23.9	62.261	997.32
80	26.7	62.216	996.59
85	29.4	62.166	995.83

NOTE 3—For the calculation of bulk density, the volume of the measure in SI units should be expressed in cubic metres, or the factor as $1/m^3$. However, for convenience the size of the measure may be expressed in litres.

8.5 Measures shall be recalibrated at least once a year or whenever there is reason to question the accuracy of the calibration.

9. Selection of Procedure

9.1 The shoveling procedure for loose bulk density shall be used only when specifically stipulated. Otherwise, the compact bulk density shall be determined by the rodding procedure for aggregates having a nominal maximum size of 1½ in. [37.5 mm] or less, or by the jigging procedure for aggregates having a nominal maximum size greater than 1½ in. [37.5 mm] and not exceeding 5 in. [125 mm].

10. Rodding Procedure

10.1 Fill the measure one-third full and level the surface with the fingers. Rod the layer of aggregate with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure two-thirds full and again level and rod as above. Finally, fill the measure to overflowing and rod again in the manner previously mentioned. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

10.2 In rodding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In rodding the second and third layers, use vigorous effort, but not more force than to cause the tamping rod to penetrate to the previous layer of aggregate.

NOTE 4—In rodding the larger sizes of coarse aggregate, it may not be possible to penetrate the layer being consolidated, especially with angular aggregates. The intent of the procedure will be accomplished if vigorous effort is used.

10.3 Determine the mass of the measure plus its contents, and the mass of the measure alone, and record the values to the nearest 0.1 lb [0.05 kg].

11. Jigging Procedure

11.1 Fill the measure in three approximately equal layers as described in 10.1, compacting each layer by placing the measure on a firm base, such as a cement-concrete floor, raising the opposite sides alternately about 2 in. [50 mm], and allowing the measure to drop in such a manner as to hit with a sharp, slapping blow. The aggregate particles, by this procedure, will arrange themselves in a densely compacted condition. Compact each layer by dropping the measure 50 times in the manner described, 25 times on each side. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

11.2 Determine the mass of the measure plus its contents, and the mass of the measure alone, and record the values to the nearest 0.1 lb [0.05 kg].

12. Shoveling Procedure

12.1 Fill the measure to overflowing by means of a shovel or scoop, discharging the aggregate from a height not to exceed 2 in. [50 mm] above the top of the measure. Exercise care to prevent, so far as possible, segregation of the particle sizes of which the sample is composed. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

12.2 Determine the mass of the measure plus its contents, and the mass of the measure alone, and record the values to the nearest 0.1 lb [0.05 kg].

13. Calculation

13.1 *Bulk Density*—Calculate the bulk density for the rodding, jigging, or shoveling procedure as follows:

$$M = (G - T)/V \quad (1)$$

or

$$M = (G - T) \times F \quad (2)$$

where:

M = bulk density of the aggregate, lb/ft³ [kg/m³],
G = mass of the aggregate plus the measure, lb [kg],
T = mass of the measure, lb [kg],
V = volume of the measure, ft³ [m³], and
F = factor for measure, ft^{-3} [m^{-3}].

13.1.1 The bulk density determined by this test method is for aggregate in an oven-dry condition. If the bulk density in terms of saturated-surface-dry (SSD) condition is desired, use the exact procedure in this test method, and then calculate the SSD bulk density using the following formula:

$$Mssd = M[1 + (A/100)] \quad (3)$$

where:

M_{SSD} = bulk density in SSD condition, lb/ft³ [kg/m³], and
A = % absorption, determined in accordance with Test Method C 127 or Test Method C 128.

13.2 *Void Content*—Calculate the void content in the aggregate using the bulk density determined by either the rodding, jigging, or shoveling procedure, as follows:

$$\%\ Voids = 100[(S \times W) - M]/(S \times W) \quad (4)$$

where:

M = bulk density of the aggregate, lb/ft³ [kg/m³],

S = bulk specific gravity (dry basis) as determined in accordance with Test Method C 127 or Test Method C 128, and
W = density of water, 62.3 lb/ft^3 [998 kg/m^3].

14. Report

14.1 Report the results for the bulk density to the nearest 1 lb/ft^3 [10 kg/m^3] as follows:

14.1.1 Bulk density by rodding, or

14.1.2 Bulk density by jigging, or

14.1.3 Loose bulk density.

14.2 Report the results for the void content to the nearest 1 % as follows:

14.2.1 Voids in aggregate compacted by rodding, %, or

14.2.2 Voids in aggregate compacted by jigging, %, or

14.2.3 Voids in loose aggregate, %.

15. Precision and Bias

15.1 The following estimates of precision for this test method are based on results from the AASHTO Materials Reference Laboratory (AMRL) Proficiency Sample Program, with testing conducted using this test method and AASHTO Method T 19/T19M. There are no significant differences between the two test methods. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

15.2 *Coarse Aggregate (bulk density)*:

15.2.1 *Single-Operator Precision*—The single-operator standard deviation has been found to be 0.88 lb/ft^3 [14 kg/m^3] (1s). Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 2.5 lb/ft^3 [40 kg/m^3] (d2s).

15.2.2 *Multilaboratory Precision*—The multilaboratory standard deviation has been found to be 1.87 lb/ft^3 [30 kg/m^3] (1s). Therefore, results of two properly conducted tests from two different laboratories on similar material should not differ by more than 5.3 lb/ft^3 [85 kg/m^3] (d2s).

15.2.3 These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision estimates were obtained from the analysis of AMRL proficiency sample data for bulk density by rodding of normal weight aggregates having a nominal maximum aggregate size of 1 in. [25.0 mm], and using a ½-ft^3 [14-L] measure.

15.3 *Fine Aggregate (bulk density)*:

15.3.1 *Single-Operator Precision*—The single-operator standard deviation has been found to be 0.88 lb/ft^3 [14 kg/m^3] (1s). Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 2.5 lb/ft^3 [40 kg/m^3] (d2s).

15.3.2 *Multilaboratory Precision*—The multilaboratory standard deviation has been found to be 2.76 lb/ft^3 [44 kg/m^3] (1s). Therefore, results of two properly conducted tests from two different laboratories on similar material should not differ by more than 7.8 lb/ft^3 [125 kg/m^3] (d2s).

15.3.3 These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision estimates were obtained from the analysis of AMRL proficiency sample data for loose bulk density from laboratories using a 1/10-ft^3 [2.8-L] measure.

15.4 No precision data on void content are available. However, as the void content in aggregate is calculated from bulk density and bulk specific gravity, the precision of the voids content reflects the precision of these measured parameters given in 15.2 and 15.3 of this test method and in Test Methods C 127 and C 128.

15.5 *Bias*—The procedure in this test method for measuring bulk density and void content has no bias because the values for bulk density and void content can be defined only in terms of a test method.

16. Keywords

16.1 aggregates; bulk density; coarse aggregate; density; fine aggregate; unit weight; voids in aggregates

Designation: C 40 – 04

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T 21

Standard Test Method for Organic Impurities in Fine Aggregates for Concrete[1]

This standard is issued under the fixed designation C 40; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers two procedures for an approximate determination of the presence of injurious organic impurities in fine aggregates that are to be used in hydraulic cement mortar or concrete. One procedure uses a standard color solution and the other uses a glass color standard.

1.2 The values given in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 33 Specification for Concrete Aggregates
C 87 Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
C 125 Terminology Relating to Concrete and Concrete Aggregates
C 702 Practice for Reducing Samples of Aggregate to Testing Size
D 75 Practice for Sampling Aggregates
D 1544 Test Method for Color of Transparent Liquids (Gardner Color Scale)

3. Significance and Use

3.1 This test method is used in making a preliminary determination of the acceptability of fine aggregates with respect to the requirements of Specification C 33 that relate to organic impurities.

3.2 The principal value of this test method is to furnish a warning that injurious amounts of organic impurities may be present. When a sample subjected to this test produces a color darker than the standard color it is advisable to perform the test for the effect of organic impurities on the strength of mortar in accordance with Test Method C 87.

4. Apparatus

4.1 *Glass Bottles*—Colorless glass graduated bottles, approximately 240 to 470-mL (8 to 16-oz) nominal capacity, equipped with watertight stoppers or caps, not soluble in the specified reagents. In no case shall the maximum outside thickness of the bottles, measured along the line of sight used for the color comparison, be greater than 63.5 mm (2.5 in.) or less than 38.1 mm (1.5 in.). The graduations on the bottles shall be in millilitres, or ounces (U.S. fluid), except that unmarked bottles may be calibrated and scribed with graduations by the user. In such case, graduation marks are required at only three points as follows:

4.1.1 *Standard Color Solution Level*—75 mL (2½ oz (U.S. fluid)),

4.1.2 *Fine Aggregate Level*—130 mL (4½ oz (U.S. fluid)), and

4.1.3 *NaOH Solution Level*—200 mL (7 oz (U.S. fluid)).

4.2 *Glass Color Standard*

4.2.1 Glass standard colors shall be used as described in Table 1 of Test Method D 1544.

NOTE 1—A suitable instrument consists of five glass color standards mounted in a plastic holder. Only the glass identified as Gardner Color Standard No. 11 is to be used as the Glass Color Standard in 9.2.

5. Reagent and Standard Color Solution

5.1 *Reagent Sodium Hydroxide Solution (3 %)*—Dissolve 3 parts by mass of reagent grade sodium hydroxide (NaOH) in 97 parts of water.

5.2 *Standard Color Solution*—Dissolve reagent grade potassium dichromate ($K_2Cr_2O_7$) in concentrated sulfuric acid (sp gr 1.84) at the rate of 0.250 g/100 mL of acid. The solution must be freshly made for the color comparison using gentle heat if necessary to effect solution.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Jan. 1, 2004. Published January 2004. Originally approved in 1921. Last previous edition approved in 1999 as C 40 – 99.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

6. Sampling

6.1 The sample shall be selected in general accordance with Practice D 75.

7. Test Sample

7.1 The test sample shall have a mass of about approximately 450 g (1 lb) and be taken from the larger sample in accordance with Practice C 702.

8. Procedure

8.1 Fill a glass bottle to the approximately 130-mL (4½-fluid oz) level with the sample of the fine aggregate (see Terminology C 125) to be tested.

8.2 Add the sodium hydroxide solution until the volume of the fine aggregate and liquid, indicated after shaking, is approximately 200 mL (7 fluid oz).

8.3 Stopper the bottle, shake vigorously, and then allow to stand for 24 h.

9. Determination of Color Value

9.1 *Standard Color Solution Procedure*—At the end of the 24-h standing period, fill a glass bottle to the approximately 75-mL (2½-fluid oz) level with the fresh standard color solution, prepared not longer than 2 h previously, as prescribed in 5.2. Hold the bottle with the test sample and the bottle with the standard color solution side-by-side, and compare the color of light transmitted through the supernatant liquid above the sample with the color of light transmitted through the standard color solution. Record whether the color of the supernatant liquid is lighter, darker, or equal to the color of the standard color solution.

9.2 *Glass Color Standard Procedure*—To define more precisely the color of the supernatant liquid of the test sample, five glass standard colors shall be used using the following colors:

Gardner Color Standard No.	Organic Plate No.
5	1
8	2
11	3 (standard)
14	4
16	5

The comparison procedure described in 9.1 shall be used, except that the organic plate number which is nearest the color of the supernatant liquid above the test specimen shall be reported. When using this procedure, it is not necessary to prepare the standard color solution.

10. Interpretation

10.1 When a sample subjected to this procedure produces a color darker than the standard color, or Organic Plate No. 3 (Gardner Color Standard No. 11), the fine aggregate under test shall be considered to possibly contain injurious organic impurities. It is advisable to perform further tests before approving the fine aggregate for use in concrete.

11. Precision and Bias

11.1 Since this test produces no numerical values, determination of the precision and bias is not possible.

12. Keywords

12.1 colorimetric test; fine aggregate; organic impurities

Designation: C 117 – 03

Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing[1]

This standard is issued under the fixed designation C 117; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of the amount of material finer than a 75-μm (No. 200) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

1.2 Two procedures are included, one using only water for the washing operation, and the other including a wetting agent to assist the loosening of the material finer than the 75-μm (No. 200) sieve from the coarser material. Unless otherwise specified, Procedure A (water only) shall be used.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

E 11 Specification for Wire Cloth and Sieves for Testing Purposes[4]

2.2 *AASHTO Standard:*

T11 Method of Test for Amount of Material Finer than 0.075-mm Sieve in Aggregate[5]

3. Summary of Test Method

3.1 A sample of the aggregate is washed in a prescribed manner, using either plain water or water containing a wetting agent, as specified. The decanted wash water, containing suspended and dissolved material, is passed through a 75-μm (No. 200) sieve. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a 75-μm (No. 200) sieve by washing.

4. Significance and Use

4.1 Material finer than the 75-μm (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, when accurate determinations of material finer than 75 μm in fine or coarse aggregate are desired, this test method is used on the sample prior to dry sieving in accordance with Test Method C 136. The results of this test method are included in the calculation in Test Method C 136, and the total amount of material finer than 75 μm by washing, plus that obtained by dry sieving the same sample, is reported with the results of Test Method C 136. Usually, the additional amount of material finer than 75 μm obtained in the dry sieving process is a small amount. If it is large, the efficiency of the washing operation should be checked. It could also be an indication of degradation of the aggregate.

4.2 Plain water is adequate to separate the material finer than 75 μm from the coarser material with most aggregates. In some cases, the finer material is adhering to the larger particles, such as some clay coatings and coatings on aggregates that have been extracted from bituminous mixtures. In these cases, the fine material will be separated more readily with a wetting agent in the water.

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[1] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

5. Apparatus and Materials

5.1 *Balance*—A balance or scale readable and accurate to 0.1 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

5.2 *Sieves*—A nest of two sieves, the lower being a 75-µm (No. 200) sieve and the upper a 1.18-mm (No. 16) sieve, both conforming to the requirements of Specification E 11.

5.3 *Container*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5.4 *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 110 ± 5°C (230± 9°F).

5.5 *Wetting Agent*—Any dispersing agent, such as liquid dishwashing detergents, that will promote separation of the fine materials.

NOTE 1—The use of a mechanical apparatus to perform the washing operation is not precluded, provided the results are consistent with those obtained using manual operations. The use of some mechanical washing equipment with some samples may cause degradation of the sample.

6. Sampling

6.1 Sample the aggregate in accordance with Practice D 75. If the same test sample is to be tested for sieve analysis according to Test Method C 136, comply with the applicable requirements of that test method.

6.2 Thoroughly mix the sample of aggregate to be tested and reduce the quantity to an amount suitable for testing using the applicable methods described in Practice C 702. If the same test sample is to be tested according to Test Method C 136, the minimum mass shall be as described in the applicable sections of that method. Otherwise, the mass of the test sample, after drying, shall conform with the following:

Nominal Maximum Size	Minimum Mass, g
4.75 mm (No. 4) or smaller	300
9.5 mm (⅜ in.)	1000
19.0 mm (¾ in.)	2500
37.5 mm (1½ in.) or larger	5000

If the nominal maximum size of the aggregate to be tested is not listed above, the next larger size listed shall be used to determine sample size.

7. Selection of Procedure

7.1 Procedure A shall be used, unless otherwise specified by the Specification with which the test results are to be compared, or when directed by the agency for which the work is performed.

8. Procedure A—Washing with Plain Water

8.1 Dry the test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). Determine the mass to the nearest 0.1 % of the mass of the test sample.

8.2 If the applicable specification requires that the amount passing the 75-µm (No. 200) sieve shall be determined on a portion of the sample passing a sieve smaller than the nominal maximum size of the aggregate, separate the sample on the designated sieve and determine the mass of the material passing the designated sieve to 0.1 % of the mass of this portion of the test sample. Use this mass as the original dry mass of the test sample in 10.1.

NOTE 2—Some specifications for aggregates with a nominal maximum size of 50 mm or greater, for example, provide a limit for material passing the 75-µm (No. 200) sieve determined on that portion of the sample passing the 25.0-mm sieve. Such procedures are necessary since it is impractical to wash samples of the size required when the same test sample is to be used for sieve analysis by Test Method C 136.

8.3 After drying and determining the mass, place the test sample in the container and add sufficient water to cover it. No detergent, dispersing agent, or other substance shall be added to the water. Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

8.4 Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

NOTE 3—If mechanical washing equipment is used, the charging of water, agitating, and decanting may be a continuous operation.

8.5 Return all material retained on the nested sieves by flushing to the washed sample. Dry the washed aggregate to constant mass at a temperature of 110 ± 5°C (230 ± 9°F) and determine the mass to the nearest 0.1 % of the original mass of the sample.

NOTE 4—Following the washing of the sample and flushing any material retained on the 75-µm (No. 200) sieve back into the container, no water should be decanted from the container except through the 75-µm sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

9. Procedure B—Washing Using a Wetting Agent

9.1 Prepare the sample in the same manner as for Procedure A.

9.2 After drying and determining the mass, place the test sample in the container. Add sufficient water to cover the sample, and add wetting agent to the water (Note 5). Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

NOTE 5—There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water and the quality of the detergent. Excessive suds may overflow the sieves and carry some material with them.

9.3 Add a second charge of water (without wetting agent) to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

9.4 Complete the test as for Procedure A.

10. Calculation

10.1 Calculate the amount of material passing a 75-µm (No. 200) sieve by washing as follows:

$$A = [(B - C)/B] \times 100 \quad (1)$$

where:

A = percentage of material finer than a 75-µm (No. 200) sieve by washing,
B = original dry mass of sample, g, and
C = dry mass of sample after washing, g.

11. Report

11.1 Report the following information:

11.1.1 Report the percentage of material finer than the 75-µm (No. 200) sieve by washing to the nearest 0.1 %, except if the result is 10 % or more, report the percentage to the nearest whole number.

11.1.2 Include a statement as to which procedure was used.

12. Precision and Bias

12.1 *Precision*—The estimates of precision of this test method listed in Table 1are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and AASHTO Method T 11. The significant differences between the methods at the time the data were acquired is that Method T 11 required, while Test Method C 117 prohibited, the use of a wetting agent. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

12.1.1 The precision values for fine aggregate in Table 1 are based on nominal 500-g test samples. Revision of this test method in 1994 permits the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 2, which indicates only minor differences due to test sample size.

NOTE 6—The values for fine aggregate in Table 1 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

12.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is made.

13. Keywords

13.1 aggregate; coarse aggregate; fine aggregate; grading; loss by washing; 75 µm (No. 200) sieve; size analysis

TABLE 1 Precision

	Standard Deviation (1s)[A], %	Acceptable Range of two Results (d2s)[A], %
Coarse Aggregate[B]		
Single-Operator Precision	0.10	0.28
Multilaboratory Precision	0.22	0.62
Fine Aggregate[C]		
Single-Operator Precision	0.15	0.43
Multilaboratory Precision	0.29	0.82

[A] These numbers represent the (1s) and (d2s) limits as described in Practice C 670.

[B] Precision estimates are based on aggregates having a nominal maximum size of 19.0 mm (¾ in.) with less than 1.5% finer than the 75-µm (No. 200) sieve.

[C] Precision estimates are based on fine aggregates having 1.0 to 3.0% finer than the 75-µm (No. 200) sieve.

TABLE 2 Precision Data for 300-g and 500-g Test Samples

Fine Aggregate Proficiency Sample				Within Laboratory		Between Laboratory	
Test Result	Sample Size	No. of Labs	Average	1s	d2s	1s	d2s
AASHTO T11/ASTM C117	500 g	270	1.23	0.08	0.24	0.23	0.66
Total material passing the No. 200 sieve by washing (%)	300 g	264	1.20	0.10	0.29	0.24	0.68

Designation: C 127 – 01

Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate[1]

This standard is issued under the fixed designation C 127; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers the determination of the average density of a quantity of coarse aggregate particles (not including the volume of voids between the particles), the relative density (specific gravity), and the absorption of the coarse aggregate. Depending on the procedure used, the density (kg/m^3 (lb/ft^3)) is expressed as oven-dry (OD), saturated-surface-dry (SSD), or as apparent density. Likewise, relative density (specific gravity), a dimensionless quantity, is expressed as OD, SSD, or as apparent relative density (apparent specific gravity). The OD density and OD relative density are determined after drying the aggregate. The SSD density, SSD relative density, and absorption are determined after soaking the aggregate in water for a prescribed duration.

