การเตรียมพอลิเมอร์ผสม UHMWPE กับ LLDPE สำหรับงานฉีดขึ้นรูป

นายทัศนพงษ์ แหยมพรรนัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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PREPARATION OF MOLDING UHMWPE AND LLDPE BLEND FOR INJECTION PROCESS

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ทัศนพงษ์ แหยมพรรนัย : การเตรียมพอลิเมอร์ผสมUHMWPE กับ LLDPE สำหรับงานฉีดขึ้นรูป (PREPARATION OF MOLDING UHMWPE AND LLDPE BLEND FOR INJECTION PROCESS) อ. ที่ปรึกษา : รศ. ดร. โสภณ เริงสำราญ, 138 หน้า, ISBN 974-13-1023-4

การผสมอัลตราไฮโมเลกุลลาร์เวทโพลีเอทิลีนน้ำหนักโมเลกุลสูง (ยูเอชเอ็ม ดับบลิวพีอี) และลิเนียร์โลเด็นซิตีโพลีเอทิลีน (แอลแอลดีพีอี) สามารถทำได้โดยผสมยูเอชเอ็ม ดับบลิวพีอีและแอลแอลดีพีอี โดยใช้เครื่องผสมสำหรับกระบวนการผสมแบบแห้งและการผสมขณะหลอม อัตราส่วนของพอลิเมอร์ผสมคือ 5, 10, 30, 50, 70, 90, 95, 100%ยูเอชเอ็มดับบลิวพีอี กระบวนการขึ้นรูปทำได้โดยกระบวนการฉีด การศึกษาด้วยเทคนิคดิฟเฟอเรนเชียลสแกนนิงแคลอริเมตรีและสแกนนิงอิเลคตรอนไมโครสโกปี ทำให้ทราบสภาพที่เข้ากันได้ พบว่าพอลิเมอร์ผสมมีความเข้ากันได้ดีในทุกอัตราส่วนผสม ทำการศึกษาสมบัติเชิงกล ได้แก่ การทนแรงกระแทกและการทนแรงดึง พบว่าการทนแรงกระแทกไม่สามารถวัดค่าได้เนื่องจากพอลิเมอร์มีความเหนียวและความต้านทานการฉีกพับที่สูง ส่วนการทนแรงดึงจะเพิ่มขึ้นตามปริมาณของยูเอชเอ็มดับบลิวพีอีที่เพิ่มขึ้น ความเหมาะสมในการนำไปใช้งานสามารถศึกษาโดยการวัดค่าการหดตัวและการพิจารณาต้นทุน พบว่าการหดตัวและต้นทุนลดลงเมื่อปริมาณของแอลแอลดีพีอีมากขึ้น

นอกจากนี้สามารถปรับปรุงสมบัติของพอลิเมอร์ผสมโดยการใช้สารเติมแต่ง สารเติมแต่งที่ใช้ ได้แก่ ใยแก้วและแป้งหิน ปริมาณของสารเติมแต่งที่ใช้ คือ 30% จะได้พอลิเมอร์เสริมแรง พบว่าพอลิเมอร์เสริมแรงมีการทนแรงกระแทกและ การทนแรงดึงมากกว่าพอลิเมอร์ผสม นอกจากนี้ใยแก้วและแป้งหินยังลดค่าการหดตัวของพอลิเมอร์ผสมได้ ค่าการหดตัวของพอลิเมอร์เสริมแรงจะลดลงได้มากกว่าเมื่อใช้แป้งหินเป็นสารเติมแต่ง ต้นทุนของพอลิเมอร์เสริมแรงลดลง 25% และ 30% เมื่อใช้ใยแก้วและแป้งหินเป็นสารเติมแต่งตามลำดับ

หลักสูตร ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์ ลายมือชื่อนิสิต..............................
สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์ ลายมือชื่ออาจารย์ที่ปรึกษา..............................
ปีการศึกษา 2543

4173409323 : MAJOR PETROCHEMISTRY AND POLYMER SCIENCE
KEYWORD : ULTRAHIGH MOLECULAR WEIGHT POLYETHYLENE (UHMWPE)/ LINEAR LOW DENSITY POLYETHYLENE (LLDPE)/ BLENDING/ INJECTION PROCESS

TASANAPONG YAMPUNRANAI : PREPARATION OF MOLDING UHMWPE AND LLDPE BLEND FOR INJECTION PROCESS. THESIS ADVISOR : ASSOC. PROF.SOPHON ROENGSUMRAN, Ph.D., 138 pp., ISBN 974-13-1023-4

Blending of ultrahigh molecular weight polyethylene (UHMWPE) and linear low density polyethylene (LLDPE) could be done by mixing UHMWPE and LLDPE. The mixer was used for dry blending and melt blending. The compositions of blended polymers were 5,10, 30, 50, 70, 90, 95, 100%UHMWPE. The processing was done by an injection process. Differential scanning calorimetry and scanning electron microscopy was used to determine the compatibility. These were found that blended polymers had good compatibility for each composition. Mechanical properties, which were impact strength and tensile strength were studied. Impact strength could not be done since blended polymers had high toughness and fatigue. Tensile strength increased when %UHMWPE increased. Shrinkage measurement and cost consideration were studied. Shrinkage and cost decreased when %LLDPE increased.

Furthermore the properties of blended polymers could be improved by fillers. Glass fiber and talcum were used as fillers. The amount of fillers was 30%. It was found that the composite polymers had higher impact strength and tensile strength than that of blended polymer. Additionally, glass fiber and talcum decreased shrinkage of blended polymers. Shrinkage of the composite polymer was dramatically decreased when using talcum as filler. The cost of the composite polymers was decreased 25% and 30% by using the glass fiber and talcum respectively.

Program of Petrochemistry and Polymer Science Student's signature............................
Field of study Petrochemistry and Polymer Science Advisor's signature.........................
Academic year 2000

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene copolymer
DSC	Differential scanning calorimetry
HDPE	High density polyethylene
HIPs	High impact polystyrene
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
NBR	Nitrile butadiene rubber
PA6	Polyamide 6
PC	Polycarbonate
POM	Polyoxymethylene
PP	Polypropylene
rpm	Revolution per minute
SAN	Styrene acrylonitrile copolymer
SEM	Scanning electron microscopy
Tm	Melting temperature
TPE	Thai Polyethylene Company Limited
TPV	Thermoplastic vulacanisates
UHMWPE	Ultra high molecular weight polyethylene

CHAPTER I

INTRODUCTION

1.1 Introduction

At present the plastic industry tends to grow up very fast resulting in high competition. Therefore, the properties of plastics have to be considered for the proper applications such as easy for processing, low cost of production and good mechanical properties.

Blending is a method which can improve the properties of the polymer for the proper application. It does not require a new type of polymer but an assembly of required properties of each polymer to give a polymer with good properties. For example, one polymer is easy to process and its cost is low but its mechanical property is not good, whereas another polymer is difficult to process and its cost is high but the mechanical property is good. Thus these two polymers should be blended to give the blended polymer, which has the required properties such as, moderate cost, easy for processing and good mechanical property.

Ultra high molecular weight polyethylene (UHMWPE) is one type of polyethylene which possesses high impact strength, is not easily broken, but has high cost and is difficult to process by an injection process because of high shrinkage. Thus the size of the obtained product will be difficult to control. Therefore, it has to be processed by extrusion or casting to a caster or a sheet first. Then it will be processed again by tooling, which can be done by milling, cutting or shearing to give the required product. This is very complicated and has high cost.

Linear low density polyethylene (LLDPE) is a useful polymer that tends to be an important polymer. It is very tough, flexible with low cost and is easy for processing. The processing can be done by many methods such as injection molding, extrusion sheet, blow molding and blow film. LLDPE is then being improved for wide applications.

Therefore, the blending of UHMWPE and LLDPE has been studied by preparing the blended polymer at various ratio of UHMWPE and LLDPE. The obtained polymer should have good properties such as easy for processing by injection molding, low cost, acceptable shrinkage, good mechanical properties and being applicable for industrial applications such as industrial bumper and machine supporter.

1.2 Objectives and scope of the research

The principal objective of this reseach is to improve the properties of UHMWPE by blending UHMWPE and LLDPE at various ratio of UHMWPE and LLDPE. The resulting blended polymers should have good properties for industrial applications such as, being acceptable, easy for processing by injection molding, low cost and acceptable mechanical properties. The compatibilities are studied by differential scanning calorimetry (DSC) and scanning electron microscopy (SEM). The tensile properties are tested by ASTM D638. Shrinkage is tested by a micrometer.

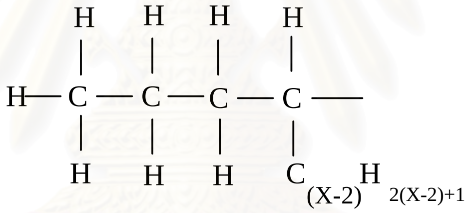
Another objective of this research is to improve the properties of blended polymer by using fillers. Glass fiber and talcum are used as fillers. Mechanical properties are studied including tensile strength and impact strength (ASTM D256). Shrinkage and cost are also being considered.

CHAPTER II

THEORETICAL CONSIDERATION

2.1 Ultrahigh molecular weight polyethylene (UHMWPE)

UHMWPE has the property like high density polyethylene (HDPE) but the viscosity is 2.3 times of HDPE. The molecular weight of UHMWPE is 3,000,000-6,000,000 mol/g. The density is 0.93 g/cc (whereas the density of PE, HDPE is 0.941-0.965 g/cc and 0.915-0.925 g/cc for LDPE). UHMWPE also has high impact strength. The color of UHMWPE is white, with opacity and it is slippery.[1,2] The molecular structure is shown in Figure 2.1.



$$\mathrm{H}-\underset{\mathrm{H}}{\overset{\mathrm{H}}{\underset{|}{\overset{|}{\mathrm{C}}}}}-\underset{\mathrm{H}}{\overset{\mathrm{H}}{\underset{|}{\overset{|}{\mathrm{C}}}}}-\underset{\mathrm{H}}{\overset{\mathrm{H}}{\underset{|}{\overset{|}{\mathrm{C}}}}}-\underset{\mathrm{C}_{(X-2)}\mathrm{H}_{2(X-2)+1}}{\overset{\mathrm{H}}{\underset{|}{\overset{|}{\mathrm{C}}}}}-$$

Figure 2.1 The molecular structure of UHMWPE

2.1.1 Chemical properties of UHMWPE

UHMWPE is highly corrosive, non-toxic, and insoluble with water or food. Thus it can be used for the food application.

The advantages of UHMWPE

1. Contains lubricant property.
2. Contains high abrasion and impact strength.
3. Contains fatigue resistance.
4. Contains sound and energy resistance.

The disadvantage of UHMWPE

The disadvantage of UHMWPE is that UHMWPE has a high viscosity, thus, it is difficult for an injection process.

2.2 Linear low density polyethylene (LLDPE)

LLDPE is a copolymer of ethylene, olefin and different alpha such as, butene, cumene. Density of LLDPE is 56.4-58.9 lb/ft^3 (0.905-0.945 g/cm^3)[3].The employed catalyst was organometallic by using low pressure. Processing of LLDPE is divided into 3 processes as follows:

1. Gas phase process
2. Solution process
3. Slurry process

LLDPE has similar density as LDPE but a different molecular structure as shown in Figure 2.2.

Figure 2.2 Differences in molecules of (a) LDPE and (b) LLDPE

2.2.1 General processing and characteristic of LLDPE

- The used pressure is very low that is equal to 6-20 atm (100-300 psi).
- Polymerization temperature employed is below 100 °C.
- The resulting polymer is a copolymer between ethylene and butene (C_4) or hexene (C_6) or octene (C_8) that has the same density as LDPE. The molecular structure of the polymer is straight with much short branching and narrow molecular weight distribution. Futhermore, the properties of LLDPE depend on the type of copolymer used (C_4, C_6 and C_8).

2.2.2 Commercial LLDPE processing

Processing of LLDPE in commercial is divided into 3 processes by different companies as follows:[4]

1. **Gas phase fluidized bed**
- Union Carbide
- British Petrochemical (BP)
2. **Solution process**
- Dupont Canada
- DOW
- D.S.M.
- Mitsui Petrochemical.
3. **Slurry process**
- Phillips
- Solvay
- V.S.I.
- Showa Denko
- Nisseki, Nippon petrochemical

2.2.3 TPE LLDPE processing

LLDPE processing of TPE is a gas phase process which is the technology of a British Petroleum Chemical Company that has the following advantages :

- Good efficiency of catalyst.
- The resulting polymer has good quality.
- Easy maintenance of processing machine.
- The resulting polymer has a melt flow index of 0.5-100 g/10 minutes and a density of 0.910-0.965 g/cm^3.

The monomers employed in the gas phase processing are butene (C_4), 4-methyl pentene (C_6), and hexene (C_6). The catalysts employed are titanium and chromium.

2.2.4 Applications of linear low density polyethylene

LLDPE has better properties than LDPE such as, impact strength , bursting strength , puncture resistance, tensile strength and glossiness.[5] Thus it was increasingly used instead of LDPE. The volume of used plastics is shown in Figure 2.6.The application of LLDPE were described as follows :

1. **Film and sheet products** is used for monolayer film which is used for heavy weight bags and as shrink film and tension film.
2. **Blow product** is used for blow molding bottle. It is tended to increase for wide application because of its good chemical resistance, permeable resistance and good-looking packaging.
3. **Injection product** can be applied for household, basket and refrigerator accessories. The advantage of LLDPE product is that it can be used for low temperature applications. Besides this, it also has wrap page resistance when exposed to high temperature, good weather resistance and can be processed into thinner film than LDPE which will decrease the cost of production.

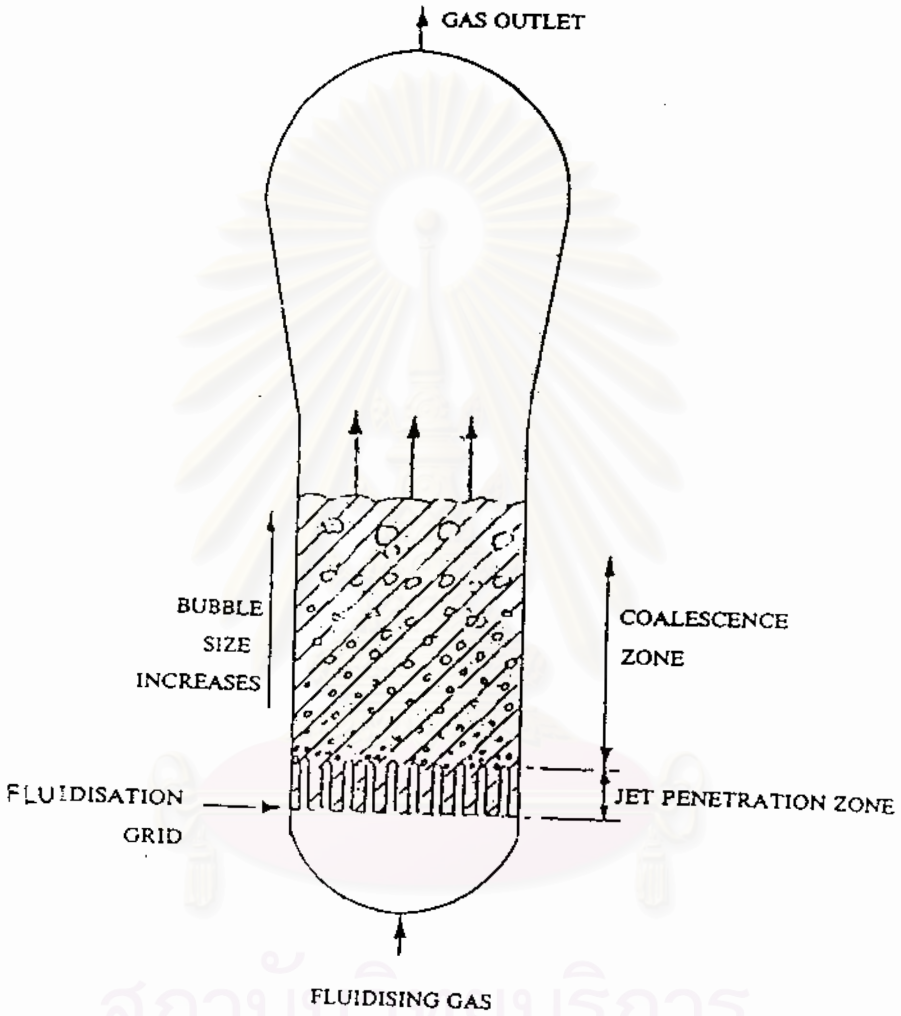


Figure 2.3 Gas flow in the fluidised bed

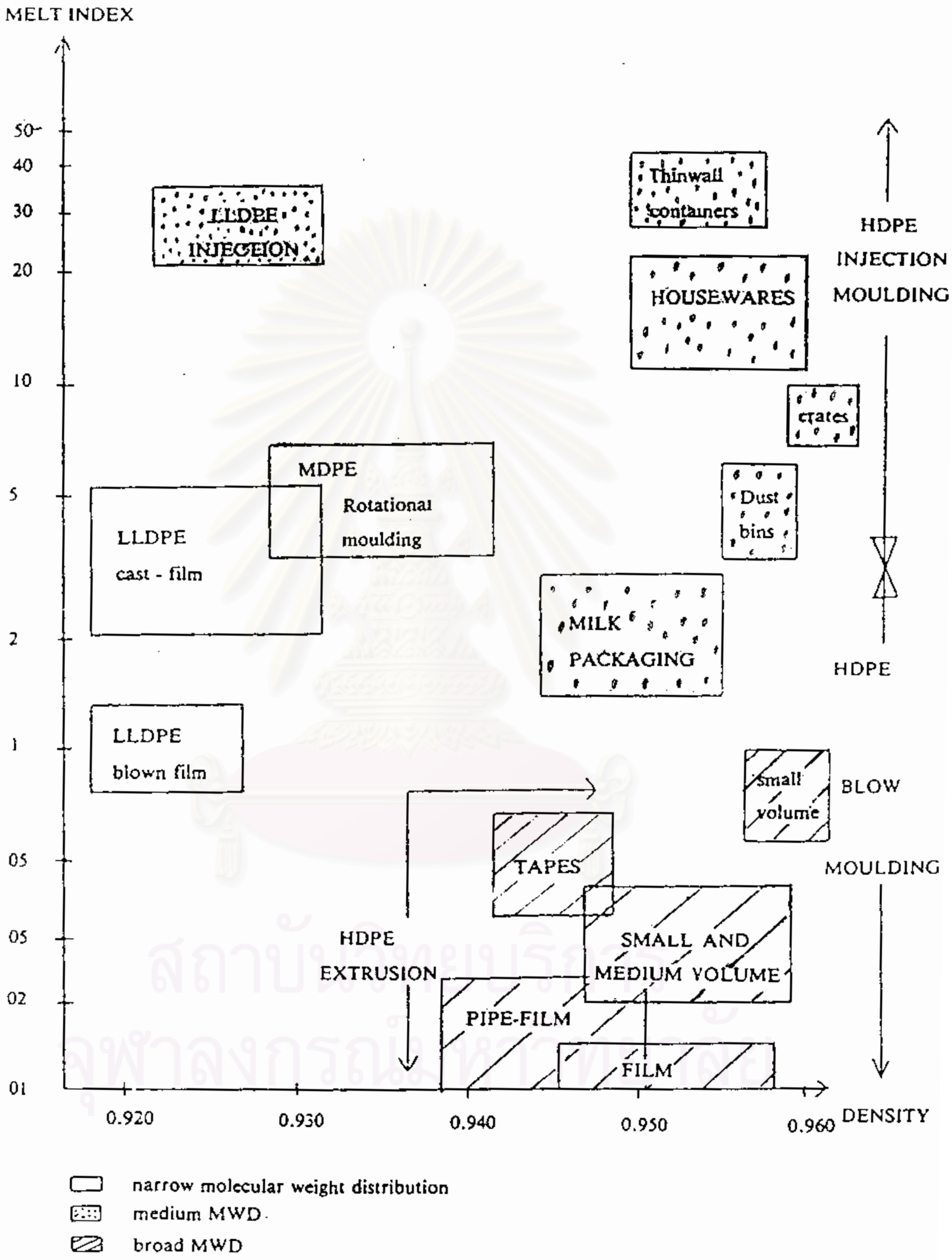


Figure 2.4 Gas phase process applications

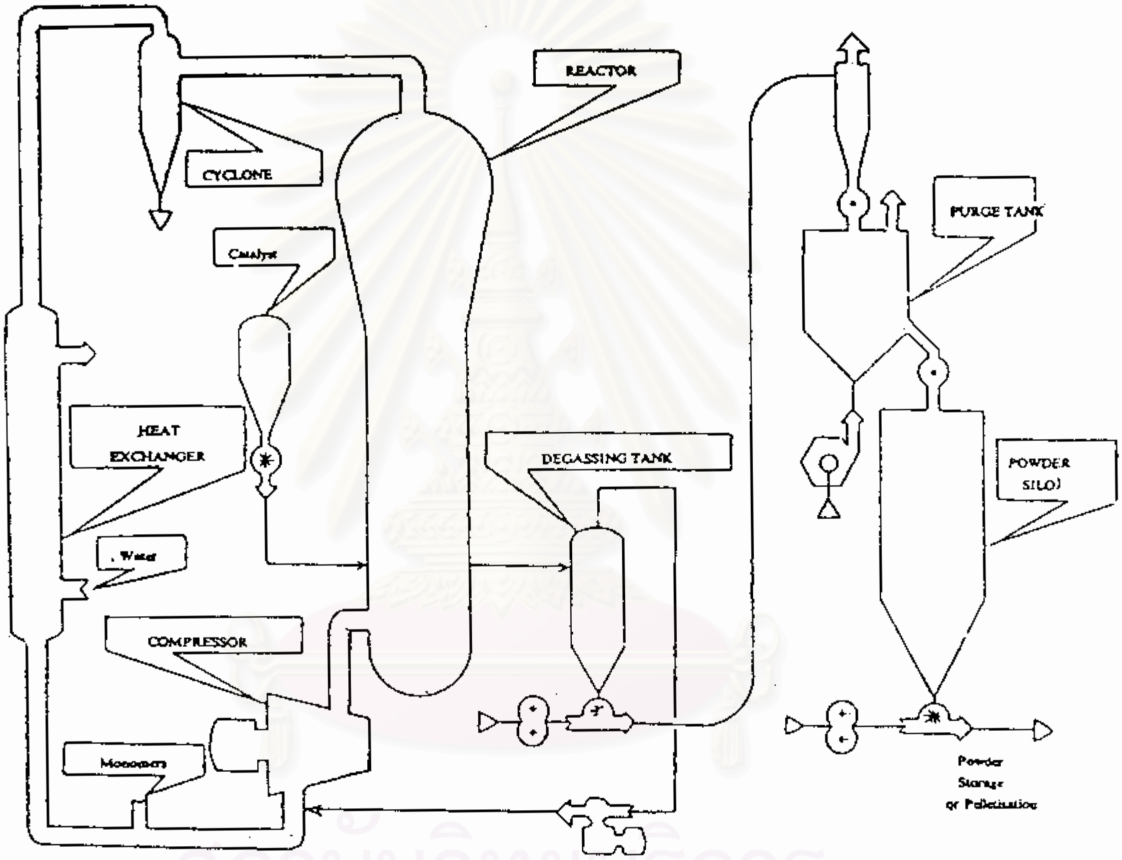


Figure 2.5 Gas phase fluid bed process

Figure 2.6 Volume of used thermoplastics

2.3 Phase morphology and properties

The properties of a polymer blend are controlled by the properties of the constituent polymers, the quantity of each polymer, the types of interactions between the polymers (e.g. chemical and physical), and the phase morphology of the blend. The phase morphology refers to the sizes and shapes of the polymer phases in the mixture. If we take a specimen of our polymer blend and cut a piece from its center and look at it under the microscope we can see the phase morphology. It is hoped that the morphology of the blend will give the blend of special properties that are not simply the sum of the constituent polymers. A good example is the use of small amounts (~20% by volume) of elastomers to increase the impact resistance of plastics: the blend should be hard and stiff like the original plastic, but tougher. If the blend had properties that were simply the average of the two polymers it would be flexible and leather-like.

It is possible to get several different phase morphologies with the same quantities of polymers in the blend: some examples of blend phase morphologies are shown in Figure 2.7.[6]

a) Polymer A dispersed in B b) Polymer B dispersed in A

c) Co-continuous d) Occluded 'salami' phases

Figure 2.7 Blend phase morphologies

a.) Dispersed phase morphology

One polymer forms discrete particles that are not connected while the other forms of the continuous phase are connected. Continuous means that all parts of the phase are connected. The dispersed phase does not necessarily have spherical particles.

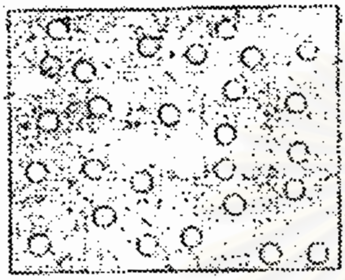
b.) Co-continuous morphology

All parts of both phases are connected.

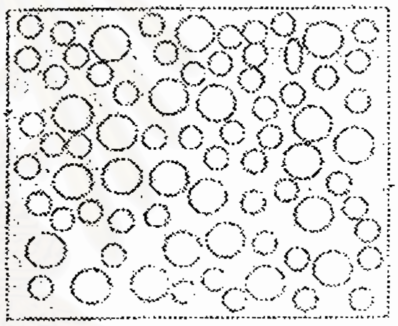
c.) Composite dispersed phase morphology

Some of the continuous phase is occluded within the dispersed phase.

