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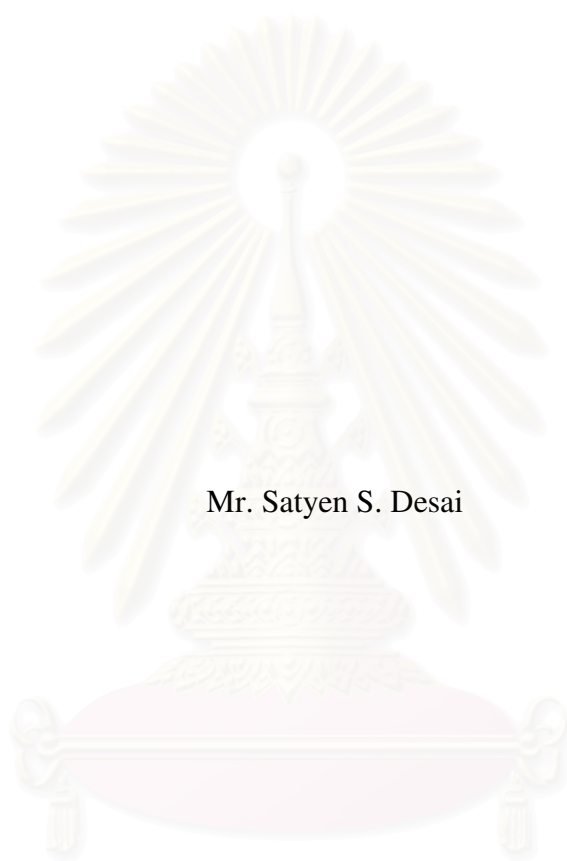
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EFFECTS OF ETHYLENE OCTENE COPOLYMER AND TALC ON MECHANICAL
PROPERTIES OF EXTRUDED POLYETHYLENE FOAM



Mr. Satyen S. Desai

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

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การผสมแอลคิพีอีและเอทิลีน-ออกทีน โคพอลิเมอร์ (อีไอซี) โดยใช้เครื่องอัดรีดขึ้นรูป แบบแทนเต็ม สัดส่วนโดยน้ำหนักของเอทิลีน-ออกทีน โคพอลิเมอร์อยู่ในช่วง 5-25% พบว่าสมบัติเชิงกลได้แก่ สมบัติทนแรงดึง อัตราการยืดออก การทดสอบโดยการกดและการทนแรงกระแทกจะเพิ่มอย่างสม่ำเสมอ แต่จะลดต่ำลงที่ 20% ของอีไอซี การเพิ่มปริมาณทัลค์ จาก 0.5 -1.0% โดยน้ำหนักทำให้จำนวนเซลล์และความหนาแน่นของเซลล์เพิ่มขึ้น ซึ่งมีผลต่อสมบัติเชิงกลของโฟมผสมที่ดีขึ้น ได้ทดสอบสมบัติการไหลของพอลิเมอร์ผสมที่มีปริมาณของอีไอซีอยู่ในช่วง 15-25% เพื่อศึกษาความสัมพันธ์ระหว่างแรงเฉือนและอัตราการยืดออกกับปริมาณอีลาสโตเมอร์และผลของลักษณะคายต่ออัตราส่วนแอลคิพีอี พบว่าเมื่อปริมาณอีลาสโตเมอร์เพิ่มขึ้น แรงเฉือน แรงเค้น และความหนืดจะเพิ่มขึ้นที่อัตราเฉือนคงที่ การทนแรงดึงต่ออัตราการยืดออกเพิ่มขึ้นแบบไม่เป็นเส้นตรง พบว่าเบลนด์ที่มีอีไอซี 20% มีค่าการทนแรงดึงต่ำกว่าเบลนด์ที่มีอีไอซี 15% และ 25% ซึ่งอาจเนื่องมาจากระบบของเบลนด์ที่มีอีไอซี 20% ไม่ผสมเป็นเนื้อเดียวกัน

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สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์ ลายมือชื่อนิติศ.....
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LDPE/EOC BLENDS