1.2 This test method is used to determine the density of the essentially solid portion of a large number of aggregate particles and provides an average value representing the sample. Distinction is made between the density of aggregate particles as determined by this test method, and the bulk density of aggregates as determined by Test Method C 29/C 29M, which includes the volume of voids between the particles of aggregates.

1.3 This test method is not intended to be used with lightweight aggregates.

1.4 The values stated in SI units are to be regarded as the standard for conducting the tests. The test results for density shall be reported in either SI units or inch-pound units, as appropriate for the use to be made of the results.

1.5 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 128 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate[2]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]

C 566 Test Method for Total Evaporable Moisture Content of Aggregate by Drying[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 448 Classification for Sizes of Aggregate for Road and Bridge Construction[3]

E 11 Specification for Wire Cloth and Sieves for Testing Purposes[4]

2.2 *AASHTO Standard:*

AASHTO No. T 85 Specific Gravity and Absorption of Coarse Aggregate[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *absorption, n*—the increase in mass of aggregate due to water penetration into the pores of the particles during a prescribed period of time, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass.

3.1.2 *oven-dry (OD), adj—related to aggregate particles,* the condition in which the aggregates have been dried by

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Aug. 10, 2001. Published October 2001. Originally published as C 127 – 36 T. Last previous edition C 127 – 88 (2001).

[2] *Annual Book of ASTM Standards,* Vol 04.02.

[3] *Annual Book of ASTM Standards,* Vol 04.03.

[4] *Annual Book of ASTM Standards,* Vol 14.02.

[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

***A Summary of Changes section appears at the end of this standard.**

heating in an oven at 110 ± 5°C for sufficient time to reach a constant mass.

3.1.3 *saturated-surface-dry (SSD), adj—related to aggregate particles*, the condition in which the permeable pores of aggregate particle are filled with water to the extent achieved by submerging in water for the prescribed period of time, but without free water on the surface of the particles.

3.1.4 *density, n*—the mass per unit volume of a material, expressed as kilograms per cubic metre (pounds per cubic foot).

3.1.4.1 *density (OD), n*—the mass of oven dry aggregate per unit volume of aggregate particles, including the volume of permeable and impermeable pores within the particles, but not including the voids between the particles.

3.1.4.2 *density (SSD), n*—the mass of saturated-surface-dry aggregate per unit volume of the aggregate particles, including the volume of impermeable pores and water-filled voids within the particles, but not including the pores between the particles.

3.1.4.3 *apparent density, n*—the mass per unit volume of the impermeable portion of the aggregate particles.

3.1.5 *relative density (specific gravity), n*—the ratio of the density of a material to the density of distilled water at a stated temperature; the values are dimensionless.

3.1.5.1 *relative density (specific gravity) (OD), n*—the ratio of the density (OD) of the aggregate to the density of distilled water at a stated temperature.

3.1.5.2 *relative density (specific gravity) (SSD), n*—the ratio of the density (SSD) of the aggregate to the density of distilled water at a stated temperature.

3.1.5.3 *apparent relative density (apparent specific gravity), n*—the ratio of the apparent density of aggregate to the density of distilled water at a stated temperature.

3.1.6 For definitions of other terms related to aggregates, see Terminology C 125.

4. Summary of Test Method

4.1 A sample of aggregate is immersed in water for 24 ± 4 h to essentially fill the pores. It is then removed from the water, the water dried from the surface of the particles, and the mass determined. Subsequently, the volume of the sample is determined by the displacement of water method. Finally, the sample is oven-dried and the mass determined. Using the mass values thus obtained and formulas in this test method, it is possible to calculate density, relative density (specific gravity), and absorption.

5. Significance and Use

5.1 Relative density (specific gravity) is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Relative density (specific gravity) is also used in the computation of voids in aggregate in Test Method C 29/C 29M. Relative density (specific gravity) (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the relative density (specific gravity) (OD) is used for computations when the aggregate is dry or assumed to be dry.

5.2 Apparent density and apparent relative density (apparent specific gravity) pertain to the solid material making up the constituent particles not including the pore space within the particles which is accessible to water.

5.3 Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for a prescribed period of time. Aggregates mined from below the water table commonly have a moisture content greater than the absorption determined by this test method, if used without opportunity to dry prior to use. Conversely, some aggregates which have not been continuously maintained in a moist condition until used are likely to contain an amount of absorbed moisture less than the 24-h soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture is determined by deducting the absorption from the total moisture content determined by Test Method C 566.

5.4 The general procedures described in this test method are suitable for determining the absorption of aggregates that have had conditioning other than the 24-h soak, such as boiling water or vacuum saturation. The values obtained for absorption by other test methods will be different than the values obtained by the prescribed soaking, as will the relative density (specific gravity) (SSD).

5.5 The pores in lightweight aggregates are not necessarily filled with water after immersion for 24 h. In fact, the absorption potential for many such aggregates is not satisfied after several days' immersion in water. Therefore, this test method is not intended for use with lightweight aggregate.

6. Apparatus

6.1 *Balance*—A device for determining mass that is sensitive, readable, and accurate to 0.05 % of the sample mass at any point within the range used for this test, or 0.5 g, whichever is greater. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the center of the platform or pan of the balance.

6.2 *Sample Container*—A wire basket of 3.35 mm (No. 6) or finer mesh, or a bucket of approximately equal breadth and height, with a capacity of 4 to 7 L for 37.5-mm (1½-in.) nominal maximum size aggregate or smaller, and a larger container as needed for testing larger maximum size aggregate. The container shall be constructed so as to prevent trapping air when the container is submerged.

6.3 *Water Tank*—A watertight tank into which the sample container is placed while suspended below the balance.

6.4 *Sieves*—A 4.75-mm (No. 4) sieve or other sizes as needed (see 7.2-7.4), conforming to Specification E 11.

7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75.

7.2 Thoroughly mix the sample of aggregate and reduce it to the approximate quantity needed using the applicable procedures in Practice C 702. Reject all material passing a 4.75-mm

(No. 4) sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. If the coarse aggregate contains a substantial quantity of material finer than the 4.75-mm sieve (such as for Size No. 8 and 9 aggregates in Classification D 448), use the 2.36-mm (No. 8) sieve in place of the 4.75-mm sieve. Alternatively, separate the material finer than the 4.75-mm sieve and test the finer material according to Test Method C 128.

NOTE 1—If aggregates smaller than 4.75 mm (No. 4) are used in the sample, check to ensure that the size of the openings in the sample container is smaller than the minimum size aggregate.

7.3 The minimum mass of test sample to be used is given as follows. Testing the coarse aggregate in several size fractions is permited. If the sample contains more than 15 % retained on the 37.5-mm (1½-in.) sieve, test the material larger than 37.5 mm in one or more size fractions separately from the smaller size fractions. When an aggregate is tested in separate size fractions, the minimum mass of test sample for each fraction shall be the difference between the masses prescribed for the maximum and minimum sizes of the fraction.

Nominal Maximum Size, mm (in.)	Minimum Mass of Test Sample, kg (lb)
12.5 (½) or less	2 (4.4)
19.0 (¾)	3 (6.6)
25.0 (1)	4 (8.8)
37.5 (1½)	5 (11)
50 (2)	8 (18)
63 (2½)	12 (26)
75 (3)	18 (40)
90 (3½)	25 (55)
100 (4)	40 (88)
125 (5)	75 (165)

7.4 If the sample is tested in two or more size fractions, determine the grading of the sample in accordance with Test Method C 136, including the sieves used for separating the size fractions for the determinations in this method. In calculating the percentage of material in each size fraction, ignore the quantity of material finer than the 4.75-mm (No. 4) sieve (or 2.36-mm (No. 8) sieve when that sieve is used in accordance with 7.2).

NOTE 2—When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and the values obtained combined for the computations described in Section 9.

8. Procedure

8.1 Dry the test sample to constant mass at a temperature of 110 ± 5°C, cool in air at room temperature for 1 to 3 h for test samples of 37.5-mm (1½-in.) nominal maximum size, or longer for larger sizes until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C). Subsequently immerse the aggregate in water at room temperature for a period of 24 ± 4 h.

8.2 Where the absorption and relative density (specific gravity) values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement in 8.1 for initial drying is optional, and, if the surfaces of the particles in the sample have been kept continuously wet until tested, the requirement in 8.1 for 24 ± 4 h soaking is also optional.

NOTE 3—Values for absorption and relative density (specific gravity) (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with 8.1. This is especially true of particles larger than 75 mm since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

8.3 Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. A moving stream of air is permitted to assist in the drying operation. Take care to avoid evaporation of water from aggregate pores during the surface-drying operation. Determine the mass of the test sample in the saturated surface-dry condition. Record this and all subsequent masses to the nearest 0.5 g or 0.05 % of the sample mass, whichever is greater.

8.4 After determining the mass in air, immediately place the saturated-surface-dry test sample in the sample container and determine its apparent mass in water at 23 ± 2.0°C. Take care to remove all entrapped air before determining its mass by shaking the container while immersed.

NOTE 4—The difference between the mass in air and the mass when the sample is submerged in water equals the mass of water displaced by the sample.

NOTE 5—The container should be immersed to a depth sufficient to cover it and the test sample while determining the apparent mass in water. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

8.5 Dry the test sample to constant mass at a temperature of 110 ± 5°C, cool in air at room temperature 1 to 3 h, or until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C), and determine the mass.

9. Calculations

9.1 *Relative Density (Specific Gravity)*:

9.1.1 *Relative Density (Specific Gravity) (OD)*—Calculate the relative density (specific gravity) on the basis of oven-dry aggregate as follows:

$$\text{Relative density (specific gravity) (OD)} = A/(B - C) \quad (1)$$

where:

A = mass of oven-dry test sample in air, g,
B = mass of saturated-surface-dry test sample in air, g, and
C = apparent mass of saturated test sample in water, g.

9.1.2 *Relative Density (Specific Gravity) (SSD)*—Calculate the relative density (specific gravity) on the basis of saturated-surface-dry aggregate as follows:

$$\text{Relative density (specific gravity) (SSD)} = B/(B - C) \quad (2)$$

9.1.3 *Apparent Relative Density (Apparent Specific Gravity)*—Calculate the apparent relative density (apparent specific gravity) as follows:

$$\text{Apparent relative density (apparent specific gravity)} = A/(A - C) \quad (3)$$

9.2 *Density*:

9.2.1 *Density (OD)*—Calculate the density on the basis of oven-dry aggregate as follows:

$$\text{Density (OD), kg/m}^3, = 997.5\, A/(B - C) \quad (4)$$

$$\text{Density (OD), lb/ft}^3, = 62.27\, A/(B - C) \quad (5)$$

NOTE 6—The constant values used in the calculations in 9.2.1-9.2.3 (997.5 kg/m^3 and 62.27 lb/ft^3) are the density of water at 23°C.

9.2.2 *Density (SSD)*—Calculate the density on the basis of saturated-surface-dry aggregate as follows:

$$\text{Density (SSD), kg/m}^3, = 997.5\ B/(B - C) \quad (6)$$

$$\text{Density (SSD), lb/ft}^3, = 62.27\ B/(B - C) \quad (7)$$

9.2.3 *Apparent Density*—Calculate the apparent density as follows:

$$\text{Apparent density, kg/m}^3 = 997.5\ A/(A - C) \quad (8)$$

$$\text{Apparent density, lb/ft}^3 = 62.27\ A/(A - C) \quad (9)$$

9.3 *Average Density and Relative Density (Specific Gravity) Values*—When the sample is tested in separate size fractions, compute the average values for density or relative density (specific gravity) of the size fraction computed in accordance with 9.1 or 9.2 using the following equation:

$$G = \frac{1}{\frac{P_1}{100\,G_1} + \frac{P_2}{100\,G_2} + \cdots \frac{P_n}{100\,G_n}} \text{ (see Appendix X1)} \quad (10)$$

where:

G = average density or relative density (specific gravity). All forms of expression of density or relative density (specific gravity) can be averaged in this manner,

$G_1, G_2 \ldots G_n$ = appropriate average density or relative density (specific gravity) values for each size fraction depending on the type of density or relative density (specific gravity) being averaged, and

$P_1, P_2, \ldots P_n$ = mass percentages of each size fraction present in the original sample (not including finer material—see 7.4).

9.4 *Absorption*—Calculate the percentage of absorption, as follows:

$$\text{Absorption, \%} = [(B - A)/A] \times 100 \quad (11)$$

NOTE 7—Some authorities recommend using the density of water at 4°C (1000 kg/m^3 or 1.000 Mg/m^3 or 62.43 lb/ft ^{3}) as being sufficiently accurate.

9.5 *Average Absorption Value*—When the sample is tested in separate size fractions, the average absorption value is the average of the values as computed in 9.4, weighted in proportion to the mass percentages of each size fraction present in the original sample (not including finer material—see 7.4) as follows:

$$A = (P_1A_1/100) + (P_2A_2/100) + \ldots\ (P_nA_n/100) \quad (12)$$

where:

A = average absorption, %,

$A_1, A_2 \ldots A_n$ = absorption percentages for each size fraction, and

$P_1, P_2, \ldots P_n$ = mass percentages of each size fraction present in the original sample.

10. Report

10.1 Report density results to the nearest 10 kg/m^3, or 0.5 lb/ft^3, relative density (specific gravity) results to the nearest 0.01, and and indicate the basis for density or relative density (specific gravity), as either (OD), (SSD), or apparent.

10.2 Report the absorption result to the nearest 0.1 %.

10.3 If the density, relative density (specific gravity) and absorption values were determined without first drying the aggregate, as permitted in 8.2, note that fact in the report.

11. Precision and Bias

11.1 The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and AASHTO Method T 85. The significant difference between the methods is that Test Method C 127 requires a saturation period of 24 ± 4 h, while Method T 85 requires a saturation period of 15 h minimum. This difference has been found to have an insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories. The precision estimates for density were calculated from values determined for relative density (specific gravity), using the density of water at 23°C for the conversion.

11.2 *Bias*—Since there is no accepted reference material for determining the bias for the procedure in this test method, no statement on bias is being made.

12. Keywords

12.1 absorption; aggregate; apparent density; apparent relative density; coarse aggregate; density; relative density; specific gravity

TABLE 1 Precision

	Standard Deviation (1s)[A]	Acceptable Range of Two Results (d2s)[A]
Single-Operator Precision:		
Density (OD), kg/m^3	9	25
Density (SSD), kg/m^3	7	20
Apparent density, kg/m^3	7	20
Relative density (specific gravity) (OD)	0.009	0.025
Relative density (specific gravity) (SSD)	0.007	0.020
Apparent relative density (apparent specific gravity)	0.007	0.020
Multilaboratory Precision:		
Density (OD), kg/m^3	13	38
Density (SSD), kg/m^3	11	32
Apparent density, kg/m^3	11	32
Relative density (specific gravity) (OD)	0.013	0.038
Relative density (specific gravity) (SSD)	0.011	0.032
Apparent relative density (apparent specific gravity)	0.011	0.032

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory proficiency sample data from laboratories using 15 h minimum saturation times and other laboratories using 24 ± 4 h saturation times. Testing was performed on normal-weight aggregates, and started with aggregates in the oven-dry condition.

APPENDIXES

(Nonmandatory Information)

X1. DEVELOPMENT OF EQUATIONS

X1.1 The derivation of the equation is from the following simplified cases using two solids. Solid 1 has a mass M_1 in grams and a volume V_1 in millilitres; its relative density (specific gravity) (G_1) is therefore M_1/V_1. Solid 2 has a mass M_2 and volume V_2, and $G_2 = M_2/V_2$. If the two solids are considered together, the relative density (specific gravity) of the combination is the total mass in grams divided by the total volume in millilitres:

$$G = (M_1 + M_2) / (V_1 + V_2) \quad \text{(X1.1)}$$

Manipulation of this equation yields the following:

$$G = \frac{1}{\frac{V_1 + V_2}{M_1 + M_2}} = \frac{1}{\frac{V_1}{M_1 + M_2} + \frac{V_2}{M_1 + M_2}} \quad \text{(X1.2)}$$

$$G = \frac{1}{\frac{M_1}{M_1 + M_2}\left(\frac{V_1}{M_1}\right) + \frac{M_2}{M_1 + M_2}\left(\frac{V_2}{M_2}\right)} \quad \text{(X1.3)}$$

However, the mass fractions of the two solids are:

$$M_1/(M_1 + M_2) = P_1/100 \text{ and } M_2/(M_1 + M_2) = P_2/100 \quad \text{(X1.4)}$$

and,

$$1/G_1 = V_1/M_1 \text{ and } 1/G_2 = V_2/M_2 \quad \text{(X1.5)}$$

Therefore,

$$G = \frac{1}{\frac{P_1}{100}\frac{1}{G_1} + \frac{P_2}{100}\frac{1}{G_2}} \quad \text{(X1.6)}$$

An example of the computation is given in Table X1.1.

TABLE X1.1 Example of Calculation of Weighted Values of Relative Density (Specific Gravity) and Absorption for a Coarse Aggregate Tested in Separate Sizes

Size Fraction, mm (in.)	% in Original Sample	Sample Mass Used in Test, g	Relative Density (Specific Gravity) (SSD)	Absorption, %
4.75 to 12.5 (No. 4 to ½)	44	2213.0	2.72	0.4
12.5 to 37.5 (½ to 1½)	35	5462.5	2.56	2.5
37.5 to 63 (1½ to 2½)	21	12593.0	2.54	3.0

Average Relative Density (Specific Gravity) (SSD)

$$G_{SSD} = \frac{1}{\frac{0.44}{2.72} + \frac{0.35}{2.56} + \frac{0.21}{2.54}} = 2.62$$

Average Absorption

$$A = (0.44)\,(0.4) + (0.35)\,(2.5) + (0.21)\,(3.0) = 1.7\ \%$$

X2. INTERRELATIONSHIPS BETWEEN RELATIVE DENSITIES (SPECIFIC GRAVITIES) AND ABSORPTION AS DEFINED IN TEST METHODS C 127 AND C 128

X2.1 Where:

S_d = relative density (specific gravity) (OD),

S_s = relative density (specific gravity) (SSD),
S_a = apparent relative density (apparent specific gravity), and
A = absorption in %.

X2.2 Calculate the values of each as follows:

$$S_s = (1 + A/100)S_d \quad \text{(X2.1)}$$

$$S_a = \frac{1}{\frac{1}{S_d} - \frac{A}{100}} = \frac{S_d}{1 - \frac{AS_d}{100}} \quad \text{(X2.2)}$$

$$S_a = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} = \frac{S_s}{1 - \left[\frac{A}{100}(S_s - 1)\right]} \quad \text{(X2.3)}$$

$$A = \left(\frac{S_s}{S_d} - 1\right) 100 \quad \text{(X2.4)}$$

$$A = \left(\frac{S_a - S_s}{S_a(S_s - 1)}\right) 100 \quad \text{(X2.5)}$$

SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Section 1 was revised.
(2) Section 2 was updated.
(3) Sections 3 through 11 were revised.
(4) The Appendix was revised.
(5) All tables were revised.

Designation: C 128 – 01ε1

Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate[1]

This standard is issued under the fixed designation C 128; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ε[1] NOTE—Table 1 was revised editorially in August 2003 to correct a typographical error in a value.