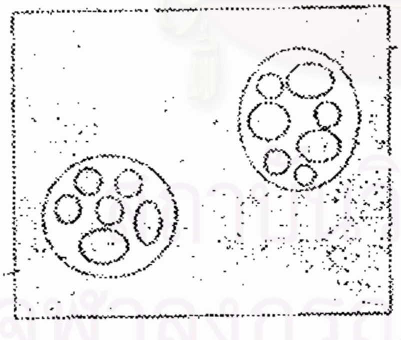
More complex morphologies can also be produced, especially if the blend contains copolymers and more than two resins. Figure 2.8 shows the examples of the morphologies found in three commercially important polymer blends.[7]



a) High impact PP 'block copolymer'



b) Thermoplastic vulcanisate 'TPV'



c) High impact polystyrene 'HIPS'
'salami morphology'

Figure 2.8 The morphologies of the polymer blends of (a) high impact PP block copolymer (b) thermoplastic vulcanisate (TPV) (c) high impact polystryrene (HIPS) ; salami morphology

a.) High impact polypropylene (HIPP)

Polypropylene has small particles (~1μm diameter) of ethylene-propylene random copolymer dispersed in a continuous phase of polypropylene homopolymer; this is the typical morphology of rubber toughened plastics. The rubber is the minor component and comprises about 15vol% . The material has slightly lower strength and stiffness than the unmodified plastic, but is much tougher. (Note: this is not really a block copolymer. It is made by polymerizing propylene for some time to produce PP homopolymer then a mixture of ethylene and propylene is added to the reactor to make the EP random copolymer).

b.) Thermoplastic vulcanisates (TPV)

TPV comprises a continuous thermoplastic phase with cross-linked rubber particles as the dispersed phase. The rubber is the major component (e.g. 70 vol%) but it is still the dispersed phase. This material has elastometric properties and can be processed like a normal thermoplastic.

c.) High impact polystyrene (HIPS)

HIPS has a slightly different morphology to high impact PP. In HIPS (and ABS) the dispersed rubber phase contains occluded polystyrene.

2.4 Polymer blending

By varying the type and quantities of polymers in the polyblend, a wide range of properties can be obtained. Problems arise, however, because the majority of polymers do not readily mix with one another, in a similar way that oil and water do not spontaneously mix, i.e. they are immiscible. When the two components mix readily to form one phase, the components are said to be miscible, e.g. water and ethanol. It two components, A and B, when mixed form two separate phases comprising A and B alone plus an additional phase containing a mixture of A and B, then the components are partially miscible.

Miscibility describes mixing at the molecular scale and is controlled by the ability of molecules to inter-diffuse: this is described by thermodynamics. The water/organic liquid systems given previously comprise low molecular weight components, the diffusion rate of which is high due to the high mobility of the molecules. Polymers, by definition, are high molecular weight molecules with low mobility, and therefore diffusion is slow. Consequently, during processing there may be insufficient time for mixing at the molecular level to occur, even in totally miscible blended polymers, and phase separation will be observed, i.e. there is also a kinetic effect.

Thermodynamics only has a significant influence upon the mixing of polymers after a fine dispersion of components has first been created by mechanical mixing.

The morphology of a phase separated polyblend, and hence its physical properties, will be dependent upon factors such as viscosity, molecular weight and weight distribution, miscibility, processing conditions and adhesion between the phases.

2.5 Terminology in polymer blending

Blended polymers can show miscibility, partial miscibility or complete immiscibility.[8] The first thermoplastic polyblends comprised polymers that were at least partially miscible, for example PVC/ABS and PPE/HIPS are miscible and in fact the most important blends comprise immiscible polymers, for example rubber toughened engineering plastics, where it is necessary for controlled phase separation to occur.

Total miscibility between polymers rarely occurs; partial miscibility and inmiscibility are the usual cases. Several types of blended polymer systems was shown in Figure 2.9.

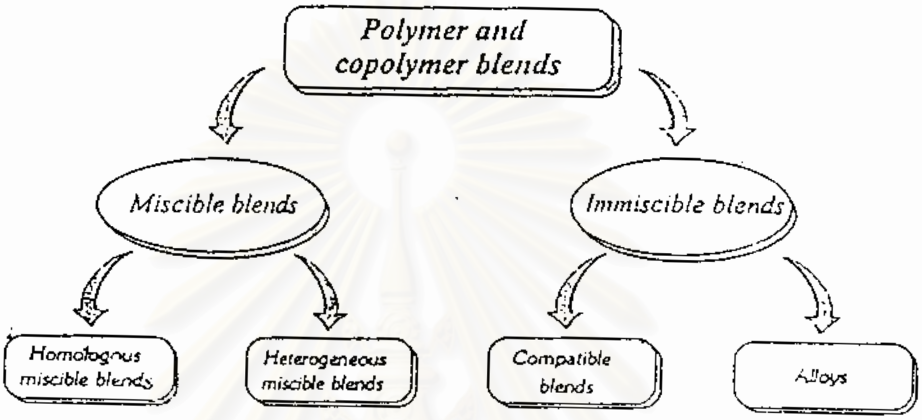


Figure 2.9 Classification of blended polymers

2.6 Blending method

There are several methods for combining two or more polymers into one material. Not every blending method is suitable for the production of all blended polymers. The choices are balanced cost and practicality. The blending method will have a large effect upon the blend morphology.

2.6.1 Polymerization blending

Polyblends may be produced by in situ polymerization of monomer mixtures, e.g. some high impact polystyrenes (HIPS) are produced by polymerizing styrene in the presence of lightly crosslinked polybutadiene or poly(styrene-co-butadiene). The morphology of the final blend is controlled by the extent of miscibility of the constituents as the polymerization reaction proceeds.

In-situ polymerization gives plastics with excellent properties, but the versatility of the process is limited due to the scale of production that is required to make the production economical.

2.6.2 Solution casting

Solutions of the component polymers are mixed and then the solvent is driven off leaving the solid polyblend. Solution blending is employed for surface coatings, but it is not suitable for other purposes due to the problems associated with handling large amounts of solvent.

2.6.3 Interpenetrating polymer networks (IPN)

IPNs are formed when two thermosetting resins are crosslinked simultaneously; the two polymers are linked by a physical network, not chemically. Semi-interpenetrating networks (SINS) are formed when a thermosetting polymer (A), with a low extent of crosslinking, is swollen with a second monomer B and/or a mixture of monomer A and B together with a crosslinking agent; the monomers then polymerize to form a linear or branched thermoplastic resin. A physically interacting interpenetrating network is formed.

2.6.4 Latex blending

This method involves the crosslinking of different elastomer suspensions (lattices), e.g. poly(styrene-co-acrylonitrile) (SAN) and polybutadiene (PB) to make acrylonitrile-butadiene-styrene (ABS). ABS can also be made from mechanical mixtures of SAN and NBR – this blend is called ABS type A.

2.6.5 Fine powder mixing

Fine powders are dry blended and then rotationally molded to produce modified articles.

2.6.6 Melt blending

Melt mixing with compounding extruders and internal mixers are the most widely used blending processes. It is a versatile technique that is particularly useful when relatively small amounts of special plastics grades are required. For example, special plastics grades in quantities smaller than 2500 kg can be produced economically by melt blending; an equivalent batch polymerizaion process may be uneconomical.

Immiscible polymers may be processed using compatibilization with additives or through chemical reactions. The latter is called reaction extrusion” (Rex).

2.7 Injection machine

Injection process is a high quality process for producing a large of product in a short time. The material is put into the hot barrel until it melts. Then, it is injected by the machine with high pressure into the closed-mold, which has a cooling system until the product is formed and taken out from the mold without deformation. The advantage of injection process is that it is proper for the production of complex products because the shape of the products can be controlled by the mold, which can control the size desirably and the product thus has the accurate shape.

Processing by injection machine provides a wide range of product. Most of products processing from injection process have weld-line behind the product or some part that cannot be easily seen which cause from runner that melted polymer is pushed into the mold.

2.7.1 Injection machine units

Injection machine has the main units as follows:[9]

2.7.1.1 Feeding unit

Feeding unit is used for material feeding by using pressure from a hydraulic unit to push the screw forward. There is another set of hydraulics to push the screw backward for preparation of the next feeding.

2.7.2.2 Injection unit

Injection unit is used to inject plastic. It is composed of different parts as follows:

a.) Nozzle

It is used for sending the plastic from the barrel to the mold and connecting the injection unit at the mold.

There are many types of nozzles such as curved type and flat type. Moreover the type of nozzle can be divided by the type of plastic as conventional nozzle and reverse nozzle.

b.) Barrel and screw

The barrel is used for heating the polymer and covering the screw. The screw is used to melt raw material and send it to the mold. The screw has a non-return valve at the head of the screw. The feed zone is the deepest position of the screw in order to increase the surface area to contact raw material.

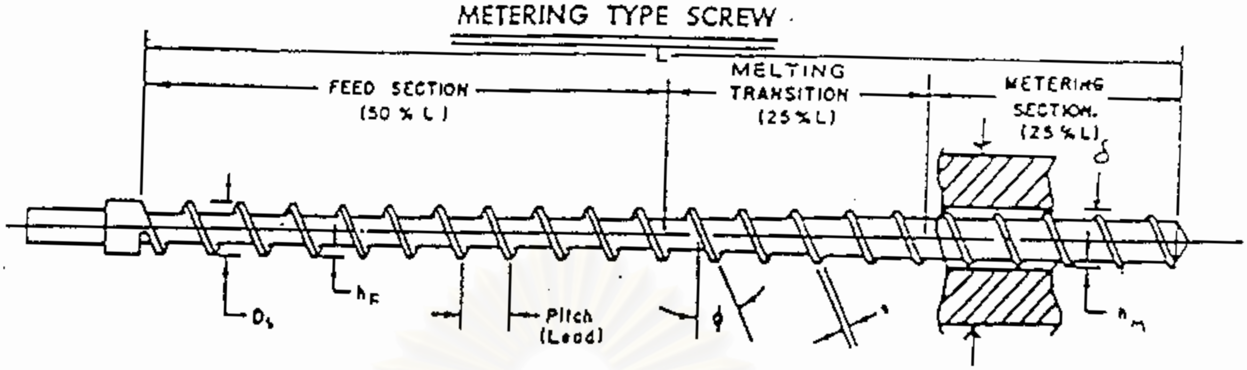


Figure 2.10 Different section of screw

c.) Heater

A heater is supplied for heating around the barrel.

d.) Screw driving motor

It is used for driving the screw back when supplying the material into the barrel.

e.) Hydraulic driving screw and gear

They are used for driving the nozzle to send melted plastic into a mold.

2.7.1.3 Clamping unit

It is used for the opening-closing of the mold. Nowadays, the hydraulic open-close unit was used open-close clamping unit may have one or two step, but the latter is more used since it provide longer life for the mold.

2.7.1.4 Ejection unit

This unit is used for ejecting the product from the mold by using pressure from the hydraulic. There are many types of ejection units in the mold depending on the application such as spur and bush.

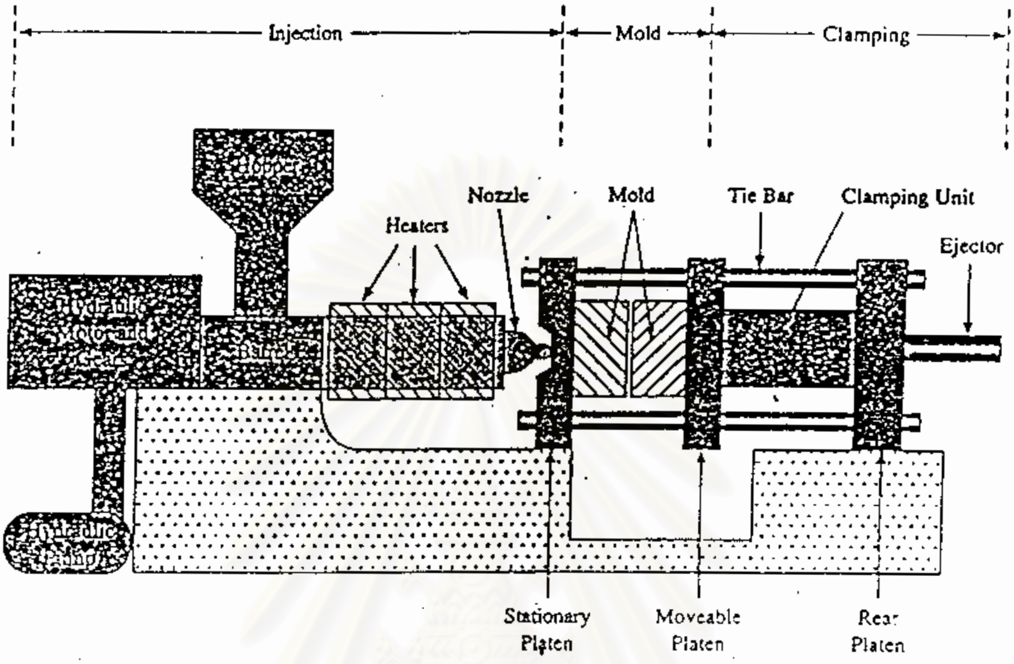


Figure 2.11 Injection mechine units

2.7.2 General injection machine steps

Working of injection machine has 4 steps as follows:

2.7.2.1 Injection step

Melted polymer at adequate volume of barrel for one shot move to above of screw for injection to mold. The screw move to the front push melted polymer to nozzle, sprue, runner, gate and mold, respectively.

2.7.2.2 Holding pressure

When the mold is filled completely of melt polymer, a small amount of melted polymer is pushed into a mold to avoid the shrinkage of polymer. Holding pressure from hydraulic unit pushes melted polymer to protect back flowing of the melted polymer. The pressure is held until the gate is frozen.

2.7.2.3 Cooling and filling

Before the gate is formed, melted polymer in the mold is cooled as the screw is backward for melting the polymer in the barrel for the next shot. When the melted polymer is filled completely, the screw is stopped and ready for the next volume.

2.7.2.4 Ejection unit

When the product in the mold is cooled enough, the mold is opened and the product is ejected by ejector pin. After that, the mold is closed and set ready for the next injection.

2.7.3 Polymer mixing

The polymer can be mixed by using two or more polymers. An additive can be mixed into the mixed polymer. There are 3 processes of mixing polymers as follows:

2.7.3.1 Dry mixer

Dry mixer (Figure 2.12) is generally used to mix the powdered resin by using various components such as plasticizer and additive. It can be applied for the mixing that contains high plasticizer since high speed mixing uses blades with the 1400 revolution per minute (rpm). These cause the resin to shear each other and production of heat because of shear stress.

When the resin and additive were mixed, bulk density is increased. The compound is cooled for the next processing step to form the product.

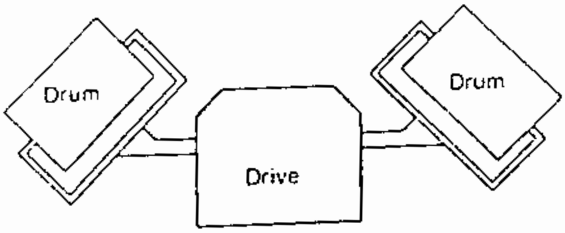


Figure 2.12 Dry mixer with two arms

2.7.3.2 Batch mixer

All components are mixed together and melted by two roll mills or in Banbury mixer as shown in Figure 2.13. The component was weighed and filled in Banbury mixer. After that, it is driven by two blades and mixes the components together for 2-4 minutes. Although the mixing time is long but the melting is complete and the melted polymer is moved to two roll mill. The mixing is continued and processed to sheet or pellet. The properties depend on the processing condition of the batch.

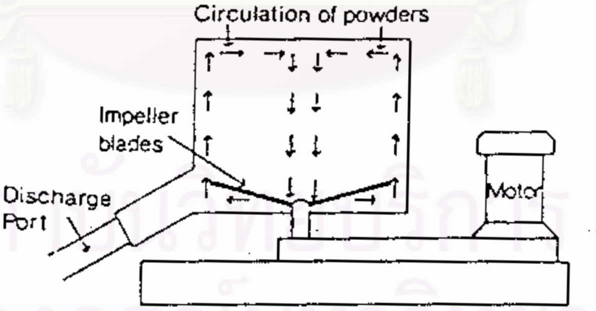


Figure 2.13 Batch mixer

2.7.3.3 Continuous mixer

The beginning process of continuous mixing is dry mixing followed by feeding the mixing composition into the continuous mixer. The mixer is cooled and processed to pellet.

The extruder for continuous mixing may use the single screw extruder, which contains a vent type or twin screw extruder.

The mixing process for feeding the mixing component into the hopper is shown in Figure 2.14. The ingredients are mixed and moved to the dye to process as a granule or strip or strand.

The important point is controlling any overheating and reproducibility, which depends on temperature and the time needed to obtain the high quality of product.

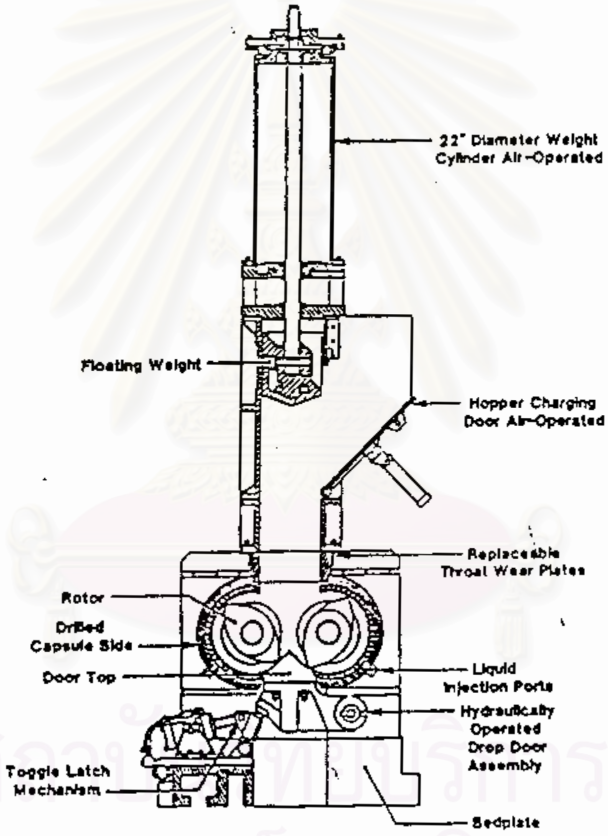


Figure 2.14 Continuous Mixer

2.8 Single screw extruder

Single screw extruder is a low efficiency extruder. Mixing depends on the flow rate of the pellet and melted polymer between the screw and the barrel and movement to the flight. Besides the effect from the heat build up in material which causes from shear stress of each pellet and shear stress between pellet and barrel is affected to control the polymer behavior.

The advantage of a single screw extruder is that it has a low cost. It is applicable and easy to modify or assemble with other devices.

The disadvantage of a single screw extruder is the difficult to control the mixing. It has a low efficiency of mixing and a low shear rate and long time of mixing.

2.9 Twin screw extruder

The twin screw extruder is divided into two types: co-rotating twin screw extruder and counter rotating twin screw extruder.

Mixing of twin screw extruder does not depend on the flow of melted polymer. When melted polymer is pushed forward, the heat from the friction of molecule is very low resulting in a homogeneous mixture.

Co-rotating twin screw extruder is worked by transferring material from flight to flight. The material contacts the barrel and moves back. So that while the material contacts one side of screw, another side also contacts the barrel. Thus the polymer is slowly mixed.

Generally, there are two types of revolutions per minute which are high revolution per minute and low revolution per minute. These are used to mix the polymer and for further processing.

The counter rotating twin screw has narrow space between the screw so that the transferring of material is better than that of the co-rotating twin screw extruder. The revolution per minute used is low to avoid high pressure.

The advantages of twin screw extruder are its high quality of mixing, use of short time, high and steady shear stress and the ability to change the type of polymer.

The disadvantages of twin screw extruder are the high machine cost and high maintenance cost.

2.10 Parameters of injection process

2.10.1 Pressure control

2.10.1.1 First stage injection pressure

This injection state is injected to completely fill the mold and hold it by using pressure to avoid the shrinkage in the mold. If there is no pressure, then will be flushed around the mold.

2.10.1.2 Second stage injection pressure

The pressure is held to push melted plastic into the mold until the gate is formed. The used pressure of this state is equal to the first stage injection pressure, except during the second stage injection pressure in which the pressure is higher than the first stage injection pressure. This is easy for adding melted polymer into the mold. When the small mold is used, the special case may be used; but, for a huge machine, the occurrence of the flash in the mold can be avoided.

2.10.1.3 Back pressure

Back pressure is the pressure in the barrel produced while the screw is driven to melt the polymer for the next injection. The used back pressure at the screw should be in the medium range since the heat that occurs in the melted polymer results from the driving of the screw. If the used back pressure is too much, the temperature of the melted polymer in front of the screw will be higher.

2.10.2 Temperature control

2.10.2.1 Rear zone temperature

This zone has the highest cooling temperature since there is much heat loss at the hopper throat area. The surface area between the barrel and polymer is decreased resulting in low heat transfer.

2.10.2.2 Middle zone temperature

The temperature of this zone is set higher than the temperature of the polymer. The polymer will have a high temperature since there is heat transfer.

2.10.2.3 Front zone temperature

The temperature of the injection machine is not too high or too low. Extruder temperature is higher than the polymer. The temperature should be set higher than the polymer 10 ^{o}C.

2.10.2.4 Nozzle zone temperature

The temperature of the nozzle is set to avoid freezing of the melted polymer.

2.10.2.5 Mold temperature

The temperature of the mold is used to control stress and warp. For the formation of the product, the cooling system of the mold is chilled water. Cooling both cavities should be set at the least difference to avoid the problem of the product.

2.10.3 Time control

2.10.3.1 First state injection time

This is used to control the time for filling the polymer and compressing it into the barrel.

2.10.3.2 Second state injection time

This is used to control the holding pressure until the melted polymer is frozen.

2.11 Effect of injection condition to the orientation of the polymer

When the melted polymer temperature is increased, the viscosity, shear stress and orientation are decreased. The decreased viscosity resulting in an increase of the pressure transfers from the screw to the cavity while the melted polymer flows into the cavity. Shear stress and orientation are also decreased. So the difference results in the change of a melted polymer temperature. The effect is that the orientation is decreased or increased.

However, the relation of the polymer chain results in a decrease of orientation. If the packing time is long, the orientation is increased.

2.12 Effect of orientation to shrinkage

The effect of orientation to shrinkage is the cooling of the melted polymer resulting in the orientation. The shrinkage depends on the orientation. If the mold temperature is high, the orientation is high resulting in high shrinkage. Besides, the shrinkage can occur from relaxation to decrease the strain.

2.13 Testing of blended polymer of UHMWPE and LLDPE

2.13.1 Differential scanning calorimetry (DSC)

DSC is one of the most widely used techniques to measure T_m.[10] This method uses individual heaters to maintain identical temperatures for two small platinum holders. One contains a small (10-30 mg) polymer sample mechanically sealed in a small aluminum pan and the other contains an empty (reference) pan, as shown in Figure 2.15. Temperatures are measured by the use of identical platinum-resistance thermisters. The differential power needed to maintain both the reference and sample pans at equal temperatures during a programmed heating cycle is then recorded as a function of temperature.

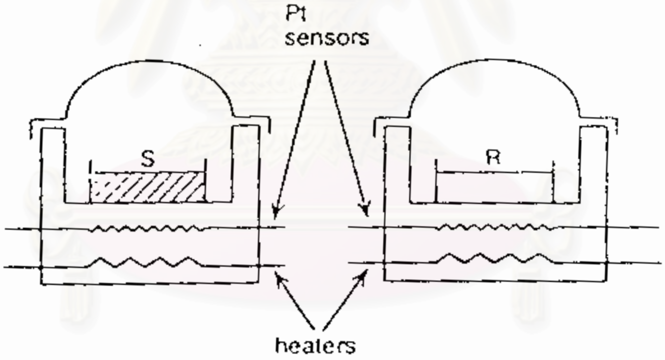


Figure 2.15 Typical DSC cells showing the sample (S) and reference (R)

2.13.2 Shrinkage testing

Shrinkage is inherent in the injection molding process. Shrinkage occurs because the density of the polymer varies from the processing temperature to the ambient temperature. During injection molding, the variation in shrinkage both globally and through the cross section of a part creates internal stresses. The so-called residual stresses induced during molding are high enough to overcome the structural integrity of the part, the part will warp upon ejection from the mold or the part will crack with external service load.

The shrinkage of molded plastic parts can be as much as 20%by volume, when measured at the processing temperature and the ambient temperature. Crystalline and semi-crystalline materials are particularly prone to thermal shrinkage. Amorphous materials tend to shrink less. When crystalline materials are cooled below their transition temperature, the molecules arrange themselves in a more orderly way, forming crystallites. On the other hand, the microstructure of amorphous materials does not change with the phase change. This difference leads to the fact that crystalline and semi-crystalline materials have a greater difference in specific volume between their melt phase and sol(crystalline)phase (Figure 2.16)

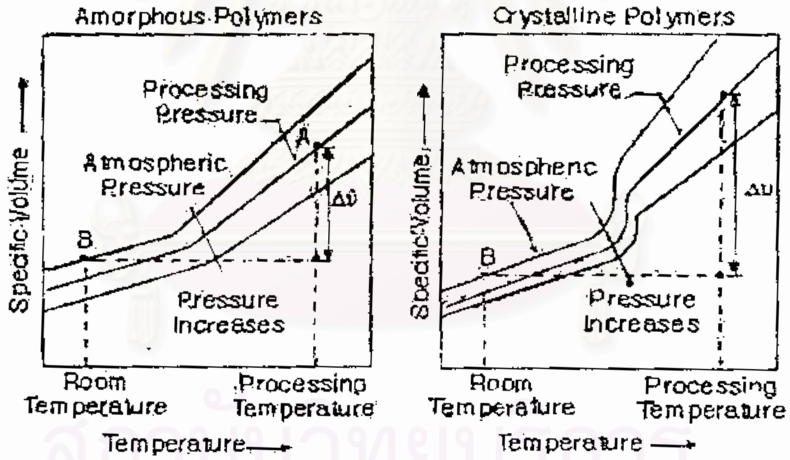


Figure 2.16 Specific volume of amorphous and crystalline polymers

Figure 2.16 shows the pυT curves for amorphous and crystalline polymers and the specific volume variation (Δυ) between the processing state (point A) and the state at room temperature and atmospheric pressure (point B). Note that the specific volume decreases as the pressure increases.