SATYEN S. DESAI : EFFECT OF ETHYLENE OCTENE COPOLYMER AND
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The blends of LDPE and Ethylene-Octene copolymer (EOC) were prepared using tandem extruder. The weight fraction of EOC in the blends was varied in the range of 5-25%. Two sets of the blended foams with talc 0.5% and 1.0% was investigated. Regardless of the amount of talc content in the blends, the mechanical properties of blends such as tensile strength, elongation, compression strength and impact strength show a steady increase with higher EOC content, except at 20% of EOC content. Increase in the amount of talc from 0.5% to 1.0% also leads to the increase in cell number and density which leads to the increase in mechanical properties of the blended foams. At the talc content 1.0% in the blends, rheological properties of blends with 15-25% of EOC were determined. The shear and elongation behavior were analyzed in terms of elastomer amount and effect of die geometry on L/D ratios. It was found that an increasing amount of EOC in the matrix, the real shear stress and the viscosity were increased at the same shear rate. On the other hand, the tensile stress on the elongation rate exhibited increasing non-linear manner. It was found that the blend with 20% EOC content has lower tensile stress than those with 15% and 25% of EOC. This might be due to incompatibility of the blend system at 20% EOC content.

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ABBREVIATIONS

$^{\circ}\text{C}$:	Degree Celsius
mm	:	Millimeter
m	:	Meter
kg	:	Kilogram
dg	:	Deci gram
L/D	:	Length / diameter
gf	:	Gram force
Hz	:	Hertz



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CHAPTER I

INTRODUCTION

Polyolefin are tough, flexible, and resistant to chemicals and abrasion. Foams made from polyolefin inherit these properties. Although classified as semi rigid foams, polyolefines foams are in general, firmer than flexible polyurethane foams. Most polyolefin foams have a closed cell structure, which makes them suitable for application where it provides resiliency for packaging applications. In addition polyolefin foams are used in construction, automobiles, insulation, sports, leisure and agriculture.

The numerous flexible and semi rigid foams of elastomer provide a broad spectrum of performance characteristics adaptable to consumer needs. From the performance point of view comfort durability and appearance while parameters such as cost weight compression resistance, rebound and modulus are more readily evaluated. At comparable densities the blend would give better properties than normal PE foam.

Commercial LDPE foam does not offer sufficient flexibility and water absorption compared to crosslinked foam. Crosslinked foam are costly and cannot be recycled. So to blends of LDPE and EOC foam would give comparable cost and properties with respect to crosslinked foam.

The global consumption of polyolefin is exceeding 170,000 MT per year. The packaging application sector has seen the greatest growth and the highest demand, but demands in other market is also substantial.

1.1 Objectives

- 1) To compare the mechanical properties of the foam which is made of LDPE and the blend of LDPE and ethylene octene copolymer.
- 2) To study the rheological properties of blends.

1.2 Scope of the research

- 1) To prepare foam sheets containing different composition, of elastomer and talc proportion.
- 2) To determine mechanical properties of foam.



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CHAPTER II

THEORY AND LITERATURE REVIEW

2.1 Theory

The most widely used system of producing foamed polymers involves dispersing a gas throughout a fluid polymer phase and stabilizing the resultant foam. In most of these systems the foam is expanded by increasing the bubble size before stabilizing the system. Foams produced by this dispersion process include several major types:

- 1) Thermoplastic polymers, which are formed first as solids then melted to provide the fluid phase, foamed, and then cooled to solidify and thus stabilize the foam.
- 2) Thermoset foam systems, in which the reactants are foamed while only partially reacted and are still fluid, followed by curing to the thermoset state to stabilize the foam.
- 3) A latex that is foamed and then stabilized by phase inversion, achieved by lowering the pH, freezing, or both, frequently with additional curing in the foamed state.

The gas that may be used for foaming may be derived from any of a number of sources: air may be whipped into the liquid, as in the frothing of latex's; gas such as carbondioxide may be dissolved in the liquid, often under pressure, and may be brought out of solution for foaming by reducing the pressure or by heating the solution; a low boiling liquid such as pentane or fluorocarbon may be dissolved in the polymer and then converted to gas by heating or by reducing the pressure; or gas may be generated by a chemical reaction, such as the reaction of an isocyanate with water, or the decomposition of azocarbonamide.

The bubbles that are formed initially may grow by diffusion of gas from solution into the bubbles, by expansion due to the heat or pressure reduction, or by the combination of two or more bubbles. If the cell membrane surrounding the bubble

remain intact, the foam is called closed cell foam. If the cell membranes rupture, some or all of the cells will be open. Extensive rupture before the foam is stabilized may lead to foam to collapse. Cooling of closed-cell foam before stabilization may lead to shrinkage, because of the reduced pressure in the cells.

