FINAL PROJECT

THE EFFECT OF PROCESSING DIRECTION ON FRICTION PROPERTIES OF Polyethyleneterephthalate (PET) and Polyethylene (PE) POLYMER FILM

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DEPARTEMEN METALURGI DAN MATERIAL
FAKULTAS TEKNIK UNIVERSITAS INDONESIA
DEPOK
NOVEMBER 2008

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This Final project report is prerequisite to obtain Sarjana Teknik

By

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AUTHENTICATION PAGE

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THE EFFECT OF PROCESSING DIRECTION ON FRICTION PROPERTIES OF Polyethyleneterephthalate (PET) and Polyethylene (PE) POLYMER FILM

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Depok, November 2008

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VALIDATION PAGE

Project report with title:

THE EFFECT OF PROCESSING DIRECTION ON FRICTION PROPERTIES OF Polyethyleneterephthalate (PET) and Polyethylene (PE) POLYMER FILM

Produce in order to fulfill the requirement to becomes Sarjana Teknik in the Department of Material Engineering, Faculty of Engineering University of Indonesia. This project report has been examined and approved on the project presentation

Depok, November 2008

Supervisor,

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PREFACE

The research with title "THE EFFECT OF PROCESSING DIRECTION ON FRICTION PROPERTIES OF Polyethyleneterephthalate (PET) and Polyethylene (PE) POLYMER FILM" is acomplished as an academic requirement to obtain Bachelor of Engineering in Monash University and Sarjana Teknik in University of Indonesia.

The writer is aware that this research is still far from perfection and has many limitations, so it may need further improvement and deeper observation.

The writer wants to thank all parties that help the writer accomplish this research. Many thanks to:

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Depok, November 2008

Leo Gading Mas

Author

HALAMAN PERNYATAAN PERSETUJUAN PUBLIKASI
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ABSTRACT

The effect of molecular orientation on coefficient of friction for polymer has been observed by some of the previous studies, although the molecular orientation effect on the coefficient of friction for different polymer is not fully understood. In order to understand these effect in Polyethylene terephtalate (PET) and Polyethylene (PE) polymer film the observation in molecular orientation was performed by doing bulk and surface properties characterization. The coefficient of friction test along different directions and optical analysis of the polymer film were conducted to confirm the effect of molecular orientation on coefficient of friction for Polyethylene terephtalate (PET) and Polyethylene (PE) polymer film.

This study suggests that there is no dependence of processing direction to the coefficient of friction for Polyethylene (PE) film altough there is apparent directional effect on their surface and bulk properties. By contrast there is slight dependency of processing direction to the coefficient of friction for Polyethylene terephtalate (PET), while there is not apparent directional effect on its surface and bulk properties.

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CHAPTER I
INTRODUCTION

The study of friction was began in the 15^{th} century when Leonardo da Vinci experimentally verified the friction force is proportional to the applied normal load and independent of the area of rubbing surfaces [1]. Friction is one of the basic system properties of materials. Friction force is the motion opposing force between two contacting surfaces to their relative movement. Based on Coulomb Law the friction force of materials can be described in term of static and kinetic frictions [2]. Static friction is the force required to initiate sliding, kinetic friction is the force required to maintain sliding. The coefficient of friction of materials depends on the frictional force of the materials because coefficient of friction is the ratio of those frictions force to normal force, thus coefficient of friction can also described as static coefficient of friction and kinetic coefficient of friction.

The friction that happens on the materials depend on various factors, many scholars reported that friction depends on materials properties such as surface energy, hardness, strain, shear strength and density. It has also been reported that friction is significantly depend on temperature and lubrications [3]. Moreover it has also been pointed out that the frictions of materials depend on the test system that employed to the materials. Different measuring system of friction could leads to different value of friction therefore it is meaningless to compare friction value from different test system.

Polymer becomes more widely used nowadays so that their friction properties become important and draw a great interest of research. For example in polymer packaging production, the coefficient of friction of polymer film is very important because they act as both dynamic force and resisting force in packaging process. The friction properties of polymer as similar to other materials is very important properties, however the frictional process of polymer differs in several important aspects from that occurs in metals. Unlike metals, the coefficient of friction of polymer is not independent to the applied load, but it rises as the load is decreased. The coefficient of friction of polymers decreases with an increase in surface roughness in contrast to the friction of metals which is independent of roughness [4].

The friction of polymer related to its mechanical properties, in addition the mechanical properties of polymer can be highly influenced by the stretching orientation such as axtrusion process which is predominant process in polymer industries[5]. Some of the previous researcher have observed that the molecular orientation affect the friction properties of the polymer however much works remain to be done in order to determine and understand the effect of stretching orientation on friction of the polymers. Therefore this current project is aimed at investigating the effect of molecular orientation on friction coefficient of polymeric materials.

In order to investigate the effect of molecular orientation on the friction coefficient of polymeric materials, it is important to conduct an investigation and understand the polymer processing mechanism which result in different stretching orientation in polymeric materials. For this purpose Polyethylene terephthalate (PET) and Polyethylene (PE) polymer film were used due to its availability and distinct mechanical properties. The stretching orientation of these films was investigated by performing bulk and surface properties characterization. Furthermore, the coefficient of friction test and optical analysis were carried on to confirm whether the molecular orientation affect the coefficient of friction.

CHAPTER II

LITERATURE REVIEW

II.1. Polymer film production

The polymer processing mechanism can affect the polymer mechanical properties which then determine the friction coefficient of the polymer. Therefore it is important to understand the processing mechanism of the polymer materials in order to find the relationship between the molecular orientation and the coefficient of friction. In this section, the processing mechanisms as well as the role of processing in affecting the molecular orientation of the polymer were illustrated. Polymer films can be produced by wide variety of processing mechanism however the underlying physics of the formation are the same [6]. Polymer films which are manufactured by extrusion can be subjected to different process after exrusion, some of these process includes blowing and stretching.