Excessive shrinkage, beyond that inherent in injection molding, can be caused by the following: low injection pressure, short hold time or cooling time, high melt temperature, high mold temperature, or low holding pressure. The relationship of shrinkage to several processing parameters and part thickness is schematically plotted in Figure 2.17.

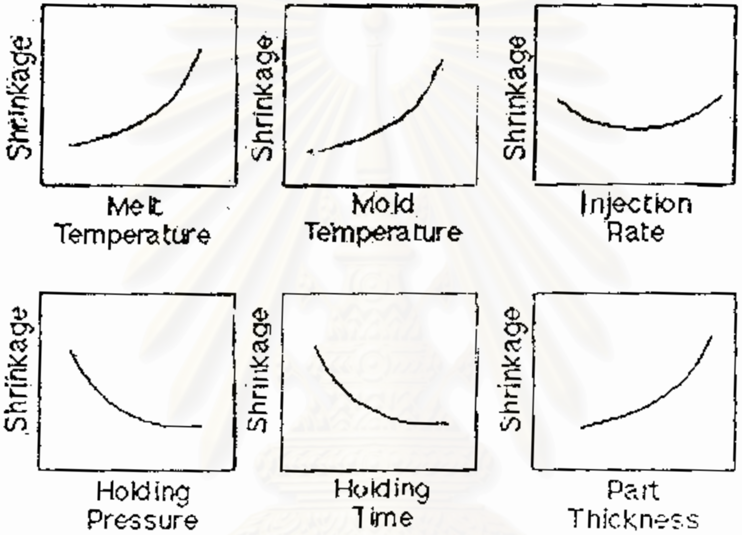


Figure 2.17 Processing and design parameters that affect part shrinkage

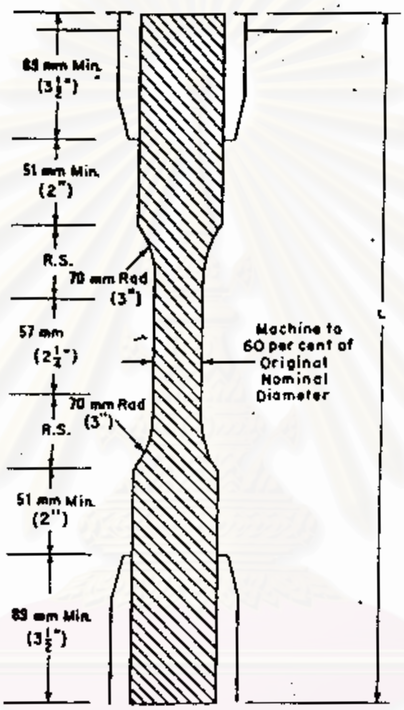
Uncompensated volumetric contraction leads to either sink marks (local surface depressions), or to void in the molding interior. Controlling part shrinkage is important in part, tool and process designs, particularly in applications requiring tight tolerances. Part shrinkage that leads to sink marks or voids can by reduced or eliminated by packing the cavity after filling. In addition, the mold design should shrink into account in order to conform to the part dimension.

2.13.3 Tensile properties testing

Tensile strength is a mechanical property of polymer, which tells of the elastometric of the polymer by testing it under weight. The testing time is short.

The used tensile testing method is ASTM D 638[11] that covers the determination of the tensile properties of plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity and testing machine speed. This method can be used for testing materials of any thickness up to 14 mm. Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

The test specimen shall be as shown in Figure 2.18. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60% of the original nominal diameter. This groove shall consist of a straight section 57.2 mm at each end joining it to the outside diameter. All surfaces of the specimen shall be free of flaws, scratches or imperfections.



DIMENSIONS OF ROD SPECIMENS

Nominal Diameter	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to be Used for 89-mm (3½-in.) Jaws
mm (in.)	mm (in.)	mm (in.)	mm (in.)
3.2 (1/8)	19.6 (0.773)	356 (14.02)	381 (15)
4.7 (3/16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (1/4)	27.7 (1.091)	364 (14.34)	381 (15)
9.5 (3/8)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (1/2)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (5/8)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (3/4)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (7/8)	51.5 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1 1/4)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1 1/2)	66.4 (2.615)	403 (15.87)	419 (16.5)
42.5 (1 3/4)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.993)	412 (16.24)	432 (17)

* For other jaws greater than 89 mm (3½ in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (¼ to ½ in.) in each jaw while maintaining maximum length of jaw grip.

Figure 2.18 The specimen for tensile strength testing

2.13.3.1 Parameter of tensile strength testing

a.) Preparation and size of specimen

The rearrangement of molecules has an effect on the tensile strength. The applied parallel weight results in a higher yield than the applied weight in the same direction of the rearrangement of the molecules.

b.) Rate of straining

If the rate of straining is increased, the tensile strength and elongation will increase too. The effect of rate of straining and modulus is shown in Figure 2.19. When the temperature increases, tensile strength and modulus increase too but elongation is decreased.

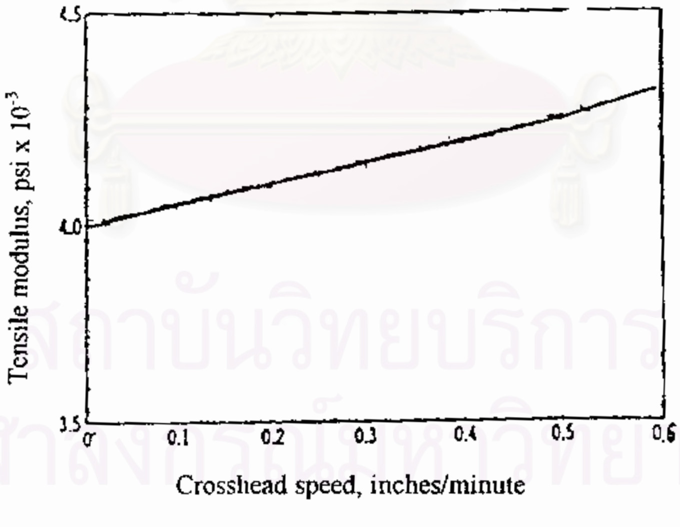
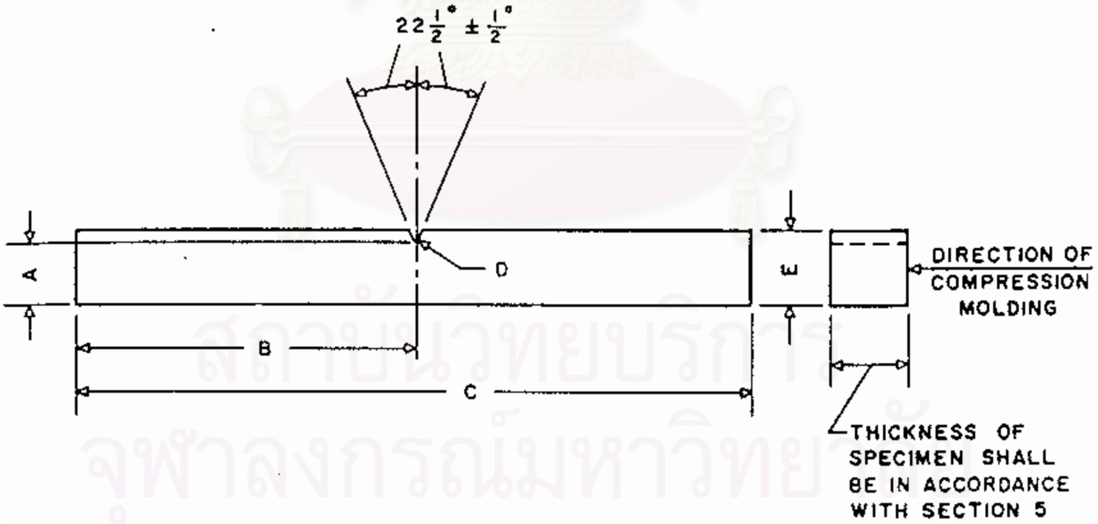


Figure 2.19 Relationship of strain rate and modulus

2.13.4 Impact testing

Impact tests measure the energy expended up to failure under conditions of rapid loading. There are a number of different types of impact tests. These include the widely used Izod and Charpy tests in which a hammerlike weight strikes a specimen and the energy-to-break is determined from the loss in the kinetic energy of the hammer. The impact test specimen of Charpy type is shown in Figure 2.20. Values of impact strength may also be calculated from the area under the stress-strain curve in high-speed tensile tests. Information obtained from impact tests may be used to determine whether a given plastic has sufficient energy-absorbing properties to be useful for a particular application. It is important that the material be tested at temperature and impact conditions close to those of actual use because impact strength will decrease with decreasing temperature and with increasing rate of deformation.



	mm	in.
A	10.16 ± 0.05	0.400 ± 0.002
B	63.50	2.500
	61.00	2.400
C	127.00	5.000
	124.50	4.900
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.15	0.500 ± 0.006

Figure 2.20 Impact test specimen (Charpy type)

2.13.5 Scanning electron microscopy (SEM)

In scanning electron microscopy, a fine beam of electrons is scanned across the surface of an opaque specimen to which a light conducting film has been applied by evaporation.[12] Secondary electrons, backscattered electrons, or (in the electron microprobe) x-ray photons emitted when the beam hits the specimen are collected to provide a signal used to modulate the intensity of the electrons beam in a television tube, scanning in synchronism with the microscope beam. Because the latter maintains its small size over large distances relative to the specimen, the resulting images have great depth of field and a remarkable three-dimension appearance. Resolution is currently limited to the order of 100A^{o}.

2.14 Literature review

Many investigations have been approached to improve the properties of blended polymer between UHMWPE and LLDPE.

Parimal and Thein[13] blended the polymer of UHMWPE and LLDPE. The processing was done by extrusion to study morphology, rheology and mechanical properties. It was found that the morphological properties would depend on mixing techniques. Rheological and mechanical properties would depend on the ratio of blended polymer.

Tincer and Coskun[14] blended UHMWPE and HDPE at various ratio to study the thermal, mechanical and morphological properties. The properties of blended polymer in terms of composition, mixing rate and molecular weight were found.

Hinrichsen et al.[15] reinforced LDPE by UHMWPE. The produced composites exhibited excellent mechanical properties, high tensile strength and low flexibility.

Boscoletto et al.[16] blended HDPE and UHMWPE by extrusion to study rheological properties and impact strength. It was found that UHMWPE is only partially dispersed. Furthermore, impact strength depended on the dispersion of UHMWPE.

Huang et al.[17] studied the impact strength of blended polymer of phenolphthalein poly(ether sulfone) and UHMWPE at different compositions. It was found that use of UHMWPE increased impact strength.

Glass fiber and talcum were introduced to many polymers to improve the properties of the polymers.

Zhang et al.[18] reinforced high density polyethylene (HDPE) by glass fiber. The melt-mixing process was used. It was found that 30% glass fiber content condition, the extended-chain crystals formed along the normal direction of glass fiber surfaces connected with each other, fully filled the matrix and led to a significant increase in the Charpy impact strength of the composite polymer.

Wang and Wu[19] prepared a group of glass fiber reinforced polymer blends by sequential compounding of a poly(butylenes terephthalate/glass fiber (PBT/GF) composite with a reactive elastomer and/or polycarbonate (PC). It was found that the impact strength increased when the PBT/GF, PC and reactive elastomer were compounded together.

Lee and Lee[20] studied the mechanical properties improvement of fiber-reinforced polymer matrix composites. The laminated composites plates were fabricated using different matrix resins and glass fibers. It was found that the maximum flexural properties were observed in the composite prepared from the glass fiber treated with 0.5 wt.% silane coupling agents.

Cho and Paul[21] prepared the glass fiber-reinforced rubber-toughened nylon6 composites. The mechanical properties of the composites toughened with acrylonitrile-butadiene-styrene (ABS) were investigated and compared with composites toughened with epoxy resin-graft-maleic anhydride. A study of the mechanical properties showed that the balance of the impact strength and stiffness for both types of systems could be significantly improved by proper incorporation of glass fibers into toughened nylon6. The differences between these two types of rubber-toughened composites are significant at high rubber content. However, the ductility of both composites toughened with rubber was significant lower than that of blends without glass fiber.

Stricker et al.[22] reinforced syndiotactic polypropene (s-PP) and isotactic polypropene (i-PP) by glass bead and talcum. It was found that composite polymer based on s-PP gave higher notched Izod impact strength than those based on i-PP, accompanied by lower Young’s modulus and yield stress. Investigations of crystallization show the nucleating effect of glass beads and talcum in the case of i-PP as well as s-PP.

Stricker et al.[23] investigated the influence of metallocene-based LLDPE containing 1-butene on the compounding of polypropene (PP) in the presence of polystyrene-block-poly(ethylene-co-1-butene)-block-polystyrene (SEBS) and talcum. It was found that the stiffness of terblends could be enhanced remarkably by addition of talcum, which acts as nucleating agent for the PP crystallization.

CHAPTER III

EXPERIMENTAL

3.1 Materials

LLDPE TPE (2009F) was obtained from Thai Polyethylene Company Limited, Thailand. The density of LLDPE is 0.92 g/cm^3. UHMWPE (L4420) was obtained from Mitsubishi Company Limited, Japan. The density of UHMWPE is 0.94 g/cm^3. Glass fiber and talcum were obtained from Vicger Pigment Company Limited, Thailand. The particle size of glass fiber and talcum is 20 and 15μ respectively. The bulk density of talcum is 2.8 g/cm^3.

3.2 Apparatus and instruments

a.) Injection machine, Battenfeld, 230 tons
b.) Tensile testing machine, Lloyd (LS 500)
d.) Universal pendulum, Ceast (6546/000)
e.) Differential scanning calorimetry, Netzsch (DSC 200)
f.) Scanning electron microscope (SEM), Joel (JSM-5300)

3.3 Processing procedures of blended polymers

3.3.1 Preparation of blended polymers

UHMWPE and LLDPE were mixed by the mixer. The ratios of the materials were varied as shown in Table 3.1.The mixing time was 3 minutes. Then, UHMWPE and LLDPE were heated at 80^{o}C for 3 hours by the hopper drier to remove the moisture.

Table 3.1 The amount of the compositions of blended polymers of UHMWPE and LLDPE

Ratio of UHMWPE : LLDPE	Amount of the compositions (g)	
	UHMWPE	LLDPE
100 : 0	3000	0
95 : 5	2850	150
90 :10	2700	300
70 : 30	2100	900
50: 50	1500	1500
30 : 70	400	2100
10 : 90	300	2700
5 : 95	150	2850
0 : 100	0	3000

3.3.2 Processing of blended polymer of UHMWPE and LLDPE

The machine condition used to process the blended polymer is shown in Table 3.2.

Table 3.2 Injection pressure, speed and time

Position of the injection machine	Pressure (P) (%)	Speed (V) (s)	Time (T) (s)
1	16	9	-
2	95	3	56
3	90	5	0.4
4	65	2	24
5	58	5	2.5
6	35	11	1.9
7	25	6	-
8	70	3	6
9	-	10	0.1
10	-	4	-
11	-	-	-
12	-	-	7

The used stroke was 5.5 centimeters.The obtained specimens were processed as a dumbbell-shape as shown in Figure 2.17. The mold temperature was 50°C.

The injection temperature at the nozzle, zone1, zone2 and zone3 of the barrel were 175, 170, 170 and 170°C, respectively.

3.4 Processing procedures of composite polymers using glass fiber as filler

3.4.1 Preparation of composite polymers using glass fiber as filler

UHMWPE, LLDPE and glass fiber were mixed by the mixer. The amount of glass fiber is 30% of the total amount. The mixing procedure is the same as that of the blended polymers as described in 3.3.1. The ratios of the materials were varied as shown in Table 3.3.

Table 3.3 The amount of the compositions of composite polymers of UHMWPE and LLDPE using glass fiber as filler

Ratio of UHMWPE : LLDPE : glass fiber	Amount of the compositions (g)		
	UHMWPE	LLDPE	Glass fiber
100 : 0 : 30	2100	-	900
90 : 10 : 30	1890	210	900
70 : 30 : 30	1470	630	900
50 : 50 : 30	1050	1050	900

3.4.2 Processing of composite polymers using glass fiber as filler

Composite polymer of UHMWPE, LLDPE and glass fiber can be obtained by processing UHMWPE, LLDPE and glass fiber by an injection process. The condition of processing is the same as that of the blended polymers as described in Table 3.2.

3.5 Processing procedures of composite polymers using talcum as filler

The composite polymers of UHMWPE and LLDPE using talcum as filler could be obtained by using the same method as the glass fiber as described in 3.4.

3.6 Testing of blended polymers of UHMWPE and LLDPE and composite polymers

Mechanical and physical properties of obtained polymers were tested by different methods as follows:

3.6.1 Differential scanning calorimetry (DSC)

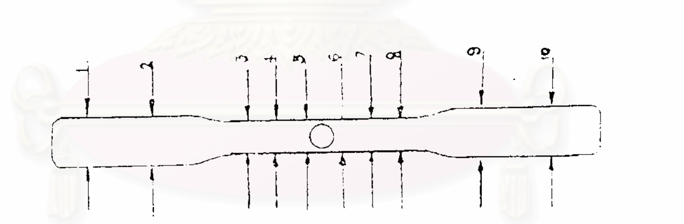
To study the compatibility of obtained polymers, DSC was used to determine the melting temperature (T_m).

3.6.2 Shrinkage testing

Shrinkages of the obtained polymers of UHMWPE and LLDPE were determined by measuring of the size of the obtained polymer to study the properties improvement of the obtained polymers. The comparison of the shrinkage of the composition was determined with each composition. The measurement is shown as follows:[11]

3.6.2.1 Thickness shrinkage measurement of the obtained polymers

Thickness of 10 positions of the obtained polymer was measured as follows:

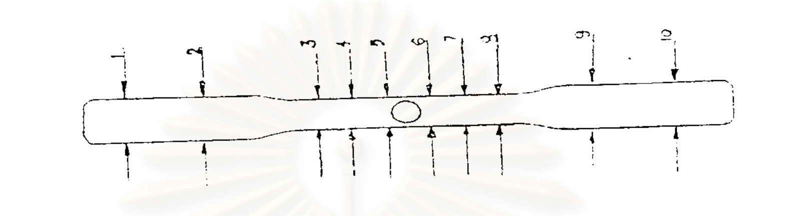


% thickness shrinkage can be obtained from the following equation.

$$\%\text{Shrinkage (Thickness)} = \frac{\text{Thickness}_{\text{mold}} - \text{Thickness}_{\text{sample}}}{\text{Thickness}_{\text{mold}}} \times 100$$

3.6.2.2 Width shrinkage measurement of the blended polymers

The width of 10 positions of the obtained polymer was measured as follows:



% width shrinkage can be obtained from the following equation.

$$\%\text{Shrinkage (Width)} = \frac{\text{Width}_{\text{mold}} - \text{Width}_{\text{sample}}}{\text{Width}_{\text{mold}}} \times 100$$

3.6.3 Tensile properties testing

Tensile properties of the obtained polymer of UHMWPE and LLDPE were determined for the study of their application by using the method as described in ASTM D638.[11] The following properties were then obtained.

a.) Tensile strength at yield

b.) Elongation at yield

c.) Elongation at break

3.6.4 Impact testing

Impact strength of the obtained polymer of UHMWPE and LLDPE was determined by impact testing method as described in ASTM D256.[11]

3.6.5 Scanning electron microscopy (SEM)

SEM was used to observe the morphology photograph for determining the dispersion of blending UHMWPE and LLDPE.

CHAPTER IV

RESULTS AND DISCUSSION

UHMWPE and LLDPE were mixed at different compositions and processed to give a blended polymer. The obtained blended polymers were tested with different methods for studying compatibility by using DSC and SEM. Improvement of the polymer was studied by determining the shrinkage and cost. Mechanical properties, including, tensile strength properties, was studied to determine for the applications.

4.1 Compatibility of blended polymer of UHMWPE and LLDPE

4.1.1 Differential scanning calorimetry (DSC)

The blended polymer samples of UHMWPE and LLDPE were tested to determine the compatibility of each composition using DSC. DSC thermograms of various ratios of UHMWPE and LLDPE (Figures 4.1-4.9) showed the endothermic energy and T_m of blended polymer. Each thermogram exhibited only one endothermic peak since the system of blended polymer absorbed energy when they were melted. These indicated that the blending of every composition of UHMWPE and LLDPE were good of compatibility.