There are types of foams prepared by processes not involving the direct dispersion of a gas in a fluid phase. These may be prepared by leaching of fugitive phase, such as a water-soluble salt, from a polymer; by sintering small particles dispersed in a heat stable matrix; by fusing initially discrete polymer particles, which entrap air or other gases; and by forming a polymer matrix around hollow spheres. The first three of these methods generally give open-cell foams, while the last type usually gives closed cell foams. These processes do not have the same steps of gas dispersion, bubble growth and stabilization as do the dispersion process, but utilize relatively straight forward chemical processes.

2.2 Fundamental principle of foam formation

2.2.1 Bubble formation

The first step in producing foam is the formation of gas bubbles in a liquid system. If the bubbles are formed in an initially truly homogenous liquid process is called self nucleation. If a second phase is initially present, especially if it is in the form of finely divided solids, the bubbles are said to form by a nucleation process, and the solid particles are called nucleating agents. In many processes without solid nucleating agents the liquid phase actually contains many microbubbles of air, and they serve as sites for bubble growth, with the formation of new bubbles of air, and they serve as sites for bubble growth, with the formation of new bubbles not being necessary. In still other cases, well-dispersed materials that locally depress the surface tension of the liquid, such as by forming many hot spots during exothermic reactions, many serve as nucleating agents. Mechanical agitation of the liquid may also be used to aid in bubble formation, as in the frothing of latex systems.

The formation of bubbles in a liquid requires an increase in the free energy of the system, ΔF

$$\Delta F = \gamma \cdot A$$

Where γ is the surface tension of the liquid and A is the total interfacial area. Thus lowering the surface tension at the site of the bubble formation will make it easier to form that bubble. Emulsifiers, wetting agents, and certain silicone oils lower the surface tension of many fluids, thus assisting in the formation of bubbles. Nucleating agents may be especially effective by providing significantly reduced surface tension at the interface between the liquid and a solid particle, or by actually having voids at this interface. The presence of voids here, or of dispersed microbubble of air, eliminates the need for the foaming gas to separate liquid from itself to form a bubble. Instead, the foaming gas can come out of solution, into the void or microbubble, and simply grow a larger bubble without having to form a new bubble.

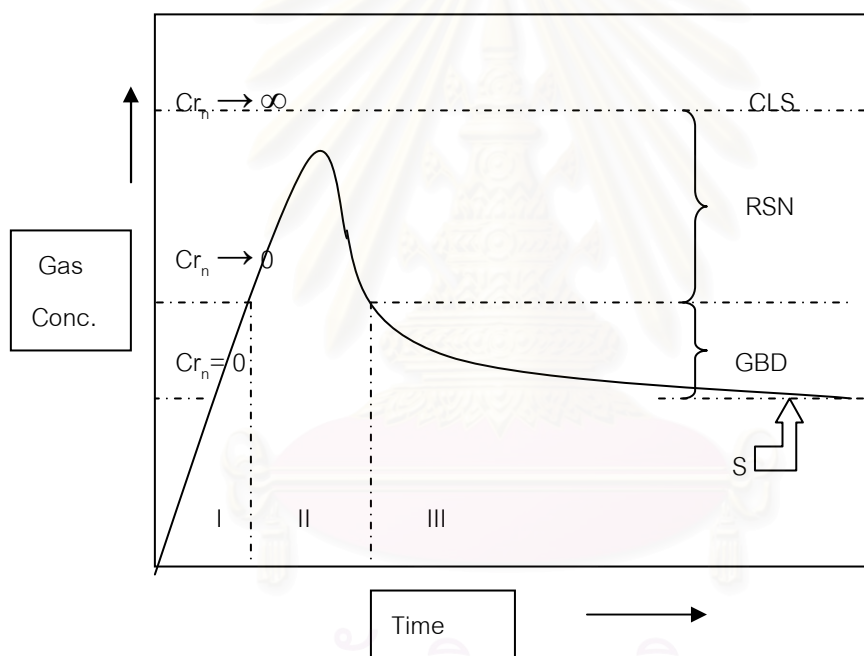


Figure 1 : Relationship between changes in gas concentration in solution and nucleation and growth of foam cells.