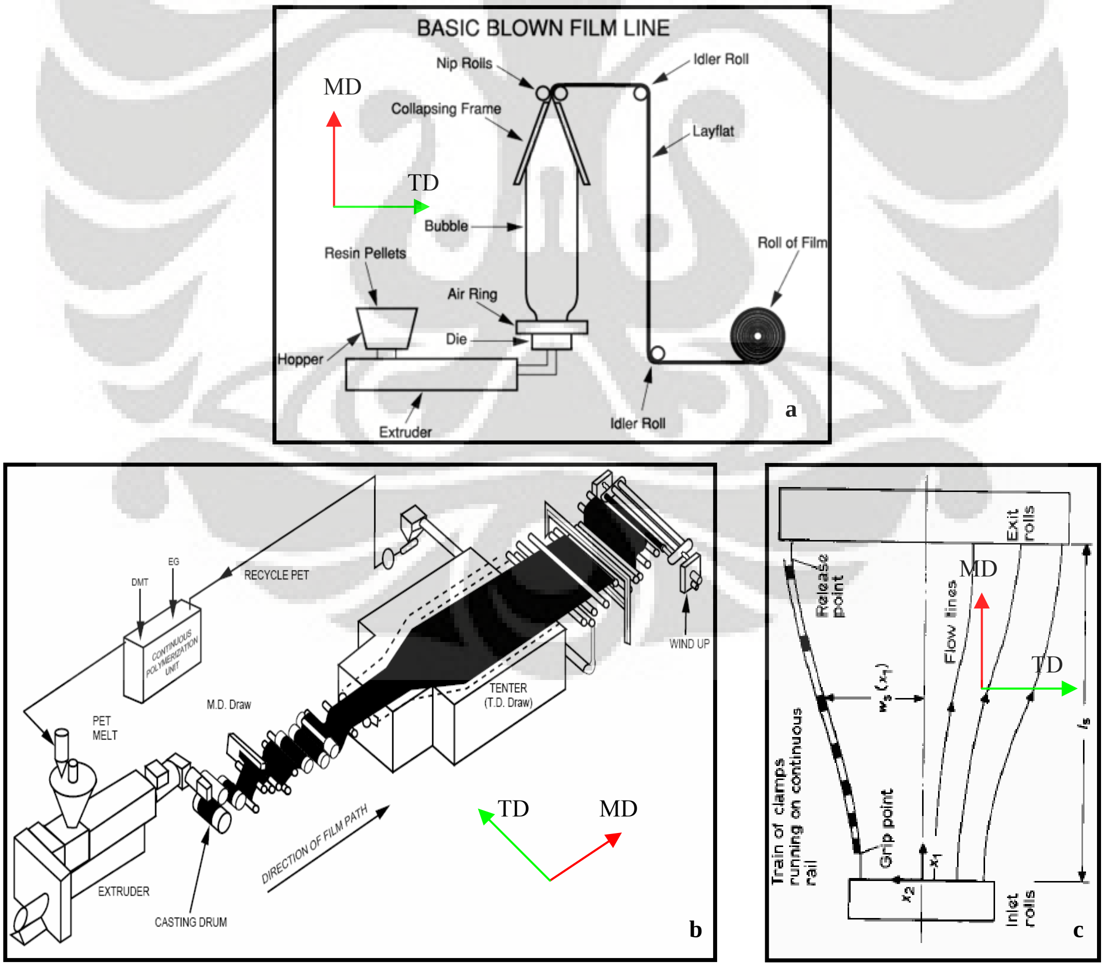

Figure II. 1: (a). Film blowing process diagram.[7] (b). Film stretching process diagram. [8](c). The tenter process.[9]

The basic film blowing process is shown in Fig II.1a, where the polymer pellets are fed to the extruder which consists of a single screw extruder which is design to melt the polymer and pump it into a tubular die. Furthermore the air is blown into the centre of the extruded tube and it cause the molten bubble to expand and thus stretched in machine direction and expanded in transverse direction. The bubble is stretch in machine direction due to the take up velocity is higher than the average velocity of the melt leaving the die. The bubble is also expand in transverse direction due to the effect of blowing as a result of the molecular orientation stretched in transverse direction. These stretching processes will determine the molecular orientation preference in the final product. After the stretching process cooling air is blowned along the bubble and causes it to crystallize and lock in the molecular orientation imparted by the stretching processes. Then the nip rolls collect the film, as well as sealing the top of the bubble to maintain the air pressure inside.

As shown in Fig II.b the film processing mechanism is similar to extrusion process in Fig II.a. The difference is that the polymer were extruded into casting drum, then the polymer being stretched in the machine direction by drawing the polymer in sets of roller with increasingly faster speed between the roller. After the forward draw the polymer transferred to tenter in order to deform it in transverse directions. In the tenter the polymer stretch in transverse direction and crystallize Fig.II.c. shows the stretching process of the film in the tenter. At this stage the polymer film molecular orientation were biaxially oriented due to drawing and stretching process. Polymer film was then cured in order to stabilize and further increase its crystallinity.
Based on their microstructural and molecular orientation polymer film can be classified into three classes [5]:

- First type of film is the film that strongly stretched on the extrusion direction therefore molecular and microstructure orientation are strongly oriented in machine direction.
- Second type of film is a film which has no orientation and their microstructure is similar to the bulk polymer.
- The third type of film is a film which has a molecular orientation, oriented in biaxial directions. This film has no machine direction effect and has good properties in all directions.

Polyethylene terephthalate (PET) and Polyethylene (PE) polymer film that were used in this study have distinct processing mechanism therefore the molecular orientation of the film are also different. PET film can be classified as the third types of polymer film due to the molecular orientation of PET is biaxially oriented by the process, while PE film classified into the first type of film because the molecular orientation of PE is strongly oriented in the machine direction [8].

II.2. Polyethylene terephthalate (PET) and Polyethylene (PE) polymer

Polyethylene terephthalate is a thermoplastic polymer which is usually synthesized by esterification reaction between terephthalic acid and ethylene glycol with water as a byproduct, or by the transesterification reaction between ethylene glycol and dimethyl terephthalate with methanol as a byproduct. The polymerization is achieved through a polycondensation reaction of the monomers which is done immediately after esterification/transesterification with ethylene glycol as byproduct [12].

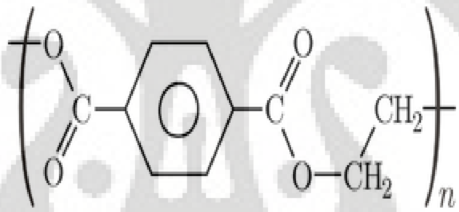

Figure II.2: Chemical structure of PET

PET consists of polymerized units of the monomer dimethyl terephthalate or ethylene terephthalate, with repeating $C_{10}H_8O_4$ units. The structure contains carbon, hydrogen, and oxygen. PET have a suitable properties to use as packaging, such as good gas, moisture and alcohol barrier, strong and good impact resistance. Therefore the application of PET usually directed to a packaging industry such as soft drink bottles, thin film, and food packaging.

PET as a thermoplastic polymer can be recycled and also incenerated, one of the uses of the recycled PET is for a fiber to use as polyester product. The degradation mechanism of PET can be achieved by various degradation mechanism such as hydrolysis, and thermal oxidation. When the degradation takes place the chain scission occurs and thus lower the molecular weight of the PET. High temperature such as UV light exsposure to PET polymer at long time could results in discoloration and formation of acetaldehyde, this could be a problem when the optical requirements of the polymer are very high, such as in packaging applications. Acetaldehyde normally exist in gas, it is forms naturraly in fruit but if it is present in the packaging product it could change the taste of the product inside the container.

There are several methods that people used in order to avoid the degradation of PET during the processing and the use of the product, such as copolymerization in order to lower the melting temperature and reduce the degree of crystallinity of PET, therefore PET can be formed at lower temperature. Stabilizer such as Phospat is often used to reduce acetaldehyde formation during degradation. Polyethylene is a polymer consisting of long chains of the monomer ethylene. Polyethylene contains carbon and hydrogen which usually produced through polymerization of ethene. It can be produced through radical polymerization, anionic addition polymerization, ion coordination polymerization or cationic addition polymerization. Each of these methods results in a different type of polyethylene.

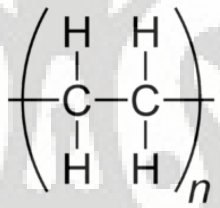

Figure II.3: Chemical Structure of PE (Polyethylene)

Based on their density and manufacturing processes, polyethylene can be classified into several types of polymer, such as LDPE, HDPE, LLDPE and etc. The mechanical properties of this polymer significantly influence by the density, type of branching, crystal structure and the molecular weight of the polymer, thus results in wide range of application. For example UHMWPE for acetabular cap material in hip joint replacement application due to high wear resistance and high impact resistance, LDPE for containers and plastic film application such as plastic wrap and plastic bags due its ductility. Almost all polyethylene film is fabricated as either cast film or blown film, the main difference between the two processes is the manner of cooling an extruded sheet of molten polymer. In general, cast films have a better appearance and gauge thickness is more readily controlled. Blown films are more evenly oriented in machine and transverse directions, thus providing greater toughness on the final product[13].