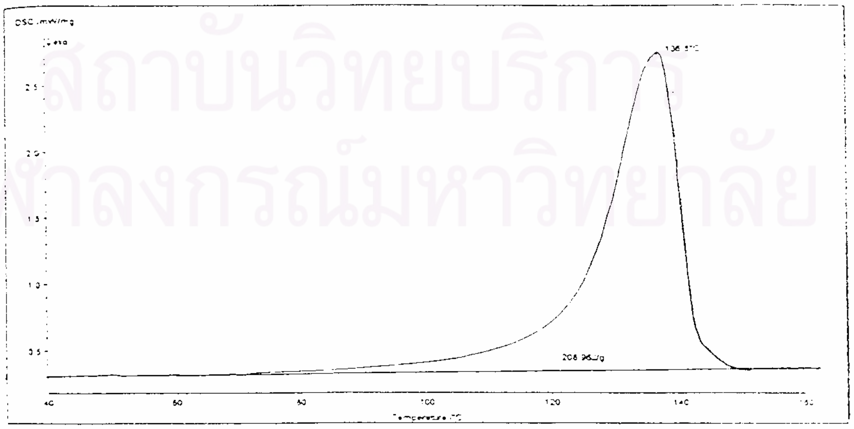


Figure 4.1 DSC thermogram of 100%UHMWPE

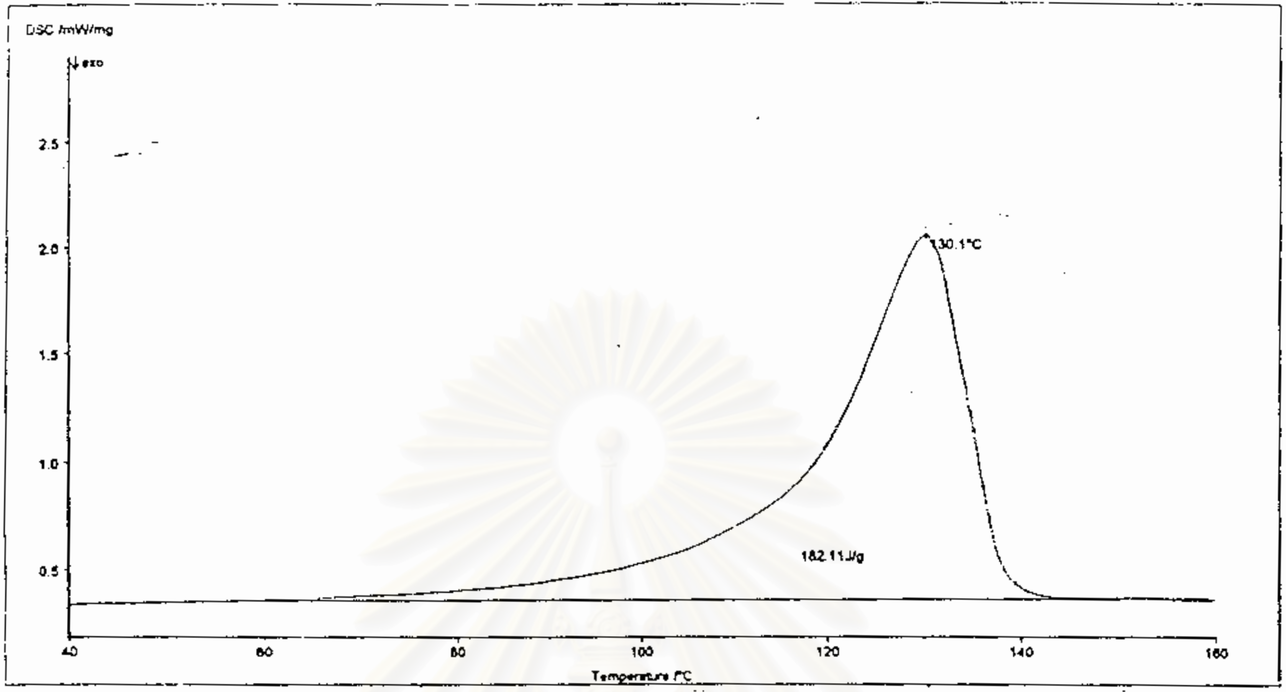


Figure 4.2 DSC thermogram of blended polymer of 95% UHMWPE and 5% LLDPE

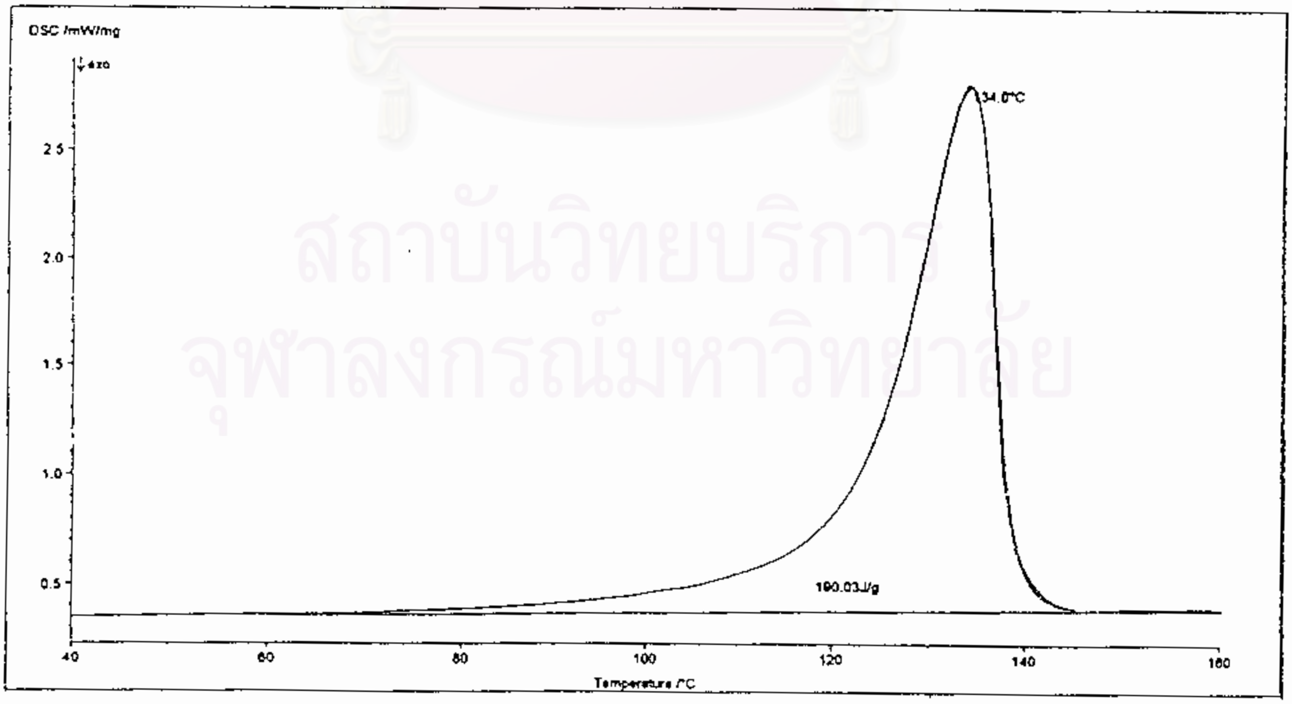


Figure 4.3 DSC thermogram of blended polymer of 90%UHMWPE and 10% LLDPE

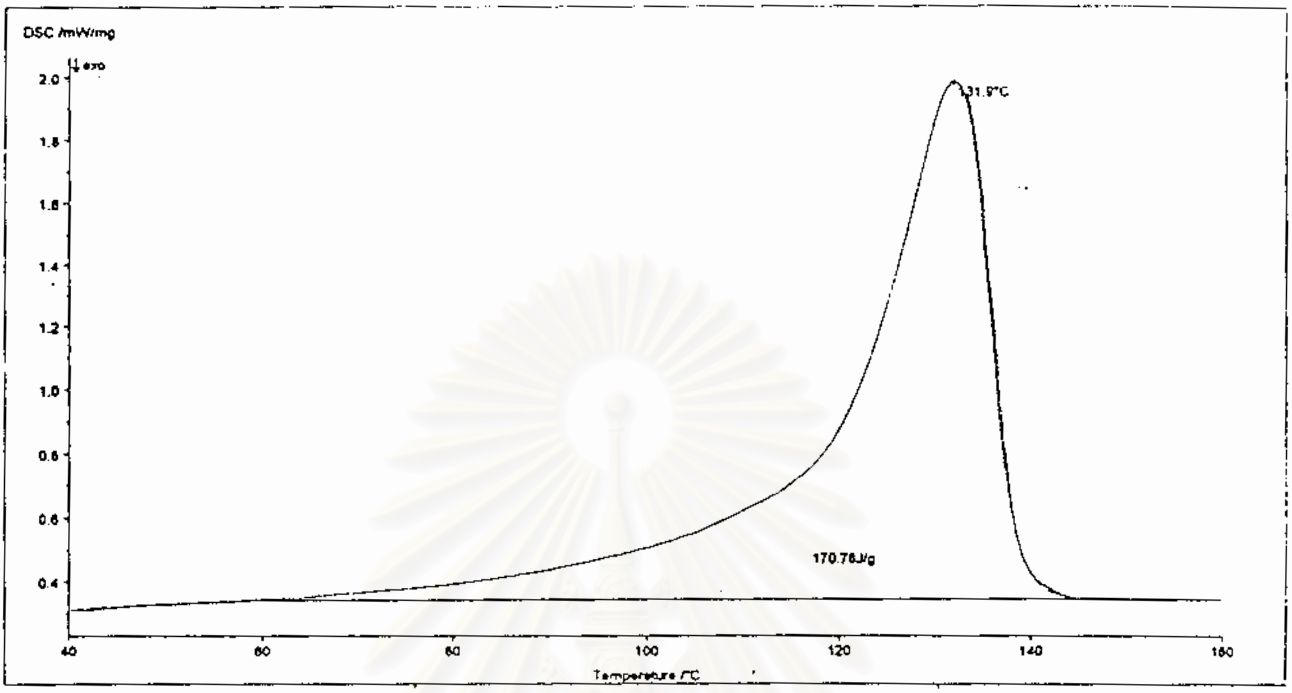


Figure 4.4 DSC thermogram of blended polymer of 70%UHMWPE and 30% LLDPE

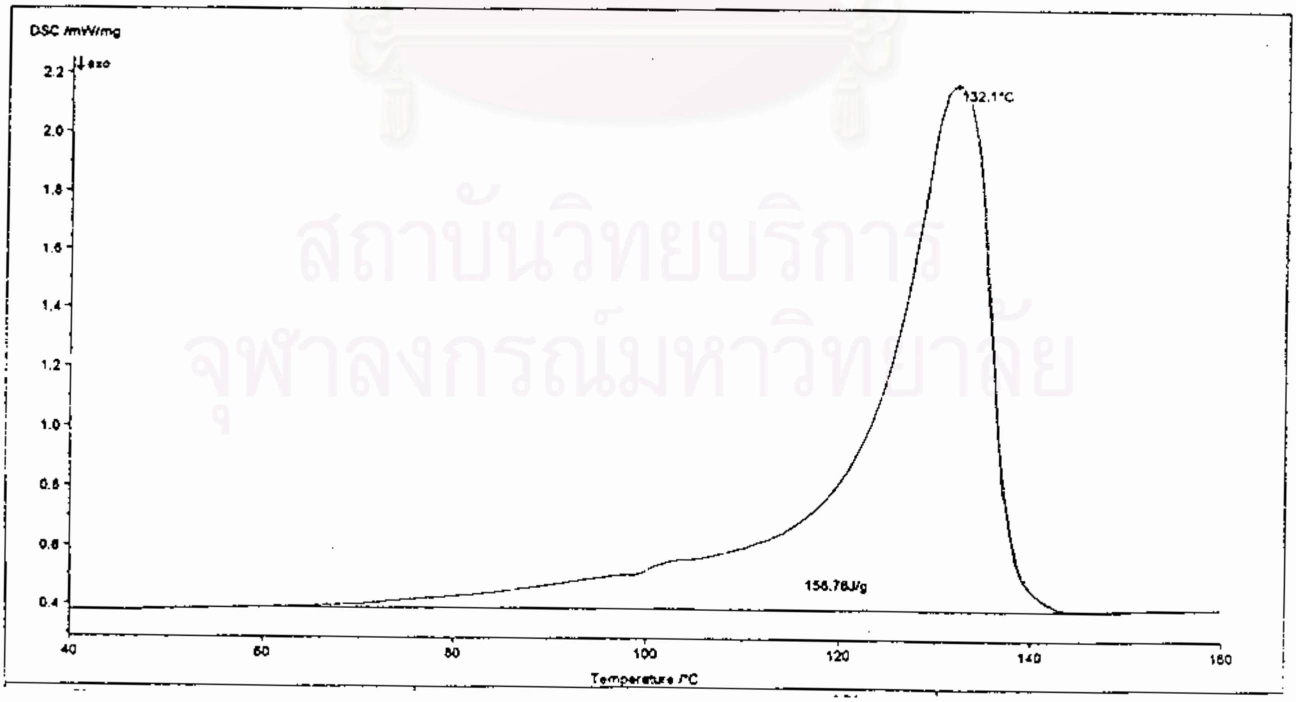


Figure 4.5 DSC thermogram of blended polymer of 50%UHMWPE and 50% LLDPE

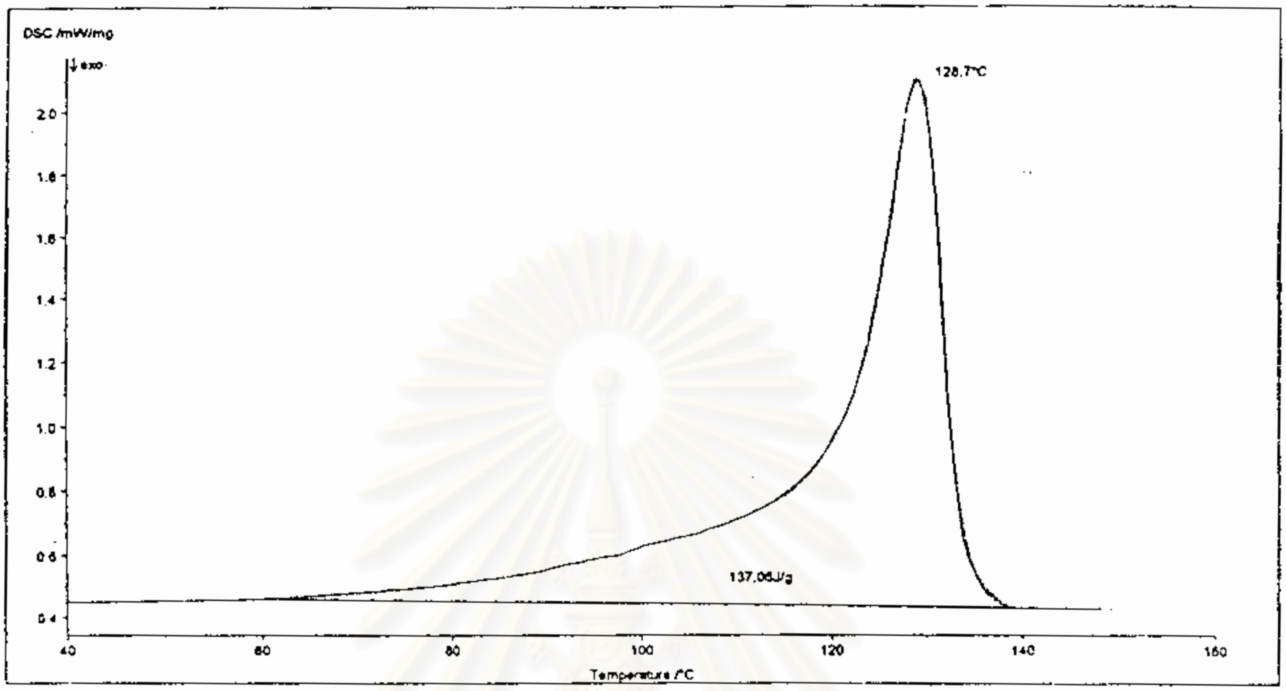


Figure 4.6 DSC thermogram of blended polymer of 30%UHMWPE and 70% LLDPE

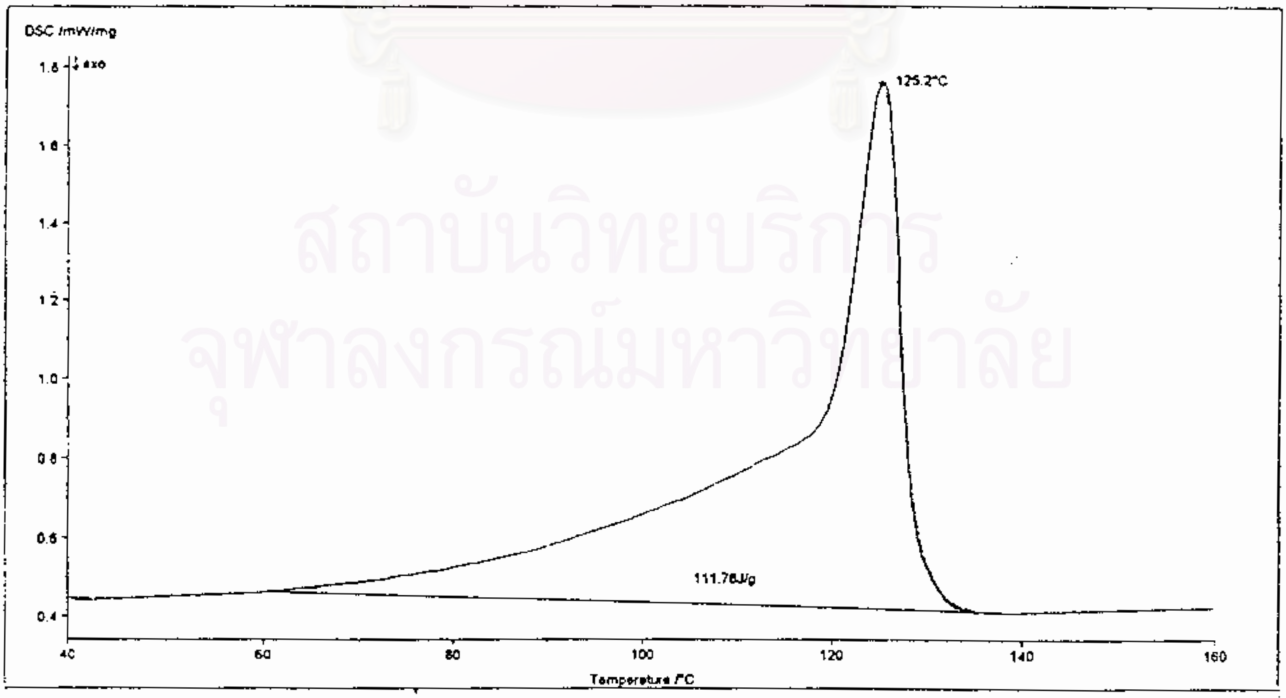


Figure 4.7 DSC thermogram of blended polymer of 10%UHMWPE and 90% LLDPE

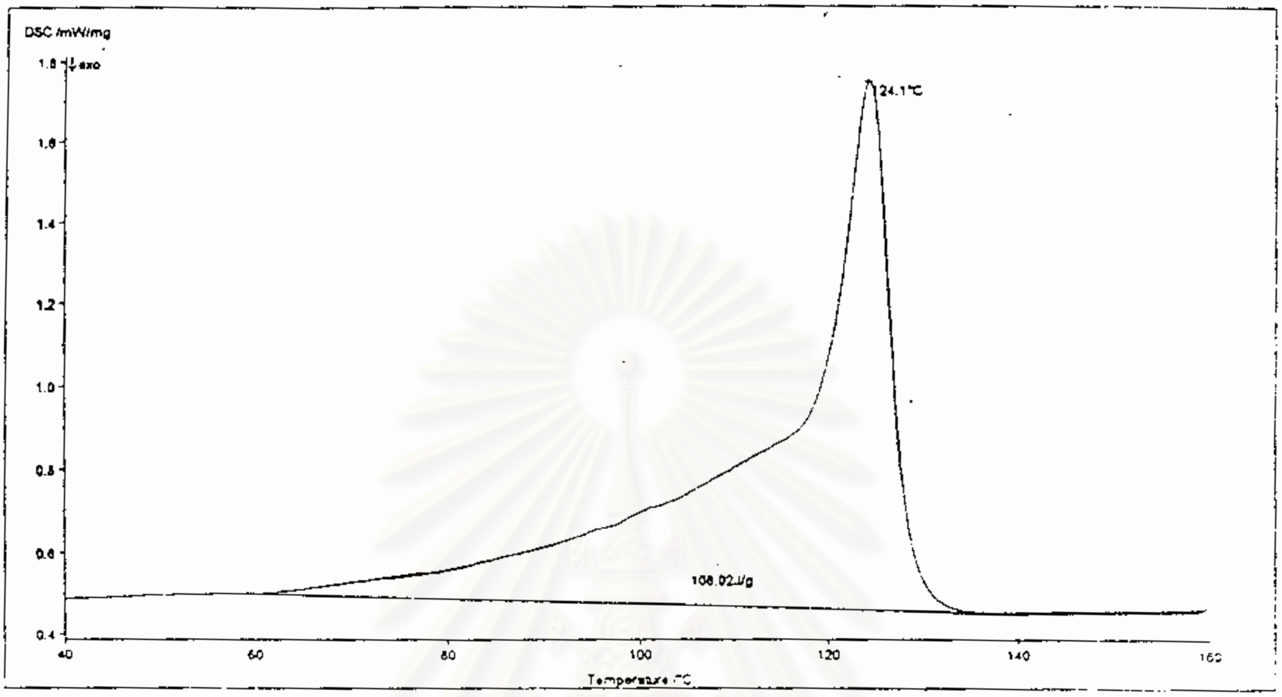


Figure 4.8 DSC thermogram of blended polymer of 5% UHMWPE and 95% LLDPE

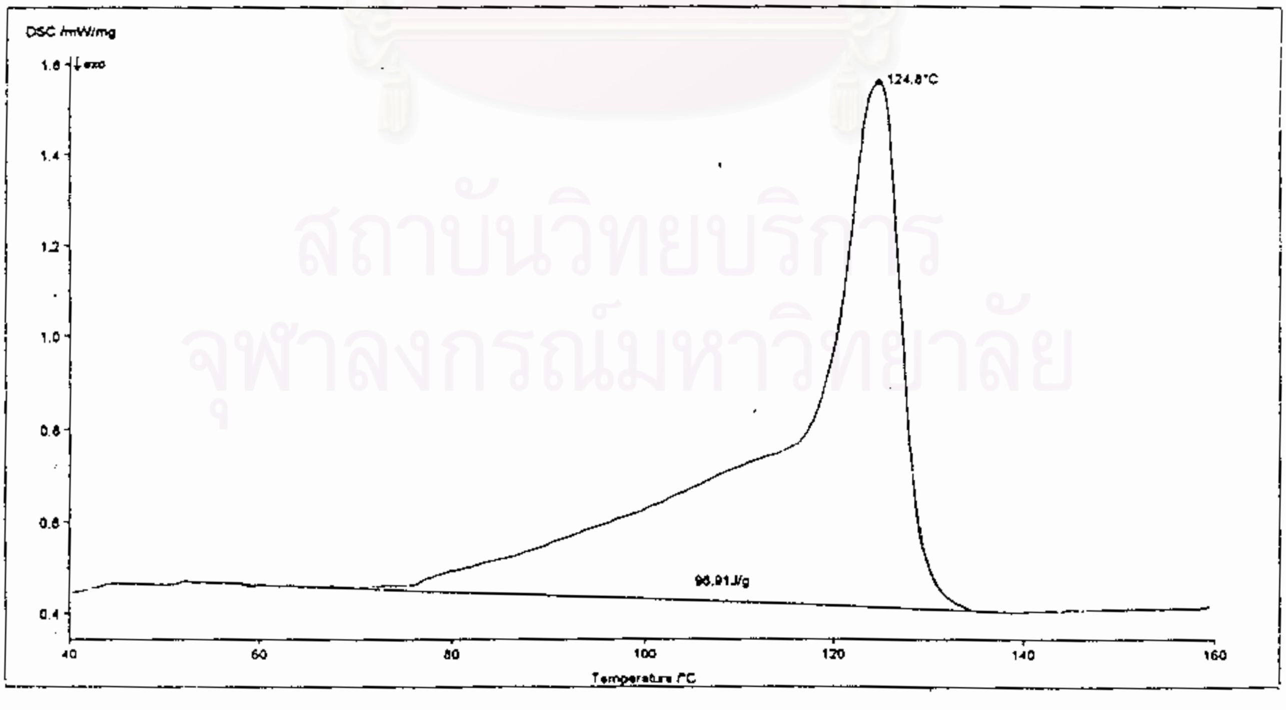


Figure 4.9 DSC thermogram of 100% LLDPE

Furthermore, if the amount of UHMWPE increased, T_m and endothermic energy would be increased (Table 4.1) since the molecular structure of UHMWPE was stronger than that of LLDPE.

Table 4.1 Composition, T_m and endothermic energy of blended polymers

% UHMWPE	% LLDPE	T_m (^oC)	Endothermic energy (J/g)
0	100	124.8	96.9
5	95	124.1	108.02
10	90	125.2	111.76
30	70	128.7	137.06
50	50	132.1	158.76
70	30	131.9	170.78
90	10	134.0	190.03
95	5	130.1	182.11
100	0	136.8	208.90

4.1.2 Scanning electron microscopy (SEM)

4.1.2.1 Dispersion of blended polymer of UHMWPE and LLDPE

Morphological properties of blended polymer of UHMWPE and LLDPE were studied by using SEM. Blending of UHMWPE and LLDPE was composed of two phased dispersions,including the matrix phase and dispersed phase. They were absolutely dispersed as shown in Figures 4.10-4.19.

SEM photograph of blended polymer of 0%UHMWPE and 10%UHMWPE (Figure 4.10) showed that the UHMWPE dispersed phase was absolutely dispersed in LLDPE, which was a matrix phase. When the amount of UHMWPE increased, LLDPE would be dispersed in UHMWPE matrix phase.Furthermore,the dispersion increased when the amount of UHMWPE increased.

Every composition showed good compatibility. Mechanical properties of the blended polymer depended on each composition. Mechanical properties of LLDPE dispersed phase in UHMWPE matrix phase would be better than UHMWPE dispersed phase in LLDPE matrix phase.

4.1.2.2 Comparison of dispersion of each %composition of blended polymers of UHMWPE and LLDPE

For SEM photographs of low %UHMWPE, the density of dispersion was low. UHMWPE was a dispersed phase, which dispersed in LLDPE, which was a matrix phase. For the blended polymers of %UHMWPE lower than 50%, density dispersion increased when the amount of UHMWPE increased. For the blended polymers of %UHMWPE more than 50%, LLDPE was a dispersed phase in UHMWPE matrix phase. When %UHMWPE increased to 70, 90 and 95%, the LLDPE dispersed phase would disperse at a higher dispersion density in UHMWPE matrix phase absolutely.

When %UHMWPE increased, the dispersion density of the dispersed phase (UHMWPE) increased (Figure 4.10). From Figures 4.11 and 4.12, they were shown that the dispersion of 100% LLDPE was similar to that of 95% LLDPE. When %UHMWPE increased (Figures 4.13 and 4.14), the dispersion density of UHMWPE dispersed phase in LLDPE matrix phase increased. For the blended polymer of 50%UHMWPE and 50% LLDPE (Figure 4.15), the dispersed phase and the matrix phase could not be distinguished. When %UHMWPE was more than 50%, UHMWPE was a matrix phase instead of LLDPE. Thus LLDPE was a dispersed phase in UHMWPE matrix phase.

From SEM photographs, they were shown that each composition had good compatibility. These results agreed wtih those obtained from the endothermic peak of the DSC experiments.