Cr_n = Nucleation Rate

GBD = Growth by diffusion

CLS = Critical Limiting Supersaturation

RSN = Rapid self nucleation

S = Saturation

From the Figure. In zone 1, the concentration of gas in solution rises until it exceeds the equilibrium saturation concentration, S , and, with more gas generation occurring (such as by chemical reaction or by heating a solution containing a low-boiling solvent), reaches the concentration where self-nucleation begins (region RSN). As long as the gas concentration is kept in the critical region (zone 2), self nucleation will occur. When enough bubbles have been formed to reduce the gas concentration in solution below the level where self-nucleation occurs, no more bubbles can be formed, but gas will still diffuse from the solution into the existing bubbles, causing them to grow in size (zone 3, region GBD). Bubble growth will continue until the gas concentration in solution has been reduced to the saturation level S .

Apparently it is very difficult to produce foams by self-nucleation process. Most successful foam systems are thought to contain either nucleating agents or dispersed micro voids.

In the case where a large number of micro voids are present initially, no new bubble formation may be necessary, but as the gas concentration exceeds saturation, as toward the end of zone 1, gas will not occur in this case, but cell growth by diffusion (zone 3) will continue until the super saturation is relieved.

2.2.2 Bubble Growth

The bubble once formed may grow by diffusion of gas from solution in the liquid phase into the bubble. The system will be more stable with fewer larger cells than with smaller cells. At equilibrium the gas pressure in a spherical bubble is larger than the pressure in the surrounding fluid, as given by

$$\Delta p = 2\gamma / r$$

Where r is the radius of the bubble. It also follows that the gas pressure in a small bubble is greater than large bubble, with reference to equation

$$\Delta p_1^2 = 2\gamma (1/ r_1 - 1/ r_2)$$

Where Δp_1^2 is the difference in pressure between the two bubbles having radii r_1 and r_2 . Thus gas will tend to diffuse from the smaller bubble into the larger one.

Both of the factors favor the loss of fine bubbles and the increase in size of larger bubbles, give sufficient time.

In the early stages of foaming when the gas volume is small, bubbles are spherical in shape. As the bubble volume grows, however, the fluid phase becomes insufficient to maintain the spherical shape, so the bubbles take on polyhedral shapes, with the fluid distributed in thin membranes between two adjacent bubbles, and in ribs or stalks where three bubbles have come into very close proximity. When bubbles grow enough to give low-density foams, the typical shapes are dodecahedrons, with many four and five-sided membrane separating the cells.

Amon and Denson studied the dynamics of foam growth and developed a model for the growth of a spherical bubble surrounded by a thin shell of liquid (29). They concluded that surface tension and initial radius were of less importance than the thermodynamic driving force, mass and momentum transfer. Han and Yoo have reviewed much of the research on bubble growth, and have applied fundamental principles to an analysis of the special case of bubble growth, during the filling of molds isothermally (30).

2.2.3 Bubble stability

To have relatively stable liquid foam, one must have at least two components in the liquid, with one preferentially adsorbed at the surface. The surface tension is controlled by the type and concentration of this adsorbed solute.

The temperature of the foam can affect stability; an increase in temperature reduces both viscosity and surface tension, making the thinning of membranes easier, and potentially leading to the rupture of membranes that are too thin to withstand existing stresses. Conversely, a rise in temperature also increases reaction rates, which can be favorable in those foams where ultimate stabilization depends on further polymerization. In certain cases the surfaces of a very thin film attract each other by van der Waals forces, also favoring continued thinning.

Two additional forces work to help stabilize liquid foams. The rupture of film requires very small activation energy because of the initial increase in area where the rupture starts. Once rupture has occurred, however, it progresses very rapidly in liquid films.

Shrinkage usually occurs in closed cell foams when a partial vacuum develops inside the cells at a time when the cell structure is not strong enough to resist the excess pressure of the atmosphere over that within the cells. Open cell foams do not have

this pressure differential and hence do not shrink unless some morphology memory favors a less expanded volume, and the modulus in the fully expanded state is not sufficient to maintain that state. During the initial foam rise the cells are closed. Closed cells become open when one or more membranes rupture, usually due to excessive thinning so that the strength of the membrane cannot resist the pressure in the cell. A critical element in producing open-cell foams is to adjust the foaming rate and the rate of stabilization so that at the peak of the foam rise many cell membranes are thin and rupture, but the ribs of the cells are strong enough to stop rupture. If the ribs could not stop the rupture, large voids would occur in the foam or the foam would collapse.