1. Scope*

1.1 This test method covers the determination of the average density of a quantity of fine aggregate particles (not including the volume of voids between the particles), the relative density (specific gravity), and the absorption of the fine aggregate. Depending on the procedure used, the density, in kg/m^3(lb/ft^3) is expressed as oven-dry (OD), saturated-surface-dry (SSD), or as apparent density. Likewise, relative density (specific gravity), a dimensionless quality, is expressed as OD, SSD, or as apparent relative density (apparent specific gravity). The OD density and OD relative density are determined after drying the aggregate. The SSD density, SSD relative density, and absorption are determined after soaking the aggregate in water for a prescribed duration.

1.2 This test method is used to determine the density of the essentially solid portion of a large number of aggregate particles and provides an average value representing the sample. Distinction is made between the density of aggregate particles as determined by this test method, and the bulk density of aggregates as determined by Test Method C 29/C 29M, which includes the volume of voids between the particles of aggregates.

1.3 This test method is not intended to be used for lightweight aggregates.

1.4 The values stated in SI units are to be regarded as the standard for conducting the tests. The test results for density shall be reported in either SI units or inch-pound units, as appropriate for the use to be made of the results.

1.5 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[2]

C 70 Test Method for Surface Moisture in Fine Aggregate[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 127 Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate[2]

C 188 Test Method for Density of Hydraulic Cement[3]

C 566 Test Method for Total Evaporable Moisture Content of Aggregate by Drying[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[4]

2.2 *AASHTO Standard:*

AASHTO No. T 84 Specific Gravity and Absorption of Fine Aggregates[5]

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 04.03.

[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

***A Summary of Changes section appears at the end of this standard.**

3.1.1 *absorption, n*—the increase in mass of aggregate due to water penetrating into the pores of the particles, during a prescribed period of time but not including water adhering to the outside surface of the particles, expressed as percentage of the dry mass.

3.1.2 *oven-dry (OD), adj—related to aggregate particles,* the condition in which the aggregates have been dried by heating in an oven at 110 ± 5°C for sufficient time to reach a constant mass.

3.1.3 *saturated-surface-dry (SSD), adj—related to aggregate particles,* the condition in which the permeable pores of aggregate particles are filled with water to the extent achieved by submerging in water for the prescribed period of time, but without free water on the surface of the particles.

3.1.4 *density, n*—the mass per unit volume of a material, expressed as kilograms per cubic metre (pounds per cubic foot).

3.1.4.1 *density (OD), n*—the mass of oven-dry aggregate particles per unit volume of aggregate particles, including the volume of permeable and impermeable pores within particles, but not including the voids between the particles.

3.1.4.2 *density (SSD), n*—the mass of saturated-surface-dry aggregate per unit volume of the aggregate particles, including the volume of impermeable voids and water-filled pores within the particles, but not including the pores between the particles.

3.1.4.3 *apparent density, n*—the mass per unit volume of the impermeable portion of the aggregate particles.

3.1.5 *relative density (specific gravity), n*—the ratio of the density of a material to the density of water at a stated temperature; the values are dimensionless.

3.1.5.1 *relative density (specific gravity), (OD), n*—the ratio of the density (OD) of the aggregate to the density of water at a stated temperature.

3.1.5.2 *relative density (specific gravity), (SSD), n*—The ratio of the density (SSD) of the aggregate to the density of water at a stated temperature.

3.1.5.3 *apparent relative density (apparent specific gravity), n*—the ratio of the apparent density of aggregate to the density of water at a stated temperature.

3.1.6 For definitions of other terms related to aggregates see Terminology C 125.

4. Summary of Test Method

4.1 A sample of aggregate is immersed in water for 24 ± 4 h to essentially fill the pores. It is then removed from the water, the water is dried from the surface of the particles, and the mass determined. Subsequently, the sample (or a portion of it) is placed in a graduated container and the volume of the sample is determined by the gravimetric or volumetric method. Finally, the sample is oven-dried and the mass determined again. Using the mass values thus obtained and formulas in this test method, it is possible to calculate density, relative density (specific gravity), and absorption.

5. Significance and Use

5.1 Relative density (specific gravity) is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Relative density (specific gravity) is also used in the computation of voids in aggregate in Test Method C 29/C 29M. Relative density (specific gravity) (SSD) is used in the determination of surface moisture on fine aggregate by displacement of water in Test Method C 70. Relative density (specific gravity) (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the density or relative density (specific gravity) (OD) is used for computations when the aggregate is dry or assumed to be dry.

5.2 Apparent density and apparent relative density (apparent specific gravity) pertain to the solid material making up the constituent particles not including the pore space within the particles that is accessible to water. This value is not widely used in construction aggregate technology.

5.3 Absorption values are used to calculate the change in the mass of an aggregate material due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for a prescribed period of time. Aggregates mined from below the water table commonly have a moisture content greater than the absorption determined by this test method, if used without opportunity to dry prior to use. Conversely, some aggregates which have not been continuously maintained in a moist condition until used are likely to contain an amount of absorbed moisture less than the 24-h soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture is determined by deducting the absorption from the total moisture content determined by Test Method C 566 by drying.

5.4 The general procedures described in this test method are suitable for determining the absorption of aggregates that have had conditioning other than the 24-h soak, such as boiling water or vacuum saturation. The values obtained for absorption by other test methods will be different than the values obtained by the prescribed 24-h soak, as will the density (SSD) or relative density (specific gravity (SSD).

5.5 The pores in lightweight aggregates are not necessarily filled with water after immersion for 24 h. In fact, the absorption potential for many such aggregates is not satisfied after several days immersion in water. Therefore, this test method is not intended for use with lightweight aggregate.

6. Apparatus

6.1 *Balance*—A balance or scale having a capacity of 1 kg or more, sensitive to 0.1 g or less, and accurate within 0.1 % of the test load at any point within the range of use for this test method. Within any 100-g range of test load, a difference between readings shall be accurate within 0.1 g.

6.2 *Pycnometer (for Use with Gravimetric Procedure)*—A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced within ± 0.1 cm^3. The volume of the container filled to mark shall be at least 50 % greater than

the space required to accommodate the test sample. A volumetric flask of 500-cm^3 capacity or a fruit jar fitted with a pycnometer top is satisfactory for a 500-g test sample of most fine aggregates.

6.3 *Flask (for Use with Volumetric Procedure)*—A Le Chatelier flask as described in Test Method C 188 is satisfactory for an approximately 55-g test sample.

6.4 *Mold and Tamper for Surface Moisture Test*—The metal mold shall be in the form of a frustum of a cone with dimensions as follows: 40 ± 3-mm inside diameter at the top, 90± 3-mm inside diameter at the bottom, and 75 ± 3 mm in height, with the metal having a minimum thickness of 0.8 mm. The metal tamper shall have a mass of 340 ± 15 g and a flat circular tamping face 25 ± 3 mm in diameter.

7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75. Thoroughly mix the sample and reduce it to obtain a test specimen of approximately 1 kg using the applicable procedures described in Practice C 702.

8. Preparation of Test Specimen

8.1 Dry the test specimen in a suitable pan or vessel to constant mass at a temperature of 110 ± 5°C. Allow it to cool to comfortable handling temperature, cover with water, either by immersion or by the addition of at least 6 % moisture to the fine aggregate, and permit to stand for 24 ± 4 h.

8.1.1 Where the absorption and relative density (specific gravity) values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement in 8.1 for initial drying is optional, and, if the surfaces of the particles in the sample have been kept continuously wet until tested, the requirement in 8.1 for 24 ± 4 h soaking is also optional.

NOTE 1—Values for absorption and for relative density (specific gravity) (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with 8.1.

8.2 Decant excess water with care to avoid loss of fines, spread the sample on a flat nonabsorbent surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying. Employ mechanical aids such as tumbling or stirring to assist in achieving the saturated surface-dry condition, if desired. Continue this operation until the test specimen approaches a free-flowing condition. Follow the procedure in 8.3 to determine if surface moisture is still present on the constituent fine aggregate particles. Make the first trial for surface moisture when there is still some surface water in the test specimen. Continue drying with constant stirring and test at frequent intervals until the test indicates that the specimen has reached a surface-dry condition. If the first trial of the surface moisture test indicates that moisture is not present on the surface, it has been dried past the saturated surface-dry condition. In this case, thoroughly mix a few millilitres of water with the fine aggregate and permit the specimen to stand in a covered container for 30 min. Then resume the process of drying and testing at frequent intervals for the onset of the surface-dry condition.

8.3 *Test for Surface Moisture*—Hold the mold firmly on a smooth nonabsorbent surface with the large diameter down. Place a portion of the partially dried fine aggregate loosely in the mold by filling it to overflowing and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Start each drop approximately 5 mm above the top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops over the surface. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. Slight slumping of the molded fine aggregate indicates that it has reached a surface-dry condition.

8.3.1 Some fine aggregate with predominately angular-shaped particles or with a high proportion of fines does not slump in the cone test upon reaching the surface-dry condition. Test by dropping a handful of the fine aggregate from the cone test onto a surface from a height of 100 to 150 mm, and observe for fines becoming airborne; presence of airborne fines indicates this problem. For these materials, consider the saturated surface-dry condition as the point that one side of the fine aggregate slumps slightly upon removing the mold.

NOTE 2—The following criteria have also been used on materials that do not readily slump:

(1) Provisional Cone Test—Fill the cone mold as described in 8.3 except only use 10 drops of the tamper. Add more fine aggregate and use 10 drops of the tamper again. Then add material two more times using 3 and 2 drops of the tamper, respectively. Level off the material even with the top of the mold, remove loose material from the base; and lift the mold vertically.

(2) Provisional Surface Test—If airborne fines are noted when the fine aggregate is such that it will not slump when it is at a moisture condition, add more moisture to the sand, and at the onset of the surface-dry condition, with the hand lightly pat approximately 100 g of the material on a flat, dry, clean, dark or dull nonabsorbent surface such as a sheet of rubber, a worn oxidized, galvanized, or steel surface, or a black-painted metal surface. After 1 to 3 s, remove the fine aggregate. If noticeable moisture shows on the test surface for more than 1 to 2 s then surface moisture is considered to be present on the fine aggregate.

(3) Colorimetric procedures described by Kandhal and Lee, Highway Research Record No. 307, p. 44.

(4) For reaching the saturated surface-dry condition on a single size material that slumps when wet, hard-finish paper towels can be used to surface dry the material until the point is just reached where the paper towel does not appear to be picking up moisture from the surfaces of the fine aggregate particles.

9. Procedure

9.1 Test by either the gravimetric procedure in 9.2 or the volumetric procedure in 9.3. Make all determinations of mass to 0.1 g.

9.2 *Gravimetric (Pycnometer) Procedure*:

9.2.1 Partially fill the pycnometer with water. Introduce into the pycnometer 500 ± 10 g of saturated surface-dry fine aggregate prepared as described in Section 8, and fill with additional water to approximately 90 % of capacity. Agitate the pycnometer as described in 9.2.1.1 (manually) or 9.2.1.2 (mechanically).

9.2.1.1 Manually roll, invert, and agitate the pycnometer to eliminate all air bubbles.

NOTE 3—About 15 to 20 min are normally required to eliminate the air bubbles by manual methods. Dipping the tip of a paper towel into the pycnometer has been found to be useful in dispersing the foam that sometimes builds up when eliminating the air bubbles. Optionally, a small amount of isopropyl alcohol may be used to disperse the foam.

9.2.1.2 Mechanically agitate the pycnometer by external vibration in a manner that will not degrade the sample. A level of agitation adjusted to just set individual particles in motion is sufficient to promote de-airing without degradation. A mechanical agitator shall be considered acceptable for use if comparison tests for each six-month period of use show variations less that the acceptable range of two results (d2s) indicated in Table 1 from the results of manual agitation on the same material.

9.2.2 After eliminating all air bubbles, adjust the temperature of the pycnometer and its contents to 23.0 ± 2.0°C if necessary by partial immersion in circulating water, and bring the water level in the pycnometer to its calibrated capacity. Determine the total mass of the pycnometer, specimen, and water.

9.2.3 Remove the fine aggregate from the pycnometer, dry to constant mass at a temperature of 110 ± 5°C, cool in air at room temperature for 1 ± ½ h, and determine the mass.

TABLE 1 Precision

	Standard Deviation (1s)[A]	Acceptable Range of Two Results (d2s)[A]
Single-Operator Precision:		
Density (OD), kg/m³	11	13
Density (SSD), kg/m³ [B†]	9.5	27
Apparent density, kg/m³	9.5	27
Relative density (specific gravity) (OD)	0.011	0.032
Relative density (specific gravity) (SSD)	0.0095	0.027
Apparent relative density (apparent specific gravity)	0.0095	0.027
Absorption[C], %	0.11	0.31
Multilaboratory Precision:		
Density (OD), kg/m³	23	64
Density (SSD), kg/m³	20	56
Apparent density, kg/m³	20	56
Relative density (specific gravity) (OD)	0.023	0.066
Relative density (specific gravity) (SSD)	0.020	0.056
Apparent relative density (apparent specific gravity)	0.020	0.056
Absorption[C], %	0.23	0.66

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory proficiency sample data from laboratories using 15 to 19-h saturation times and other laboratories using 24 ± 4-h saturation time. Testing was performed on normal weight aggregates, and started with aggregates in the oven-dry condition.

[B†] Revised editorially to correct a typographical error in August 2003.

[C] Precision estimates are based on aggregates with absorptions of less than 1 % and may differ for manufactured fine aggregates and the aggregates having absorption values greater than 1 %.

9.2.4 Determine the mass of the pycnometer filled to its calibrated capacity with water at 23.0 ± 2.0°C.

9.3 *Volumetric (Le Chatelier Flask) Procedure*:

9.3.1 Fill the flask initially with water to a point on the stem between the 0 and the 1-mL mark. Record this initial reading with flask and contents within the temperature range of 23.0 ± 2.0°C. Add 55 ± 5 g of fine aggregate in the saturated surface-dry condition (or other measured quantity as necessary). After all fine aggregate has been introduced, place the stopper in the flask and roll the flask in an inclined position, or gently whirl it in a horizontal circle so as to dislodge all entrapped air, continuing until no further bubbles rise to the surface (Note 4). Take a final reading with the flask and contents within 1°C of the original temperature.

NOTE 4—A small measured amount (not to exceed 1 mL) of isopropyl alcohol may be used to eliminate foam appearing on the water surface. The volume of alcohol used must be subtracted from the final reading (R_2).

9.3.2 For determination of the absorption, use a separate 500 ± 10-g portion of the saturated surface-dry fine aggregate, dry to constant mass, and determine the dry mass.

10. Calculations

10.1 *Symbols*:

A = mass of oven dry specimen, g

B = mass of pycnometer filled with water, to calibration mark, g

C = mass of pycnometer filled with specimen and water to calibration mark, g

R_1= initial reading of water level in Le Chatelier flask, mL

R_2= final reading of water in Le Chatelier flask, mL

S = mass of saturated surface-dry specimen (used in the gravimetric procedure for density and relative density (specific gravity), or for absorption with both procedures), g

S_1= mass of saturated surface-dry specimen (used in the volumetric procedure for density and relative density (specific gravity)), g

10.2 *Relative Density (Specific Gravity)*:

10.2.1 *Relative Density (Specific Gravity) (Oven dry)*—Calculate the relative density (specific gravity) on the basis of oven-dry aggregate as follows:

10.2.1.1 *Gravimetric Procedure*:

$$\text{Relative density (specific gravity) (OD)} = A/(B + S - C) \quad (1)$$

10.2.1.2 *Volumetric Procedure*:

$$\text{Relative density (specific gravity) (OD)} = [S_1\,(A/S)]/[0.9975\,(R_2 - R_1)] \quad (2)$$

10.2.2 *Relative Density (Specific Gravity) Saturated Surface-dry)*—Calculate the relative density (specific gravity) on the basis of saturated surface-dry aggregate as follows:

10.2.2.1 *Gravimetric Procedure*:

$$\text{Relative density (specific gravity) (SSD)} = S/(B + S - C) \quad (3)$$

10.2.2.2 *Volumetric Procedure*:

$$\text{Relative density (specific gravity) (SSD)} = S_1/[0.9975\,(R_2 - R_1)] \quad (4)$$

10.2.3 *Apparent Relative Density (Apparent Specific Gravity)*—Calculate the apparent relative density (apparent specific gravity) as follows:

10.2.3.1 *Gravimetric Procedure*:

$$\text{Apparent relative density (apparent specific gravity)} = A/(B + A - C) \quad (5)$$

10.2.3.2 *Volumetric Procedure*:

$$\text{Apparent relative density (apparent specific gravity)} = \frac{S_1\,(A/S)}{0.9975\,(R_2 - R_1) - [(S_1/S)(S - A)]} \quad (6)$$

10.3 *Density*:

10.3.1 *Density (Oven-dry)*—Calculate the density on the basis of oven-dry aggregates as follows:

10.3.1.1 *Gravimetric Procedure*:

$$\text{Density (OD), kg/m}^3 = 997.5\,A/(B + S - C) \quad (7)$$

$$\text{Density (OD), lb/ft}^3 = 62.27\,A/(B + S - C) \quad (8)$$

10.3.1.2 *Volumetric Procedure*:

$$\text{Density (OD), kg/m}^3 = 997.5\,S_1\,(A/S)/[0.9975\,(R_2 - R_1)] \quad (9)$$

$$\text{Density (OD), lb/ft}^3 = 62.27\,S_1\,(A/S)/[0.9975\,(R_2 - R_1)] \quad (10)$$

NOTE 5—The constant values used in the calculations in 10.3.1-10.3.3 (997.5 kg/m^3 and 62.27 lb/ft^3) are the density of water at 23°C. Some authorities recommend using the density of water at 4°C (1000 kg/m^3 or 1000 Mg/m^3 or 62.43 lb/ft^3) as being sufficiently accurate.

10.3.2 *Density (Saturated surface-dry)*—Calculate the density on the basis of saturated surface-dry aggregate as follows:

10.3.2.1 *Gravimetric Procedure*:

$$\text{Density (SSD), kg/m}^3 = 997.5\,S/(B + S - C) \quad (11)$$

$$\text{Density (SSD), lb/ft}^3 = 62.27\,S/(B + S - C) \quad (12)$$

10.3.2.2 *Volumetric Procedure*:

$$\text{Density (SSD), kg/m}^3 = 997.5\,S_1/[0.9975\,(R_2 - R_1)] \quad (13)$$

$$\text{Density (SSD), lb/ft}^3 = 62.27\,S_1/[0.9975\,(R_2 - R_1)] \quad (14)$$

10.3.3 *Apparent Density*—Calculate the apparent density as follows:

10.3.3.1 *Gravimetric Procedure*:

$$\text{Apparent density (SSD), kg/m}^3 = 997.5\,A/(B + A - C) \quad (15)$$

$$\text{Apparent density (SSD), lb/ft}^3 = 62.27\,A/(B + A - C) \quad (16)$$

10.3.3.2 *Volumetric Procedure*:

$$\text{Apparent density (SSD), kg/m}^3, = \frac{997.5\,S_1\,(A/S)}{0.9975\,(R_2 - R_1) - [(S_1/S)(S - A)]} \quad (17)$$

$$\text{Apparent density (SSD), lb/ft}^3, = \frac{62.27\,S_1\,(A/S)}{0.9975\,(R_2 - R_1) - [(S_1/S)(S - A)]} \quad (18)$$

10.4 *Absorption*—Calculate the percentage of absorption as follows:

$$\text{Absorption, \%} = 100\,[(S - A)/A] \quad (19)$$

11. Report

11.1 Report density results to the nearest 10 kg/m^3, or 0.5 lb/ft^3, relative density (specific gravity) results to the nearest 0.01, and indicate the basis for density or relative density (specific gravity), as either oven-dry (OD), saturated-surface-dry (SSD), or apparent.

11.2 Report the absorption result to the nearest 0.1 %.

11.3 If the density and relative density (specific gravity) values were determined without first drying the aggregate, as permitted in 8.2, note that fact in the report.