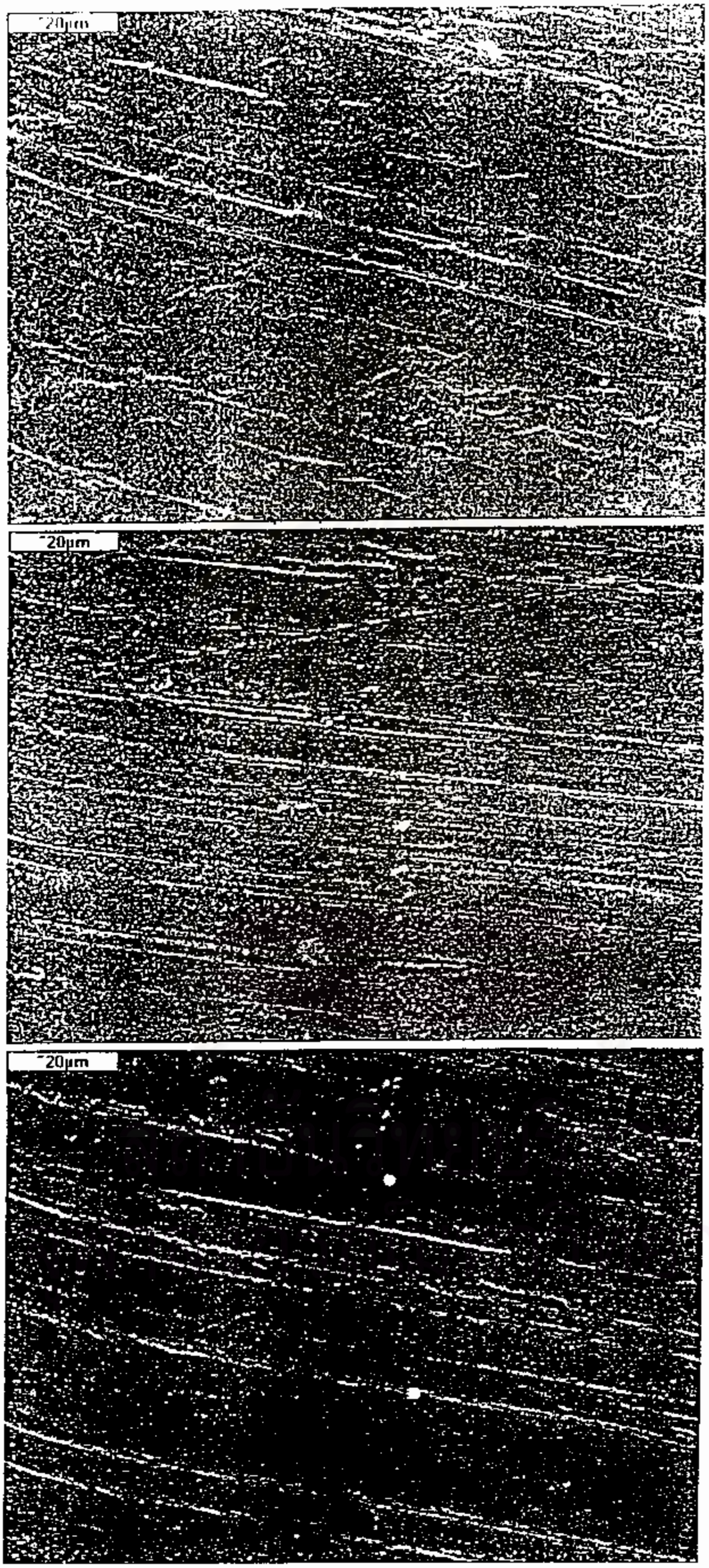


Figure 4.10 Comparison of SEM photographs of blended polymer of (a) 0%UHMWPE (b) 10%UHMWPE (c) 30% UHMWPE

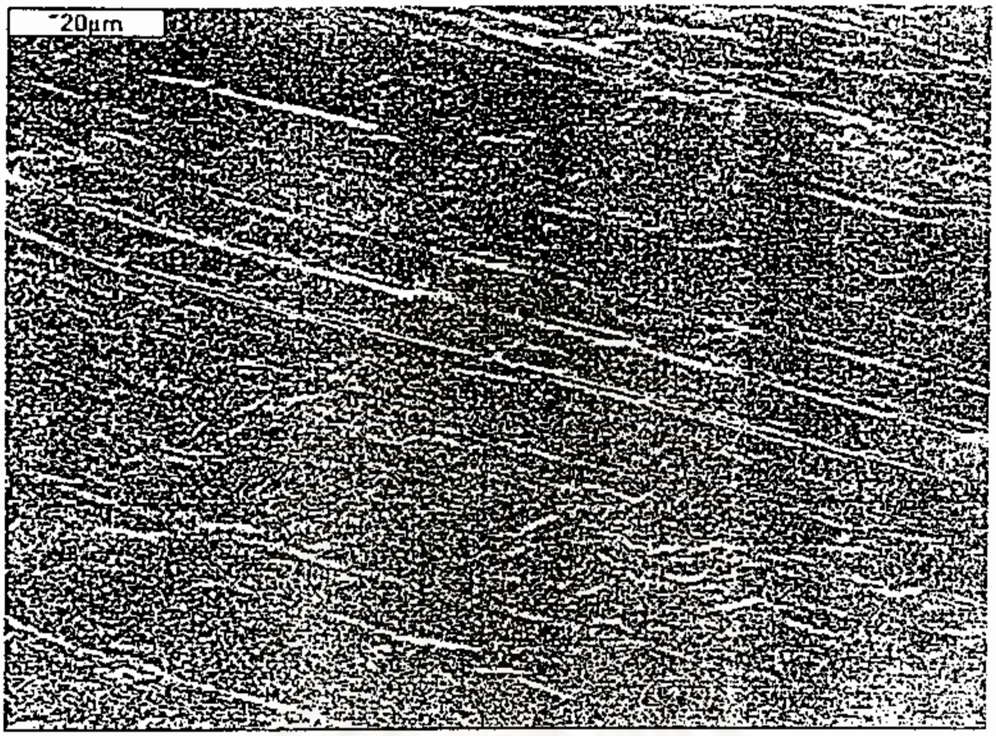


Figure 4.11 SEM photograph of 100%LLDPE

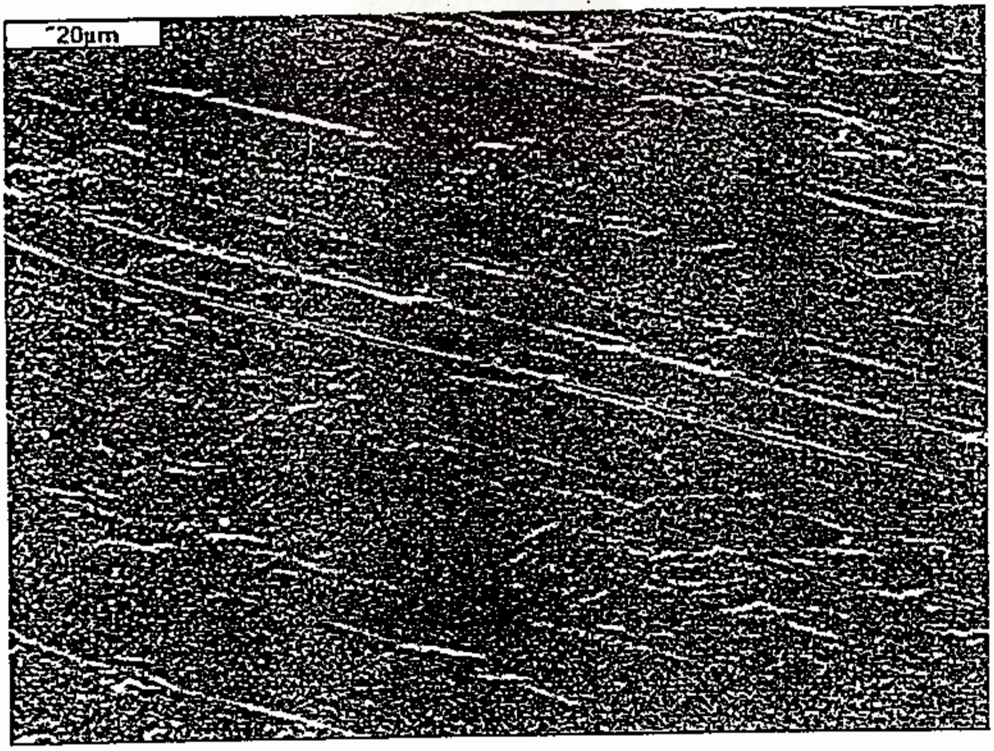


Figure 4.12 SEM photograph of blended polymer of 5%UHMWPE and 95%LLDPE

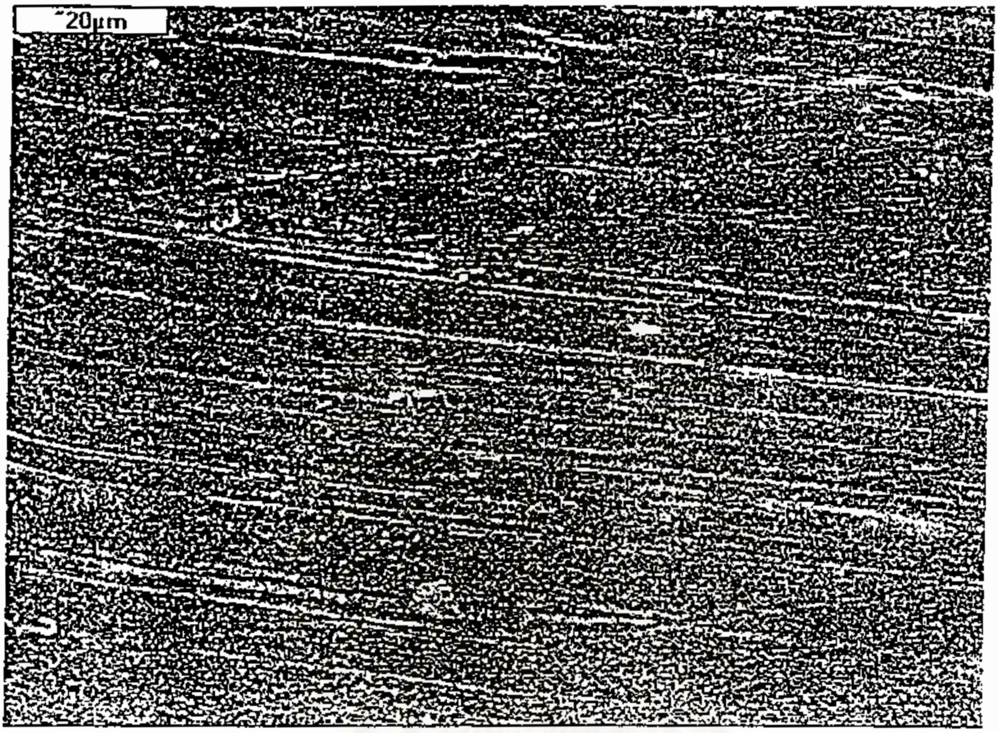


Figure 4.13 SEM photograph of blended polymer of 10%UHMWPE and 90%LLDPE

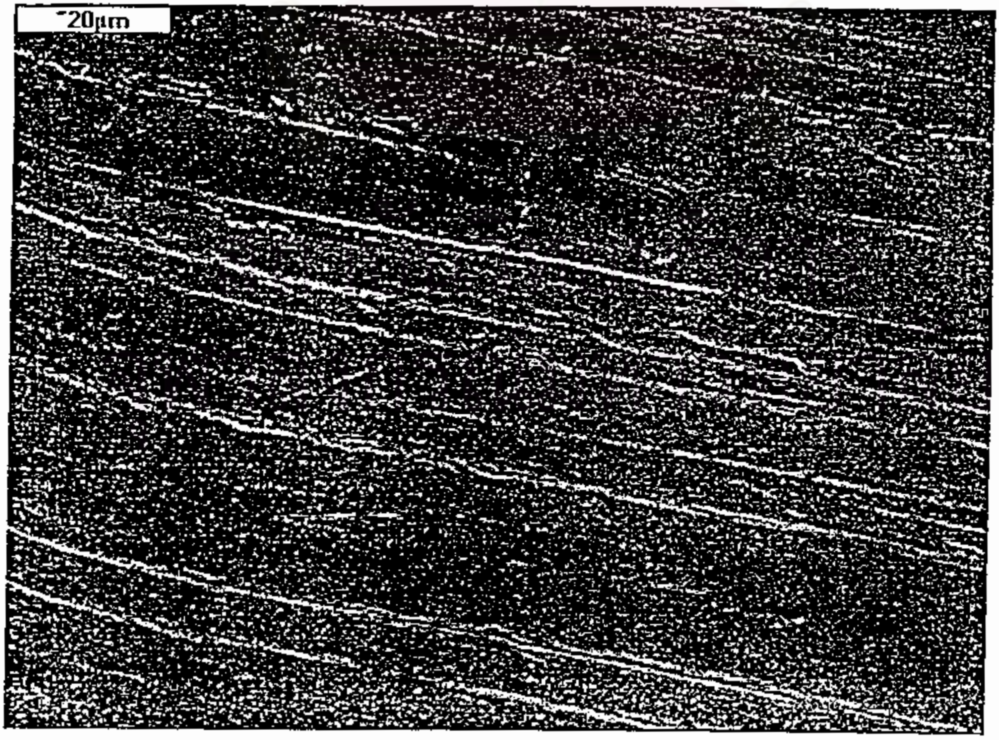


Figure 4.14 SEM photograph of blended polymer of 30%UHMWPE and 70%LLDPE

Figure 4.15 SEM photograph of blended polymer of 50%UHMWPE and 50%LLDPE

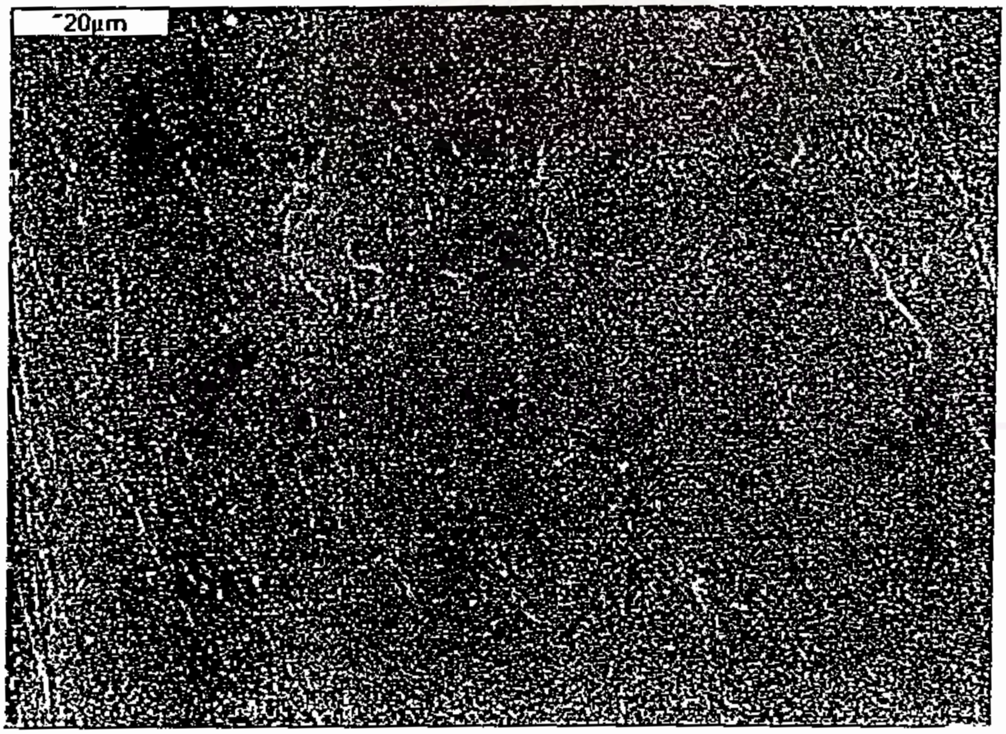


Figure 4.16 SEM photograph of blended polymer of 70%UHMWPE and 30%LLDPE

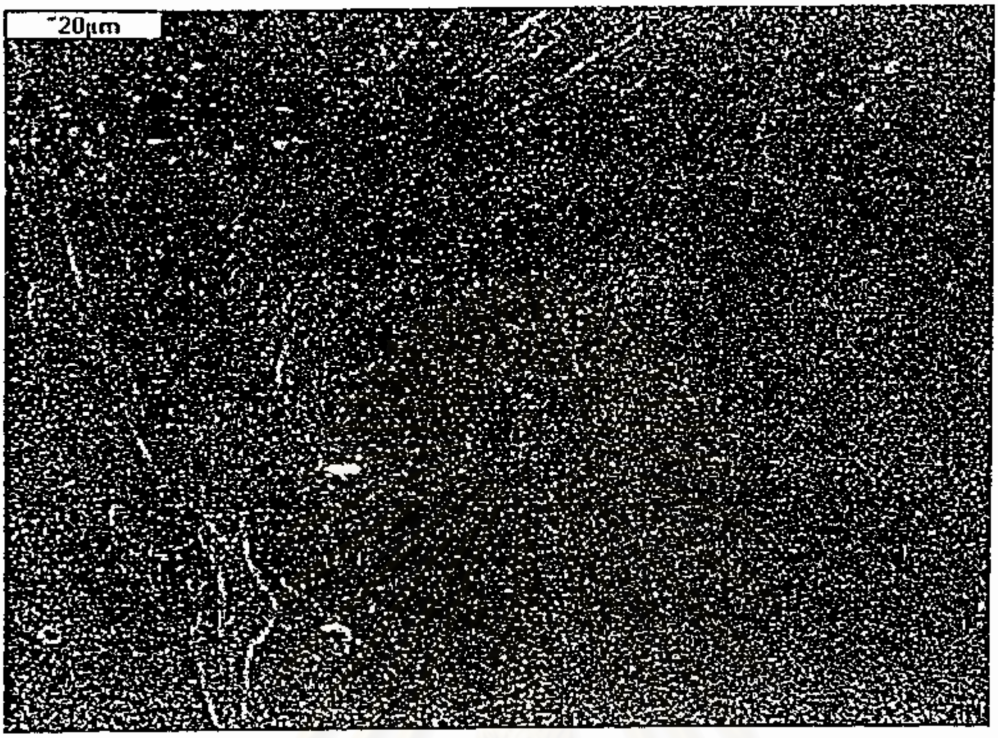


Figure 4.17 SEM photograph of blended polymer of 90%UHMWPE and 10%LLDPE

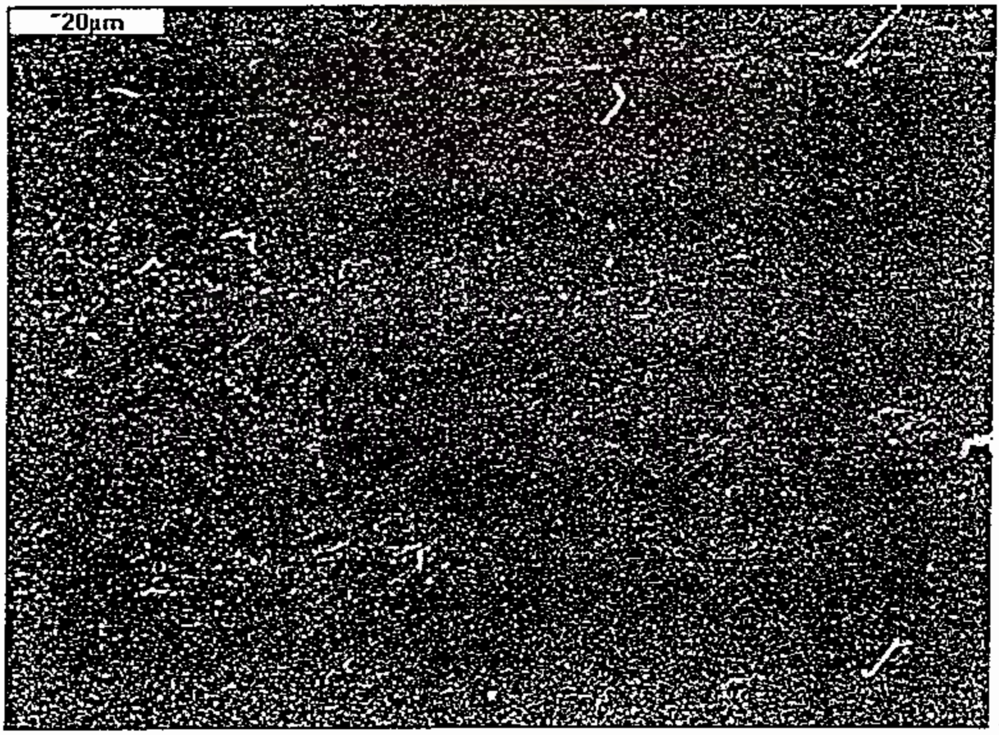


Figure 4.18 SEM photograph of blended polymer of 95% UHMWPE and 5%LLDPE

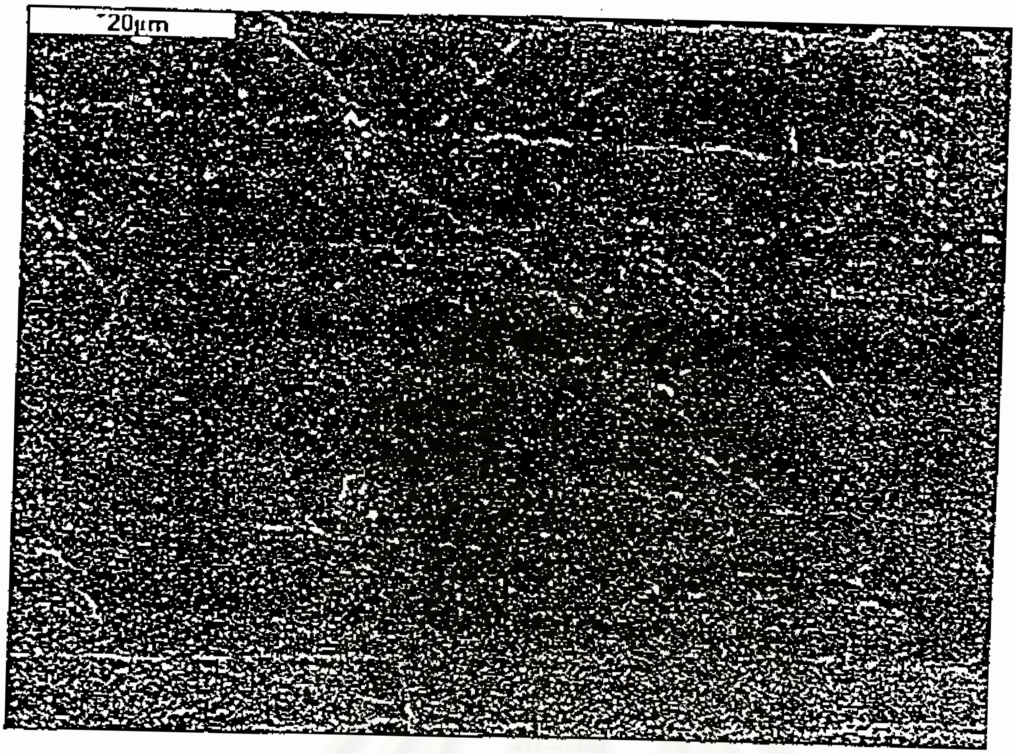


Figure 4.19 SEM photograph of 100%UHMWPE

4.2 Study of tensile properties

Tensile properties were studied for being used in industrial. The commercial engineering type polymer should have good mechanical properties. Thus tensile properties were determined since polymer should have high strength for safety applications.

Table 4.2 showed that %UHMWPE of blended polymer had an effect on the tensile properties. The higher %UHMWPE, the higher the tensile strength. Tensile strength of 100%UHMWPE was less than that of 90%UHMWPE since LLDPE had an effect on the structure of blended polymer. LLDPE in blended polymer absorbed the stress so that the tensile strength was higher than that of 100%UHMWPE polymer. Thus the composition of blended polymers should be considered for the application.

Table 4.2 Tensile properties of blended polymer of UHMWPE and LLDPE

%UHMWPE	Maximum stress (MPa)	%Elongation at yield	%Elongation at break
100	64.41	8.51	9.12
95	69.32	9.58	12.26
90	65.00	9.89	11.52
70	60.43	9.38	9.82
50	42.77	9.93	9.93
30	26.80	11.28	12.04
10	13.57	77.04	172.90
5	14.91	243.10	247.50
0	14.78	256.40	282.00

Comparison of tensile properties of UHMWPE and LLDPE blended polymers and the other engineering type polymers (Table 4.3) showed that the tensile strength of 90% UHMWPE was closed to that of polycarbonate, which had a very high tensile strength. For 70% UHMWPE, the tensile strength was closed to that of polyamide (PA6) and polyacetal (POM) which were widely used as engineering type polymers. Tensile strength of 50% UHMWPE was closed to that of acrylonitrile-butadiene-styrene copolymer (ABS). Thus the ratio of the composition of UHMWPE and LLDPE blended polymer could be chosen for the proper application and could be properly used instead of the other polymers.

For the %UHMWPE below 30%, %Elongation was very high. Thus the stiffness would be very low. The engineering type polymer does not require high elongation since the stiffness will be low when using.

Table 4.3 Comparison of tensile strength at yield of blended polymers of UHMWPE and LLDPE and other engineering type polymers

%UHMWPE of blended polymer	Tensile strength at yield (MPa)
50	43
70	60
90	65
Polyacetal (POM)	60
ABS	35-43
Polyamide (PA6)	50
Polycarbonate	66

4.3 Properties improvement of blended polymer of UHMWPE and LLDPE

4.3.1 Shrinkage testing

The blended polymers of UHMWPE and LLDPE were measured for their width and thickness according to 3.4.2. The width and thickness averages were determined to study the effect of the rario of UHMWPE and LLDPE on the shrinkage.

4.3.1.1 Thickness shrinkage

From Table 4.4, it was shown that UHMWPE had high thickness shrinkage. If the thickness shrinkage was more than 3%, it would be difficult to control the size of the polymers. Also the surface of blended polymer was not smooth. When LLDPE was mixed with UHMWPE and processed under the same condition, the thickness averages were measured at different ratios of UHMWPE and LLDPE. The shrinkage of UHMWPE decreased when LLDPE was blended with UHMWPE. The result indicated that %thickness shrinkage of blended polymers were lower than that of 100%UHMWPE polymer.

From Table 4.4, %UHMWPE had an effect on %thickness shrinkage. If the amount of UHMWPE increased, %thickness shrinkage would increase because of high crystallinity of UHMWPE.

Table 4.4 Average thickness shrinkage of blended polymers of UHMWPE and LLDPE at different compositions of %UHMWPE

The positions of measuring[a]	Thickness (mm)								
	%UHMWPE								
	100	95	90	70	50	30	10	5	0
1	2.89	2.89	3.12	3.12	3.07	3.17	3.19	3.18	3.18
2	3.07	2.94	3.13	3.13	3.09	3.17	3.18	3.17	3.17
3	2.94	3.03	3.03	3.02	3.14	3.17	3.19	3.18	3.17
4	3.08	3.09	3.04	3.08	3.22	3.16	3.18	3.18	3.19
5	3.09	3.09	3.05	3.10	3.21	3.16	3.19	3.18	3.20
6	3.07	3.09	3.04	3.09	3.19	3.17	3.18	3.18	3.18
7	3.15	3.17	3.03	3.05	3.17	3.18	3.18	3.18	3.16
8	3.16	3.16	3.15	3.11	3.08	3.15	3.19	3.18	3.18
9	3.18	3.16	3.14	3.17	3.03	3.15	3.18	3.18	3.18
10	3.17	3.14	3.17	3.15	2.99	3.17	3.19	3.18	3.18
Average thickness (mm)	3.08	3.08	3.09	3.10	3.12	3.17	3.18	3.18	3.18
%Shrinkage	3.77	3.89	3.42	3.12	2.55	1.08	0.48	0.66	0.68

[a] The positions were according to 3.6.2.1.

For an injection process, %shrinkage should be less than 3%. Otherwise the shape and the size of the product could not be controlled because of the shrinkage. Shrink mask and wrap page could then be occurred. Therefore, %UHMWPE should be less than 50% for a good injection process.

4.3.1.2 Width shrinkage

%Width shrinkage of blended polymers was tested. The result was shown in Table 4.5. It was indicated that UHMWPE had lower width shrinkage than thickness shrinkage. So the width shrinkage had a little effect on the shrinkage of blended polymers. This might be due to higher freezing of thickness resulting in the rearrangement of molecules of different thickness, which had higher shrinkage than the width shrinkage. When LLDPE was mixed with UHMWPE and processed at the same condition, LLDPE would decrease %shrinkage of blended polymer. The higher amount of LLDPE, the lower %shrinkage. Since the molecular structure of LLDPE was difficult for the rearrangement. Thus %shrinkage of blended polymer decreased.

Table 4.5 Average width shrinkage of blended polymers of UHMWPE and LLDPE at different compositions of %UHMWPE

%UHMWPE	100%	95%	90%	70%	50%	30%	10%	5%	0%
%Shrinkage at the positions 1, 2, 9, 10[a]	1.95	1.95	1.95	1.96	1.97	1.98	1.98	1.98	1.98
%Shrinkage at the positions 3-8[a]	0.96	0.96	0.97	0.98	0.98	0.98	0.98	0.98	0.98

[a] The positions were according to 3.6.2.2.