Closed cell foams are produced when the cell membranes are sufficiently strong to withstand rupture at the maximum foam rise, and the modulus of the polymer is increased rapidly to a high level so that the cells are dimensionally stable in spite of the development of a partial vacuum within the cells. Shrinkage is especially difficult to overcome in low-density, flexible and semi-flexible closed-cell foams.

2.3 Blowing agents for foamed polymers

The various components used in the foaming polymers may be classified in several ways. The most general classification is based on the mechanism by which gas is liberated by these compounds, called blowing agents.

2.3.1 Chemical blowing agents

These are individual's compounds or mixtures of compounds that liberate gas as a result of chemical reactions, including thermal decomposition, or as a result of chemical reactions of chemical blowing agents or interactions of chemical blowing agents with other component.

Chemical blowing agents include those compounds that undergo chemical transformation during the process of foaming; among the physical agents are the compounds not subjected to chemical transformation. In this case, gases used for foaming are classified as physical blowing agents.

Properties of Chemical Blowing Agents

Chemical blowing agents are easily processed with ordinary equipment.

The requirements for chemical blowing agents are

- 1) The temperature of decomposition of chemical blowing agents must be close to the melting point and hardening temperature of the polymer.
- 2) Gas must be liberated within certain narrow temperature range.
- 3) The rate of gas liberation must be adequately high, and must be controllable by temperature, pressure, and the decomposition of activators.
- 4) The gas liberated and the products of its decomposition must be non corrosive, nontoxic, and nonflammable; compounds that liberate nitrogen or carbon dioxide are preferable.
- 5) The chemical blowing agents and the gas liberated must readily disperse or dissolve in the polymer composition.
- 6) The decomposition of chemical blowing agent must not be accompanied by the release of so much heat that or cause destruction of the matrix.
- 7) The rate of liberation of gas must not decrease appreciably during the process of thermal decomposition of the chemical-blowing agent as the internal pressure in the system increases.
- 8) Under normal conditions, the gases liberated during decomposition of the chemical blowing agent must have a low rate of diffusion in the polymer, that is, they must stay in the mass being foamed for a rather long time.

2.3.2 Physical blowing agents

These are compounds that liberate gases as a result of physical processes at elevated temperatures or reduced pressures physical blowing agents do not undergo chemical transformation themselves, and most are liquids. Usually they are gases that are introduced directly into polymer composition for the purpose of forming the cellular structure.

Properties of Physical blowing agents

They are low-boiling volatile liquids such as aliphatic and halogenated hydrocarbons, low boiling alcohol's, ethers, ketones, aromatic hydrocarbons and solid absorbents saturated with gases or low boiling liquids.

The ideal requirement must be as follows

- 1) It must be inert in the liquid phase; that is, it must not affect the physical and chemical properties of polymers and other components of the formulation.
- 2) It must be soluble in or mix readily with the foaming formulation.
- 3) In the gaseous state it must be thermally and chemically inert.
- 4) It must have low vapor pressure at room temperature.
- 5) It must be highly volatile under the action either of external heat or of reaction heat, and must have a low heat capacity and low latent heat of gas formation.
- 6) In the gaseous form it must have a lower rate of diffusion in polymer than air.
- 7) It must not be corrosive, neither flammable or combustible.

Volatile liquids are the most important groups of physical blowing agents. Liquids of low volatility are used in the production of foams. When the compounds of low volatility are used to foam polymers, the negative heat effect resulting from the latent heat of vaporization must be considered. That is why these compounds are very convenient for making large sized and thick walled articles. Liquids of low volatility are widely used as physical blowing agents in the production of foams.

Freons (Chlorofluorocarbons, CFCs)

Freons are mostly used in the production of foamed polyurethanes. Freon 11 and Freon 113 in concentrations of 5-10 wt % are also used for foaming polystyrene and polyethylene.

The extensive use of freons as physical blowing agents is due to their incombustibility, low toxicity, low diffusion coefficients in polymer films, and low coefficients of thermal conductivity than air and other gaseous compounds.

The low coefficient of thermal conductivity lead to a highly adiabatic foaming process, and consequently makes it possible to control the process precisely. It also results in foams with excellent insulating properties.