12. Precision and Bias

12.1 *Precision*—The estimates of precision of this test method (listed in Table 1) are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and AASHTO Method T 84. The significant difference between the methods is that Test Method C 128 requires a saturation period of 24 ± 4 h, and AASHTO Test Method T 84 requires a saturation period of 15 to 19 h. This difference has been found to have an insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories. The precision estimates for density were calculated from values determined for relative density (specific gravity), using the density of water at 23°C for the conversion.

12.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for this test method, no statement on bias is being made.

13. Keywords

13.1 absorption; aggregate; aparent density; apparent relative density; density; fine aggregate; relative density; specific gravity

APPENDIX

(Nonmandatory Information)

X1. INTERRELATIONSHIPS BETWEEN RELATIVE DENSITIES (SPECIFIC GRAVITIES) AND ABSORPTION AS DEFINED IN TEST METHODS C 127 AND C 128

X1.1 This appendix gives mathematical interrelationships among the three types of relative densities (specific gravities) and absorption. These may be useful in checking the consistency of reported data or calculating a value that was not reported by using other reported data.

X1.2 Where:

S_d = relative density (specific gravity) (OD),
S_s = relative density (specific gravity) (SSD),
S_a = apparent relative density (apparent specific gravity), and
A = absorption, in %.

Calculate the values of each as follows:

$$S_s = (1 + A/100)S_d \quad \text{(X1.1)}$$

$$S_s = \frac{1}{\frac{1}{S_d} - \frac{A}{100}} = \frac{S_d}{1 - \frac{AS_d}{100}} \quad \text{(X1.2)}$$

$$\text{or } S_a = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} \quad \text{(X1.3)}$$

$$= \frac{S_s}{1 = \frac{A}{100}(S_s - 1)}$$

$$A = \left(\frac{S_s}{S_d} - 1\right) 100 \quad \text{(X1.4)}$$

$$A = \left(\frac{S_a - S_s}{S_a (S_s - 1)}\right) 100 \quad \text{(X1.5)}$$

SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Entire standard was rewritten.

Designation: C 136 – 01

Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates[1]

This standard is issued under the fixed designation C 136; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2 Some specifications for aggregates which reference this method contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information purposes only. Specification E 11 designates the size of sieve frames with inch units as standard, but in this test method the frame size is designated in SI units exactly equivalent to the inch units.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 117 Test Method for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

E 11 Specification for Wire-Cloth and Sieves for Testing Purposes[4]

2.2 *AASHTO Standard:*

AASHTO No. T 27 Sieve Analysis of Fine and Coarse Aggregates[5]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, refer to Terminology C 125.

4. Summary of Test Method

4.1 A sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

5. Significance and Use

5.1 This test method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

5.2 Accurate determination of material finer than the 75-µm (No. 200) sieve cannot be achieved by use of this method alone. Test Method C 117 for material finer than 75-µm sieve by washing should be employed.

6. Apparatus

6.1 *Balances*—Balances or scales used in testing fine and coarse aggregate shall have readability and accuracy as follows:

6.1.1 For fine aggregate, readable to 0.1 g and accurate to 0.1 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

6.1.2 For coarse aggregate, or mixtures of fine and coarse aggregate, readable and accurate to 0.5 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

6.2 *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

***A Summary of Changes section appears at the end of this standard.**

frames shall conform to the requirements of Specification E 11. Nonstandard sieve frames shall conform to the requirements of Specification E 11 as applicable.

NOTE 1—It is recommended that sieves mounted in frames larger than standard 203.2-mm (8 in.) diameter be used for testing coarse aggregate to reduce the possibility of overloading the sieves. See 8.3.

6.3 *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in 8.4 is met in a reasonable time period.

NOTE 2—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 min) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a small sample of coarse aggregate or fine aggregate.

6.4 *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75. The size of the field sample shall be the quantity shown in Practice D 75 or four times the quantity required in 7.4 and 7.5 (except as modified in 7.6), whichever is greater.

7.2 Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in Practice C 702. The sample for test shall be approximately the quantity desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined quantity shall not be permitted.

NOTE 3—Where sieve analysis, including determination of material finer than the 75-µm sieve, is the only testing proposed, the size of the sample may be reduced in the field to avoid shipping excessive quantities of extra material to the laboratory.

7.3 *Fine Aggregate*—The size of the test sample, after drying, shall be 300 g minimum.

7.4 *Coarse Aggregate*—The size of the test sample of coarse aggregate shall conform with the following:

Nominal Maximum Size, Square Openings, mm (in.)	Test Sample Size, min, kg (lb)
9.5 (⅜)	1 (2)
12.5 (½)	2 (4)
19.0 (¾)	5 (11)
25.0 (1)	10 (22)
37.5 (1½)	15 (33)
50 (2)	20 (44)
63 (2½)	35 (77)
75 (3)	60 (130)
90 (3½)	100 (220)
100 (4)	150 (330)
125 (5)	300 (660)

7.5 *Coarse and Fine Aggregate Mixtures*—The size of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate in 7.4.

7.6 *Samples of Large Size Coarse Aggregate*—The size of sample required for aggregate with 50-mm nominal maximum size or larger is such as to preclude convenient sample reduction and testing as a unit except with large mechanical splitters and sieve shakers. As an option when such equipment is not available, instead of combining and mixing sample increments and then reducing the field sample to testing size, conduct the sieve analysis on a number of approximately equal sample increments such that the total mass tested conforms to the requirement of 7.4.

7.7 In the event that the amount of material finer than the 75-µm (No. 200) sieve is to be determined by Test Method C 117, proceed as follows:

7.7.1 For aggregates with a nominal maximum size of 12.5 mm (1/2 in.) or less, use the same test sample for testing by Test Method C 117 and this method. First test the sample in accordance with Test Method C 117 through the final drying operation, then dry sieve the sample as stipulated in 8.2-8.7 of this method.

7.7.2 For aggregates with a nominal maximum size greater than 12.5 mm (½ in.), a single test sample may be used as described in 7.7.1, or separate test samples may be used for Test Method C 117 and this method.

7.7.3 Where the specifications require determination of the total amount of material finer than the 75-µm sieve by washing and dry sieving, use the procedure described in 7.7.1.

8. Procedure

8.1 Dry the sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F).

NOTE 4—For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless: (*1*) the nominal maximum size is smaller than about 12.5 mm (½ in.); (*2*) the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4); or (*3*) the coarse aggregate is highly absorptive (a lightweight aggregate, for example). Also, samples may be dried at the higher temperatures associated with the use of hot plates without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles, and temperatures are not so great as to cause chemical breakdown of the aggregate.

8.2 Select sieves with suitable openings to furnish the information required by the specifications covering the material to be tested. Use additional sieves as desired or necessary to provide other information, such as fineness modulus, or to regulate the amount of material on a sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy or sieving described in 8.4.

8.3 Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75-mm (No. 4), the quantity retained on any sieve at the completion of the sieving operation shall not exceed 7 kg/m^2 of sieving surface area (Note 5). For sieves with openings 4.75 mm (No. 4) and larger, the quantity retained in kg shall not exceed the product of 2.5 × (sieve opening, mm × (effective sieving area, m^2)). This quantity is shown in Table 1 for five sieve-frame dimensions in common

TABLE 1 Maximum Allowable Quantity of Material Retained on a Sieve, kg

Sieve Opening Size, mm	Nominal Dimensions of Sieve[A]				
	203.2-mm dia[B]	254-mm dia[B]	304.8-mm dia[B]	350 by 350 mm	372 by 580 mm
	Sieving Area, m^2				
	0.0285	0.0457	0.0670	0.1225	0.2158
125	[C]	[C]	[C]	[C]	67.4
100	[C]	[C]	[C]	30.6	53.9
90	[C]	[C]	15.1	27.6	48.5
75	[C]	8.6	12.6	23.0	40.5
63	[C]	7.2	10.6	19.3	34.0
50	3.6	5.7	8.4	15.3	27.0
37.5	2.7	4.3	6.3	11.5	20.2
25.0	1.8	2.9	4.2	7.7	13.5
19.0	1.4	2.2	3.2	5.8	10.2
12.5	0.89	1.4	2.1	3.8	6.7
9.5	0.67	1.1	1.6	2.9	5.1
4.75	0.33	0.54	0.80	1.5	2.6

[A] Sieve frame dimensions in inch units: 8.0-in. diameter; 10.0-in. diameter, 12.0-in. diameter; 13.8 by 13.8 in. (14 by 14 in. nominal); 14.6 by 22.8 in. (16 by 24 in. nominal).

[B] The sieve area for round sieve frames is based on an effective diameter 12.7 mm (½ in.) less than the nominal frame diameter, because Specification E 11 permits the sealer between the sieve cloth and the frame to extend 6.35 mm (¼ in.) over the sieve cloth. Thus the effective sieving diameter for a 203.2-mm (8.0-in.) diameter sieve frame is 190.5 mm (7.5 in.). Some manufacturers of sieves may not infringe on the sieve cloth by the full 6.35 mm (¼ in.).

[C] Sieves indicated have less than five full openings and should not be used for sieve testing except as provided in 8.6.

use. In no case shall the quantity retained be so great as to cause permanent deformation of the sieve cloth.

8.3.1 Prevent an overload of material on an individual sieve by one of the following methods:

8.3.1.1 Insert an additional sieve with opening size intermediate between the sieve that may be overloaded and the sieve immediately above that sieve in the original set of sieves.

8.3.1.2 Split the sample into two or more portions, sieving each portion individually. Combine the masses of the several portions retained on a specific sieve before calculating the percentage of the sample on the sieve.

8.3.1.3 Use sieves having a larger frame size and providing greater sieving area.

NOTE 5—The 7 kg/m^2 amounts to 200 g for the usual 203.2-mm (8-in.) diameter sieve (with effective sieving surface diameter of 190.5 mm (7.5 in.)).

8.4 Continue sieving for a sufficient period and in such manner that, after completion, not more than 1 % by mass of the material retained on any individual sieve will pass that sieve during 1 min of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203-mm (8 in.) diameter sieves to verify the sufficiency of sieving.

8.5 In the case of coarse and fine aggregate mixtures, the portion of the sample finer than the 4.75-mm (No. 4) sieve may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

8.5.1 Alternatively, the portion finer than the 4.75-mm (No. 4) sieve may be reduced in size using a mechanical splitter according to Practice C 702. If this procedure is followed, compute the mass of each size increment of the original sample as follows:

$$A = \frac{W_1}{W_2} \times B \quad (1)$$

where:

A = mass of size increment on total sample basis,
W_1 = mass of fraction finer than 4.75-mm (No. 4) sieve in total sample,
W_2 = mass of reduced portion of material finer than 4.75-mm (No. 4) sieve actually sieved, and
B = mass of size increment in reduced portion sieved.

8.6 Unless a mechanical sieve shaker is used, hand sieve particles larger than 75 mm (3 in.) by determining the smallest sieve opening through which each particle will pass. Start the test on the smallest sieve to be used. Rotate the particles, if necessary, in order to determine whether they will pass through a particular opening; however, do not force particles to pass through an opening.

8.7 Determine the mass of each size increment on a scale or balance conforming to the requirements specified in 5.1 to the nearest 0.1 % of the total original dry sample mass. The total mass of the material after sieving should check closely with original mass of sample placed on the sieves. If the amounts differ by more than 0.3 %, based on the original dry sample mass, the results should not be used for acceptance purposes.

8.8 If the sample has previously been tested by Test Method C 117, add the mass finer than the 75-µm (No. 200) sieve determined by that method to the mass passing the 75-µm (No. 200) sieve by dry sieving of the same sample in this method.

9. Calculation

9.1 Calculate percentages passing, total percentages retained, or percentages in various size fractions to the nearest 0.1 % on the basis of the total mass of the initial dry sample. If the same test sample was first tested by Test Method C 117, include the mass of material finer than the 75-µm (No. 200) size by washing in the sieve analysis calculation; and use the total dry sample mass prior to washing in Test Method C 117 as the basis for calculating all the percentages.

9.1.1 When sample increments are tested as provided in 7.6, total the masses of the portion of the increments retained on each sieve, and use these masses to calculate the percentages as in 9.1.

9.2 Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: 150-µm (No. 100), 300-µm (No. 50), 600-µm (No. 30), 1.18-mm (No. 16), 2.36-mm (No. 8), 4.75-mm (No. 4), 9.5-mm (⅜-in.), 19.0-mm (¾-in.), 37.5-mm (1½-in.), and larger, increasing in the ratio of 2 to 1.

10. Report

10.1 Depending upon the form of the specifications for use of the material under test, the report shall include the following:

10.1.1 Total percentage of material passing each sieve, or

10.1.2 Total percentage of material retained on each sieve, or

10.1.3 Percentage of material retained between consecutive sieves.

10.2 Report percentages to the nearest whole number, except if the percentage passing the 75-µm (No. 200) sieve is less than 10 %, it shall be reported to the nearest 0.1 %.

10.3 Report the fineness modulus, when required, to the nearest 0.01.

11. Precision and Bias

11.1 *Precision*—The estimates of precision for this test method are listed in Table 2. The estimates are based on the results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by Test Method C 136 and AASHTO Test Method T 27. The data are based on the analyses of the test results from 65 to 233 laboratories that tested 18 pairs of coarse aggregate proficiency test samples and test results from 74 to 222 laboratories that tested 17 pairs of fine aggregate proficiency test samples (Samples No. 21 through 90). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

11.1.1 The precision values for fine aggregate in Table 2 are based on nominal 500-g test samples. Revision of this test method in 1994 permits the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 3, which indicate only minor differences due to test sample size.

NOTE 6—The values for fine aggregate in Table 2 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

TABLE 2 Precision

	Total Percentage of Material Passing		Standard Deviation (1s), %[A]	Acceptable Range of Two Results (d2s), %[A]
Coarse Aggregate:[B]				
Single-operator precision	<100	≥95	0.32	0.9
	<95	≥85	0.81	2.3
	<85	≥80	1.34	3.8
	<80	≥60	2.25	6.4
	<60	≥20	1.32	3.7
	<20	≥15	0.96	2.7
	<15	≥10	1.00	2.8
	<10	≥5	0.75	2.1
	<5	≥2	0.53	1.5
	<2	>0	0.27	0.8
Multilaboratory precision	<100	≥95	0.35	1.0
	<95	≥85	1.37	3.9
	<85	≥80	1.92	5.4
	<80	≥60	2.82	8.0
	<60	≥20	1.97	5.6
	<20	≥15	1.60	4.5
	<15	≥10	1.48	4.2
	<10	≥5	1.22	3.4
	<5	≥2	1.04	3.0
	<2	>0	0.45	1.3
Fine Aggregate:				
Single-operator precision	<100	≥95	0.26	0.7
	<95	≥60	0.55	1.6
	<60	≥20	0.83	2.4
	<20	≥15	0.54	1.5
	<15	≥10	0.36	1.0
	<10	≥2	0.37	1.1
	<2	>0	0.14	0.4
Multilaboratory precision	<100	≥95	0.23	0.6
	<95	≥60	0.77	2.2
	<60	≥20	1.41	4.0
	<20	≥15	1.10	3.1
	<15	≥10	0.73	2.1
	<10	≥2	0.65	1.8
	<2	>0	0.31	0.9

[A] These numbers represent, respectively, the (1s) and (d2s) limits described in Practice C 670.

[B] The precision estimates are based on aggregates with nominal maximum size of 19.0 mm (¾ in.).

11.2 *Bias*—Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

12. Keywords

12.1 aggregate; coarse aggregate; fine aggregate; gradation; grading; sieve analysis; size analysis

TABLE 3 Precision Data for 300-g and 500-g Test Samples

Fine Aggregate Proficiency Sample				Within Laboratory		Between Laboratory	
Test Result	Sample Size	Number Labs	Average	1s	d2s	1s	d2s
ASTM C136/AASHTO T27							
Total material passing the No. 4 sieve (%)	500 g	285	99.992	0.027	0.066	0.037	0.104
	300 g	276	99.990	0.021	0.060	0.042	0.117
Total material passing the No. 8 sieve (%)	500 g	281	84.10	0.43	1.21	0.63	1.76
	300 g	274	84.32	0.39	1.09	0.69	1.92
Total material passing the No. 16 sieve (%)	500 g	286	70.11	0.53	1.49	0.75	2.10
	300 g	272	70.00	0.62	1.74	0.76	2.12
Total material passing the No. 30 sieve (%)	500 g	287	48.54	0.75	2.10	1.33	3.73
	300 g	276	48.44	0.87	2.44	1.36	3.79
Total material passing the No. 50 sieve (%)	500 g	286	13.52	0.42	1.17	0.98	2.73
	300 g	275	13.51	0.45	1.25	0.99	2.76
Total material passing the No. 100 sieve (%)	500 g	287	2.55	0.15	0.42	0.37	1.03
	300 g	270	2.52	0.18	0.52	0.32	0.89
Total Material passing the No. 200 sieve (%)	500 g	278	1.32	0.11	0.32	0.31	0.85
	300 g	266	1.30	0.14	0.39	0.31	0.85

SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporatedsince the last issue.

(1) Paragraph 8.4 was revised.

Designation: C 143/C 143M – 03

Standard Test Method for Slump of Hydraulic-Cement Concrete[1]

This standard is issued under the fixed designation C 143/C 143M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field.

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

3. Summary of Test Method

3.1 A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete.

4. Significance and Use

4.1 This test method is intended to provide the user with a procedure to determine slump of plastic hydraulic-cement concretes.

NOTE 1—This test method was originally developed to provide a technique to monitor the consistency of unhardened concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is not clearly and consistently shown. Care should therefore be taken in relating slump results obtained under field conditions to strength.

4.2 This test method is considered applicable to plastic concrete having coarse aggregate up to 1½ in. [37.5 mm] in size. If the coarse aggregate is larger than 1½ in. [37.5 mm] in size, the test method is applicable when it is performed on the fraction of concrete passing a 1½-in. [37.5-mm] sieve, with the larger aggregate being removed in accordance with the section titled "Additional Procedure for Large Maximum Size Aggregate Concrete" in Practice C 172.

4.3 This test method is not considered applicable to non-plastic and non-cohesive concrete.

NOTE 2—Concretes having slumps less than ½ in. [15 mm] may not be adequately plastic and concretes having slumps greater than about 9 in. [230 mm] may not be adequately cohesive for this test to have significance. Caution should be exercised in interpreting such results.

5. Apparatus

5.1 *Mold*—The test specimen shall be formed in a mold made of metal not readily attacked by the cement paste. The metal shall not be thinner than 0.060 in. [1.5 mm] and if formed by the spinning process, there shall be no point on the mold at which the thickness is less than 0.045 in. [1.15 mm]. The mold shall be in the form of the lateral surface of the frustum of a cone with the base 8 in. [200 mm] in diameter, the top 4 in. [100 mm] in diameter, and the height 12 in. [300 mm]. Individual diameters and heights shall be within ±⅛ in. [3 mm] of the prescribed dimensions. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Fresh Concrete Testing.

Current edition approved July 10, 2003. Published September 2003. Originally approved in 1922. Last previous edition approved in 2000 as C 143/C 143 – 00.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

***A Summary of Changes section appears at the end of this standard.**

handles similar to those shown in Fig. 1. The mold shall be constructed without a seam. The interior of the mold shall be relatively smooth and free from projections. The mold shall be free from dents, deformation, or adhered mortar. A mold which clamps to a nonabsorbent base plate is acceptable instead of the one illustrated, provided the clamping arrangement is such that it can be fully released without movement of the mold and the base is large enough to contain all of the slumped concrete in an acceptable test.