4.3.2 Cost

The cost of the blended polymer of UHMWPE and LLDPE can be calculated by domestic costs of UHMWPE and LLDPE. Domestic cost of UHMWPE (Mitzubishi, L4420) is 400 baht/kg. Domestic cost of LLDPE (TPE, 2009F) is 30 baht/kg. Table 4.6 indicated that the blended polymer cost would be decreased if the amount of UHMWPE decreased and the amount of LLDPE increased. Engineering type polymer costs is shown in Table 4.7.

Table 4.6 Cost of the blended polymers of UHMWPE and LLDPE at different compositions

% UHMWPE	Cost (baht/kg)	% LLDPE	Cost (baht/kg)	Cost of blended polymer[a] (baht/kg)
100	300.00	0	0.00	300.00
95	285.00	5	1.50	286.50
90	270.00	10	3.00	273.00
70	210.00	30	27.00	237.00
50	150.00	50	15.00	165.00
30	90.00	70	21.00	111.00
10	30.00	90	27.00	57.00
5	15.00	95	28.50	43.50
0	0.00	100	30.00	30.00

[a] Cost of the blended polymer does not include processing cost.

Table 4.7 Engineering type polymer cost (Thailand)

Type of polymers	Acrylnitrile-butadiene-styrene (ABS)	Polyacetal (POM)	Polyamide (PA6)	Polybutylene-terephthalate (PBT)	Polycarbonate (PC)
Cost (baht/kg)	60	80	140	200	170

Comparison between Tables 4.6 and 4.7, the cost of the blended polymer of 10%UHMWPE was closed to that of ABS. The cost of 20%UHMWPE was closed to the cost of POM. The cost of 30-50% UHMWPE was closed to PA6. The cost of 60% UHMWPE was closed to that of polycarbonate. Thus this blended polymer is one choice of new material for application to replace the other polymers as described.

4.4 Effect of glass fiber on the properties of blended polymer of UHMWPE and LLDPE

The properties of blended polymer can be improved by using the filler.[18-23] Glass fiber was chosen as filler. The composite polymers could then be obtained. The studies were done on the composition of 50%UHMWPE, 70%UHMWPE, 90%UHMWPE and 100%UHMWPE. Since the previous studies were shown that the composition of 50%UHMWPE could be used instead of acrylonitrile-butadiene-styrene copolymer (ABS), 70%UHMWPE could be used instead of polyacetal and polyamide (PA6) and 90%UHMWPE could be used instead of polycarbonate. The amount of the glass fiber was 30% of the total amount.[19] The mechanical properties of the composite polymers that are tensile strength and impact strength were studied. Shrinkage and cost were also determined.

4.4.1 Effect of glass fiber on tensile strength

Table 4.8 and Figure 4.20 show that the tensile strength of each composition of blended polymer increased when the glass fiber was filled. Maximum stress of the composition of 50%UHMWPE, 70%UHMWPE, 90%UHMWPE and 100%UHMWPE composite polymers were 116, 125, 131 and 135 MPa, respectively compared with the blended polymers without glass fiber which were 42, 60, 65 and 64 Mpa, respectively. This was shown that the structure strength of the composite polymers increased by the glass fiber. Thus the tensile strength was then improved.

Furthermore, the tensile strength of the composite polymers increased when %UHMWPE increased. The polymers with high %UHMWPE contained more amount of UHMWPE than the polymers with low %UHMWPE. Thus the structure strength of composite polymers was then increased by %UHMWPE because of the strength of the structure of UHMWPE. Tensile strength of 100%UHMWPE was less than that of 90%UHMWPE as described in 4.2.

Table 4.8 Tensile strength of the blended polymers of UHMWPE and LLDPE compared with the composite polymers using glass fiber as filler

Compositions of UHMWPE of Blended polymer	Tensile strength of the polymers of UHMWPE and LLDPE (MPa)	
	Without glass fiber	30%Glass fiber
50% UHMWPE	42	116
70% UHMWPE	60	125
90% UHMWPE	65	131
100%UHMWPE	64	135

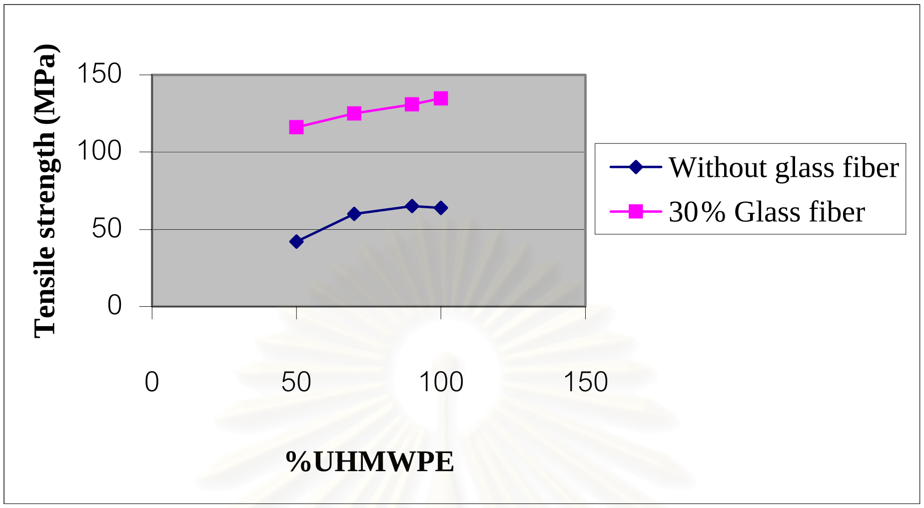


Figure 4.20 Effect of 30% glass fiber on the tensile strength of blended polymers

4.4.2 Effect of glass fiber on impact strength

For the blended polymers without glass fiber, the impact strength testing could not be done because of high toughness and fatigue. When the blended polymers were filled with the glass fibers, toughness and fatigue of the polymers decreased. Thus the impact strength testing could be done. The result was shown in Table 4.9 and Figure 4.21. They were shown that the impact strength of the composite polymers was high. Since Flexural, toughness and fatigue of the blended polymers were decreased by the glass fiber.

Furthermore, the impact strength of the composite polymers increased when %UHMWPE increased because the structure of UHMWPE had high strength.

Table 4.9 Impact strength of the composite polymers using glass fiber as filler

Compositions of UHMWPE of composite polymers	Impact strength (J/m)
50% UHMWPE	98
70% UHMWPE	110
90% UHMWPE	113
100% UHMWPE	112

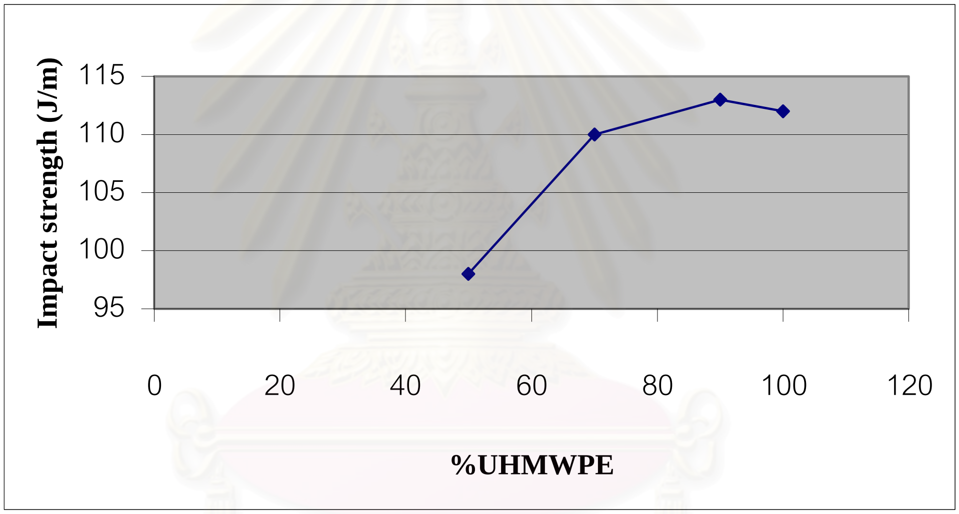


Figure 4.21 Effect of 30% glass fiber on the impact strength of blended polymers

4.4.3 Effect of glass fiber on thickness shrinkage

Since the width shrinkage of blended polymers had little effect on the shrinkage of blended polymers as described in 4.3.1.2. Thus the thickness shrinkage would be considered.

The structure of composite polymer had more stiffness since the structure of composite polymer contained glass fiber. Thus the shrinkage decreased when the glass fiber was filled with the blended polymer. Glass fiber would act as a skeleton after the shrinkage occurred resulting in lower shrinkage as shown in Tables 4.10, 4.11 and Figure 4.22. Thickness shrinkage also increased when %UHMWPE increased because of high crystallinity of UHMWPE.

Table 4.10 Average thickness shrinkage of composite polymers of UHMWPE and LLDPE using 30% glass fiber as filler

The positions of measuring[a]	Thickness (mm)			
	%UHMWPE			
	50	70	90	100
1	3.15	3.14	3.13	3.13
2	3.15	3.14	3.13	3.12
3	3.14	3.14	3.14	3.12
4	3.15	3.14	3.13	3.13
5	3.15	3.15	3.13	3.12
6	3.14	3.14	3.14	3.12
7	3.15	3.15	3.13	3.13
8	3.15	3.14	3.13	3.12
9	3.16	3.14	3.13	3.12
10	3.15	3.14	3.13	3.12
Average thickness (mm)	3.15	3.14	3.13	3.12
%Shrinkage	1.56	1.88	2.19	2.50

[a] The positions were according to 3.6.2.1.

Table 4.11 Thickness shrinkage of the blended polymers of UHMWPE and LLDPE compared with the composite polymers using glass fiber as filler

Compositions of UHMWPE	Thickness shrinkage of the polymers of UHMWPE and LLDPE (%)	
	Without glass fiber	30% Glass fiber
50% UHMWPE	2.55	1.56
70% UHMWPE	3.12	1.88
90% UHMWPE	3.42	2.19
100% UHMWPE	3.77	2.50

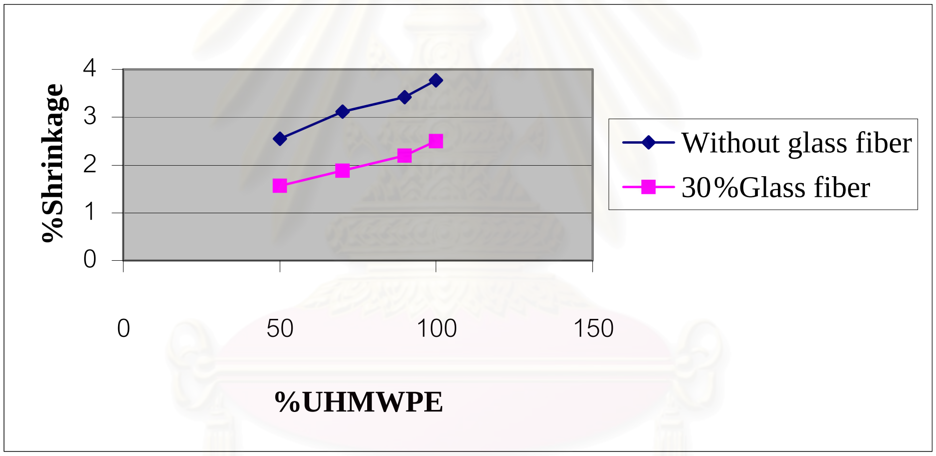


Figure 4.22 Effect of 30% glass fiber on the shrinkage of blended polymers

4.4.4 Effect of glass fiber on cost

When the blended polymers were filled with the glass fibers, the cost decreased by 25% as shown in Table 4.12 and Figure 4.23. Furthermore, the cost of the composite polymers increased when the amount of UHMWPE increased. Since the cost of UHMWPE was higher than that of LLDPE.

Table 4.12 The cost of the blended polymers of UHMWPE and LLDPE compared with the composite polymers using glass fiber as filler

% UHMWPE	Cost of the polymers of UHMWPE and LLDPE (baht/kg)	
	Without glass fiber	30% Glass fiber[a]
50% UHMWPE	165.00	129.00
70% UHMWPE	237.00	173.40
90% UHMWPE	273.00	204.60
100% UHMWPE	300.00	223.50

[a] The cost of the glass fiber is 45 baht/kg.

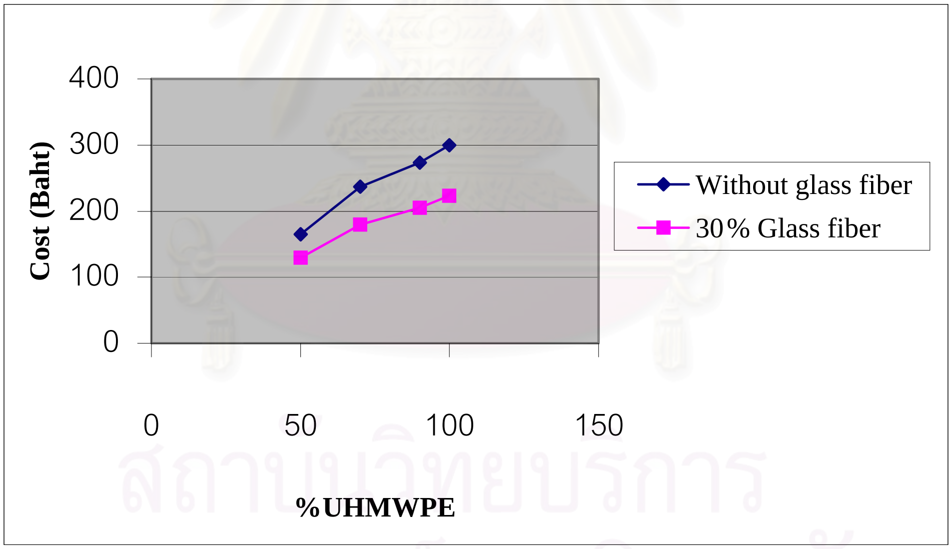


Figure 4.23 Effect of 30% glass fiber on the cost of blended polymers

4.5 Effect of talcum on the properties of blended polymer of UHMWPE and LLDPE

The properties of blended polymer can also be improved by using talcum as filler.[22-23] The studied of mechanical properties, shrinkage and cost were done on the 100%UHMWPE, 90%UHMWPE, 70%UHMWPE and 50%UHMWPE composite polymers. The amount of the talcum is 30% of the total amount.[19]

4.5.1 Effect of talcum on tensile strength

Table 4.13 and Figure 4.24 show that the tensile strength of each composition of blended polymer increased when the talcum was filled. Maximum stress of the composition of 50%UHMWPE, 70%UHMWPE, 90%UHMWPE and 100%UHMWPE composite polymers were 115, 120, 125 and 124 MPa, respectively compared with the blended polymers without glass fiber which were 42, 60, 65 and 64 Mpa, respectively. This was shown that the structure strength of the composite polymers increased by the talcum. Thus the tensile strength was then improved. Furthermore, the tensile strength of the composite polymers increased when %UHMWPE increased because of the structure strength of UHMWPE. Tensile strength of 100%UHMWPE was less than that of 90%UHMWPE as described in 4.2.

Table 4.13 Tensile strength of the blended polymers of UHMWPE and LLDPE compared with the composite polymers using talcum as filler

%UHMWPE	Tensile strength of the polymers of UHMWPE and LLDPE (MPa)	
	Without talcum	30% Talcum
50% UHMWPE	42	115
70% UHMWPE	60	120
90% UHMWPE	65	125
100% UHMWPE	64	124

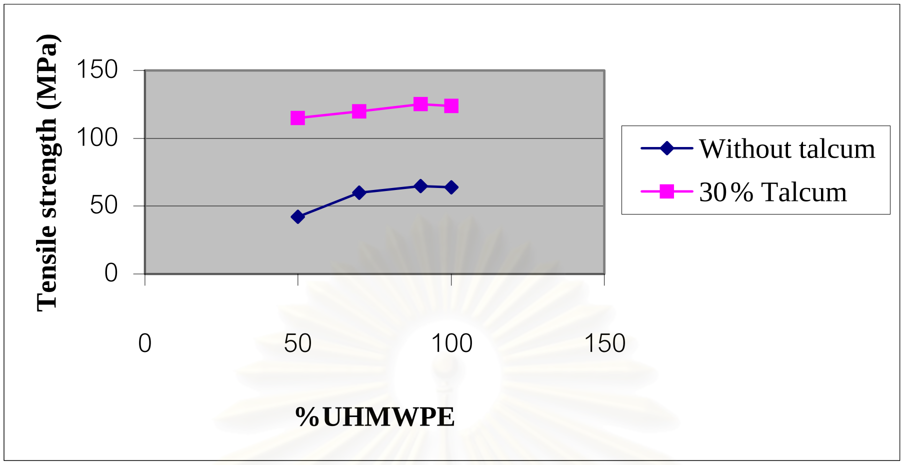


Figure 4.24 Effect of 30% talcum on the tensile strength of blended polymers

4.5.2 Effect of talcum on impact strength

Table 4.14 and Figure 4.25 show the impact strength of the composite polymers of 50%, 70%, 90% and 100%UHMWPE, which were 101, 105, 107 and 106, respectively. Thus the composite polymers had higher stiffness and impact strength than that of blended polymer since the structure of talcum was stiff. So the structure strength of the composite polymers increased by using talcum. Furthermore, the impact strength of the composite polymers increased when %UHMWPE increased because the structure of UHMWPE had high strength. But when 100%UHMWPE polymer was filled with 30%talcum, the impact strength decreased. Since LLDPE had an effect on the flexural of the blended polymers.

Table 4.14 Impact strength of the composite polymers using talcum as filler

Compositions of UHMWPE of composite polymers	Impact strength (J/m)
50% UHMWPE	101
70% UHMWPE	105
90% UHMWPE	107
100% UHMWPE	106

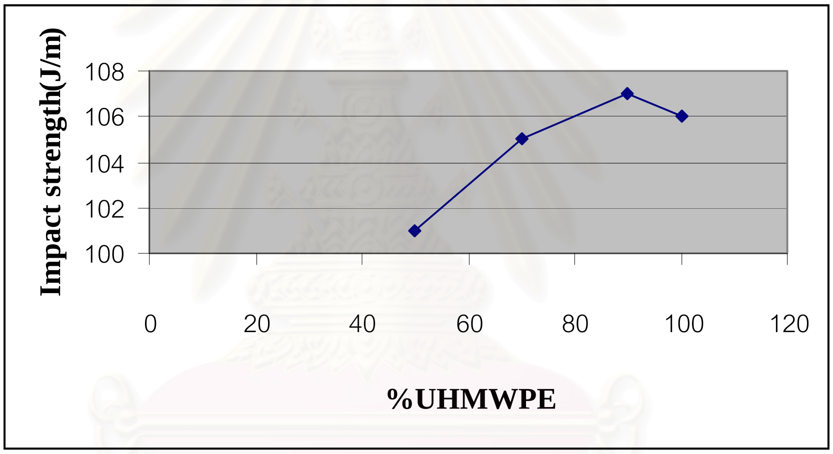


Figure 4.25 Effect of 30% talcum on the impact strength of blended polymers

4.5.3 Effect of talcum on thickness shrinkage

From Tables 4.15, 4.16 and Figure 4.26, they were shown that the thickness shrinkage of composite polymer was less than that of the blended polymer. The structure of composite polymers had more stiffness because of the agglomerates of talcum in composite polymers. Furthermore the thickness increased when %UHMWPE increased.

Table 4.15 Average thickness shrinkage of composite polymers of UHMWPE and LLDPE using 30% talcum as filler

The positions of measuring[a]	Thickness (mm)			
	%UHMWPE			
	50	70	90	100
1	3.15	3.14	3.14	3.13
2	3.15	3.14	3.14	3.13
3	3.14	3.14	3.14	3.14
4	3.15	3.14	3.15	3.14
5	3.15	3.15	3.14	3.13
6	3.14	3.14	3.14	3.14
7	3.15	3.15	3.16	3.14
8	3.15	3.14	3.14	3.14
9	3.16	3.14	3.14	3.14
10	3.15	3.14	3.14	3.14
Average thickness (mm)	3.15	3.14	3.14	3.14
%shrinkage	1.70	1.75	1.80	1.98

[a] The positions were according to 3.6.2.1.

Table 4.16 Thickness shrinkage of the blended polymers of UHMWPE and LLDPE compared with the composite polymers using talcum as filler

%UHMWPE	Thickness shrinkage of the polymers of UHMWPE and LLDPE (%)	
	Without talcum	30% Talcum
50% UHMWPE	2.55	1.70
70% UHMWPE	3.12	1.75
90% UHMWPE	3.42	1.80
100% UHMWPE	3.77	1.98

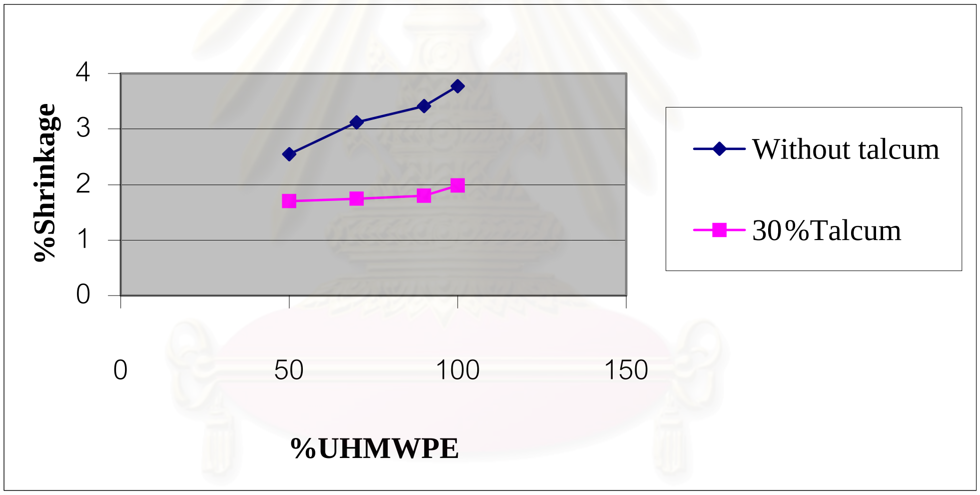


Figure 4.26 Effect of 30% talcum on the shrinkage of blended polymers

4.5.4 Effect of talcum on cost

From Table 4.17 and Figure 4.27, they were shown that the cost of composite polymers was 30% lower than that of the blended polymers. Thus the cost and mechanical properties of composite polymers should be considered for industrial applications.

Table 4.17 Cost of the blended polymers of UHMWPE and LLDPE compared with the composite polymers using talcum as filler

%UHMWPE	Cost of the polymers of UHMWPE and LLDPE (bath/kg)	
	Without talcum	30% talcum[a]
50% UHMWPE	165.00	116.10
70% UHMWPE	237.00	116.50
90% UHMWPE	273.00	191.70
100% UHMWPE	300.00	210.60

[a] The cost of talcum is 2.00 baht/kg.

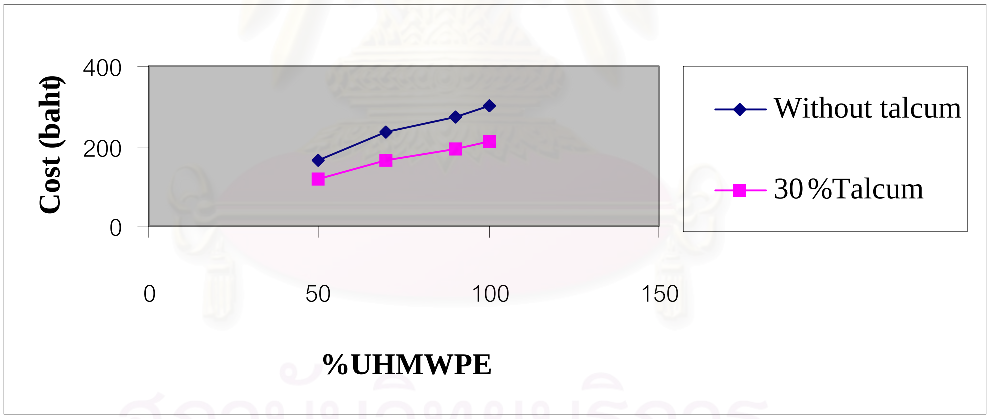


Figure 4.27 Effect of 30% talcum on the cost of blended polymers

4.6 Comparing an effect of 30%glass fiber with 30%talcum on composite polymers

4.6.1 Tensile strength

From Table 4.18 and Figure 4.28, they were shown that tensile strength of composite polymers using glass fiber as filler, was higher than that of talcum as filler. Since the particle of talcum was agglomerate but the particle of glass fiber was shop straining. Thus the glass fiber improved tensile strength of the blended polymer better than that of talcum.