Freons however are gradually being phased out as blowing agents, as well as in other application, because of the ozone depletion problem. It has been generally accepted that freons do react with and destroy ozone in the stratosphere, resulting in an increase in harmful ultraviolet radiation in the 290-320 nm region that is the region with the most harmful affects for human health. In addition, these molecules also contribute to the green house effect when they reach stratosphere because they are good thermal insulators.

Aliphatic Hydrocarbons

Aliphatic Hydrocarbons form C5 to C7 obtained from low boiling petroleum fractions are widely used as physical blowing agents. These hydrocarbons are readily available and have low toxicity. A liquid physical blowing agent is introduced either under pressure at the stage of processing into a polymer melt.

2.4 Selection of foaming agent.

The type of blowing agent used in the plastic processing is critically important in determine morphology of produced foams. Typically a physical-blowing agent is used for the low density foam processing without crosslinking where as chemical blowing agent is used for the low-density foam processing that involves crosslinking. Low density foams with a volume expansion ratio higher then 40 uses environmentally hazardous blowing agent such as CFC, HFCFC etc in extrusion foam processing. While blowing agent such as pentane and butane is used in low density foam processing, where expansion ratio is less the 40.

In order to determine the type of blowing agent to be used in processing the maximum achievable theoretical volume expansion ratios of pentane and butane were

calculated based on 5-wt % of blowing agent. The maximum theoretical volume expansion ratio of extruded foam can be calculated as

$$V_t = \text{Polymer volume} + \text{Gas Volume} / \text{Polymer Volume}$$

$$V_t = 1 + m_{\text{gas}} / m_p * V_{\text{gas}} / V_p$$

Where V_{gas} is the specific volume of blowing agent at the crystallization temperature of LDPE materials and V_p is the specific volume of LDPE material at room temperature. The specific volume of pentane and butane are $430 \text{ cm}^3/\text{gm}$ and $600 \text{ cm}^3/\text{gm}$ respectively and the maximum theoretical expansion ratio are 21 and 30 respectively at 5 wt % of blowing agents.

2.5 Selection of polymer.

Among polyolefin resin, LDPE is the most suitable for the extrusion process as the polymer can be make foams having a wide range of densities ($19 - 150 \text{ kg/m}^3$). Linear polyolefines are difficult to extrude to low density foams; due to their low extensional viscosity and heat diffusion.

While the extensional viscosity of a polymer determines bubble stability the shear viscosity of a polymer affects extrusion rate and the dispersion of blowing agents in the primary extruder. The shear viscosity of the mixture of polymer and blowing agents affects the heat transfer in the secondary extruder, and the pressure inside the die. The blowing agent plasticizes the polymer; thereby reducing it's viscosity.

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2.6 Literature Survey

Comparison to the other kind of crosslinked thermoset foam recyclable polyolefin foam is environmental friendly material but it increases the degree of foaming (expansion ratio) in the foam extrusion process. It was revealed that the degree of foaming and the size of the gas bubbles was directly related to the melt tension of the polymer melt regardless of the structure and the molecular weight of the polymer resin and the temperature of the polymer melt. This implies that the ability to sustain the cell in the melt state is critical foaming parameter in the extrusion process (1). Previous study on the batch processing and the characterization of microcellular foamed high-density polyethylene (HDPE/iPP) reports that the cell density is greater than 10^9 cells/cm³ and fully-grown cells smaller than 10 micrometer. The study also shows that the morphology and the crystallinity of semi crystalline polymers have a great influence on the solubility and diffusivity of the blowing agent on the cellular structure of the foam (2).

Research on effective means for the control of cell growth to achieve a desired expansion ratio and prevention of cell coalescence in HIPS foam was observed by tailoring the extrusion processing parameters and cell density of 10^{10} cells/cm³ was observed and the expansion range of 1.5 to 23 was obtained(3).

It was studied that escape of blowing agent from the foam cause to contract and have low expansion. To promote the large volume expansion ratio the strategies were as follows 1) To use a branched material for preventing cell coalescence to use a long chain blowing agent with low diffusivity 2) To lower the melt temperature for decreasing gas loss during expansion and 3) To optimize the processing condition in the die for avoiding too rapid crystallization, use of branched PP resin was required to achieve large volume expansion because prevention of cell coalescence will retard gas loss from the extruded foam of the environment (4).