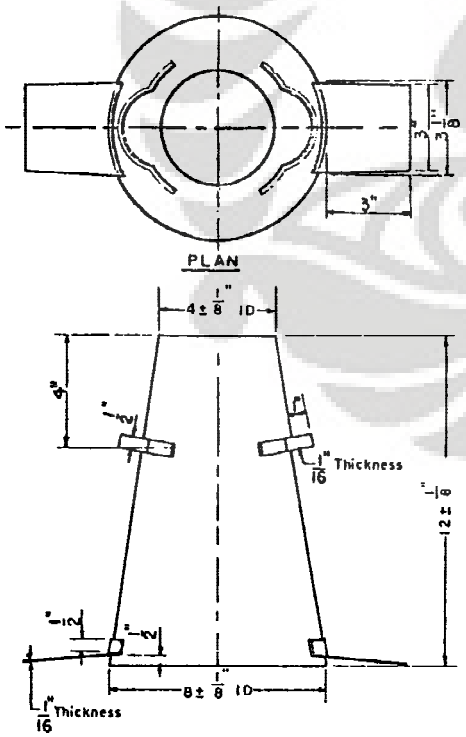
5.1.1 Mold with alternative materials.

5.1.1.1 Molds other than metal are allowed if the following requirements are met: The mold shall meet the shape, height, and internal dimensional requirements of 5.1. The mold shall be sufficiently rigid to maintain the specified dimensions and tolerances during use, resistant to impact forces, and shall be nonabsorbent. The mold shall be demonstrated to provide test results comparable to those obtained when using a metal mold meeting the requirements of 5.1. Comparability shall be demonstrated on behalf of the manufacturer by an independent testing laboratory. Test for comparability shall consist of not less than 10 pairs of comparisons performed at each of 3 different slumps ranging from 2 to 6 in. [50 to 150 mm]. No individual test results shall vary by more than 0.50 in. [15 mm] from that obtained using the metal mold. The average test results of each slump range obtained using the mold constructed of alternative material shall not vary by more than 0.30 in. [10 mm] from the average of test results obtained using the metal mold. Manufacturer comparability test data shall be available to users and laboratory inspection authorities (see Note 3). If any changes in material or method of manufacture are made, tests for comparability shall be repeated.

NOTE 3—Because the slump of concrete decreases with time and higher temperatures, it will be advantageous for the comparability tests to be performed by alternating the use of metal cones and alternative material cones, to utilize several technicians, and to minimize the time between test procedures.

5.1.1.2 If the condition of any individual mold is suspected of being out of tolerance from the as manufactured condition, a single comparative test shall be performed. If the test results differ by more than 0.50 in. [15 mm] from that obtained using the metal mold, the mold shall be removed from service.

5.2 *Tamping Rod*—A round, straight steel rod ⅝ in. [16 mm] in diameter and approximately 24 in. [600 mm] in length, having the tamping end or both ends rounded to a hemispherical tip, the diameter of which is ⅝ in. [16 mm].



Dimensional Units									
in.	1/16	⅛	½	1	3	3⅛	4	8	12
mm	[2]	[3]	[15]	[25]	[75]	[80]	[100]	[200]	[300]

FIG. 1 Mold for Slump Test

6. Sample

6.1 The sample of concrete from which test specimens are made shall be representative of the entire batch. It shall be obtained in accordance with Practice C 172.

7. Procedure

7.1 Dampen the mold and place it on a flat, moist, nonabsorbent (rigid) surface. It shall be held firmly in place during filling by the operator standing on the two foot pieces. From the sample of concrete obtained in accordance with Section 6, immediately fill the mold in three layers, each approximately one third the volume of the mold.

NOTE 4—One third of the volume of the slump mold fills it to a depth of 2⅝ in. [70 mm]; two thirds of the volume fills it to a depth of 6⅛ in. [160 mm].

7.2 Rod each layer with 25 strokes of the tamping rod. Uniformly distribute the strokes over the cross section of each layer. For the bottom layer, this will necessitate inclining the rod slightly and making approximately half of the strokes near the perimeter, and then progressing with vertical strokes spirally toward the center. Rod the bottom layer throughout its depth. Rod the second layer and the top layer each throughout its depth, so that the strokes just penetrate into the underlying layer.

7.3 In filling and rodding the top layer, heap the concrete above the mold before rodding is started. If the rodding operation results in subsidence of the concrete below the top edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all times. After the top layer has been rodded, strike off the surface of the concrete by means of a screeding and rolling motion of the tamping rod. Continue to hold the mold down firmly and remove concrete from the area surrounding the base of the mold to preclude interference with the movement of slumping concrete. Remove the mold immediately from the concrete by raising it carefully in a vertical direction. Raise the mold a distance of 12 in. [300 mm] in 5 ± 2 s by a steady upward lift with no lateral or torsional motion. Complete the entire test from the start of the filling through removal of the mold without interruption and complete it within an elapsed time of 2½ min.

7.4 Immediately measure the slump by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs (Note 5), disregard the test and make a new test on another portion of the sample.

NOTE 5—If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, the concrete probably lacks necessary plasticity and cohesiveness for the slump test to be applicable.

8. Report

8.1 Report the slump in terms of inches [millimetres] to the nearest ¼ in. [5 mm] of subsidence of the specimen during the test.

9. Precision and Bias [3]

9.1 *Precision*—The estimates of precision for this test method are based upon results from tests conducted in Fayetteville, Arkansas by 15 technicians from 14 laboratories representing 3 states. All tests at 3 different slump ranges, from 1.0 in. [25 mm] to 6.5 in. [160 mm], were performed using one load of truck-mixed concrete. The concrete was delivered and tested at a low slump, with water then being added and mixed into the remaining concrete to independently produce moderate and finally high-slump concrete. The concrete mixture that used a No. 67 crushed limestone aggregate and a washed river sand, contained 500 lb of cementitious materials per cubic yard [297 kg of cementitious material per cubic metre]. The 500 lb [227 kg] were equally divided between a C150, Type I/II cement and a Class C fly ash. A double dosage of a chemical retarder was used in an attempt to minimize slump losses and maintain workability of the concrete. Concrete temperatures ranged from 86 to 93°F [30 to 34°C]. Slump losses averaged 0.68 in. [17 mm] during the 20 min required to perform a series of 6 tests at 1 slump range. Testing was performed alternately using metal and plastic molds, which were determined to produce comparable results. Precision data thus applies to both metal and plastic molds. A total of 270 slump tests were performed.

9.1.1 *Inch-Pound [SI]*—The data used to develop the precision statement were obtained using metric units (millimetres). The precision values shown in inch-pound units are conversions from the millimetre measurements, which were recorded to the nearest 1 mm.

9.1.2 *Measure of Variability*—The standard deviation was determined to be the most consistent measure of variability and was found to vary with the slump value.

9.1.3 *Single-Operator Precision*—The single-operator standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by the same operator performing successive tests, one immediately following the other. Acceptable results of two properly conducted tests by the same operator on the same material (Note 6) will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and single-operator precision.

9.1.4 *Multilaboratory Precision*—The multilaboratory standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by different operators from different laboratories performing tests less than 4 min apart. Therefore, acceptable results of two properly conducted slump tests on the same material (Note 6) by two different laboratories will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and multilaboratory precision.

NOTE 6—"Same materials," is used to mean freshly mixed concrete from one batch.

9.2 *Bias*—This test method has no bias since slump is defined only in terms of this test method.

10. Keywords

10.1 concrete; cone; consistency; plasticity; slump; workability

TABLE 1 Precision

Slump and Type Index	Standard Deviation (1s)[A]		Acceptable Range of Two Results (d2s)[A]	
Single-Operator Precision:	in.	[mm]	in.	[mm]
Slump 1.2 in. [30 mm]	0.23	[6]	0.65	[17]
Slump 3.4 in. [85 mm]	0.38	[9]	1.07	[25]
Slump 6.5 in. [160 mm]	0.40	[10]	1.13	[28]
Multilaboratory Precision:				
Slump 1.2 in. [30 mm]	0.29	[7]	0.82	[20]
Slump 3.4 in. [85 mm]	0.39	[10]	1.10	[28]
Slump 6.5 in. [160 mm]	0.53	[13]	1.50	[37]

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670.

[3] The test data used to develop this precision statement were based on tests performed in September 1997. A report of test results is on file at ASTM International Headquarters. Request RR: C09-1022.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C 143/C 143M – 00) that may impact the use of this standard. (Approved July 10, 2003.)

(*1*) Revised 7.3 to clarify instructions for performing slump test.

(*2*) Changed "slump cone" to "mold" in sections 7.3 and 9.1.

Designation: C 192/C 192M – 02

Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory[1]

This standard is issued under the fixed designation C 192/C 192M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers procedures for making and curing test specimens of concrete in the laboratory under accurate control of materials and test conditions using concrete that can be consolidated by rodding or vibration as described herein.

1.2 The values stated in either inch-pound units or SI units shall be regarded separately as standard. The SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of each other. Combining values from the two systems may result in nonconformance.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 70 Test Method for Surface Moisture in Fine Aggregate[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 127 Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate[2]

C 128 Test Method for Density, Relative Density (Specific Gravity) and Absorption of Fine Aggregate[2]

C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]

C 143/C 143M Test Method for Slump of Hydraulic Cement Concrete[2]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[2]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 330 Specification for Lightweight Aggregates for Structural Concrete[2]

C 403/C 403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance[2]

C 470/C 470M Specification for Molds for Forming Concrete Test Cylinders Vertically[2]

C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[3]

C 566 Test Method for Total Moisture Content of Aggregate by Drying[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 1064 Test Method for Temperature of Freshly Mixed Portland-Cement Concrete[2]

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[2]

2.2 *American Concrete Institute Publications:* [4]

211.3 Practice for Selecting Proportions for No-Slump Concrete

309 Guide for Concrete Consolidation

3. Significance and Use

3.1 This practice provides standardized requirements for preparation of materials, mixing concrete, and making and curing concrete test specimens under laboratory conditions.

3.2 If specimen preparation is controlled as stipulated herein, the specimens may be used to develop information for the following purposes:

3.2.1 Mixture proportioning for project concrete,

3.2.2 Evaluation of different mixtures and materials,

3.2.3 Correlation with nondestructive tests, and

3.2.4 Providing specimens for research purposes.

NOTE 1—The concrete test results for concrete specimens made and cured using this practice are widely used. They may be the basis for

[1] This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] Available from the American Concrete Institute, P.O. Box 9094, Farmington Hills, MI 48333-9094.

acceptance testing for project concrete, research evaluations, and other studies. Careful and knowledgeable handling of materials, mixing concrete, molding test specimens, and curing test specimens is necessary. Many laboratories performing this important work are independently inspected or accredited. Practice C 1077 identifies and defines duties, responsibilities, including minimum responsibilities of the laboratory personnel and minimum technical requirements for laboratory equipment used. Many laboratories ensure qualified technicians by participating in national certification programs such as the American Concrete Institute Laboratory Technician Program or an equivalent program.

4. Apparatus

4.1 *Molds, General*—Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall conform to the dimensions and tolerances specified in the method for which the specimens are required. Molds shall hold their dimensions and shape under all conditions of use. Watertightness of molds during use shall be judged by their ability to hold water poured into them. Test procedures for watertightness are given in the section on Test Methods for Elongation, Absorption, and Watertightness of Specification C 470/C 470M. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax, shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

4.2 *Cylinder Molds:*

4.2.1 *Molds for Casting Specimens Vertically* shall conform to the requirements of 4.1 and Specification C 470/C 470M.

4.2.2 *Horizontal Molds for Creep Test Cylinders* shall conform to the requirements of 4.1 and to the requirements for symmetry and dimensional tolerance in the section on General Requirements except for verticality requirements of Specification C 470/C 470M. The use of horizontal molds is intended only for creep specimens that contain axially embedded strain gages. Molds for creep cylinders to be filled while supported in a horizontal position shall have a filling slot parallel to the axis of the mold which extends the full length to receive the concrete. The width of the slot shall be one half the diameter of the specimen. If necessary the edges of the slot shall be reinforced to maintain dimensional stability. Unless specimens are to be capped or ground to produce plane ends, the molds shall be provided with two machined metal end plates at least 1 in. [25 mm] thick and the working surfaces shall comply with the requirements for planeness and surface roughness given in the section on Capping Plates of Practice C 617. Provision shall be made for fixing both end plates firmly to the mold. The inside surface of each end plate shall be provided with at least three lugs or studs approximately 1 in. [25 mm] long, firmly fastened to the plate for embedment in the concrete. One base plate shall be drilled from the inside at an angle to permit the lead wire from the strain gage to exit the specimen through the edge of the plate. Provision shall be made for accurately positioning the strain gage. All necessary holes shall be as small as possible to minimize disturbance to subsequent strain measurements and shall be sealed to prevent leakage.

4.3 *Beam and Prism Molds* shall be rectangular in shape (unless otherwise specified) and of the dimensions required to produce the desired specimen size. The inside surfaces of the molds shall be smooth and free from indentations. The sides, bottom, and ends shall be at right angles to each other and shall be straight and true and free of warpage. Maximum variation from the nominal cross section shall not exceed ⅛ in. [3 mm] for molds with depth or breadth of 6 in. [150 mm] or more, or 1⁄16 in. [2 mm] for molds of smaller depth or breadth. Except for flexure specimens, molds shall not vary from the nominal length by more than 1⁄16 in. [2 mm]. Flexure molds shall not be shorter than 1⁄16 in. [2 mm] of the required length, but may exceed it by more than that amount.

4.4 *Tamping Rods*—Two sizes are specified in ASTM methods. Each shall be a round, straight steel rod with at least the tamping end rounded to a hemispherical tip of the same diameter as the rod. Both ends may be rounded, if preferred.

4.4.1 *Larger Rod*, ⅝ in. [16 mm] in diameter and approximately 24 in. [600 mm] long.

4.4.2 *Smaller Rod*, ⅜ in. [10 mm] in diameter and approximately 12 in. [300 mm] long.

4.5 *Mallets*—A mallet with a rubber or rawhide head weighing 1.25 ± 0.50 lb [0.6 ± 0.20 kg] shall be used.

4.6 *Vibrators*:

4.6.1 *Internal Vibrators*—The vibrator frequency shall be at least 7000 vibrations per minute [115 Hz] while the vibrator is operating in the concrete. The diameter of a round vibrator shall be no more than one fourth the diameter of the cylinder mold or one fourth the width of the beam or prism mold. Other shaped vibrators shall have a perimeter equivalent to the circumference of an appropriate round vibrator. The combined length of the vibrator shaft and vibrating element shall exceed the depth of the section being vibrated by at least 3 in. [75 mm].

NOTE 2—For information on size and frequency of various vibrators and method to periodically check vibrator frequency, see ACI 309.

4.6.2 *External Vibrators*—The two types of external vibrators permitted are either table or plank. The external vibrator frequency shall be 3600 vibrations per minute [60 Hz] or higher.

4.6.3 Provisions shall be made for clamping the mold securely to the apparatus for both types of vibrators.

NOTE 3—Vibratory impulses are frequently imparted to a table or plank vibrator through electromagnetic means, or by use of an eccentric weight on the shaft of an electric motor or on a separate shaft driven by a motor.

4.7 *Small Tools*—Tools and items such as shovels, pails, trowels, wood float, blunted trowels, straightedge, feeler gage, scoops, rulers, rubber gloves, and metal mixing bowls shall be provided.

4.8 *Slump Apparatus*—The apparatus for measurement of slump shall conform to the requirements of Test Method C 143/C 143M.

4.9 *Sampling and Mixing Pan*—The pan shall be flat-bottom and of heavy-gage metal, watertight, of convenient depth, and of sufficient capacity to allow easy mixing by shovel or trowel of the entire batch; or, if mixing is by machine, to receive the entire batch on discharge of the mixer and allow remixing in the pan by trowel or shovel.

4.10 *Wet-Sieving Equipment*—If wet-sieving is required, the

equipment shall conform to the requirements of Practice C 172.

4.11 *Air Content Apparatus*—The apparatus for measuring air content shall conform to the requirements of either Test Methods C 231 or C 173.

4.12 *Scales*—Scales for determining the mass of batches of materials and concrete shall be accurate within 0.3 % of the test load at any point within the range of use.

NOTE 4—In general the mass of small quantities should not be determined on large capacity scales. In many applications the smallest mass determined on a scale should be greater than about 10 % of the maximum capacity of the scale; however, this will vary with the performance characteristics of the scale and the required accuracy of the determination. Acceptable scales used for determining the mass for concrete materials preferably should determine mass accurately to about 0.1 % of total capacity and the foregoing precaution is applicable. However, certain analytical and precision balances are exceptions to this rule and should weigh accurately to 0.001 %. Particular care must be exercised in measuring small quantities of material by determining the difference between two much larger masses.

4.13 *Temperature Measuring Device*—The temperature measuring device shall conform to the requirements of Test Method C 1064.

4.14 *Concrete Mixer*—A power-driven concrete mixer shall be a revolving drum, tilting mixer, or suitable revolving pan or revolving-paddle mixer capable of thoroughly mixing batches of the prescribed sizes at the required slump.

NOTE 5—A pan mixer is usually more suitable for mixing concrete with less than 1-in. [25 mm] slump than a revolving drum mixer. The rate of rotation, degree of tilt, and rated capacity of tilting mixers are not always suitable for laboratory mixed concrete. It may be found desirable to reduce the rate of rotation, decrease the angle of tilt from the horizontal, and use the mixer at somewhat less than the manufacturer's rated capacity.

5. Specimens

5.1 *Cylindrical Specimens*—Cylinders for such tests as compressive strength, Young's modulus of elasticity, creep, and splitting tensile strength may be of various sizes with a minimum of 2-in. [50-mm] diameter by 4-in. [100-mm] length. Where correlation or comparison with field-made cylinders (Practice C 31/C 31M) is desired, the cylinders shall be 6 by 12 in. [or 150 by 300 mm]. Otherwise, dimensions should be governed in accordance with 5.4 and the specific test method concerned.

NOTE 6—When molds in SI units are required and not available, equivalent inch-pound unit size mold should be permitted.

5.1.1 Cylindrical specimens for tests other than creep shall be molded and allowed to harden with the axis of the cylinder vertical.

5.1.2 Cylindrical creep specimens may be cast with the cylindrical axis either vertical or horizontal and allowed to harden in the position in which cast.

5.2 *Prismatic Specimens*—Beams for flexural strength, prisms for freezing and thawing, bond, length change, volume change, etc., shall be formed with their long axes horizontal, unless otherwise required by the method of test in question, and shall conform in dimension to the requirements of the specific test method.

5.3 *Other Specimens*—Other shapes and sizes of specimens for particular tests may be molded as desired following the general procedures set forth in this practice.

5.4 *Specimen Size versus Aggregate Size*—The diameter of a cylindrical specimen or minimum cross-sectional dimension of a rectangular section shall be at least three times the nominal maximum size of the coarse aggregate in the concrete as defined in Terminology C 125. Occasional over-size aggregate particles (of a size not normally found in the average aggregate grading) shall be removed by hand picking during the molding of the specimens. When the concrete contains aggregate larger than that appropriate for the size of the molds or equipment to be used, wet-sieve the sample as described in Practice C 172.

5.5 *Number of Specimens*—The number of specimens and the number of test batches are dependent on established practice and the nature of the test program. Guidance is usually given in the test method or specification for which the specimens are made. Usually three or more specimens are molded for each test age and test condition unless otherwise specified (Note 7). Specimens involving a given variable should be made from three separate batches mixed on different days. An equal number of specimens for each variable should be made on any given day. When it is impossible to make at least one specimen for each variable on a given day, the mixing of the entire series of specimens should be completed in as few days as possible, and one of the mixtures should be repeated each day as a standard of comparison.

NOTE 7—Test ages often used are 7 and 28 days for compressive strength tests, or 14 and 28 days for flexural strength tests. Specimens containing Type III cement are often tested at 1, 3, 7, and 28 days. For later test ages, 3 months, 6 months, and 1 year are often used for both compressive and flexural strength tests. Other test ages may be required for other types of specimens.

6. Preparation of Materials

6.1 *Temperature*—Before mixing the concrete, bring the concrete materials to room temperature in the range from 68 to 86°F [20 to 30°C], except when the temperature of the concrete is stipulated. When a concrete temperature is stipulated, the method proposed to obtain the concrete temperature needs approval of the stipulator.