II.3. Coefficient of friction test

Coefficient of friction test of polymer could be done by various techniques namely pin on disc, spring and pendulum. Probably the most suitable coefficient of friction tester machines for polymer films is the machines which consist of moving plane and stationary sled which is shown in Fig II.4 below.

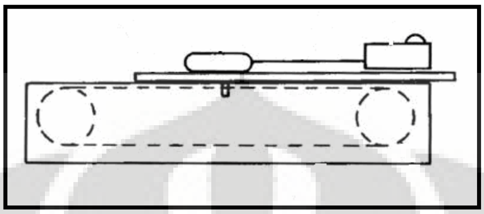

Figure II.4: Schematic diagram of coefficient of friction test.

ASTM D1894 was the standard for the coefficient of friction of polymer films by this test method. The test speed load and sample dimension were referred to this standard. The coefficient of friction test by this method covers the coefficient of static and kinetic friction for the polymer which could be correlated to actual performance of the polymer film therefore this test method is relevant and appropriate for research and industrials uses.

II.4. Optical Analysis

Optical analysis of polymer film could be done by various microscopy techniques (TEM, SEM, Optical microscope) and various characterization techniques (AFM, XPS). However microscopy techniques and characterization techniques are not sophisticated enough to present complete topographical data of the polymer or sometimes the characterization techniques could damaged the polymer film. Optical analysis in this study was performed by Optical profilometer. Non contact optical profilometer is surface characterization techniques which could provide the surface topographical data of the polymer sample without damaging the polymer film. Moreover optical profilometer is suitable for this study because it provides three dimensional topographical images which are very useful in analysing the effect of friction to polymer film.

CHAPTER III
EXPERIMENTAL METHODS

III.1. Materials Preparation

Polyethylene terephthalate (PET) and Polyethylene (PE) polymer film was used in this experiment. This polymer films was chosen for this study due to significant difference in their microstructural orientation which was obtained from their processing mechanism therefore the coefficient of friction of this polymer films were expected to have different effect. Polyethylene terephthalate (PET) film and Polyethylene (PE) films were obtained from duPont and used as received. Fig III.1 (a and b) below are PET and PE samples that were used in this experiment, the machine direction which are extrusion direction is shown with red arrow in figure IIIc.

Figure III.1 : (a). Polyethylene terephthalate film. (b). Polethylene Film (c). PET and PE film in machine direction.

III.2. Microstructural Characterization

In this section, the microstructural characterization of Polyethyleneterphtalate (PET) film and Polyethylene (PE) film were observed by examining the microstructural anisotropy in bulk properties and surface properties of the polymer film samples. Moreover, surface properties were examined because the coefficient of friction does not depend on the bulk properties of the film samples.

III.2.1. Bulk Properties Characterization

Bulk properties characterization was done for Polyethylene terephthalate (PET) and polyethylene (PE) film samples in order to observe their bulk microstructural anisotropy. This bulk properties characterization was done by doing tensile test and deflection test to the samples. The dimension of Polyethylene terephthalate (PET) and polyethylene (PE) samples for tensile test and deflection test was 0.06 mm in thickness, 50 mm in length and 10 mm in width. Samples were cut in the machine direction, 15, 30, 45, 60, 75, and 90 degrees to the machine direction in order to find the directional dependences of the samples to the ductility and stiffness.

- Tensile test.

Tensile test of the film samples were performed by using tensile tester machine (INSTRON Micro tester, model 5848) in Fig III.2 below. The test were conducted with 40mm/min strain rate, the gauge length before sample tested and after sample failed was recorded in order to obtain the ductility of the sample. Ductility of each sample was measured by dividing the gauge length of the sample before test was performed and after the sample failed. The ductility of samples in different direction was used to examine the bulk properties anisotropy of the samples.

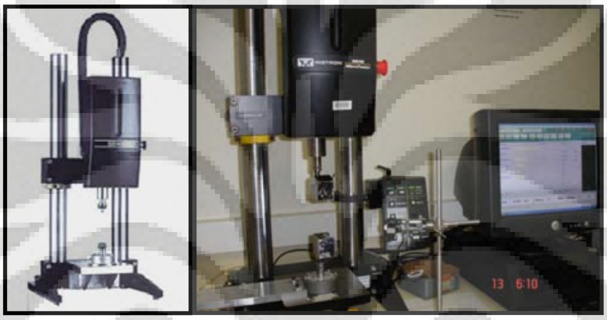

Figure III.2 : INSTRON micro tester

- Deflection Test.

Deflection test were conducted in order to find the effect of microstructural orientation to the relative modulus of the PET and PE samples. Deflection test was performed for both PET and PE samples by measuring the deflection of the polymer film samples under its own weight. The sample for this test was 50 mm in length, 10mm in width and 0.06mm in thickness, The test was performed in edged bench with 10 mm^2 of the sample attach to the bench and 40mm of its length hanging down the bench.

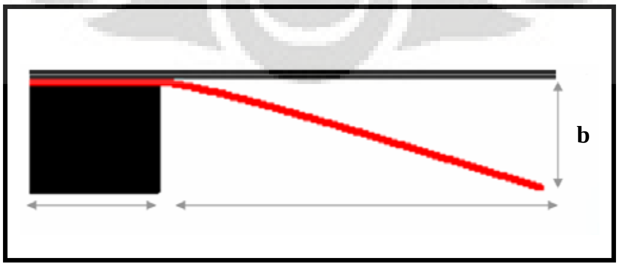

Figure III.3 : Schematic diagram of deflection test

The relative modulus of the sample was measured by dividing the modulus relative to the biggest deflection value and multiplies it by 100 percent. The deflection of the samples was the legth b in the Fig 7 above. The relative modulus of the sample in different direction was used to obtain the microstructural anisotropy of the samples.

III.2.2. Surface properties characterization

Surface properties characterizations of the samples were examined by etching and observing the microstructure under optical profilometry in order to find the surface microstructural anisotropy of the samples. Polymer film samples were placed in a beaker glass consist of 40 % Potassium Hydroxide solution, 25%Ethanol Amine, 10%Ethylene Glycol, 35%H_2O. The beaker glass was placed in the magnetic stirrer and stirred for 1 hour before washed with ethanol and examine by optical profilometer. The samples etched in order to dissolve the amorphous region of the sample. Microstructure orientation on the surface of the sample was analyzed by optical profilometry. The optical profilometry images before and after etching were used to determine the effect of etching to the surface of the samples.

III.3. Coefficient of Friction Test

Coefficient of friction test were conducted under ASTM D1894 standard for coefficient of friction test. IDM instrument coefficient of friction tester model number: C0008 were used to conduct the test with constant normal force (weight of sled * gravity = 1.98 N) and constant speed of moving plane 150mm/min. Mark 10 program was used to display the force versus time graph in computer. Samples for coefficient of friction test were cut into 250 mm (10") in the machine direction and 130 mm (5") in the transverse direction while the samples which are attached to the sled was cut 120 mm square with a thickness of 0.254 mm. Polymer film sample were cut in 0 (machine direction), 15^0, 30^0, 45^0, 60^0, 75^0, and 90^0 (transverse direction) to the machine direction as could bee seen in Fig III.4.b, coefficient of friction test were conducted for the same pair of samples and under similar environment.