The final volume expansion ratio of extruded PP foams blown with butane was governed by either the loss of the blowing agent or the crystallization of the polymer matrix. A charge coupling device (CCD) camera was installed at the die exit to monitor the shape of the extruded PP foam. It was found that the gas loss mode was dominant at high temperature and the crystallization mode was dominant at low temperature. When the gas loss mode was dominant the volume expansion ratio increased with decreasing temperature because of the reduced amount of gas loss. By

contrast when the crystallization mode was dominant, the expansion ratio increased with increasing temperature because the delayed solidification of the polymer (5).

The principle of the basic extrusion system design is to shape a nucleated polymer/gas solution flow under pressure and accurate temperature control. In this way the initial cell growth is controlled so as to prevent degradation of nucleated cell density during shaping (6).

The cell density of the foam increases with increased amount of blowing agent for both carbon dioxide and isopentane. The cell morphology for the two (linear and branched) PP were found to be significantly different. A slightly lower nuclei density was observed in branched PP foams than in the linear pp. Branched PP has closed cell while linear PP showed connecting cells. This indicates that the branched structure play an important role in cell morphology through its effect on the melt strength and melt elasticity (7).

Comparison of the tensile and rheological properties of ethylene/ethylene octene copolymer shows that increasing the fraction of copolymer in the blend results in a decrease in its stiffness. However the energy dampening properties of these blends benefit from the presence of the copolymer (8).

As talc is used as the nucleating agent it was found that expansion curve moved towards low temperature, indicating that the expanded foams of high talc content were more susceptible to gas loss. This change was analyzed by CCD camera of the extruded PP foam (9). Increase in the nucleating agent from 1% and above made a very fine cell structure in the polymeric foam but this tends to decrease in the amount of the blowing agent since very fine nucleates in the polymeric foam is formed the polymer does not have a tendency to absorb gas as the cell are quite closed to each other and this increases the density of the product (10).

Increase in the amount of elastomer produces the melt that is too viscous and very difficult to extrude using the present equipment generally elastomeric foam are made by different process called blown sponge and latex foam (12).

Increase the amount of lubricating agent above the specified limit produces the irregular flow of the polymer due to slippage of the blend. The purpose of the lubricant is internal as well as external lubricant.

Rheological behavior of polymeric melts is an important aspect for predicting flow field within the melts during processing, and has a strong influence on the final

properties of the articles after solidification. Studies related to rheological behavior on pure polymeric melts has been well documented, while such studies on molten polymer blends are quite limited, but indispensably important (13). Blend properties have shown strong dependence on characteristics of each pure component, e.g. the viscosity ratio and the interfacial adhesion between the disperse phase and the matrix (14). Capillary rheometer is the most common technique used to determine deformation of polymeric melts under shear flow (15). It can also be used to evaluate the elastic effect such as die or extrudate swell behavior (16). A number of studies have reported the extrudate swell as a function of the length-to-diameter ratio (L/D) of the die, the pressure drop across the die, entry angle of the die, shear stress, shear rate, and so on (17-20).

Elastomeric polyolefins are suitable materials for foam extrusion, e.g. profile extrusion of tubing and hose, due to their excellent properties such as excellent toughness, good flexibility, and good transparency (21). Due to its long branching units among the various elastomeric polyolefins, ethylene-octene copolymer (EOC) has been shown to provide the lowest glass transition temperature (T_g) and the least apparent degree of crystallinity, thus the greatest toughening contribution, in comparison with other elastomeric polyolefins, such as ethylene-propylene or ethylene-butadiene copolymer (22).

Moly et al. (23) studied the elastic behavior and extrudate swell of molten linear low-density polyethylene (LLDPE)/ethylene-vinyl acetate (EVA) blends and reported that the extrudate swell increased with increasing shear rate and elastomer content, and that a critical shear rate was observed at the onset of the melt fracture. Liang (24) investigated the elastic behavior of low-density polyethylene (LDPE)/LLDPE blends by capillary extrusion and found that the extrudate swell increased linearly with increasing wall shear stress and the entry pressure drop and decreased with increasing the die length-to-diameter ratio and that a maximum in the extrudate swell was observed at a 50:50 w/w blend ratio. McNally et al. (22) showed that the viscosity values of isotactic polypropylene (iPP)/EOC blends followed the prediction by the log additive principle and the blends showed partial miscibility only when the EOC content was 10 wt.% or less. Silva et al. (13) studied rheological behavior of iPP/EOC and iPP/ethylene-propylene-diene copolymer (EPDM) and showed that, at high shear rates, both types of blends presented similar rheological

behavior, possibly due to the alignment of the EOC branches. Nayak et al. (25) studied the rheological behavior of both neat and precipitated silica-filled EOC vulcanized with addition of a blowing agent and showed that incorporation of the blowing agent led to decreased shear-thinning behavior resulting in an increase in the power-law index. Power law index is also called the pseudoplasticity index. The power law equation was applied to express the rheological behaviour of the system for instance.