6.2 *Cement*—Store the cement in a dry place, in moisture-proof containers, preferably made of metal. The cement shall be thoroughly mixed to provide a uniform supply throughout the tests. It shall be passed through a 850-µm [No. 20] or finer sieve to remove all lumps, remixed on a plastic sheet, and returned to sample containers.

6.3 *Aggregates*—In order to preclude segregation of a coarse aggregate, separate into individual size fractions and for each batch recombine in the proper proportions to produce the desired grading.

NOTE 8—Only rarely is a coarse aggregate batched as a single size fraction. The number of size fractions will generally be between 2 and 5 for aggregate smaller than 2½ in. [60 mm]. When a size fraction to be batched is present in amounts in excess of 10 %, the ratio of the opening of the larger to the smaller sieve should not exceed 2.0. More closely sized groups are sometimes advisable.

6.3.1 Unless fine aggregate is separated into individual size fractions, maintain it in a damp condition or restore to a damp condition until use, to prevent segregation, unless material uniformly graded is subdivided into batch size lots using a

sample splitter with proper size openings. If unusual gradings are being studied, the fine aggregate may need to be dried and separated into individual sizes. In this instance, if the total quantity of fine aggregate required is larger than can be efficiently blended in a single unit, then the individual size fractions should be determined in a mass required for each individual batch. When the total quantity of fine aggregate needed for the complete investigation is such that it can be thoroughly mixed, blended, and maintained in a damp condition, then it should be handled in that manner. Determine the specific gravity and absorption of aggregates in accordance with either Test Methods C 127 or C 128.

6.3.2 Before incorporating in concrete, prepare the aggregate to ensure a definite and uniform condition of moisture. Determine the weight of aggregate to be used in the batch by one of the following procedures:

6.3.2.1 Determine the mass of low-absorption aggregates (absorption less than 1.0 %) in the room-dry condition with allowance made for the amount of water that will be absorbed from the unset concrete (Note 9). This procedure is particularly useful for coarse aggregate which must be batched as individual sizes; because of the danger of segregation it can be used for fine aggregate only when the fine aggregate is separated into individual size fractions.

NOTE 9—When using aggregates with low absorption in room-dry condition the amount of water that will be absorbed by the aggregates before the concrete sets may be assumed to be 80 % of the difference between the 24-h absorption of the aggregates determined by Test Methods C 127 or C 128, and the amount of water in the pores of the aggregates in their room-dry state, as determined by Test Method C 566.

6.3.2.2 Individual size fractions of aggregate may be weighed separately, recombined into a tared container in the amounts required for the batch, and immersed in water for 24 h prior to use. After immersion the excess water is decanted and the combined weight of aggregate and mixing water determined. Allowance shall be made for the amount of water absorbed by the aggregate. The moisture content of the aggregates may be determined in accordance with Test Methods C 70 and C 566.

6.3.2.3 The aggregate may be brought to and maintained in a saturated condition, with surface moisture contained in sufficiently small amounts to preclude loss by draining, at least 24 h prior to use. When this method is used, the moisture content of the aggregate must be determined to permit calculation of proper quantities of the damp aggregate. The quantity of surface moisture present must be counted as a part of the required amount of mixing water. Surface moisture in fine aggregate may be determined in accordance with Test Methods C 70 and C 566, making due allowance for the amount of water absorbed. The method outlined here (moisture content slightly exceeding absorption) is particularly useful for fine aggregate. It is used less frequently for coarse aggregate because of the difficulty of accurately determining the moisture content, but if used, each size fraction must be handled separately to ensure that the proper grading is obtained.

6.3.2.4 Aggregates, fine or coarse, may be brought to and maintained in a saturated surface-dry condition until batched for use. This method is used primarily to prepare material for batches not exceeding ¼ ft^3 [0.007 m^3] in volume. Care must be taken to prevent drying during weighing and use.

6.4 *Lightweight Aggregates*—The procedures for specific gravity, absorption, and preparation of aggregates mentioned in this practice pertain to materials with normal absorption values. Lightweight aggregates, air-cooled slag, and certain highly porous or vesicular natural aggregate may be so absorptive as to be difficult to treat as described. The moisture content of lightweight aggregate at the time of mixing may have important effects on properties of freshly mixed and hardened concretes such as slump loss, compressive strength, and resistance to freezing and thawing.

6.5 *Admixtures*—Powdered admixtures that are entirely or largely insoluble, that do not contain hygroscopic salts and are to be added in small quantities, should be mixed with a portion of the cement before introduction into the batch in the mixer so as to ensure thorough distribution throughout the concrete. Essentially insoluble materials which are used in amounts exceeding 10 % by mass of cement, such as pozzolans, should be handled and added to the batch in the same manner as cement. Powdered admixtures which are largely insoluble but contain hygroscopic salts may cause balling of cement and should be mixed with the sand. Water-soluble and liquid admixtures should be added to the mixer in solution in the mixing water. The quantity of such solution used shall be included in the calculation of the water content of the concrete. Admixtures, incompatible in concentrated form, such as solutions of calcium chloride and certain air-entraining and set-retarding admixtures, should not be intermixed prior to their addition to concrete. The time, sequence, and method of adding some admixtures to a batch of concrete can have important effects on concrete properties such as time of set and air content. The method selected must remain unchanged from batch to batch.

NOTE 10—The mixing apparatus and accessories shall be thoroughly cleaned to ensure that chemical additions or admixtures used in dissimilar batches of concrete do not affect subsequent batches.

7. Procedure

7.1 *Mixing Concrete:*

7.1.1 *General*—Mix concrete in a suitable mixer or by hand in batches of such size as to leave about 10 % excess after molding the test specimens. Hand-mixing procedures are not applicable to air-entrained concrete or concrete with no measurable slump. Hand mixing should be limited to batches of ¼ ft^3 [0.007 m^3] volume or less. Mixing procedures are given in 7.1.2 and 7.1.3. However, other procedures may be used when it is desired to simulate special conditions or practices, or when the procedures specified are impracticable. A machine-mixing procedure suitable for drum-type mixers is described. It is important not to vary the mixing sequence and procedure from batch to batch unless the effect of such variation is under study.

7.1.2 *Machine Mixing*—Prior to starting rotation of the mixer add the coarse aggregate, some of the mixing water, and the solution of admixture, when required, in accordance with 6.5. When feasible, disperse the admixture in the mixing water before addition. Start the mixer, then add the fine aggregate, cement, and water with the mixer running. If it is impractical

for a particular mixer or for a particular test to add the fine aggregate, cement, and water while the mixer is running, these components may be added to the stopped mixer after permitting it to turn a few revolutions following charging with coarse aggregate and some of the water (Note 11). Mix the concrete, after all ingredients are in the mixer, for 3 min followed by a 3-min rest, followed by a 2-min final mixing. Cover the open end or top of the mixer to prevent evaporation during the rest period. Take precautions to compensate for mortar retained by the mixer so that the discharged batch, as used, will be correctly proportioned (Note 12). To eliminate segregation, deposit machine-mixed concrete in the clean, damp mixing pan and remix by shovel or trowel until it appears to be uniform.

NOTE 11—An experienced operator may add water incrementally during mixing to adjust to the desired slump.

NOTE 12—It is difficult to recover all of the mortar from mixers. To compensate for this difficulty one of the following procedures may be used to ensure the correct final proportions in the batch:

(1) "Buttering" the Mixer—Just prior to mixing the test batch, the mixer is "buttered" by mixing a batch proportioned to simulate closely the test batch. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch.

(2) "Over-Mortaring" the Mix—The test mix is proportioned by the use of an excess mortar, the amount established in advance, to compensate for that which, on the average, adheres to the mixer. In this case the mixer is cleaned before mixing the test batch.

7.1.3 *Hand Mixing*—Mix the batch in a watertight, clean (Note 10), damp, metal pan or bowl, with a bricklayer's blunted trowel, using the following procedure when aggregates have been prepared in accordance with 6.3.2.1, 6.3.2.3, and 6.3.2.4.

7.1.3.1 Mix the cement, powdered insoluble admixture, if used, and fine aggregate without addition of water until they are thoroughly blended.

7.1.3.2 Add the coarse aggregate and mix the entire batch without addition of water until the coarse aggregate is uniformly distributed throughout the batch.

7.1.3.3 Add water, and the admixture solution if used, and mix the mass until the concrete is homogeneous in appearance and has the desired consistency. If prolonged mixing is necessary because of the addition of water in increments while adjusting the consistency, discard the batch and make a new batch in which the mixing is not interrupted to make trial consistency tests.

7.1.4 *Mixed Concrete*—Select the portions of the batch of mixed concrete to be used in tests for molding specimens so as to be representative of the actual proportions and condition of the concrete. When the concrete is not being remixed or sampled cover it to prevent evaporation.

7.2 *Slump, Air Content, Yield, and Temperature:*

7.2.1 *Slump*—Measure the slump of each batch of concrete immediately after mixing in accordance with Test Method C 143/C 143M.

NOTE 13—The slump test is unsuitable for concrete so dry that it slumps less than ¼ in. [6 mm]. No-slump concrete may be tested by one of several means described in ACI 211.3.

7.2.2 *Air Content*—Determine the air content, when required, in accordance with either Test Methods C 173 or C 231. Test Method C 231 should not be used with concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. Discard the concrete used for the determination of air content.

7.2.3 *Yield*—Determine the yield of each batch of concrete, if required, in accordance with Test Method C 138. Concrete used for slump and yield tests may be returned to the mixing pan and remixed into the batch.

7.2.4 *Temperature*—Determine the temperature of each batch of concrete in accordance with Test Method C 1064.

7.3 *Making Specimens:*

7.3.1 *Place of Molding*—Mold specimens as near as practicable to the place where they are to be stored during the first 24 h. If it is not practicable to mold the specimens where they will be stored, move them to the place of storage immediately after being struck off. Place molds on a rigid surface free from vibration and other disturbances. Avoid jarring, striking, tilting, or scarring of the surface of the specimens when moving the specimens to the storage place.

7.3.2 *Placing*—Place the concrete in the molds using a scoop, blunted trowel, or shovel. Select each scoopful, trowelful, or shovelful of concrete from the mixing pan to ensure that it is representative of the batch. It may be necessary to remix the concrete in the mixing pan with a shovel or trowel to prevent segregation during the molding of specimens. Move the scoop or trowel around the top edge of the mold as the concrete is discharged in order to ensure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate within the mold. Further distribute the concrete by use of a tamping rod prior to the start of consolidation. In placing the final layer the operator shall attempt to add an amount of concrete that will exactly fill the mold after compaction. Do not add nonrepresentative samples of concrete to an underfilled mold.

7.3.2.1 *Number of Layers*—Make specimens in layers as indicated in Table 1.

7.4 *Consolidation:*

7.4.1 *Methods of Consolidation*—Preparation of satisfactory specimens requires different methods of consolidation. The methods of consolidation are rodding, and internal or external vibration. Base the selection of the method on the slump, unless the method is stated in the specifications under which the work is being performed. Rod or vibrate concrete

TABLE 1 Number of Layers Required for Specimens

Specimen Type and Size	Mode of Consolidation	Numbers of Layers of Approximate Equal Depth
Cylinders: Diameter, in. [mm]		
3 or 4 [75 to 100]	rodding	2
6 [150]	rodding	3
9 [225]	rodding	4
up to 9 [225]	vibration	2
Prisms and horizontal creep Cylinders: Depth, in. [mm]		
up to 8 [200]	rodding	2
over 8 [200]	rodding	3 or more
up to 8 [200]	vibration	1
over 8 [200]	vibration	2 or more

with slump greater than or equal to 1 in. [25 mm]. Vibrate concrete with slump less than 1 in. (Note 14). Do not use internal vibration for cylinders with a diameter less than 4 in. [100 mm], and for beams or prisms with breath or depth less than 4 in.

NOTE 14—Concrete of such low water content that it cannot be properly consolidated by the methods described herein is not covered by this practice. Provisions for specimens and methods of testing will be found in the standards concerned. There are concretes that can be consolidated by external vibration, but additional forces on the surface are required to embed the coarse aggregate thoroughly and consolidate the mixture. For such mixtures the following procedures may be followed: using external vibration fill 6 by 12-in. [150 by 300-mm] cylinder molds in 3 in. [75 mm] lifts using a 10-lb [4.5-kg] cylindrical surcharge, or 3 by 6-in. [75 by 150-mm] cylinder molds in 2 in. [50 mm] lifts using a 2.5-lb [1-kg] cylindrical surcharge. The surcharge should have a diameter ¼ in. [6 mm] less than the inside of the mold. Simultaneously each lift should be compacted by external vibration with the surcharge on the top surface of the concrete, until the mortar begins to ooze around the bottom of the surcharge.

7.4.2 *Rodding*—Place the concrete in the mold, in the required number of layers of approximately equal volume. Rod each layer with the rounded end of the rod using the number of strokes and size of rod specified in Table 2. Rod the bottom layer throughout its depth. Distribute the strokes uniformly over the cross section of the mold and for each upper layer allow the rod to penetrate through the layer being rodded and into the layer below approximately 1 in. [25 mm]. After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. Use an open hand to tap light-gage single-use molds which are susceptible to damage if tapped with a mallet. After tapping, spade the concrete along the sides and ends of beam and prism molds with a trowel or other suitable tool.

7.4.3 *Vibration*—Maintain a uniform duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and large air bubbles cease to break through the top surface. Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 15). Overvibration may cause segregation. Fill the molds and vibrate in the required number of approximately equal layers (Table 2). Place all the concrete for each layer in the mold before starting vibration of that layer. When placing the final layer, avoid overfilling by more than ¼ in. [6 mm]. When the finish is applied after vibration, add only enough concrete with a trowel to overfill the mold about ⅛ in. [3 mm], work it into the surface and then strike it off.

NOTE 15—Generally, no more than 5 s of vibration should be required for each insertion to adequately consolidate the concrete with a slump greater than 3 in. [75 mm]. Longer times may be required for lower slump concrete, but the vibration time should rarely have to exceed 10 s per insertion.

7.4.3.1 *Internal Vibration*—In compacting the specimen insert the vibrator slowly and do not allow the vibrator to rest on or touch the bottom or sides of the mold or strike embedded items such as strain meters. Slowly withdraw the vibrator so that no large air pockets are left in the specimen.

7.4.3.2 *Cylinders*—The number of insertions of the vibrator is given in Table 3. When more than one insertion per layer is required, distribute the insertions uniformly within each layer. Allow the vibrator to penetrate into the layer below approximately 1 in. [25 mm]. After each layer is vibrated, tap the outside of the mold at least 10 times with the mallet to close the holes that remain and to release entrapped air voids. Use an open hand to tap cardboard or single-use metal molds that are susceptible to damage if tapped with a mallet.

7.4.3.3 *Beams, Prisms, and Horizontal Creep Cylinders*—Insert the vibrator at intervals not exceeding 6 in. [150 mm] along the center line of the long dimension of the specimen, or along both sides but not in contact with the strain gage in the case of creep cylinders. For specimens wider than 6 in. [150 mm], use alternating insertions along two lines. Allow the shaft of the vibrator to penetrate into the bottom layer approximately 1 in. [25 mm]. After each layer is vibrated, tap the outsides of the mold sharply at least 10 times with the mallet to close holes left by vibrating and to release entrapped air voids.

7.4.4 *External Vibration*—When external vibration is used, take care to ensure that the mold is rigidly attached to or securely held against the vibrating element or vibrating surface (Note 14).

7.5 *Finishing*—After consolidation by any of the methods, strike off the surface of the concrete and float or trowel it in accordance with the method concerned. If no finish is specified, finish the surface with a wood or magnesium float. Perform all finishing with the minimum manipulation necessary to produce

TABLE 2 Diameter of Rod and Number of Roddings to be Used in Molding Test Specimens

Cylinders		
Diameter of Cylinder, in. [mm]	Diameter of Rod in. [mm]	Number of Strokes/Layer
2 [50] to <6 [150]	⅜[10]	25
6 [150]	⅝ [16]	25
8 [200]	⅝ [16]	50
10 [250]	⅝ [16]	75
Beams and Prisms		
Top Surface Area of Specimen, in.^{2}[cm^2]	Diameter of Rod in. (mm)	Number of Roddings/Layer
25 [160] or less	⅜[10]	25
26 to 49 [165 to 310]	⅜[10]	one for each 1 in.^{2}[7 cm^2] of surface
50 [320] or more	⅝ [16]	one for each 2 in.^{2}[14 cm^2] of surface
Horizontal Creep Cylinders		
Diameter of Cylinder in. [mm]	Diameter of Rod in. [mm]	Number of Roddings/Layer
6 [150]	⅝[16]	50 total, 25 along both sides of axis

TABLE 3 Number of Vibrator Insertions per Layer

Specimen Type and Size	Number of Insertions per Layer
Cylinder: Diameter, in. [mm]	
4 in. [200 mm]	1
6 in. [150 mm]	2
9 in. [225 mm]	4

a flat even surface that is level with the rim or edge of the mold and which has no depressions or projections larger than ⅛ in. [3 mm].

7.5.1 *Cylinders*—After consolidation finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits, or with a wood float or trowel. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste which is permitted to harden and cure with the specimen. See the section on Capping Materials of Practice C 617.

7.5.2 *Horizontally Cast Creep Cylinders*—After consolidation strike off the specimen with a trowel or float, then trowel the minimum amount required to form the concrete in the opening concentrically with the rest of the specimen. Use a screed curved to the radius of the specimen to more precisely shape and finish the concrete in the opening.

8. Curing

8.1 *Initial Curing*—To prevent evaporation of water from unhardened concrete, cover the specimens immediately after finishing, preferably with a nonabsorptive, nonreactive plate or a sheet of tough, durable impervious plastic. Specimens shall be stored immediately after finishing until the removal of the molds to prevent loss of moisture from the specimens. Select an appropriate procedure or combination of procedures that will prevent moisture loss and is nonabsorptive and nonreactive with the concrete. When wet burlap is used for covering, the burlap must not be in contact with the fresh concrete surface and care must be exercised to keep the burlap wet until the specimens are removed from the molds. Placing a sheet of plastic over the burlap will facilitate keeping it wet. To prevent damage to specimens, protect the outside of cardboard molds from contact with wet burlap or other sources of water until the molds are removed. Record the maximum and minimum ambient temperatures during the initial curing.

8.2 *Removal from Molds*—Remove the specimens from the molds 24 ± 8 h after casting. For concrete with prolonged setting time, molds shall not be removed until 20 ± 4 h after final set. If needed, determine the setting times in accordance with Test Method C 403/C 403M.

8.3 *Curing Environment*—Unless otherwise specified all specimens shall be moist cured at 73.5 ± 3.5°F [23.0 ± 2.0°C] from the time of molding until the moment of test (Note 16). Storage during the first 48 h of curing shall be in a vibration-free environment. As applied to the treatment of demolded specimens, moist curing means that the test specimens shall have free water maintained on the entire surface area at all times. This condition is met by using water storage tanks or a moist room in accordance with the requirements of Specification C 511. Cure structural lightweight concrete cylinders in accordance with Specification C 330.

NOTE 16—The temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

8.4 *Flexural Strength Test Specimens*—Cure the flexural strength test specimens in accordance with 8.1 and 8.2 except that while in storage for a minimum period of 20 h immediately prior to testing they shall be immersed in water saturated with calcium hydroxide at 73 ± 3°F [23 ± 2°C]. At the end of the curing period, between the time the specimen is removed from curing until testing is completed, drying of the surfaces shall be prevented.

NOTE 17—Relatively small amounts of drying of the surface of flexural strength specimens will induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9. Precision and Bias

9.1 Data to establish precision statements for various testing required by this standard were obtained in the Concrete Proficiency Sample Program of the Cement and Concrete Reference Laboratory.