Table 4.18 Tensile strength of the composite polymers using fiber and talcum as fillers

%UHMWPE	Tensile strength of the composite polymers of UHMWPE and LLDPE (MPa)	
	30% Glass fiber	30% Talcum
50% UHMWPE	116	115
70% UHMWPE	125	120
90% UHMWPE	131	125
100% UHMWPE	135	124

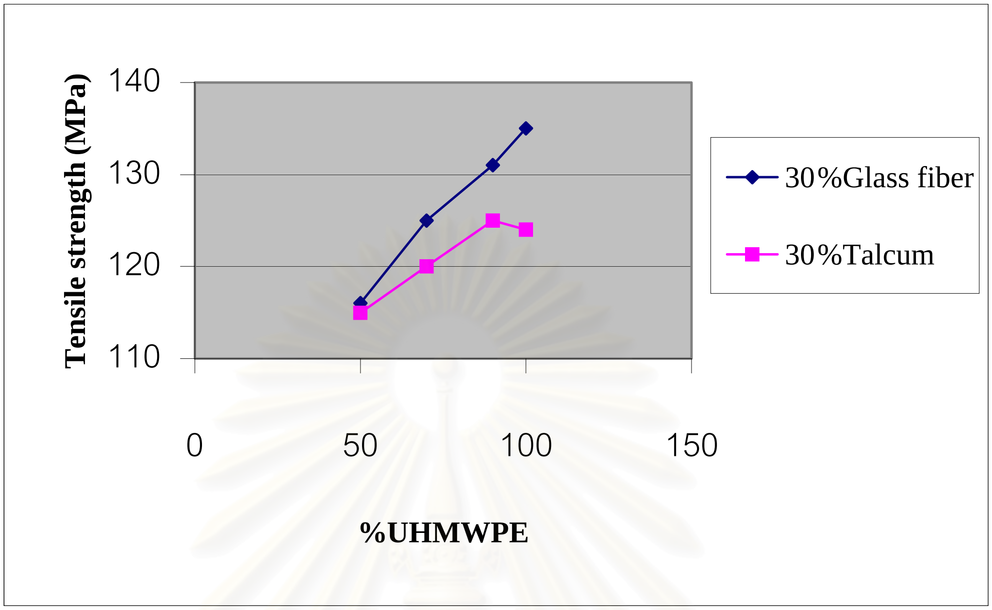


Figure 4.28 Tensile strength of composite polymers using glass fiber and talcum as fillers

4.6.2 Impact strength

Impact strength of the composite polymers using glass fiber as filler, was higher than that of talcum as filler because the particle of the glass fiber had more structure strength than the particle of talcum resulting in higher impact strength (Table 4.19 and Figure 4.29).

Table 4.19 Impact strength of the composite polymers using fiber and talcum as fillers

%UHMWPE	Impact strength of the composite polymers of UHMWPE and LLDPE (MPa)	
	30% Glass fiber	30% Talcum
50% UHMWPE	98	101
70% UHMWPE	110	105
90% UHMWPE	113	107
100% UHMWPE	112	106

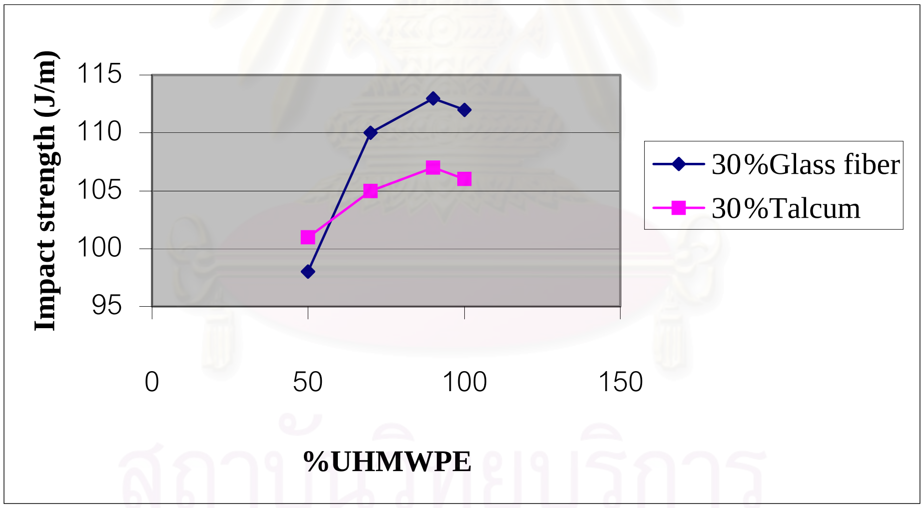


Figure 4.29 Impact strength of composite polymers using glass fiber and talcum as fillers

4.6.3 Thickness shrinkage

Thickness shrinkage of the composite polymers using talcum as filler was lower than that of glass fiber as filler. Since the agglomerates of talcum increased the stiffness of the composite polymers. The agglomerates were less packed than the shop straining structure of glass fiber resulting in lower shrinkage as shown in Table 4.20 and Figure 4.30.

Table 4.20 Thickness shrinkage of the composite polymers using fiber and talcum as fillers

%UHMWPE	Thickness shrinkage of the composite polymers of UHMWPE and LLDPE (%)	
	30% Glass fiber	30% Talcum
50% UHMWPE	1.56	1.70
70% UHMWPE	1.88	1.75
90% UHMWPE	2.19	1.80
100% UHMWPE	2.50	1.98

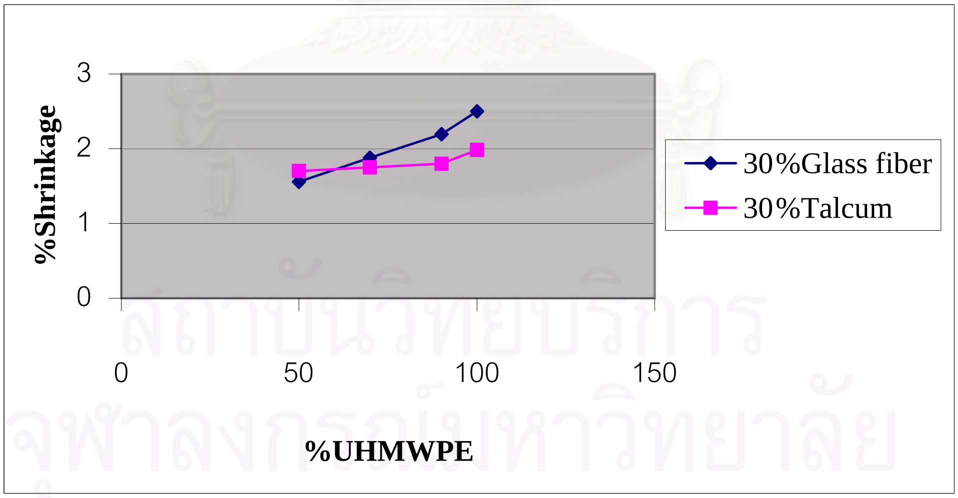


Figure 4.30 Thickness shrinkage of composite polymers using glass fiber and talcum as fillers

CHAPTER V

CONCLUSION AND SUGGESTION FOR FUTURE WORK

5.1 Conclusion

Blended polymers of UHMWPE and LLDPE were prepared by varying the composition of the two polymers to improve the properties of the polymer. Thus the processing could be done by an injection process instead of tooling after casting or extrusion.

The compatibility of the blended polymers of UHMWPE and LLDPE was studied by using DSC to determine T_m. Each peak of DSC thermograms was same for each different composition used. Every peak was shown as only one peak. This was shown that UHMWPE and LLDPE could be mixed throughly.

Morphological property of blended polymers of UHMWPE and LLDPE was studied by using SEM. From SEM photographs, dispersion of blended polymers of UHMWPE and LLDPE was dispersed phase of one polymer absolutely dispersed in matrix phase of another polymer for every composition. The composition of UHMWPE and LLDPE had an effect on the density dispersion of the dispersed phase and matrix phase of the blended polymers of UHMWPE and LLDPE.

Thus the properties of the blended polymers of UHMWPE and LLDPE were improved. The advantages of LLDPE are low shrinkage and low cost. Besides it could be processed by an injection process. These advantages of LLDPE were used to improve the properties of UHMWPE, which are difficult for an injection process, high shrinkage and high cost. The blending of UHMWPE and LLDPE would then improve the properties of the polymer. Processing by an injection could be done. The cost was also reduced. Nevertheless, the ratio of the composition should be determined for a proper application since the composition of the polymer has an effect on the physical properties of the polymer.

The ratio of UHMWPE and LLDPE should be determined for the proper application to be used instead of the other engineering types polymers so the processing cost would be decreased. For example, blending 50%UHMWPE and 50%LLDPE can be processed to produced a blended polymer, which can be used as a helmet instead of using ABS. Furthermore, blending of 70%UHMWPE and 30%LLDPE can be processed, which can be used as a gear, bumper and part of the engine instead of using nylon6 or polyacetal. blending 90%UHMWPE and 10%LLDPE can be processed, which can be used instead of polycarbonate.

The comparison of blended polymers of UHMWPE and LLDPE and other commercially engineering type polymers indicated that the price of blended polymers of 50%UHMWPE and 50%LLDPE was 3 times higher than ABS. The cost of blended polymer of 70%UHMWPE and 30%LLDPE was similar to that of polyacetal. The cost of blended polymer of 90%UHMWPE and 10%LLDPE was also similar to that of polycarbonate.

Thus UHMWPE and LLDPE could be blended. These two polymers were compatible. The properties of the polymer were also improved for an injection process by using the proper composition. These could be used instead of the other commercially engineering type polymers.

The properties of blended polymers can also be improved by using the fillers. Glass fiber and talcum were used as fillers. The amount of fillers was 30%. It was found that tensile strength of the composite polymers much more increased than that of the blended polymers. Moreover the tensile strength increased when %UHMWPE increased. Toughness and fatigue of composite polymers decreased when the blended polymers were filled with the fillers. Thus the impact strength increased. When %UHMWPE increased, the impact strength also increased. The cost of the composite polymers was decreased 25% and 30% by using the glass fiber and talcum respectively.

Tensile strength and impact strength of glass fiber composite polymers were higher than talcum composite polymers. Since the shop straining structure of glass fiber more reinforced the structure of blended polymers than the agglomerates structure of talcum. But the shrinkage of the composite polymers was more decreased when using talcum as filler because of the stiffness of the structure. Furthermore, the cost was more decreased when using talcum as filler since the cost of talcum is lower than that of glass fiber.

5.2 Suggestion for future work

The other fillers such as calcium carbonate, long strain fiber, barium sulfate should be determined for the proper application. The shape and size of the fillers should also be varied. The new type of the composite polymer should then be obtained.

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Appendix

Table A1 Properties of different polymers

Properties	Test method ASTM	Unit	Polyacetal copolymer		ABS (High impact grade)	Polyamide (Nylon6)	Polycarbonate	Polybutylene terephthalate (PBT)
			DURACON					
			M90-44	GH-25				
Glass fiber content	-	%	0	25	0	0	0	0
Specific gravity	D792	-	1.41	1.59	1.01-1.05	1.12-1.14	1.20	1.03-1.38
Tensile strength (Max.)	D638	MPa	60	127	35-43	79	66	56-59
Elongation	D638	%	60	3.0	5-75	30-100	110	50-300
Flexural strength (Max.)	D790	MPa	96	193	37-75	107	93	86-115
Flexural modulus	D790	MPa	2,580	7,550	1,270-2,550	2,640	2,350	2,250-2,740
Izod impact strength (notched)	D256	J/m	63	78	323-500	32-117	122	37-53

Table A2 Tensile properties of 100%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	2173	72.42	10.88	11.05
2	3.000	10.000	2173	72.42	9.293	9.304
3	3.000	10.000	1942	64.73	8.752	9.822
4	3.000	10.000	1598	53.27	6.511	7.283
5	3.000	10.000	1776	59.20	7.109	8.152
		Mean	1932	64.41	8.509	9.122
		Std. Dev	250.8	8.361	1.749	1.462
		Range	574.5	19.15	4.367	3.765
		Median	1942	64.73	8.752	9.304
		Maximum	2173	72.42	10.88	11.05
		Minimum	1598	53.27	6.511	7.283

<u>First Page Inputs</u>

Product Code : 100%UHMWPE
Batch Reference :
Product Description :
Date 8/31/2000
Operator
Temperature [C] : 24
Relative Humidity : 67

<u>Machine Settings</u>

Stress Range : 1000.0 MPa
Strain Range : 500.0 %
Speed : 500.0 mm/min
Sample Length : 115.0 mm
Preload 0.0000 N
Auto Return : ON

Table A3 Tensile properties of blended polymer of 5%UHMWPE and 95%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	2020	67.33	10.57	12.26
2	3.000	10.000	1782	59.40	8.533	8.543
3	3.000	10.000	2018	67.25	8.783	8.783
4	3.000	10.000	2025	67.50	10.57	10.87
5	3.000	10.000	1954	65.13	9.446	9.478
		Mean	1960	65.32	9.578	9.986
		Std. Dev	103.5	3.450	0.9608	1.560
		Range	243.0	8.100	2.033	3.717
		Median	2018	67.25	9.446	9.478
		Maximum	2025	67.50	10.57	12.26
		Minimum	1782	59.40	8.533	8.543

First Page Inputs

Product Code	: 95%UHMWPE
Batch Reference	:
Product Description	
Date	8/31/2000
Operator	
Temperature (C)	24
Relative Humidity	67

Machine Settings

Stress Range	: 1000.0 MPa
Strain Range	: 500.0 %
Speed	: 500.0 mm/min
Sample Length	115.0 mm
Preload	0.0000 N
Auto Return	ON

Table A4 Tensile properties of blended polymer of 10%UHMWPE and 90%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	1950	65.00	9.891	11.52
2	3.000	10.000	1850	61.67	8.641	8.674
3	3.000	10.000	1944	64.80	9.783	10.08
4	3.000	10.000	1952	65.07	11.18	11.22
5	3.000	10.000	1884	62.80	9.783	9.822
		Mean	1916	63.87	9.855	10.26
		Std. Dev.	46.41	1.547	0.8994	1.145
		Range	102.0	3.400	2.537	2.848
		Median	1944	64.80	9.783	10.08
		Maximum	1952	65.07	11.18	11.52
		Minimum	1850	61.67	8.641	8.674

First Page Inputs

Product Code	: 90%UHMWPE
Batch Reference	:
Product Description	:
Date	8/31/2000
Operator	
Temperature [C]	: 24
Relative Humidity	: 67

Machine Settings

Stress Range	: 1000.0 MPa
Strain Range	: 500.0 %
Speed	: 500.0 mm/min
Sample Length	: 115.0 mm
Preload	: 0.0000 N
Auto Return	: ON

Table A5 Tensile properties of blended polymer of 30%UHMWPE and 70%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	1862	62.07	9.913	11.15
2	3.000	10.000	1814	60.47	8.533	8.543
3	3.000	10.000	1864	62.13	10.23	10.27
4	3.000	10.000	1682	56.07	8.426	8.778
5	3.000	10.000	1842	61.40	9.783	10.34
		Mean	1813	60.43	9.376	9.817
		Std. Dev.	75.84	2.528	0.8352	1.114
		Range	182.0	6.067	1.800	2.609
		Median	1842	61.40	9.783	10.27
		Maximum	1864	62.13	10.23	11.15
		Minimum	1682	56.07	8.426	8.543

First Page Inputs

Product Code	: 70%UHMWPE
Batch Reference	
Product Description	:
Date	: 8/31/2000
Operator	
Temperature [C]	: 24
Relative Humidity	67

Machine Settings

Stress Range	: 1000.0 MPa
Strain Range	: 500.0 %
Speed	: 500.0 mm/min
Sample Length	: 115.0 mm
Preload	: 0.0000 N
Auto Return	: ON

Table A6 Tensile properties of blended polymer of 50%UHMWPE and 50%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	1269	42.30	9.730	9.743
2	3.000	10.000	1317	43.90	10.43	10.43
3	3.000	10.000	1241	41.38	8.870	8.870
4	3.000	10.000	1346	44.85	10.60	10.60
5	3.000	10.000	1243	41.42	10.00	10.00
		Mean	1283	42.77	9.929	9.931
		Std. Dev	46.48	1.549	0.6855	0.6845
		Range	104.3	3.475	1.735	1.735
		Median	1269	42.30	10.00	10.00
		Maximum	1346	44.85	10.60	10.60
		Minimum	1241	41.38	8.870	8.870

First Page Inputs

Product Code : 50%UHMWPE
Batch Reference :
Product Description
Date : 8/31/2000
Operator :
Temperature [C] 24
Relative Humidity 67

Machine Settings

Stress Range : 1000.0 MPa
Strain Range : 500.0 %
Speed : 500.0 mm/min
Sample Length : 115.0 mm
Preload : 0.0000 N
Auto Return : ON

Table A7 Tensile properties of blended polymer of 70%UHMWPE and 30%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	804.0	26.80	11.30	11.91
2	3.000	10.000	785.6	26.19	10.43	10.79
3	3.000	10.000	762.4	25.41	11.53	12.26
4	3 000	10.000	807.0	26.90	10.90	12.70
5	3.000	10.000	822.0	27.40	12.23	12.52
		Mean	796.2	26.54	11.28	12.04
		Std. Dev	22.90	0.7634	0.6734	0.7578
		Range	59.60	1.987	1.791	1.909
		Median	804.0	26.80	11.30	12.26
		Maximum	822.0	27 40	12.23	12 70
		Minimum	762.4	25 41	10 43	10 79

First Page Inputs

Product Code : 30%UHMWPE
Batch Reference :
Product Description :
Date 8/31/2000
Operator
Temperature [C] 24.
Relative Humidity . 67

Machine Settings

Stress Range : 1000.0 MPa
Strain Range : 500.0 %
Speed : 500.0 mm/min
Sample Length 115.0 mm
Preload : 0.0000 N
Auto Return : ON

Test Results [TENX-010] Tensile Stress/Elongation [XHead] H50KS/05 - 25kN Loadcell QMat 1.23

Table A8 Tensile properties of blended polymer of 90%UHMWPE and 10%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	384.0	12.80	16.09	347.0
2	3.000	10.000	406.5	13.55	158.8	161.7
3	3.000	10.000	401.5	13.38	15.87	88.70
4	3.000	10.000	390.8	13.03	17.93	89.89
5	3.000	10.000	452.5	15.08	176.5	177.4
		Mean	407.1	13.57	77.04	172.9
		Std. Dev.	26.89	0.8963	82.96	105.4
		Range	68.50	2.283	160.7	258.3
		Median	401.5	13.38	17.93	161.7
		Maximum	452.5	15.08	176.5	347.0
		Minimum	384.0	12.80	15.87	88.70

First Page Inputs

Product Code : 10%UHMWPE
Batch Reference
Product Description
Date : 8/31/2000
Operator :
Temperature [C] : 24
Relative Humidity : 67

Machine Settings

Stress Range : 1000.0 MPa
Strain Range : 500.0 %
Speed : 500.0 mm/min
Sample Length : 115.0 mm
Preload : 0.0000 N
Auto Return : ON

Table A9 Tensile properties of blended polymer of 95%UHMWPE and 5%LLDPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	433.5	14.45	233.0	241.7
2	3.000	10.000	444.0	14.80	229.2	232.3
3	3.000	10.000	440.0	14.67	238.3	241.7
4	3.000	10.000	468.5	15.62	276.5	276.5
5	3.000	10.000	450.0	15.00	238.3	245.2
		Mean	447.2	14.91	243.1	247.5
		Std. Dev	13.33	0.4445	19.09	16.91
		Range	35.00	1.167	47.30	44.17
		Median	444.0	14.80	238.3	241.7
		Maximum	468.5	15.62	276.5	276.5
		Minimum	433.5	14.45	229.2	232.3

<u>First Page Inputs</u>

Product Code	: 5%UHMWPE
Batch Reference	:
Product Description	: LLDPE=5
Date	: 8/31/2000
Operator	:
Temperature [C]	: 24
Relative Humidity	: 67

<u>Machine Settings</u>

Load Range	: 1000.0 N
Extension Range	: 500.0 mm
Speed	: 500.0 mm/min
Sample Length	: 115.0 mm
Preload	: 0.0000 N
Auto Return	: ON

Table A10 Tensile properties of 100%UHMWPE

Specimen No	Thickness mm	Width mm	Max Force N	Max Stress MPa	Ext at Max %	Ext at Brk %
1	3.000	10.000	451.5	15.05	255.0	363.3
2	3.000	10.000	453.5	15.12	255.7	258.1
3	3.000	10.000	432.5	14.42	237.2	239.3
4	3.000	10.000	456.5	15.22	265.7	276.5
5	3.000	10.000	422.5	14.08	268.5	273.0
		Mean	443.3	14.78	256.4	282.0
		Std. Dev.	14.96	0.4986	12.29	47.72
		Range	34.00	1.133	31.30	124.0
		Median	451.5	15.05	255.7	273.0
		Maximum	456.5	15.22	268.5	363.3
		Minimum	422.5	14.08	237.2	239.3

First Page Inputs

Product Code : 0%UHMWPE
Batch Reference :
Product Description :
Date : 8/31/2000
Operator :
Temperature [C] : 24
Relative Humidity : 67

Machine Settings

Stress Range : 1000.0 MPa
Strain Range : 500.0 %
Speed : 500.0 mm/min
Sample Length : 115.0 mm
Preload : 0.0000 N
Auto Return : ON

Table A11 Width shrinkage measurement of 100%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.98	1.98	1.99	1.96	1.99	1.98	1.97	1.95	1.95	1.95	1.97
2	1.98	1.98	1.98	1.98	1.99	1.98	1.98	1.98	1.97	1.99	1.98
3	0.98	0.98	0.98	0.98	0.97	0.98	0.98	0.98	0.97	0.99	0.98
4	0.98	0.98	0.98	0.98	0.98	0.97	0.98	0.98	0.97	0.99	0.98
5	0.98	0.98	0.98	0.98	0.98	0.97	0.98	0.98	0.98	0.99	0.98
6	0.98	0.98	0.98	0.98	0.98	0.97	0.98	0.98	0.98	0.99	0.98
7	0.98	0.98	0.98	0.98	0.98	0.97	0.98	0.98	0.98	0.99	0.98
8	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.98
9	1.99	1.98	1.98	1.98	1.95	1.98	1.98	1.98	1.98	1.99	1.98
10	1.98	1.99	1.97	1.98	1.98	1.97	1.98	1.95	1.97	1.98	1.98

Table A12 Width shrinkage measurement of blended polymer of 5%UHMWPE and 95%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.97	1.97	1.97	1.97	1.98	1.98	1.99	1.98	1.97	1.98	1.98
2	1.97	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
3	0.98	0.98	0.98	0.98	0.98	0.96	0.98	0.98	0.97	0.97	0.98
4	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
5	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98
6	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.97	0.98	0.97	0.98
7	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
8	0.98	0.98	0.98	0.98	0.98	0.97	0.98	0.99	0.98	0.97	0.98
9	1.98	1.96	1.98	1.98	1.95	1.98	1.97	1.98	1.98	1.98	1.97
10	1.95	1.98	1.96	1.98	1.96	1.98	1.97	1.98	1.98	1.98	1.97

Table A13 Width shrinkage measurement of blended polymer of 10%UHMWPE and 90%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.98	1.99	1.98	1.98	1.98	1.98	1.98	1.98	1.97	1.97	1.98
2	1.97	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.97	1.97	1.98
3	0.98	0.99	0.99	0.97	0.98	0.98	0.99	0.98	0.97	0.98	0.98
4	0.98	0.97	0.96	0.98	0.97	0.98	0.96	0.99	0.98	0.97	0.97
5	0.98	0.98	0.97	0.96	0.98	0.96	0.99	0.98	0.99	0.97	0.98
6	0.97	0.99	0.98	0.97	0.98	0.97	0.98	0.98	0.99	0.98	0.98
7	0.97	0.98	0.98	0.98	0.97	0.98	0.98	0.99	0.98	0.97	0.98
8	0.99	0.98	0.98	0.99	0.97	0.99	0.98	0.99	0.97	0.98	0.98
9	1.97	1.98	1.98	1.96	1.98	1.98	1.98	1.98	1.97	1.97	1.98
10	1.96	1.96	1.97	1.97	1.98	1.98	1.98	1.98	1.98	1.99	1.98

Table A14 Width shrinkage measurement of blended polymer of 30%UHMWPE and 70%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.98	1.99	1.98	1.98	1.98	1.98	1.98	1.98	1.97	1.97	1.98
2	1.97	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.97	1.97	1.98
3	0.98	0.99	0.99	0.97	0.98	0.98	0.99	0.98	0.97	0.98	0.98
4	0.98	0.97	0.96	0.98	0.97	0.98	0.96	0.99	0.98	0.97	0.97
5	0.98	0.98	0.97	0.96	0.98	0.98	0.99	0.98	0.99	0.97	0.98
6	0.97	0.99	0.98	0.98	0.98	0.99	0.98	0.98	0.99	0.98	0.98
7	0.97	0.98	0.98	0.98	0.97	0.98	0.98	0.99	0.98	0.97	0.98
8	0.99	0.98	0.98	0.99	0.98	0.99	0.98	0.99	0.97	0.98	0.98
9	1.97	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.97	1.97	1.98
10	1.96	1.96	1.97	1.97	1.98	1.98	1.98	1.98	1.97	1.97	1.97

Table A15 Width shrinkage measurement of blended polymer of 50%UHMWPE and 50%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.97	1.98	1.97	1.99	1.98	1.98	1.97	1.95	1.95	1.94	1.97
2	1.97	1.95	1.96	1.98	1.98	1.97	1.97	1.98	1.95	1.95	1.97
3	0.97	0.97	0.96	0.98	0.97	0.96	0.98	0.97	0.98	0.97	0.97
4	0.97	0.98	0.97	0.98	0.99	0.98	0.98	0.97	0.99	0.98	0.98
5	0.97	0.98	0.99	0.97	0.98	0.98	0.99	0.98	0.98	0.99	0.98
6	0.98	0.99	0.98	0.98	0.99	0.98	0.98	0.99	0.98	0.97	0.98
7	0.98	0.98	0.98	0.98	0.99	0.98	0.99	0.98	0.98	0.98	0.98
8	0.97	0.99	0.99	0.98	0.98	0.98	0.99	0.98	0.98	0.99	0.98
9	1.98	1.97	1.98	1.98	1.97	1.98	1.97	1.98	1.98	1.97	1.98
10	1.95	1.95	1.96	1.96	1.97	1.95	1.96	1.94	1.95	1.96	1.96