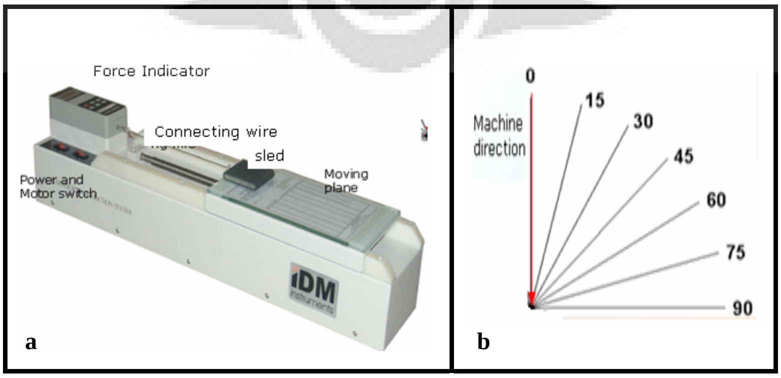

Figure III.4. : (a) IDM instrument coefficient of friction test. (b) Cutting direction of samples for coefficient of friction test.

The force gauge displayed the force required to hold the sled from moving after 150mm plane movement, this force then displayed in Mark 10 program as force versus time graph. Typical graph which displayed in the computer consists of static and kinetic coefficient of friction. The first peak of the force is the Static coefficient of friction, the static COF is the force required to move one surface to another at the start. while the kinetic friction force is the force required to move one surface over another force applied normal to those surface once it progress, the value of kinetic force is generally lower than static friction of the samples. The average kinetic friction was obtained by averaging kinetic friction force. This average kinetic force then divide by the normal forces that acting on the plane in order to obtain coefficient of friction value for each sample.

III.4. Optical Analysis

Surface profiles of the samples after friction test were examined by optical profilometer in Fig III.4 below (Optical profilometer; Wyko NT 1100). The surface profile images used to observe the friction effect to the surface profile of the samples. All samples were cleaned with ethanol before examined by optical profilometer. Optical profilometry image of the samples were taken by 20X maginification in order to give detailed information on the surface profile of the samples.

Figure III.5 : Optical Profilometer Wyko NT 1100

CHAPTER IV
RESULTS AND DISCUSSION

This study was aimed to investigate the effect of molecular orientation on the coefficient of friction of polymeric materials. First of all investigation on the stretching orientation on the polymer film was done by observing the bulk and surface properties anisotropy of the sample, bulk properties observation by performing tensile test, deflection test, surface properties by etching and optical profilometry of the samples. The coefficient of friction test of this polymer in six different directions was performed in machine direction in order to investigate the molecular orientation on the coefficient of friction of polymer film. Finally optical analysis by using optical profilometer was performed to confirm the molecular orientation effect on the coefficient of friction of the polymer samples.

IV.1. Anisotropy of the materials

This section present the experimental results for the Polyethylene terephthalate (PET) and polyethylene (PE) samples investigated in this project. The data for bulk properties anisotropy are given first, followed by surface properties anisotropy, coefficient of friction and finally the surface profile anisotropy of materials.

IV.1.1. Bulk properties anisotropy

Figures IV.1 a and b show the ductility of PET and PE samples along different directions ranging from along the machine direction to 345^0 to the machine direction, taken at 15^0 intervals.

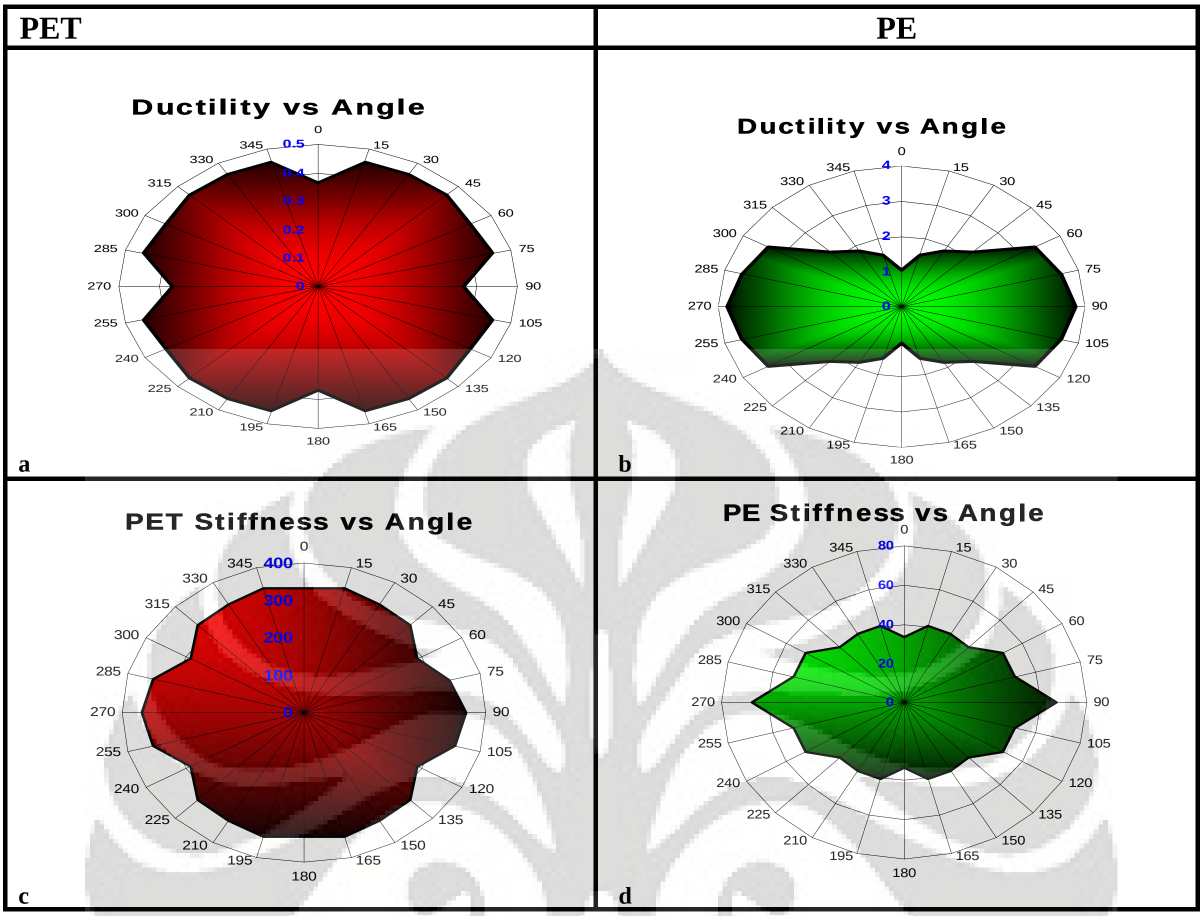

Figure IV.1. : (a) Radar graph of PET ductility. (b) Radar graph of PE ductility. (c) Radar graph of PET stiffness (d) Radar graph of PE stiffness.

In general Fig IV.1 a shows that the ductility value of PET is similar in all direction. The lowest strain value was 0.37 for both machine and transverse direction, which may be due to the processing mechanism of the films. PET films were stretched significantly in machine and transverse direction therefore the abilities to deform in machine and transverse direction were lesser compare to other directions. Moreover the stiffness values for PET show insignificant differences for different orientation.

Figure IV.1 b shows result of ductility test for PE samples. It can be seen that the strain value of PE samples has anisotropy between transverse direction and other directions, the ductility of transverse direction samples was significantly higher (3.8) compare to other directions. The deformation processing of PE film during extrusion film blowing mostly happened in machine direction or extrusion direction while the transverse direction did not significantly deform, hence the ability to deform in transverse direction was higher than other directions. Moreover the stiffness or relative modulus of PE shows highest in transverse directions. Furthermore the ductility and relative modulus of PET and PE samples shows that PE sample has bulk properties anisotropy while PET sample have a similar bulk properties in all directions.