9.2 The single-operator standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 0.7 in., 0.9 lb/ft^3, 0.3 %, and 203 psi, respectively; therefore the results of properly conducted tests on two trial batches made in the same laboratory should not differ by more than 2.0 in., 2.5 lb/ft^3, 0.8 %, and 574 psi, respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a constant water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 in. [50 mm] or over 6 in. [150 mm], or concrete made with other than normal weight aggregate or aggregate larger than 1 in. [25 mm] nominal maximum size.

9.3 The multilaboratory standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 1.0 in., 1.4 lb/ft^3 0.4 %, and 347 psi, respectively; therefore, the results of properly conducted tests on single trial batches made in two different laboratories should not differ by more than 2.8 in., 4.0 lb/ft^3, 1.1 %, and 981 psi, respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a prescribed water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 in. [50 mm] or over 6 in. [150 mm], or concrete made with other than normal weight aggregate or aggregate larger than 1 in. [25 mm] nominal maximum size.

9.4 *Bias*—The procedures for the test methods in 9.3 have no bias because the values obtained from each of those test methods are defined only in terms of the test method.

10. Keywords

10.1 concrete; cylinders; laboratory; prisms; strength testing

Designation: C 617 – 98 (Reapproved 2003)

Standard Practice for Capping Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C 617; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers apparatus, materials, and procedures for capping freshly molded concrete cylinders with neat cement and hardened cylinders and drilled concrete cores with high-strength gypsum plaster or sulfur mortar.

1.2 The values stated in inch-pound units are to be regarded as the standard. The SI equivalents of inch-pound units may be approximate.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific precaution statements see 4.3 and 6.2.3.1.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)

C 150 Specification for Portland Cement

C 472 Test Methods for Physical Testing of Gypsum, Gypsum Plasters and Gypsum Concrete

C 595M Specification for Blended Hydraulic Cements

C 1231 Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

2.2 *ANSI Standard:*

B46.1 Standard for Surface Texture (Surface, Roughness, Waviness and Lay)[3]

3. Significance and Use

3.1 This practice describes procedures for providing plane surfaces on the ends of freshly molded concrete cylinders, hardened cylinders, or drilled concrete cores when the end surfaces do not conform with the planeness and perpendicularity requirements of applicable standards. Practice C 1231 describes alternative procedures using unbonded caps or pad caps.

4. Capping Equipment

4.1 *Capping Plates*—Neat cement caps and high-strength gypsum-plaster caps shall be formed against a glass plate at least ¼ in. (6 mm) thick, a machined metal plate at least 0.45 in. (11 mm) thick, or a polished plate of granite or diabase at least 3 in. (76 mm) thick. Sulfur mortar caps shall be formed against similar metal or stone plates except that the recessed area which receives molten sulfur shall not be deeper than ½ in. (12 mm). In all cases, plates shall be at least 1 in. (25 mm) greater in diameter than the test specimen and the working surfaces shall not depart from a plane by more than 0.002 in. (0.05 mm) in 6 in. (152 mm). The surface roughness of newly finished metal plates shall not exceed that set forth in Table 4 of American National Standard B46.1, or 125 µin. (3.2 µm) for any type of surface and direction of lay. The surface, when new, shall be free of gouges, grooves, or indentations beyond those caused by the finishing operation. Metal plates that have been in use shall be free of gouges, grooves, and indentations greater than 0.010 in. (0.25 mm) deep or greater than 0.05 in.^{2}(32 mm^2) in surface area.

NOTE 1—A Rockwell hardness of 48 HRC is suggested for capping plates of devices used to form sulfur mortar caps.

4.2 *Alignment Devices*—Suitable alignment devices, such as guide bars or bull's-eye levels, shall be used in conjunction with capping plates to ensure that no single cap will depart from perpendicularity to the axis of a cylindrical specimen by more than 0.5° (approximately equivalent to ⅛ in. in 12 in. (3.2 mm in 305 mm)). The same requirement is applicable to the relationship between the axis of the alignment device and the surface of a capping plate when guide bars are used. In addition, the location of each bar with respect to its plate must

[1] This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Mechanical Engineers, 345 E. 47th Street, New York, NY 10017.

be such that no cap will be off-centered on a test specimen by more than 1/16 in. (2 mm).

4.3 *Melting Pots for Sulfur Mortars*—Pots used for melting sulfur mortars shall be equipped with automatic temperature controls and shall be made of metal or lined with a material that is nonreactive with molten sulfur.

4.3.1 **Caution:** Melting pots equipped with peripheral heating will ensure against accidents during reheating of cooled sulfur mixture that have a crusted-over surface. When using melting pots not so equipped, a build-up of pressure under the hardened surface crust on subsequent reheating may be avoided by use of a metal rod that contacts the bottom of the pot and projects above the surface of the fluid sulfur mix as it cools. The rod should be of sufficient size to conduct enough heat to the top on reheating to melt a ring around the rod first and thus avoid the development of pressure. A large metal ladle can be substituted for the rod.

4.3.1.1 Use sulfur melting pots in a hood to exhaust the fumes to outdoors. Heating over an open flame is dangerous because the flash point of sulfur is approximately 440°F (227°C) and the mixture can ignite due to overheating. Should the mixture start to burn, covering will snuff out the flame. The pot should be recharged with fresh material after the flame has been extinguished.

5. Capping Materials

5.1 The strength of the capping material and the thickness of the caps shall conform to the requirements of Table 1.

5.1.1 If sulfur mortar, high strength gypsum plaster and other materials except neat cement paste are to be used to test concrete with a strength greater than 7000 psi (50 MPa), the manufacturer or the user of the material must provide documentation:

5.1.1.1 That the average strength of 15 cylinders capped with the material is not less than 98 percent of the average strength of 15 companion cylinders capped with neat cement paste or 15 cylinders ground plane to within 0.002 in. (0.05 mm).

5.1.1.2 That the standard deviation of the strengths of the capped cylinders is not greater than 1.57 times that of the standard deviation of the reference cylinders.

5.1.1.3 That the cap thickness requirements were met in the qualification tests, and

5.1.1.4 Of the hardening time of the caps used in the qualification tests.

TABLE 1 Compressive Strength and Maximum Thickness of Capping Materials

Cylinder Compressive Strength psi (MPa)	Minimum Strength of Capping Material	Maximum Average Thickness of Cap	Maximum Thickness Any Part of Cap
500 to 7000 psi (3.5 to 50 MPa)	5000 psi (35 MPa) or cylinder strength whichever is greater	1/4 in. (6 mm)	5/16 in. (8 mm)
greater than 7000 psi (50 MPa)	Compressive strength not less than cylinder strength, except as provided in 5.1.1	1/8 in. (3 mm)	3/16 in. (5 mm)

5.1.2 Additionally, the qualification test report must include the compressive strength of 2 in. cubes of the material qualified and of neat cement paste cubes, if used. Capping materials conforming to these requirements is permitted to be used for cylinders with strengths up to 20 percent greater than the concrete tested in these qualification tests. The manufacturer must requalify lots of material manufactured on an annual basis or whenever there is a change in the formulation or the raw materials. The user of the material must retain a copy of the qualification results, and the dates of manufacture of material qualified and of the material currently being used. See Table 2.

5.1.3 The compressive strength of capping materials shall be determined by testing 2 in. cubes following the procedure described in Test Method C 109. Except for sulfur mortars, molding procedures shall be as in Test Method C 109 unless other procedures are required to eliminate large entrapped air voids. See Test Methods C 472 for alternative compaction procedures. Cure cubes in the same environment for the same length of time as the material used to cap specimens.

5.1.4 The strength of the capping material shall be determined on receipt of a new lot and at intervals not exceeding three months. If a given lot of the capping material fails to conform to the strength requirements, it shall not be used, and strength tests of the replacement material shall be made weekly until four consecutive determinations conform to specification requirements.

5.2 *Neat Hydraulic Cement Paste*:

5.2.1 Make qualification tests of the neat hydraulic cement paste prior to use for capping to establish the effects of water-cement ratio and age on compressive strength of 2 in. (50 mm) cubes.

NOTE 2—The cements used generally conform to Specification C 150 Types I, II or III; however, Specification C 595 blended cements, calcium aluminate or other hydraulic cements producing acceptable strength may be used.

5.2.2 Mix the neat cement paste to the desired consistency at a water-cement ratio equal to or less than that required to produce the required strength, generally 2 to 4 h before the paste is to be used (Note 3). Remix as necessary to maintain acceptable consistency (Note 4). Some retempering of the paste is acceptable if the required water-cement ratio is not exceeded. Optimum consistency is generally produced at water-cement ratios of 0.32 to 0.36 by mass for Type I and Type II cements and 0.35 to 0.39 by mass for Type III cements.

NOTE 3—Freshly mixed pastes tend to bleed, shrink, and make unacceptable caps. The 2 to 4 h period is generally appropriate for portland cements.

NOTE 4—The required consistency of the paste is determined by the appearance of the cap when it is stripped. Fluid paste results in streaks in the cap. Stiff paste results in thick caps.

5.3 *High-Strength Gypsum Cement Paste*:

5.3.1 No fillers or extenders may be added to neat high-strength gypsum cement paste subsequent to the manufacture of the cement. (Note 5) Qualification tests shall be made to determine the effects of water-cement ratio and age on compressive strength of 2 in. (50 mm) cubes. Retarders may be used to extend working time, but their effects on required water-cement ratio and strength must be determined. (Note 6)

TABLE 2 Sample Report of Qualification of a Capping Material

NOTE—Manufacturer: Testing Supplies Co.
Capping Material: Super Strong AAA-Sulfor mortar
Lot: 12a45 Date Tested: 11/3/98
Signed by:_____ (testing agency and responsible official)

Item	Capping Material	Control Cylinders	Ratio	Criteria	Pass/Fail
		Concrete Cylinder Test Data			
Type of capping material	Sulfur	Ground			
Average Concrete Strength, psi [MPa]	11 061 (76.2)	11 008 (75.9)	1.005	>0.98 Xc	Pass
Standard Deviation, psi [MPa]	376 (2.59)	250 (1.72)	1.504	≤1.57 C	Pass
Number of cylinders tested	15	15			
Cap age when cylinders tested	7 days	na			
		Capping Material Test Data			
Average cap thickness, in. [mm]	0.11 (2.8)	na			
Compressive strength of 2 in. [50 mm] cubes, psi (MPa)	12 195 (91)				
Cube age when tested.	7 days				
Maximum concrete strength qualified, psi (MPa)				1.2 Av. Str = 13 273 (91.5)[A]	

[A] Nominally a specified strength of 11 000 psi (75 MPa) and perhaps somewhat higher.

NOTE 5—Low-strength molding plaster, plaster of paris, or mixtures of plaster of paris and portland cement are unsuitable for capping.

NOTE 6—The water-gypsum cement ratio should be between 0.26 and 0.30. Use of low water-cement ratios and vigorous mixing will usually permit development of 5000 psi (35 MPa) at ages of 1 or 2 h. Higher water-gypsum cement ratios extend working time, but reduce strength.

5.3.2 Mix the neat gypsum cement paste at the desired water-cement ratio and use it promptly since it sets rapidly.

5.4 *Sulfur Mortar*:

5.4.1 Proprietary or laboratory prepared sulfur mortars are permitted if allowed to harden a minimum of 2 h before testing concrete with strength less than 5000 psi (35 MPa). For concrete strengths of 5000 psi or greater, sulfur mortar caps must be allowed to harden at least 16 h before testing, unless a shorter time has been shown to be suitable as specified in 5.1.1.

5.4.2 *Determination of Compressive Strength*—Prepare test specimens using a cube mold and base plate conforming to the requirements of Test Method C 109 and a metal cover plate conforming in principle to the design shown in Fig. 1 (Note 7). Bring the various parts of the apparatus to a temperature of 68 to 86°F (20 to 30°C), lightly coat the surfaces that will be in contact with the sulfur mortar with mineral oil, and assemble near the melting pot. Bring the temperature of the molten-sulfur mortar in the pot within a range of 265 to 290°F (129 to 143°C), stir thoroughly, and begin casting cubes. Using a ladle, or other suitable pouring device, quickly fill each of the three compartments until the molten material reaches the top of the filling hole. Allow sufficient time for maximum shrinkage, due to cooling, and solidification to occur (approximately 15 min) and refill each hole with molten material (Note 8). After

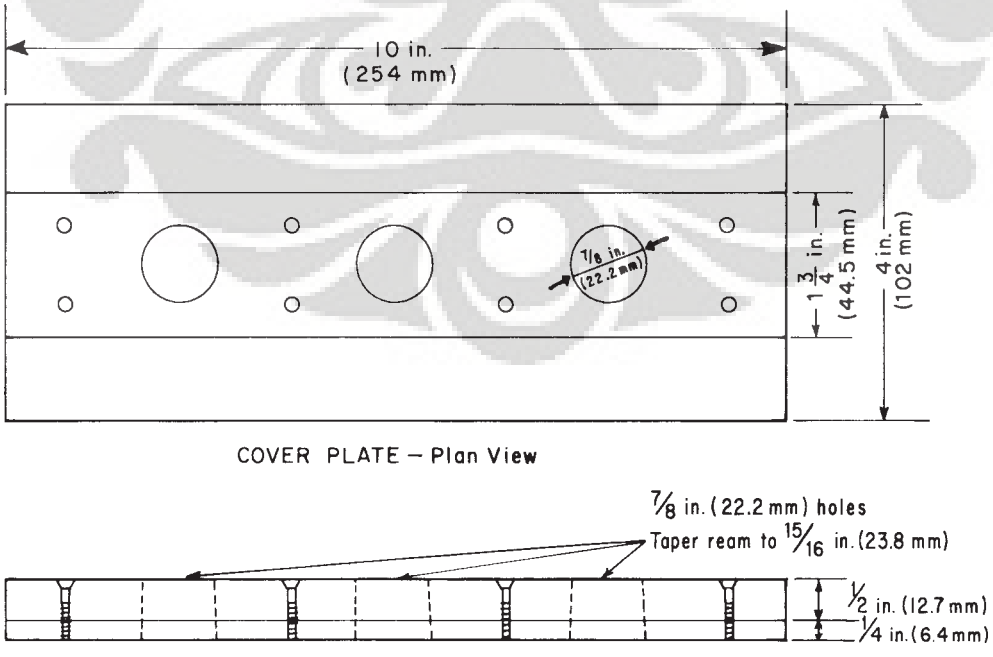

FIG. 1 Sketch of Cover Plate for 2-in. (50-mm) Cube Mold

solidification is complete, remove the cubes from the mold without breaking off the knob formed by the filling hole in the cover plate. Remove oil, sharp edges, and fins from the cubes and check the planeness of the bearing surfaces in the manner described in Test Method C 109. After storage at room temperature to the desired age, but not less than 2 h, test cubes in compression following the procedure described in Test Method C 109, and calculate the compressive strength.

NOTE 7—If desired, a plane phenol formaldehyde (bakelite) plate of ⅛-in. (3-mm) thickness, provided with three appropriately spaced filling holes, may be inserted between the cover plate and the mold to slow the rate of cooling of test specimens.

NOTE 8—The second filling helps to prevent the formation of a large void or shrinkage pipe in the body of a cube. However, such defects may occur no matter how much care is exercised, and it therefore is advisable to inspect the interior of tested sulfur mortar cubes for homogeneity whenever the strength values obtained are significantly lower than anticipated.

6. Capping Procedures

6.1 *Freshly Molded Cylinders*—Use only neat portland cement pastes (Note 9) to cap freshly molded cylinders. Make caps as thin as practicable. Do not apply the neat paste to the exposed end until the concrete has ceased settling in the molds, generally from 2 to 4 h after molding. During the molding of the cylinder, strike off the upper end even with or slightly below the plane of the rim of the mold. Remove free water and laitance from the top of the specimen immediately before capping. Form the cap by placing a conical mound of paste on the specimen and then gently pressing a freshly oiled capping plate on the conical mound until the plate contacts the rim of the mold. A very slight twisting motion may be required to extrude excess paste and minimize air voids in the paste. The capping plate must not rock during this operation. Carefully cover the capping plate and mold with a double layer of damp burlap and a polyethylene sheet to prevent drying. Removal of the capping plate after hardening may be accomplished by tapping the edge with a rawhide hammer in a direction parallel to the plane of the cap.

NOTE 9—Type I neat cement caps generally require at least 6 days to develop acceptable strength and Type III neat cement caps at least 2 days. Dry concrete specimens will absorb water from freshly mixed neat cement paste and produce unsatisfactory caps. Neat cement paste caps will shrink and crack on drying and, therefore, should be used only for specimens that are to be moist cured continuously until time of testing.

NOTE 10—High-strength gypsum caps soften and deteriorate on contact with water and cannot be used on freshly mixed concrete or stored in a moist room for more than very brief periods.

6.2 *Hardened Concrete Specimens*:

6.2.1 *General*—If an end of a specimen has a coating or deposit of oily or waxy materials that would interfere with the bond of the cap, remove such coatings or deposits. If necessary, the ends of a specimen may be slightly roughened with a steel file or wire brush to produce proper adhesion of the cap. If desired, capping plates may be coated with a thin layer of mineral oil or grease to prevent the capping material from adhering to the surface of the plate.

6.2.2 *End Condition*—The distance of any point on an uncapped end from a plane that passes through the highest point of the end surface and is perpendicular to the axis of the cylinder shall not exceed ⅛ in. (3 mm) (Note 11). If the end exceeds this limit, the end of the cylinder shall be cut, lapped or ground prior to capping.

NOTE 11—This provision is to control the difference between the thickest and thinnest parts of a cap. The distance may be checked using a square with one blade touching the cylinder parallel to the cylinder axis and the other blade touching the highest point on the end of the cylinder. The distance between the blade of the square and the lowest point on the end of the cylinder is measured.

6.2.3 *Capping with High-Strength Gypsum Plaster or Neat Cement Paste*—Mix the paste as described in Section 2. Do not exceed the water-cement ratio determined in qualification tests. Form the caps as described in 6.1 using capping plates described in 4.1 to achieve the alignment required in 4.2 (Note 12). Generally, capping plates may be removed within 45 min with gypsum cement pastes and after 12 h with neat cement paste, without visibly damaging the cap.

NOTE 12—A number of methods have been used to obtain the desired perpendicularity of the cap to the axis of the cylinder. A mound of paste can be placed on a capping plate and the specimen lowered into it. A bull's-eye level on the top of the cylinder helps obtain alignment. A mound of paste can be placed on top of the cylinder and a capping plate pressed into it, again using the bull's-eye level. A better system is to make a half-height mold with a vertical split so that it can be slipped over the hardened cylinder. A clamp is used to position the mold and to ensure the required cap thickness. The mound of paste can then be placed either on a capping plate or on top of the cylinder and pressed until the plate contacts the mold. As Noted earlier, very stiff paste may require excessive pressure and produce thick or defective caps.

6.2.4 *Capping with Sulfur Mortar*—Prepare sulfur mortar for use by heating to about 265°F (130°C) as determined by an all-metal thermometer inserted near the center of the mass. Check the temperature at approximately hourly intervals during capping. Empty the pot and recharge with fresh material at intervals to ensure that the oldest material in the pot has not been used more than five times. When capping concrete cylinders with a compressive strength of 5000 psi (35 MPa) or greater, it is not permitted to reuse compound recovered from the capping operation or old caps. Fresh sulfur mortar must be dry at the time it is placed in the pot as dampness may cause foaming. Keep water away from molten sulfur mortar for the same reason. The capping plate or device should be warmed before use to slow the rate of hardening and permit the production of thin caps. Oil the capping plate lightly and stir the molten sulfur mortar immediately prior to pouring each cap. The ends of moist cured specimens shall be dry enough at the time of capping to preclude the formation of steam or foam pockets under or in the cap larger than ¼ in. (6 mm) in diameter. Replace caps with steam pockets or voids larger than ¼ in. (6 mm) (Note 13). To ensure that the cap is bonded to the surface of the specimen, the end of the specimen shall not be oiled prior to the application of the cap. When using a vertical device, pour the mortar onto the surface of the capping plate, lift the cylinder above the plate and contact the cylinder sides with the guides, slide the cylinder down the guides onto the capping plate while keeping constant contact with the alignment guides. The cylinder end should continue to rest on the capping plate with cylinder sides in positive contact with the

alignment guides until the mortar has hardened. Use sufficient material to cover the cylinder end after the sulfur mortar solidifies.