Table A16 Width shrinkage measurement of blended polymer of 70%UHMWPE and 30%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.97	1.96	1.98	1.98	1.97	1.96	1.96	1.97	1.98	1.97	1.97
2	1.95	1.96	1.95	1.97	1.96	1.97	1.95	1.98	1.96	1.97	1.96
3	0.99	0.97	0.98	0.98	0.97	0.96	0.99	0.97	0.98	0.98	0.98
4	0.98	0.99	0.97	0.98	0.99	0.97	0.98	0.98	0.97	0.99	0.98
5	0.99	0.98	0.98	0.99	0.97	0.98	0.98	0.97	0.99	0.99	0.98
6	0.99	0.98	0.98	0.97	0.98	0.98	0.98	0.97	0.98	0.97	0.98
7	0.98	0.97	0.98	0.98	0.99	0.99	0.98	0.98	0.97	0.98	0.98
8	0.98	0.99	0.99	0.97	0.98	0.98	0.97	0.98	0.99	0.98	0.98
9	1.96	1.98	1.97	1.96	1.95	1.98	1.97	1.95	1.94	1.96	1.95
10	1.98	1.95	1.96	1.96	1.97	1.95	1.97	1.95	1.98	1.96	1.96

Table A17 Width shrinkage measurement of blended polymer of 90%UHMWPE and 10%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.98	1.95	1.97	1.96	1.94	1.95	1.97	1.94	1.95	1.96	1.96
2	1.93	1.94	1.97	1.95	1.93	1.94	1.96	1.94	1.97	1.95	1.95
3	0.95	0.95	0.95	0.96	0.98	0.98	0.97	0.96	0.95	0.97	0.96
4	0.95	0.97	0.98	0.95	0.96	0.95	0.96	0.97	0.98	0.98	0.97
5	0.98	0.98	0.97	0.96	0.96	0.98	0.97	0.96	0.98	0.97	0.97
6	0.96	0.97	0.98	0.98	0.99	0.98	0.99	0.98	0.97	0.98	0.98
7	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
8	0.98	0.98	0.98	0.97	0.98	0.96	0.97	0.98	0.97	0.98	0.97
9	1.95	1.96	1.94	1.97	1.96	1.94	1.95	1.93	1.94	1.95	1.95
10	1.95	1.94	1.95	1.93	1.96	1.95	1.94	1.95	1.97	1.96	1.95

Table A18 Width shrinkage measurement of blended polymer of 95%UHMWPE and 5%LLDPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.95	1.97	1.96	1.95	1.98	1.94	1.97	1.95	1.98	1.94	1.96
2	1.93	1.96	1.95	1.94	1.96	1.94	1.94	1.96	1.95	1.97	1.95
3	0.93	0.96	0.98	0.97	0.98	0.96	0.94	0.93	0.95	0.96	0.96
4	0.95	0.95	0.95	0.95	0.94	0.96	0.96	0.97	0.96	0.93	0.95
5	0.94	0.95	0.97	0.95	0.96	0.96	0.96	0.97	0.97	0.97	0.97
6	0.96	0.97	0.98	0.99	0.97	0.95	0.97	0.94	0.97	0.96	0.98
7	0.96	0.97	0.96	0.96	0.95	0.98	0.95	0.96	0.97	0.97	0.96
8	0.97	0.96	0.94	0.96	0.97	0.98	0.97	0.96	0.97	0.97	0.97
9	1.95	1.96	1.98	1.94	1.94	1.97	1.97	1.97	1.94	1.96	1.96
10	1.95	1.94	1.95	1.94	1.95	1.95	1.94	1.96	1.94	1.94	1.95

Table A19 Width shrinkage measurement of 100%UHMWPE

No. of specimens / Positions of specimens	Width shrinkage (%)										Average width shrinkage (%)
	1	2	3	4	5	6	7	8	9	10	
1	1.94	1.96	1.98	1.95	1.95	1.94	1.97	1.97	1.95	1.94	1.96
2	1.93	1.96	1.95	1.94	1.94	1.94	1.96	1.96	1.97	1.97	1.95
3	0.92	0.96	0.98	0.97	0.98	0.96	0.94	0.93	0.95	0.96	0.96
4	0.94	0.95	0.95	0.94	0.93	0.96	0.96	0.98	0.96	0.93	0.95
5	0.94	0.95	0.97	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.96
6	0.95	0.97	0.98	0.99	0.96	0.95	0.97	0.94	0.98	0.96	0.97
7	0.96	0.97	0.96	0.96	0.94	0.98	0.95	0.98	0.98	0.97	0.96
8	0.97	0.96	0.94	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97
9	1.94	1.96	1.97	1.94	1.93	1.97	1.94	1.97	1.94	1.97	1.95
10	1.94	1.94	1.94	1.94	1.94	1.95	1.94	1.96	1.94	1.94	1.94

Table A20 Thickness measurement 100%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.17	3.19	3.18	3.18	3.19	3.17	3.18	3.16	3.18	3.19	3.18
2	3.19	3.18	3.18	3.19	3.18	3.16	3.18	3.18	3.15	3.18	3.17
3	3.19	3.17	3.14	3.18	3.13	3.12	3.14	3.19	3.18	3.21	3.17
4	3.19	3.19	3.19	3.19	3.19	3.20	3.19	3.19	3.19	3.19	3.19
5	3.21	3.19	3.20	3.20	3.18	3.19	3.19	3.19	3.19	3.21	3.20
6	3.20	3.18	3.19	3.18	3.16	3.14	3.15	3.19	3.19	3.19	3.18
7	3.16	3.15	3.16	3.16	3.16	3.16	3.19	3.18	3.16	3.16	3.16
8	3.19	3.18	3.18	3.18	3.18	3.18	3.18	3.19	3.19	3.19	3.18
9	3.18	3.18	3.18	3.18	3.19	3.19	3.16	3.19	3.18	3.18	3.18
10	3.18	3.18	3.18	3.17	3.18	3.16	3.18	3.18	3.18	3.18	3.18

Table A21 Thickness measurement of blended polymer of 5%UHMWPE and 95%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18
2	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.12	3.18	3.17
3	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18
4	3.18	3.18	3.18	3.16	3.18	3.17	3.18	3.18	3.18	3.18	3.18
5	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18
6	3.18	3.18	3.18	3.18	3.18	3.19	3.19	3.18	3.19	3.18	3.18
7	3.18	3.18	3.18	3.18	3.18	3.16	3.18	3.18	3.18	3.18	3.18
8	3.18	3.18	3.16	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18
9	3.18	3.18	3.18	3.17	3.18	3.18	3.18	3.18	3.18	3.18	3.18
10	3.18	3.17	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18	3.18

Table A22 Thickness measurement of blended polymer of 10%UHMWPE and 90%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.18	3.20	3.19	3.18	3.19	3.19	3.19	3.19	3.19	3.19	3.19
2	3.18	3.19	3.15	3.18	3.19	3.19	3.19	3.19	3.16	3.20	3.18
3	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.16	3.19	3.19
4	3.19	3.19	3.16	3.19	3.15	3.19	3.17	3.19	3.17	3.19	3.18
5	3.19	3.18	3.19	3.18	3.19	3.19	3.19	3.18	3.18	3.19	3.19
6	3.19	3.18	3.18	3.18	3.19	3.16	3.18	3.19	3.18	3.19	3.18
7	3.19	3.19	3.19	3.19	3.18	3.17	3.19	3.19	3.16	3.19	3.18
8	3.19	3.19	3.17	3.18	3.19	3.19	3.19	3.19	3.19	3.19	3.19
9	3.19	3.19	3.15	3.19	3.16	3.19	3.16	3.19	3.19	3.19	3.18
10	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19

Table A23 Thickness measurement of blended polymer of 30%UHMWPE and 70%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.17	3.16	3.17	3.17	3.17	3.17	3.17	3.18	3.17	3.18	3.17
2	3.17	3.17	3.17	3.17	3.17	3.18	3.17	3.17	3.17	3.17	3.17
3	3.17	3.17	3.17	3.17	3.17	3.16	3.16	3.17	3.18	3.17	3.17
4	3.16	3.16	3.17	3.16	3.16	3.17	3.16	3.16	3.16	3.16	3.16
5	3.16	3.16	3.16	3.15	3.16	3.16	3.16	3.16	3.15	3.15	3.16
6	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.16	3.16	3.17
7	3.18	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17
8	3.16	3.16	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.16	3.15
9	3.15	3.15	3.15	3.16	3.15	3.15	3.15	3.15	3.16	3.16	3.15
10	3.16	3.17	3.17	3.17	3.17	3.17	3.17	3.16	3.17	3.17	3.17

Table A24 Thickness measurement of blended polymer of 50%UHMWPE and 50%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.08	3.08	3.10	3.05	3.06	3.08	3.10	3.04	3.05	3.06	3.07
2	3.09	3.15	3.11	3.07	3.08	3.00	3.09	3.12	3.11	3.08	3.09
3	3.15	3.19	3.16	3.16	3.14	3.10	3.12	3.13	3.14	3.15	3.14
4	3.23	3.23	3.21	3.20	3.20	3.22	3.21	3.23	3.22	3.23	3.22
5	3.22	3.29	3.23	3.24	3.20	3.19	3.21	3.22	3.23	3.10	3.21
6	3.17	3.20	3.21	3.25	3.17	3.15	3.16	3.20	3.16	3.20	3.19
7	3.15	3.20	3.16	3.19	3.13	3.15	3.16	3.20	3.15	3.11	3.08
8	3.03	3.15	3.13	3.10	3.01	3.02	3.03	3.08	3.12	3.16	3.15
9	3.00	3.05	3.01	3.00	2.98	2.99	3.10	3.08	3.06	3.06	3.03
10	3.00	3.01	2.97	2.97	2.97	2.95	2.99	3.01	3.00	2.98	2.99

Table A25 Thickness measurement of blended polymer of 70%UHMWPE and 30%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.00	3.12	3.13	3.04	3.15	3.13	3.11	3.12	3.14	3.11	3.12
2	3.02	3.12	3.14	3.11	3.16	3.14	3.15	3.14	3.16	3.12	3.13
3	2.93	3.06	3.00	3.06	3.06	3.05	3.00	3.04	3.02	2.93	3.02
4	3.02	3.16	3.06	3.15	3.06	3.06	3.11	3.13	3.04	3.02	3.08
5	3.04	3.16	3.07	3.14	3.07	3.07	3.13	3.14	3.05	3.11	3.10
6	3.03	3.14	3.07	3.10	3.05	3.06	3.13	3.12	3.04	3.11	3.09
7	3.02	3.08	3.04	3.04	3.04	3.05	3.10	3.08	3.02	3.02	3.05
8	3.02	2.97	3.00	3.14	3.15	3.19	3.17	3.18	3.17	3.12	3.11
9	3.12	3.18	3.16	3.17	3.18	3.17	3.19	3.17	3.17	3.17	3.17
10	3.14	3.14	3.12	3.18	3.19	3.18	3.17	3.12	3.12	3.16	3.15

Table A26 Thickness measurement of blended polymer of 90%UHMWPE and 10%LLDPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.01	3.04	3.14	3.12	3.13	3.14	3.15	3.14	3.17	3.16	3.12
2	3.12	3.14	3.13	3.14	3.15	3.12	3.13	3.14	3.12	3.15	3.13
3	3.01	3.00	3.04	3.05	3.06	3.01	3.00	3.02	3.08	3.01	3.03
4	3.03	3.03	3.04	3.06	3.07	3.05	3.02	3.04	3.02	3.06	3.04
5	3.04	3.03	3.05	3.07	3.10	3.05	3.05	3.00	3.03	3.07	3.05
6	3.03	3.03	3.03	3.07	3.07	3.03	3.03	3.03	3.02	3.05	3.04
7	3.05	3.03	3.02	3.03	3.07	3.04	3.03	3.03	3.02	3.04	3.03
8	3.17	3.17	3.18	2.90	3.17	3.18	3.17	3.17	3.19	3.16	3.15
9	3.19	3.15	3.07	3.06	3.18	3.16	3.17	3.10	3.16	3.16	3.14
10	3.18	3.17	3.18	3.17	3.16	3.17	3.18	3.17	3.18	3.18	3.17

Table A27 Thickness measurement of blended polymer of 95%UHMWPE and 5%LLDPE

No. of specimens Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	2.87	2.96	2.87	2.91	2.86	2.86	2.94	2.86	2.87	2.87	2.89
2	2.89	2.98	3.03	2.95	2.90	3.05	2.96	2.87	2.90	2.90	2.94
3	2.95	3.03	3.04	3.13	3.00	3.04	3.10	2.94	3.06	2.96	3.03
4	3.06	3.13	3.06	3.14	3.07	3.08	3.14	3.03	3.08	3.06	3.09
5	3.07	3.15	3.07	3.13	3.08	3.06	3.15	3.04	3.10	3.08	3.09
6	3.07	3.10	3.05	3.10	3.05	3.07	3.10	3.04	3.17	3.15	3.09
7	3.18	3.18	3.16	3.15	3.16	3.18	3.17	3.18	3.15	3.18	3.17
8	3.14	3.19	3.17	3.15	3.16	3.17	3.14	3.17	3.16	3.17	3.16
9	3.12	3.16	3.14	3.18	3.12	3.17	3.16	3.17	3.18	3.18	3.16
10	3.04	3.08	3.06	3.18	3.17	3.17	3.16	3.19	3.18	3.18	3.14

Table A28 Thickness measurement of 100%UHMWPE

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	2.86	2.96	2.87	2.91	2.86	2.86	2.94	2.86	2.87	2.87	2.89
2	3.26	3.25	3.03	2.95	2.90	3.05	3.20	3.25	2.90	2.90	3.07
3	2.95	2.60	2.60	3.12	3.15	2.89	3.10	2.94	3.06	2.96	2.94
4	3.06	3.13	3.06	3.14	3.07	3.08	3.14	3.03	3.05	3.06	3.08
5	3.07	3.15	3.07	3.13	3.08	3.06	3.15	3.00	3.10	3.08	3.09
6	3.07	3.10	3.05	3.10	3.05	3.07	3.10	3.04	3.06	3.05	3.07
7	3.06	3.06	3.25	3.18	3.17	3.18	3.17	3.18	3.12	3.17	3.15
8	3.17	3.18	3.18	3.12	3.14	3.17	3.18	3.14	3.14	3.18	3.16
9	3.17	3.17	3.19	3.17	3.17	3.19	3.17	3.17	3.17	3.18	3.18
10	3.18	3.19	3.17	3.16	3.17	3.18	3.17	3.17	3.18	3.16	3.17

Table A29 Tensile strength of composite polymer of 50%UHMWPE and 50%LLDPE using glass fiber as filler

Specimens	Tensile strength (MPa)
1	116.3
2	117.0
3	116.2
4	116.5
5	116.8
6	116.4
7	115.8
8	116.2
9	116.1
10	116.3
Average	116.4

Table A30 Tensile strength of composite polymer of 70%UHMWPE and 30%LLDPE using glass fiber as filler

Specimens	Tensile strength (MPa)
1	125.3
2	125.4
3	125.9
4	125.6
5	125.3
6	126.0
7	125.2
8	124.8
9	125.5
10	125.7
Average	125.4

Table A31 Tensile strength of composite polymer of 90%UHMWPE and 10%LLDPE using glass fiber as filler

Specimens	Tensile strength (MPa)
1	131.2
2	131.5
3	131.4
4	132.3
5	131.2
6	131.0
7	132.2
8	131.1
9	131.3
10	131.3
Average	131.4

Table A32 Tensile strength of composite polymer of 100%UHMWPE using glass fiber as filler

Specimens	Tensile strength (MPa)
1	135.2
2	134.8
3	134.9
4	135.0
5	135.0
6	135.1
7	134.7
8	135.3
9	135.2
10	135.0
Average	135.0

Table A33 Tensile strength of composite polymer of 50%UHMWPE and 50%LLDPE using talcum as filler

Specimens	Tensile strength (MPa)
1	114.8
2	115.2
3	115.3
4	114.7
5	115.8
6	115.0
7	115.6
8	114.9
9	115.2
10	115.3
Average	115.2

Table A34 Tensile strength of composite polymer of 70%UHMWPE and 30%LLDPE using talcum as filler

Specimens	Tensile strength (MPa)
1	120.3
2	119.8
3	119.8
4	119.7
5	120.5
6	120.8
7	120.6
8	120.3
9	120.1
10	120.0
Average	120.2

Table A35 Tensile strength of composite polymer of 90%UHMWPE and 10%LLDPE using talcum as filler

Specimens	Tensile strength (MPa)
1	126.2
2	125.9
3	125.2
4	125.4
5	125.2
6	125.2
7	125.3
8	125.3
9	125.4
10	125.1
Average	125.4

Table A36 Tensile strength of composite polymer of 100%UHMWPE using talcum as filler

Specimens	Tensile strength (MPa)
1	124.2
2	123.9
3	124.5
4	124.2
5	124.0
6	124.3
7	124.1
8	124.0
9	124.2
10	124.0
Average	124.1

Table A37 Impact strength of composite polymer of 50%UHMWPE and 50%LLDPE using glass fiber as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0124	1.22	98.39
2	0.0122	1.21	99.18
3	0.0124	1.22	98.39
4	0.0123	1.20	97.56
5	0.0123	1.21	98.37
6	0.0121	1.18	97.52
7	0.0123	1.21	98.37
8	0.0124	1.22	98.39
9	0.0122	1.22	100.00
10	0.0122	1.20	98.36
		Average Impact strength (J/m)	98.45

Table A38 Impact strength of composite polymer of 70%UHMWPE and 30%LLDPE using glass fiber as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0123	1.36	110.57
2	0.0120	1.31	109.17
3	0.0122	1.35	110.66
4	0.0119	1.20	110.82
5	0.0122	1.32	110.20
6	0.0120	1.33	110.83
7	0.0123	1.36	110.57
8	0.0118	1.31	111.02
9	0.0121	1.34	110.74
10	0.0123	1.33	108.13
		Average Impact strength (J/m)	110.27

Table A39 Impact strength of composite polymer of 90%UHMWPE and 10%LLDPE using glass fiber as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0123	1.40	113.82
2	0.0120	1.36	113.33
3	0.0120	1.36	113.33
4	0.0121	1.38	114.05
5	0.0121	1.38	114.05
6	0.0123	1.40	113.82
7	0.0117	1.32	112.82
8	0.0125	1.41	112.80
9	0.0121	1.38	114.05
10	0.0123	1.38	112.20
		Average Impact strength (J/m)	113.43

Table A40 Impact strength of composite polymer of 100%UHMWPE using glass fiber as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0123	1.38	112.20
2	0.0125	1.41	112.80
3	0.0120	1.35	112.50
4	0.0121	1.36	112.40
5	0.0121	1.36	112.40
6	0.0122	1.37	112.30
7	0.0123	1.38	112.20
8	0.0123	1.38	112.20
9	0.0120	1.35	112.50
10	0.0119	1.34	112.61
		Average Impact strength (J/m)	112.41

Table A41 Impact strength of composite polymer of 50%UHMWPE and 50%LLDPE using talcum as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0119	1.21	101.68
2	0.0118	1.20	101.69
3	0.0121	1.24	102.48
4	0.0122	1.23	100.82
5	0.0121	1.23	101.65
6	0.0120	1.21	100.83
7	0.0123	1.24	100.81
8	0.0122	1.24	101.64
9	0.0123	1.25	101.63
10	0.0125	1.25	100.00
		Average Impact strength (J/m)	101.32

Table A42 Impact strength of composite polymer of 70%UHMWPE and 30%LLDPE using talcum as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0118	1.24	105.08
2	0.0120	1.27	105.83
3	0.0121	1.27	104.96
4	0.0121	1.26	104.13
5	0.0120	1.26	105.00
6	0.0120	1.27	105.83
7	0.0124	1.30	104.84
8	0.0123	1.30	105.69
9	0.0122	1.28	104.92
10	0.0124	1.31	105.65
		Average Impact strength (J/m)	105.19

Table A43 Impact strength of composite polymer of 90%UHMWPE and 10%LLDPE using talcum as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0122	1.31	107.38
2	0.0122	1.33	109.02
3	0.0123	1.32	107.32
4	0.0124	1.32	106.45
5	0.0120	1.29	107.50
6	0.0121	1.29	106.61
7	0.0122	1.31	107.38
8	0.0122	1.31	107.38
9	0.0124	1.33	107.26
10	0.0123	1.32	107.32
		Average Impact strength (J/m)	107.36

Table A44 Impact strength of composite polymer of 100%UHMWPE using talcum as filler

Specimens	Thickness (m)	Impact force (J)	Impact strength (J/m)
1	0.0121	1.29	106.61
2	0.0122	1.30	106.56
3	0.0120	1.28	106.67
4	0.0120	1.28	106.67
5	0.0119	1.25	105.04
6	0.0122	1.29	105.74
7	0.0123	1.31	106.50
8	0.0120	1.27	105.83
9	0.0121	1.29	106.61
10	0.0123	1.31	106.50
		Average Impact strength (J/m)	106.27

Table A45 Thickness measurement of composite polymer of 50%UHMWPE and 50%LLDPE using glass fiber as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.16	3.15	3.14	3.15	3.14	3.15	3.15	3.15	3.15	3.15	3.15
2	3.15	3.14	3.15	3.15	3.15	3.14	3.14	3.15	3.15	3.15	3.15
3	3.15	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
4	3.16	3.15	3.15	3.15	3.15	3.15	3.16	3.15	3.15	3.14	3.15
5	3.15	3.15	3.15	3.15	3.16	3.16	3.15	3.15	3.15	3.14	3.15
6	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.14
7	3.16	3.15	3.16	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
8	3.15	3.14	3.15	3.15	3.15	3.15	3.15	3.16	3.15	3.16	3.15
9	3.16	3.16	3.16	3.15	3.16	3.16	3.14	3.16	3.16	3.14	3.16
10	3.14	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.16	3.15

Table A46 Thickness measurement of composite polymer of 70%UHMWPE and 30%LLDPE using glass fiber as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.15	3.14	3.14	3.14	3.13	3.14	3.14	3.14	3.14	3.13	3.14
2	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.15	3.14
3	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.13	3.14	3.14
4	3.14	3.14	3.13	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
5	3.14	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.14	3.16	3.15
6	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.15	3.14
7	3.13	3.15	3.15	3.15	3.15	3.15	3.15	3.14	3.15	3.14	3.15
8	3.14	3.16	3.14	3.14	3.14	3.14	3.14	3.14	3.13	3.13	3.14
9	3.14	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.15	3.15	3.14
10	3.13	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.13	3.14

Table A47 Thickness measurement of composite polymer of 90%UHMWPE and 10%LLDPE using glass fiber as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.14	3.14	3.14	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
2	3.13	3.13	3.13	3.14	3.13	3.13	3.13	3.13	3.13	3.12	3.13
3	3.13	3.14	3.13	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
4	3.14	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
5	3.14	3.14	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.14	3.13
6	3.13	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
7	3.13	3.14	3.14	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
8	3.13	3.13	3.14	3.13	3.13	3.13	3.13	3.13	3.14	3.14	3.13
9	3.13	3.13	3.13	3.14	3.13	3.13	3.13	3.13	3.12	3.13	3.13
10	3.13	3.14	3.13	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14

Table A48 Thickness measurement of composite polymer of 100%UHMWPE using glass fiber as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.12	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
2	3.12	3.12	3.12	3.13	3.12	3.12	3.12	3.12	3.13	3.13	3.12
3	3.13	3.12	3.13	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
4	3.12	3.12	3.13	3.13	3.13	3.13	3.13	3.13	3.12	3.13	3.13
5	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.13	3.12
6	3.11	3.12	3.12	3.12	3.12	3.12	3.12	3.13	3.12	3.13	3.12
7	3.12	3.12	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
8	3.12	3.12	3.12	3.12	3.12	3.13	3.12	3.12	3.12	3.13	3.12
9	3.11	3.12	3.12	3.13	3.12	3.12	3.12	3.12	3.12	3.12	3.12
10	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.11	3.11	3.12

Table A49 Thickness measurement of composite polymer of 50%UHMWPE and 50%LLDPE using talcum as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.14	3.15	3.15	3.15	3.14	3.15	3.15	3.15	3.15	3.15	3.15
2	3.14	3.14	3.14	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
3	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.13	3.13	3.14
4	3.16	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
5	3.15	3.15	3.15	3.15	3.14	3.15	3.15	3.15	3.15	3.14	3.15
6	3.14	3.14	3.14	3.14	3.14	3.15	3.14	3.14	3.15	3.13	3.14
7	3.15	3.15	3.15	3.15	3.15	3.14	3.15	3.15	3.15	3.14	3.15
8	3.15	3.15	3.15	3.15	3.15	3.15	3.14	3.15	3.15	3.15	3.15
9	3.16	3.16	3.15	3.16	3.16	3.16	3.16	3.16	3.15	3.16	3.16
10	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15

Table A50 Thickness measurement of composite polymer of 70%UHMWPE and 30%LLDPE using talcum as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.14	3.14	3.14	3.14	3.14	3.15	3.14	3.14	3.14	3.15	3.14
2	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
3	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.15	3.14
4	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
5	3.14	3.15	3.15	3.15	3.15	3.15	3.14	3.15	3.15	3.15	3.15
6	3.14	3.14	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14
7	3.15	3.14	3.15	3.15	3.15	3.15	3.14	3.15	3.15	3.15	3.15
8	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.15	3.14	3.14	3.14
9	3.15	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14
10	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14

Table A51 Thickness measurement of composite polymer of 90%UHMWPE and 10%LLDPE using talcum as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.14
2	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.15	3.15	3.14
3	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.15	3.14	3.14
4	3.14	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.16	3.15	3.15
5	3.15	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.13	3.14
6	3.14	3.14	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14
7	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.15	3.15	3.16
8	3.15	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
9	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.14
10	3.14	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14

Table A52 Thickness measurement of composite polymer of 100%UHMWPE using talcum as filler

No. of specimens / Positions of specimens	Thickness (mm)										Average thickness (mm)
	1	2	3	4	5	6	7	8	9	10	
1	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.14	3.13	3.14	3.13
2	3.14	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
3	3.14	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.14
4	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.14	3.14
5	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.14	3.13	3.13
6	3.15	3.15	3.15	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
7	3.14	3.14	3.14	3.14	3.14	3.14	3.15	3.15	3.15	3.14	3.14
8	3.15	3.14	3.14	3.14	3.14	3.15	3.14	3.14	3.14	3.14	3.14
9	3.13	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.13	3.14
10	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14

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