IV.1.2. Surface properties anisotropy

Figure IV.2 shows PET and PE samples surface profile in dimension of 228 μm X 300 μm. These figures clearly show the difference in surface profile of PET and PE samples.

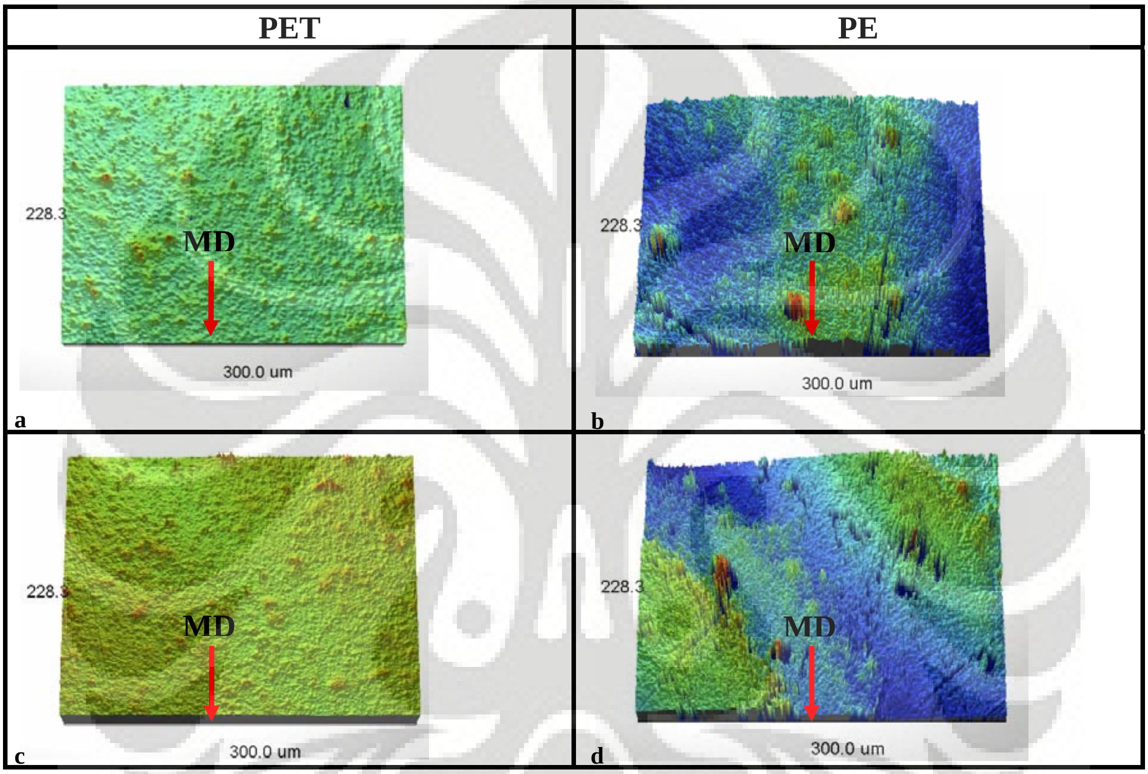

Figure IV.2 : (a) PET sample surface before etching, (b) PE sample surface before etching, (c) PET sample surface after etching, (d) PET sample surface after etching.

The surface profile of PE sample shows undulation which aligned with the machine direction while PET surface did not have a pattern that could confirm machine directional effect on the surface. The undulation that appears in PE samples could be clearly seen from the height differences in the figure IV.2 and the profile of the surface which consist of valley and hills. These results may suggest that the molecular orientation of the PE film oriented in the machine direction while the PET sample does not have strong machine direction effect and the molecular chain may lies in the film with little or no orientation. Moreover this figure also shows that etching by potassium hydroxide for 1 hour could not reveal the microstructure of the samples and did not affect the surface profile of the samples.

IV.2. Coefficient of friction

Figure IV.3 shows radar plot of friction coefficient for Polyethyleneterphtalate (PET) film and Polyethylene (PE) film.

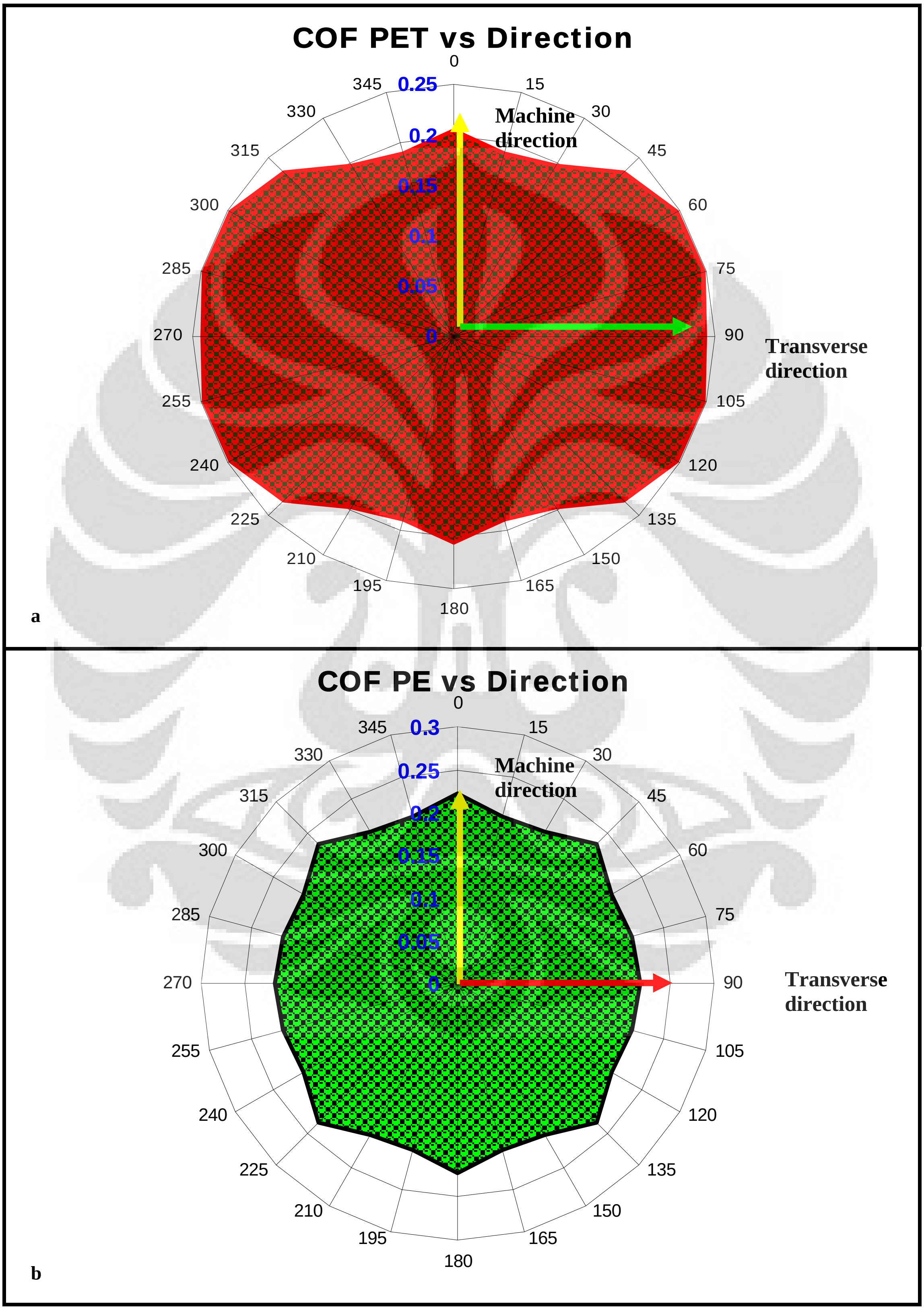

Figure IV.3 : (a) Radar plot PET COF vs Direction. (b) Radar plot PE COF vs Direction.