NOTE 13—Periodically, the sulfur mortar cap should be examined after testing for air or steam pockets in the cap. Before testing, the cap can be tapped with a coin or rubbed with a light metal implement to see if a hollow sound can be detected. Caps with hollow areas should be removed and recapped.

6.2.4.1 **Caution:** Hydrogen sulfide gas may be produced during capping when sulfur mortar is contaminated with organic materials such as paraffin or oil. The gas is colorless and has a notoriously bad odor of rotten eggs; however, the odor should not be relied upon as a warning sign, since the sensitivity to the odor disappears rapidly on exposure. High concentrations are lethal and less concentrated dosages may produce nausea, stomach distress, dizziness, headache, or irritation of the eyes. For this and other reasons, the melting pot must be located under a hood with an exhaust fan and that capping area must be well ventilated.

6.2.5 *Daily Check*:

6.2.5.1 During each day's capping operation, check the planeness of the caps prior to compression testing on at least three specimens, selected at random, representing the start, middle, and end of the run. Check planeness with a straightedge and feeler gage, making a minimum of three measurements on different diameters to ensure that the surface of the caps do not depart from a plane by more than 0.002 in. (0.05 mm). Check also for hollow areas (Note 13). Record the results of these determinations in the quality control documentation for the laboratory. If caps fail to satisfy the planeness requirement or have hollow areas, remove and reapply the caps.

6.2.5.2 During each day's compressive strength testing operation, check the thickness of caps on at least three specimens, selected at random, from the start, middle, and end of that day's operation. After completing the compression test, recover at least six pieces of capping material from the top of the selected specimen (Note 14). The pieces shall be selected at random and be distributed over the entire area of the cap. The selected pieces shall have debonded completely from the concrete. Measure and record the thicknesses of the pieces to the nearest 0.01 in. (0.2 mm) using a micrometer, caliper or other thickness measurement device. Compare the average and maximum thicknesses with the values in Table 1. Record the results of the thickness determinations in the quality control documentation for the laboratory.

NOTE 14—Caps may be removed by using a hammer and sharp chisel. Place the chisel tip at the bond line and nearly parallel with the plane of the cap so as to create a wedging action when the chisel is struck with the hammer. Recovery of the entire cap may be simplified by placing duct tape over the cap prior to attempting its removal. The tape will keep the pieces of capping material from being dispersed during removal and will simplify the selection of pieces uniformly distributed over the cap area.

7. Protection of Specimens After Capping

7.1 Maintain moist cured specimens in a moist condition between the completion of capping and the time of testing by returning them to moist storage or wrapping them with a double layer of wet burlap. Do not store specimens with gypsum plaster caps immersed in water or for more than 4 h in a moist room. Protect plaster caps from dripping water.

7.2 Do not test capped specimens before the capping material has sufficient time to develop the strength required in 5.1.

Designation: C 496/C 496M – 04

Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C 496/C 496M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers the determination of the splitting tensile strength of cylindrical concrete specimens, such as molded cylinders and drilled cores.

1.2 The values stated in either inch-pound or SI units are to be regarded separately as standard. The SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 The text of this standard references notes that provide explanatory material. These notes shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field

C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. Summary of Test Method

3.1 This test method consists of applying a diametral compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uniaxial compressive strength test result.

3.2 Thin, plywood bearing strips are used to distribute the load applied along the length of the cylinder.

3.3 The maximum load sustained by the specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength.

4. Significance and Use

4.1 Splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength (modulus of rupture).

4.2 Splitting tensile strength is used in the design of structural lightweight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement.

5. Apparatus

5.1 *Testing Machine*—The testing machine shall conform to the requirements of Test Method C 39/C 39M and be of a type with sufficient capacity that will provide the rate of loading prescribed in 7.5.

5.2 *Supplementary Bearing Bar or Plate*—If the diameter or the largest dimension of the upper bearing face or the lower bearing block is less than the length of the cylinder to be tested, a supplementary bearing bar or plate of machined steel shall be used. The surfaces of the bar or plate shall be machined to within ± 0.001 in. [0.025 mm] of planeness, as measured on any line of contact of the bearing area. It shall have a width of at least 2 in. [50 mm], and a thickness not less than the distance

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing Concrete for Strength.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

from the edge of the spherical or rectangular bearing block to the end of the cylinder. The bar or plate shall be used in such manner that the load will be applied over the entire length of the specimen.

5.3 *Bearing Strips*—Two bearing strips of nominal ⅛ in. [3.2 mm] thick plywood, free of imperfections, approximately 1 in. [25 mm] wide, and of a length equal to, or slightly longer than, that of the specimen shall be provided for each specimen. The bearing strips shall be placed between the specimen and both the upper and lower bearing blocks of the testing machine or between the specimen and supplemental bars or plates, when used (see 5.2). Bearing strips shall not be reused.

6. Test Specimens

6.1 The test specimens shall conform to the size, molding, and curing requirements set forth in either Practice C 31/C 31M (field specimens) or Practice C 192/C 192M (laboratory specimens). Drilled cores shall conform to the size and moisture-conditioning requirements set forth in Test Method C 42/C 42M. Moist-cured specimens, during the period between their removal from the curing environment and testing, shall be kept moist by a wet burlap or blanket covering, and shall be tested in a moist condition as soon as practicable.

6.2 The following curing procedure shall be used for evaluations of light-weight concrete: specimens tested at 28 days shall be in an air-dry condition after 7 days moist curing followed by 21 days drying at 73.5 ± 3.5°F [23.0 ± 2.0°C] and 50 ± 5 % relative humidity.

7. Procedure

7.1 *Marking*—Draw diametral lines on each end of the specimen using a suitable device that will ensure that they are in the same axial plane (see Fig. 1, Fig. 2 and Note 1), or as an alternative, use the aligning jig shown in Fig. 3 (Note 2).

NOTE 1—Figs. 1 and 2 show a suitable device for drawing diametral lines on each end of a 6 in. by 12 in. [150 mm by 300 mm] cylinder in the same axial plane. The device consists of three parts as follows:

(1) A length of 4-in. [100-mm] steel channel, the flanges of which have been machined flat,

(2) A section, part a, that is grooved to fit smoothly over the flanges of the channel and that includes cap screws for positioning the vertical member of the assembly, and

(3) A vertical bar, part b, for guiding a pencil or marker,

The assembly (part a and part b) is not fastened to the channel and is positioned at either end of the cylinder without disturbing the position of the specimen when marking the diametral lines.

NOTE 2—Fig. 4 is a detailed drawing of the aligning jig shown in Fig. 3 for achieving the same purpose as marking the diametral lines. The device consists of:

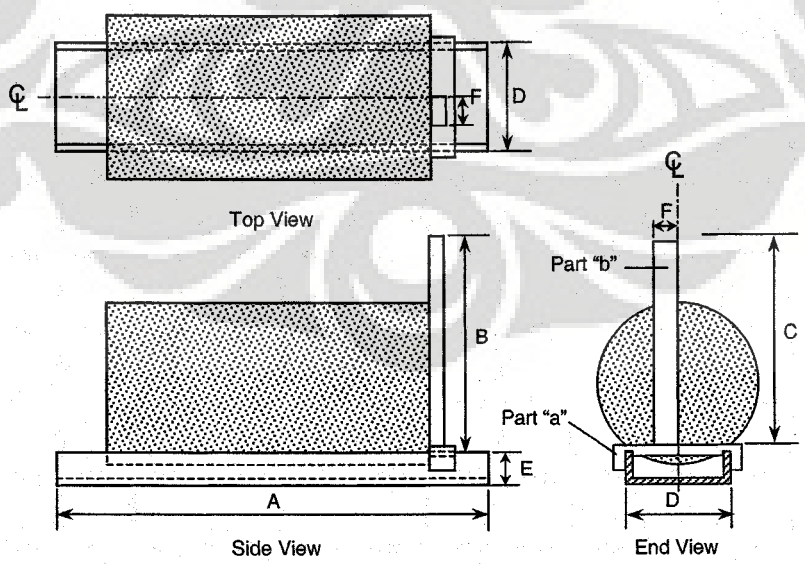
(1) A base for holding the lower bearing strip and cylinder,

(2) A supplementary bearing bar conforming to the requirements in Section 5 as to critical dimensions and planeness, and

(3) Two uprights to serve for positioning the test cylinder, bearing strips, and supplementary bearing bar.

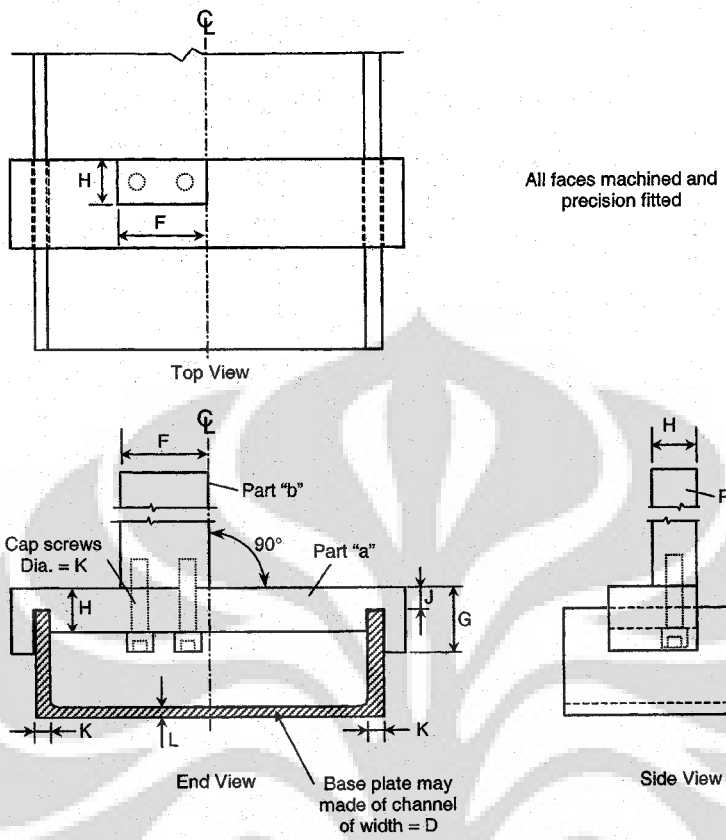
7.2 *Measurements*—Determine the diameter of the test specimen to the nearest 0.01 in. [0.25 mm] by averaging three diameters measured near the ends and the middle of the specimen and lying in the plane containing the lines marked on the two ends. Determine the length of the specimen to the nearest 0.1 in. [2 mm] by averaging at least two length measurements taken in the plane containing the lines marked on the two ends.

7.3 *Positioning Using Marked Diametral Lines*—Center one of the plywood strips along the center of the lower bearing block. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip. Place a second plywood strip lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder. Position the assembly to ensure the following conditions:



A	B	C	D	E	F
16 in	8 ¼ in.	8 in.	4 in.	1 ¼ in.	1 in.
400 mm	205 mm	200 mm	100 mm	32 mm	25 mm

FIG. 1 General Views of a Suitable Apparatus for Marking End Diameters Used for Alignment of Specimen in Testing Machine



D	F	G	H	J	K	L
4 in.	1 in.	¾ in.	½ in.	¼ in.	3/16 in.	1/8 in.
100 mm	25 mm	20 mm	13 mm	6 mm	4.8 mm	3.2 mm

FIG. 2 Detailed Plans for a Suitable Apparatus for Marking End Diameters Used for Aligning the Specimen

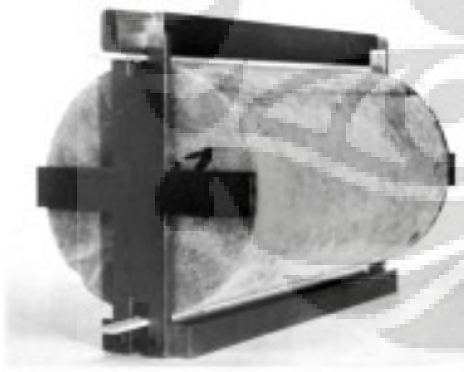


FIG. 3 Jig for Aligning Concrete Cylinder and Bearing Strips

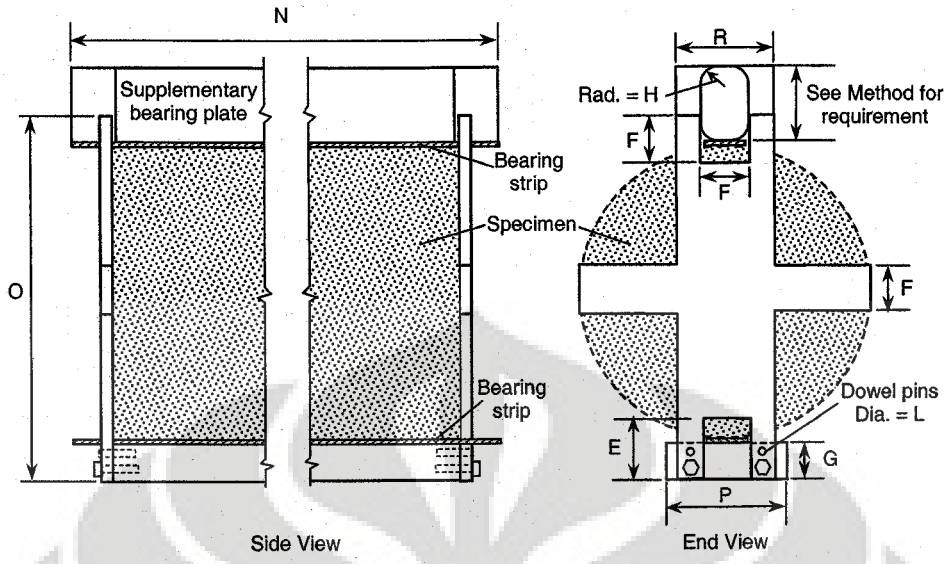
7.3.1 The projection of the plane of the two lines marked on the ends of the specimen intersects the center of the upper bearing plate, and

7.3.2 The supplementary bearing bar or plate, when used, and the center of the specimen are directly beneath the center of thrust of the spherical bearing block (see Fig. 5).

7.4 *Positioning by Use of Aligning Jig*—Position the bearing strips, test cylinder, and supplementary bearing bar by means of the aligning jig as illustrated in Fig. 3 and center the jig so that the supplementary bearing bar and the center of the specimen are directly beneath the center of thrust of the spherical bearing block.

7.5 *Rate of Loading*—Apply the load continuously and without shock, at a constant rate within the range 100 to 200 psi/min [0.7 to 1.4 MPa/min] splitting tensile stress until failure of the specimen (Note 3). Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and the appearance of the concrete.

NOTE 3—The relationship between splitting tensile stress and applied load is shown in Section 8. The required loading range in splitting tensile stress corresponds to applied total load in the range of 11 300 to 22 600 lbf [50 to 100 kN]/min for 6 by 12-in. [150 by 300-mm] cylinders.



N	O	P	R	E	F	G	H	L
15 in.	7 ½ in.	2 ½ in.	2 in.	1 ¼ in.	1 in.	¾ in.	½ in.	1/8 in.
375 mm	190 mm	65 mm	50 mm	32 mm	25 mm	20 mm	13 mm	3 mm

FIG. 4 Detailed Plans for a Suitable Aligning Jig for 6 by 12 in. [150 by 300 mm] Specimen

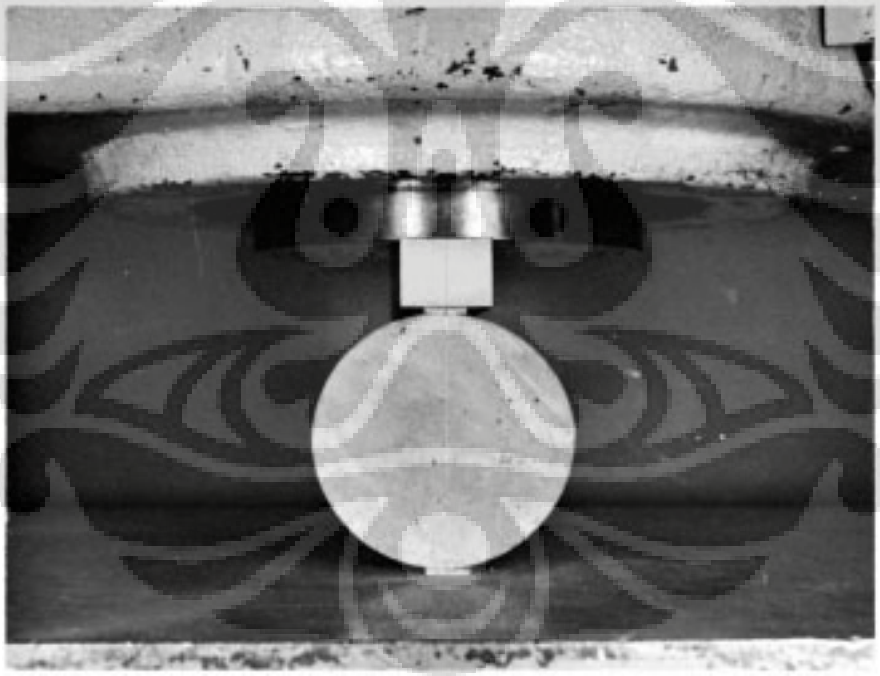


FIG. 5 Specimen Positioned in a Testing Machine for Determination of Splitting Tensile Strength

8. Calculation

8.1 Calculate the splitting tensile strength of the specimen as follows:

$$T = 2P/\pi ld \quad (1)$$

where:

T = splitting tensile strength, psi [MPa],
P = maximum applied load indicated by the testing machine, lbf [N],
l = length, in. [mm], and
d = diameter, in. [mm].

9. Report

9.1 Report the following information:
9.1.1 Identification number,
9.1.2 Diameter and length, in. [mm],
9.1.3 Maximum load, lbf [N],
9.1.4 Splitting tensile strength calculated to the nearest 5 psi [0.05 MPa],
9.1.5 Estimated proportion of coarse aggregate fractured during test,
9.1.6 Age of specimen,
9.1.7 Curing history,
9.1.8 Defects in specimen,
9.1.9 Type of fracture, and
9.1.10 Type of specimen.

10. Precision and Bias

10.1 *Precision*—An interlaboratory study of this test method has not been performed. Available research data,[3] however, suggests that the within batch coefficient of variation is 5 % (see Note 4) for 6 × 12-in. [150 × 300-mm] cylindrical specimens with an average splitting tensile strength of 405 psi [2.8 MPa]. Results of two properly conducted tests on the same material, therefore, should not differ by more than 14 % (see Note 4) of their average for splitting tensile strengths of about 400 psi [2.8 MPa].

NOTE 4—These numbers represent, respectively, the (1s %) and (d2s %) limits as defined in Practice C 670.

10.2 *Bias*—The test method has no bias because the splitting tensile strength can be defined only in terms of this test method.

11. Keywords

11.1 cylindrical concrete specimens; splitting tension; tensile strength

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C 496 – 96, that may impact the use of this test method. (Approved February 1, 2004)

(*1*) Revised 1.2.
(*2*) Added 1.4.
(*3*) Revised 5.1, 6.1, Section 2, and Note 1 to correct references.
(*4*) Revised 5.2, 6.2, 7.2, 7.5, 10.1, and Note 4 by metrication rules.
(*5*) Revised Section 4.
(*6*) Revised 3.2 and 5.3.
(*7*) Revised Note 2.
(*8*) Figs. 1, 2, and 4 were revised and redrawn.