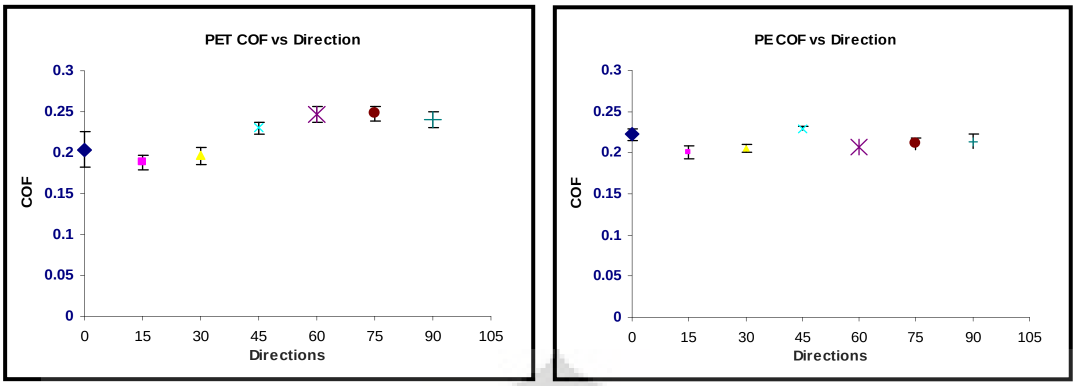

Figure IV.4 : Standard deviation of COF value for PET and PE

The friction force value for PET and PE samples in each direction was obtained by averaging five kinetic friction forces from five measurements in each direction. The coefficient of friction (μ) for every direction was measured by using equation below:

$$\mu = \frac{f}{N}$$

Equation IV.1: Coefficient of friction equation.

In order to determine the coefficient of friction of the samples in each direction, the average kinetic friction force (f) were divided by the normal force (N= 1.986 N) that acting on the sled. Fig IV.3 a and b shows the radar graph of coefficient of friction versus direction results for PET and PE samples.

The result of friction coefficient for PE sample from 0 to 345^0 degrees revealed that the coefficient of friction value almost similar in every directions. Coefficient of friction values for PE samples were in a range of 0.2 – 0.22. Coefficient of friction result of PET samples revealed that there was anisotropy of coefficient of friction value for PET samples. Coefficient of friction value for 45, 65 and 90^0 to the machine direction shows coefficient of friction in these directions are higher than 15, 30, and machine direction. Coefficient of friction values were in the range of 0.23-0.25 for 45, 65 and 90^0 degrees to machine direction while the coefficient of friction value for machine direction, 15^0, and 30^0 to machine directions were 0.203, 0.188, and 0.196. The coefficient of friction results indicate that there is a huge anisotropy in the coefficient of friction for PET samples whereas PE sample shows little anisotropy on the coefficient of friction results.

IV.3. Surface profilometry

In order to observe the surface profile effect to coefficient of friction of the PET and PE samples, optical profilometry of the PET and PE samples were performed. Figure IV.5 shows surface profiles of PET and PE samples after friction test along machine direction and across machine direction.

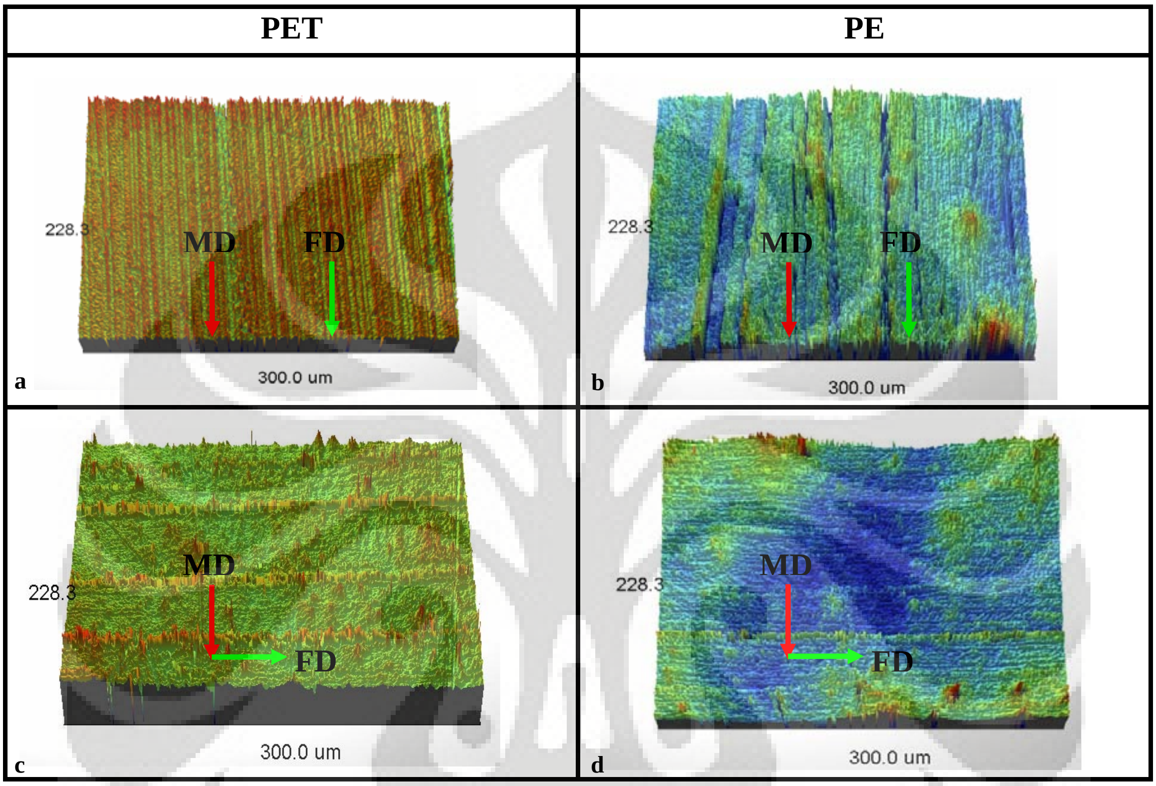

Figure IV.5 : (a) Surface profile of PET before etching. (b) Surface profile of PE before etching. (c) Surface profile of PET after etching. (d) Surface profile of PE after etching.

The surface profiles in Fig IV.5. were the surface profiles of the samples on the sled after 7500 mm friction test. Coefficient of friction test were conducted for the same pair of samples in similar environment. Figure IV.5 a and c shows the friction tests were conducted along machine direction of PET and PE samples, therefore the resulting scratch was parallel to the machine direction. Figure IV.5 b and d shows the friction tests were conducted across the machine direction of PET and PE sample, therefore the resulting scratch was 90^0 to the machine direction.

In order to find the directional dependences effect on friction of PET and PE samples, comparison between the surface profile after friction test along machine direction and across machine direction of PET and PE samples were observed. Through comparison of the Fig IV.5 b and d it could be seen that the frictions along machine direction and across machine directions on PE samples did not shows significant differences. Both of these figure shows pronounced effect regardless the friction was done along machine direction or across machine directions, however it appears that the scratches on the surface of PE samples were independent to undulation that was happened in the surface profile of PE samples. Figure IV.5 a and c of PET samples after friction along and across machine directions shows a significant differences, friction test along machine direction shown in Fig IV.5 a has more pronounced effect on the surface profile compare to friction test across the machine direction shown in Fig IV.5 c. The differences in surface profile after friction test of PET samples indicates that the PET samples has slight directional dependences on directionality.

The relation between the coefficient of friction to the stretching orientation of polymer has been a subject of some previous research. Although some of the research could not found the dependences of friction to the molecular orientation. The coefficient of friction results of this experiment which involving the optical analysis on the surface of the materials are indicates that there are an effect of molecular orientation on the coefficient of friction of materials.

CHAPTER V
CONCLUSION and FUTURE WORK

The molecular orientation, bulk properties and surface properties anisotropy of Polyethylene terephthalate (PET) and Polyethylene (PE) polymer film along different directions have been examined. The coefficient of friction test for Polyethylene terephthalate (PET) and Polyethylene (PE) sample were also observed, as well as optical analysis to analyze the molecular orientation dependences to the coefficient of friction. The results found in this study are summarized as follows:

(a). PET film have similar properties in all direction which may indicate that molecular chain lies in the film with little or no orientation, while PE film have anisotropy on the properties, that may be due to the position of molecular chain which lies in the machine direction.

(b). The friction coefficient of PET shows anisotropy in directions regardless the non apparent directional effect on their surface and bulk properties.

(c). The friction coefficient of Polyethylene (PE) is similar in every direction regardless the apparent directional effect on the surface and bulk properties.

In conclusion this study found that the friction coefficient of Polyethylene (PE) is independent of molecular orientation while on the other hand friction coefficient of Polyethylene terephtalate (PET) is slightly dependent on the molecular orientation.

It is clear from this study that much work remains to be done to determine and understand the effects of the molecular orientation on the coefficient of friction for various types of polymers. Some of the future work that could be done to observe and understand the effect of the molecular orientation on the coefficient of friction characteristic of polymer includes observing this effect on different polymeric materials, microscopy imaging such as TEM and polarized light microscope, XRD to further confirm the molecular orientation on the film.

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APPENDIX

DUCTILITY TEST vs Direction

PE		PET	
Angle	**Strain**	**Angle**	**Strain**
0	1,04	0	0,363636
15	1,52	15	0,454545
30	1,8	30	0,454545
45	2,2	45	0,454545
60	3,36	60	0,440909
75	3,6	75	0,454545
90	3,8	90	0,363636
105	3,6	105	0,454545
120	3,36	120	0,440909
135	2,2	135	0,454545
150	1,8	150	0,454545
165	1,52	165	0,454545
180	1,04	180	0,363636
195	1,52	195	0,454545
210	1,8	210	0,454545
225	2,2	225	0,454545
240	3,36	240	0,440909
255	3,6	255	0,454545
270	3,8	270	0,363636
285	3,6	285	0,454545
300	3,36	300	0,440909
315	2,2	315	0,454545
330	1,8	330	0,454545
345	1,52	345	0,454545

Deflection Test vs Angle

PE

Deflection test		stifness
0	3	33,33333
15	2,5	40
30	2,5	40
45	2,5	40
60	2	50
75	2	50
90	1,5	66,66667
105	2	50
120	2	50
135	2,5	40
150	2,5	40
165	2,5	40
180	3	33,33333
195	2,5	40
210	2,5	40
225	2,5	40
240	2	50
255	2	50
270	1,5	66,66667
285	2	50
300	2	50
315	2,5	40
330	2,5	40
345	2,5	40

PET

Deflection test		stifness
0	0,3	333,3333
15	0,29	344,8276
30	0,3	333,3333
45	0,3	333,3333
60	0,32	312,5
75	0,3	333,3333
90	0,28	357,1429
105	0,3	333,3333
120	0,32	312,5
135	0,3	333,3333
150	0,3	333,3333
165	0,29	344,8276
180	0,3	333,3333
195	0,29	344,8276
210	0,3	333,3333
225	0,3	333,3333
240	0,32	312,5
255	0,3	333,3333
270	0,28	357,1429
285	0,3	333,3333
300	0,32	312,5
315	0,3	333,3333
330	0,3	333,3333
345	0,29	344,8276

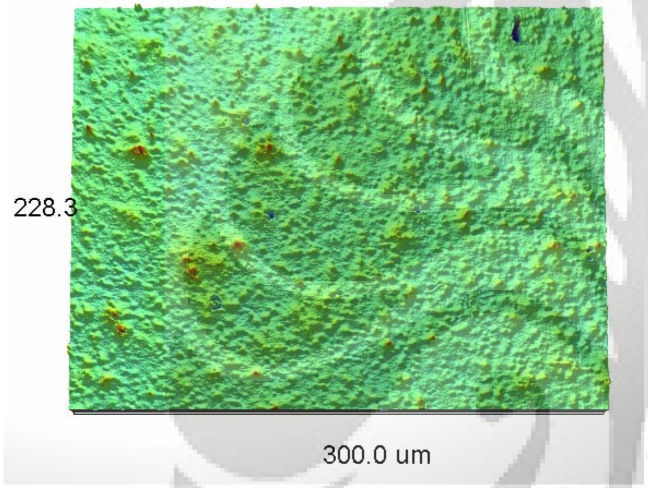
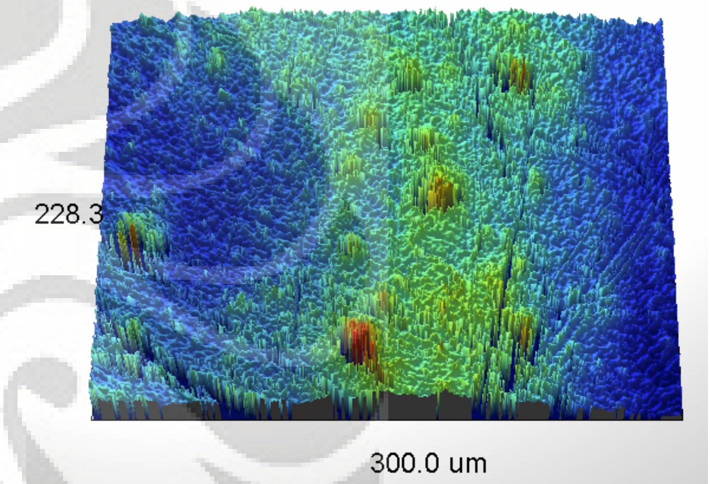
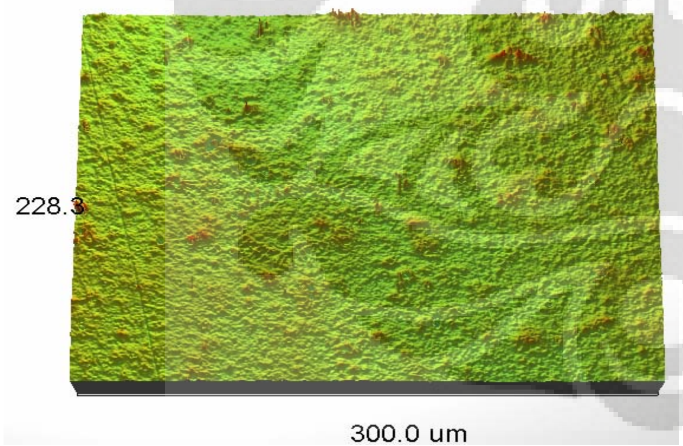
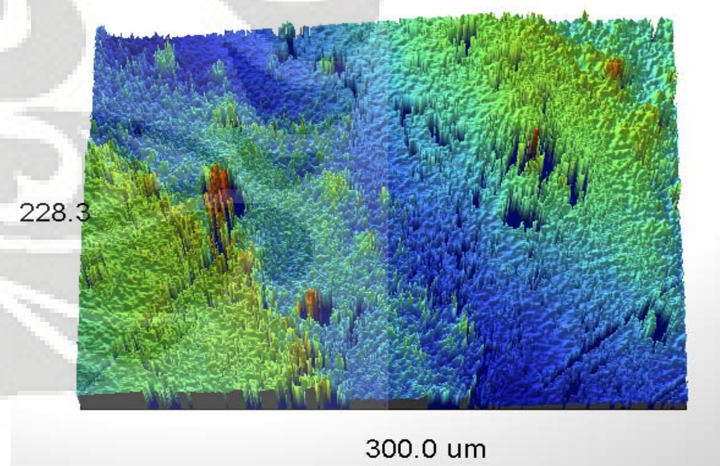
Coefficient of Friction test of PET

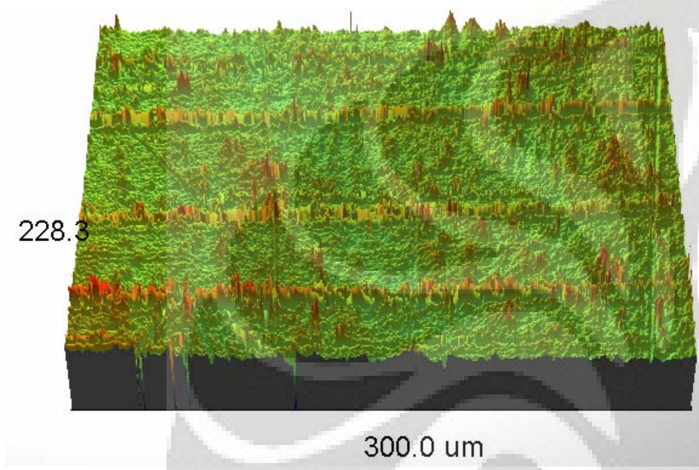
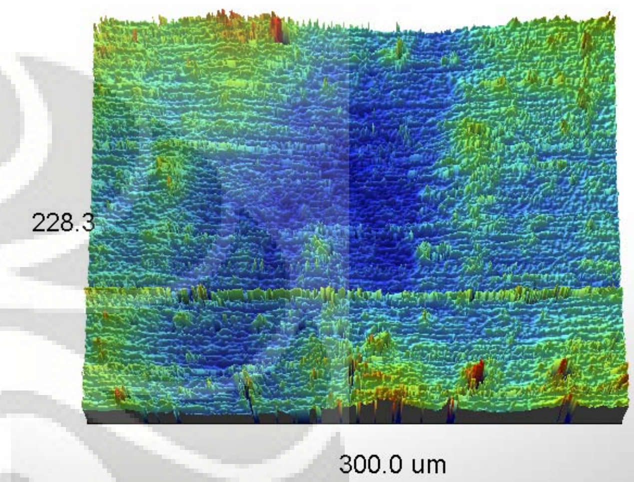
	COF					
Angle	1	2	3	4	5	average
0	0,243402	0,251075	0,239919	0,261436	0,203985	0,203985
15	0,258558	0,2527	0,245267	0,247336	0,23439	0,188188
30	0,261042	0,248218	0,244561	0,246533	0,234052	0,196058
45	0,266753	0,270398	0,280734	0,28532	0,280973	0,23
60	0,21377	0,198152	0,193601	0,18619	0,188576	0,246881
75	0,200748	0,203485	0,181195	0,182424	0,263088	0,24765
90	0,242117	0,242117	0,218249	0,236527	0,236527	0,239963
105	0,200748	0,203485	0,181195	0,182424	0,263088	0,24765
120	0,21377	0,198152	0,193601	0,18619	0,188576	0,246881
135	0,266753	0,270398	0,280734	0,28532	0,280973	0,23
150	0,261042	0,248218	0,244561	0,246533	0,234052	0,196058
165	0,258558	0,2527	0,245267	0,247336	0,23439	0,188188
180	0,243402	0,251075	0,239919	0,261436	0,203985	0,203985
195	0,258558	0,2527	0,245267	0,247336	0,23439	0,188188
210	0,261042	0,248218	0,244561	0,246533	0,234052	0,196058
225	0,266753	0,270398	0,280734	0,28532	0,280973	0,23
240	0,21377	0,198152	0,193601	0,18619	0,188576	0,246881
255	0,200748	0,203485	0,181195	0,182424	0,263088	0,24765
270	0,242117	0,242117	0,218249	0,216527	0,216527	0,239963
285	0,200748	0,203485	0,181195	0,182424	0,263088	0,24765
300	0,21377	0,198152	0,193601	0,18619	0,188576	0,246881
315	0,266753	0,270398	0,280734	0,28532	0,280973	0,23
330	0,261042	0,248218	0,244561	0,246533	0,234052	0,196058
345	0,258558	0,2527	0,245267	0,247336	0,23439	0,188188

Coefficient of Friction test of PE

	COF					
Angle	1	2	3	4	5	average r
0	0,228646	0,231093	0,219349	0,215643	0,215773	0,222101
15	0,211769	0,201822	0,197915	0,196429	0,194788	0,200545
30	0,20988	0,194659	0,200068	0,209227	0,209574	0,204682
45	0,239498	0,238673	0,215905	0,237327	0,213726	0,229026
60	0,213371	0,20829	0,208204	0,203381	0,200928	0,206835
75	0,219886	0,210222	0,21553	0,209522	0,200857	0,211203
90	0,227039	0,215136	0,211819	0,210059	0,204324	0,213675
105	0,219886	0,210222	0,21553	0,209522	0,200857	0,211203
120	0,213371	0,20829	0,208204	0,203381	0,200928	0,206835
135	0,239498	0,238673	0,215905	0,237327	0,213726	0,229026
150	0,20988	0,194659	0,200068	0,209227	0,209574	0,204682
165	0,211769	0,201822	0,197915	0,196429	0,194788	0,200545
180	0,228646	0,231093	0,219349	0,215643	0,215773	0,222101
195	0,211769	0,201822	0,197915	0,196429	0,194788	0,200545
210	0,20988	0,194659	0,200068	0,209227	0,209574	0,204682
225	0,239498	0,238673	0,215905	0,237327	0,213726	0,229026
240	0,213371	0,20829	0,208204	0,203381	0,200928	0,206835
255	0,219886	0,210222	0,21553	0,209522	0,200857	0,211203
270	0,227039	0,215136	0,211819	0,210059	0,204324	0,213675
285	0,219886	0,210222	0,21553	0,209522	0,200857	0,211203
300	0,213371	0,20829	0,208204	0,203381	0,200928	0,206835
315	0,239498	0,238673	0,215905	0,237327	0,213726	0,229026
330	0,20988	0,194659	0,200068	0,209227	0,209574	0,204682
345	0,211769	0,201822	0,197915	0,196429	0,194788	0,200545

OPTICAL PROFILOMETER

Before friction	**Mylar (PET)**	**Polyethylene**
Cleaned		
Etched		

Friction	PET	Polyethylene
Across etched		
Along etched