$$\tau = \kappa(\dot{\gamma}_{wa})^n$$

τ = shear stress

$\dot{\gamma}$ = shear rate

The linear regression analysis was applied for the plot of shear stress and shear rate to obtain slope n and intercept k . the power law index was plotted against blowing agent at different temperature. They found that increase in power law index value with an increase in blowing agent.



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CHAPTER III

EXPERIMENTAL MATERIALS

3.1 Materials

The material used in the study was commercial Low density Polyethylene (LDPE) JJ 4324 of density 0.931 gm/cm^3 and melt flow index of 5.50 gm/10min supplied by Thai Petrochemical Industry (TPI). Engage 8450 EOC the copolymer of ethylene-octene with 17 % of comonomer content was provided by Dupont Dow Elastomers (Tokyo, Japan) with melt flow index 1.0 dg/min and density of 0.908 g/cm^3 . Nucleating agent (Talc), lubricating agent, glycerol monostearate (95%) was provided by Riveta Malaysia Sdn Bhd. Blowing agent (LPG) from PTT petroleum.

3.2 Instruments

1. Tandem extruder.
2. Constant injection gas pump.
3. Tumbler mixer
4. Universal testing machine.
5. 4X microscope.
6. Compression testing machine.
7. Analytical balance
8. Thickness gauge
9. Volume displacement equipment.
10. Falling dart impact tester.

3.3 Method of Preparation.

The low density PE foam is prepared by extrusion process which employed a volatile organic blowing agents. The expansion process involves three fundamental steps, bubble initiation(nucleation), bubble growth and stabilization. Nucleation (formation of expandable bubbles) begins at a initiation site within a polymer melt that has been supersaturated with blowing agent.

Table 2 : Composition of LDPE/EOC/Talc/Wax for foam sheet in set 2.**Set 2**

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Name	F21	F22	F23	F24	F25	F26
LDPE	98.5 %	93.5 %	88.5 %	83.5 %	78.5 %	73.5 %
Elastomer	0 %	5 %	10 %	15 %	20 %	25 %
Talc	1.0 %	1.0 %	1.0 %	1.0 %	1.0 %	1.0 %
Wax	1.0 %	1.0 %	1.0 %	1.0 %	1.0 %	1.0 %

3.4.1 Extrusion process

A conventional extruder is modified to mix in the blowing agent and to cool the melt to the optimum foaming temperature. A VOBA is injected under pressure into the mixing section of the extruder, where it is homogeneously mixed with the molten polymer. The mixture is then cooled to lowest permissible temperature (the foaming temperature) and extruded out through the die orifice. The cells are nucleated as the melt is decompressed during it's transit through the die land; the cells grow rapidly as the melt leaves the die. The foamed body is then cooled and aged. The unit process involve in the foam extrusion process were as follows.

- 1) Plasticizing and pumping of the base polymer
- 2) Dispersing and solubilizing blowing agent in the polymer melt.
- 3) Cooling the resultant mixture to a uniform low temperature.
- 4) Shaping the melt through a die orifice sized to build a sufficient die pressure to prevent prefoaming.
- 5) Expanding the melt to stable cellular structure.
- 6) Cooling and aging the foam to a dimensionally stable body.

The extrusion temperature profile and other parameters are as follows

Extruder 1

Zone 1 : 165 °C

Zone 2 : 175 °C

Zone 3 : 180 °C

Zone 4 180 °C

Zone 5 : 185 °C (Screen Changer)

Extruder 2

Zone 6 : 160 °C

Zone 7 : 135 °C

Zone 8 : 115 °C

Zone 9 : 95 °C

Zone 10 : 93 °C (Die Head)

Pressure Primary Extruder : 90 Kg/cm²

Pressure Gas pump (Injection) : 70 – 110 Kg/cm²

Pressure Secondary extruder : 80 Kg/cm²

Gas injection rate 32 Hz.

Screw Speed primary 55 Hz.

Screw Speed Secondary 32 Hz.

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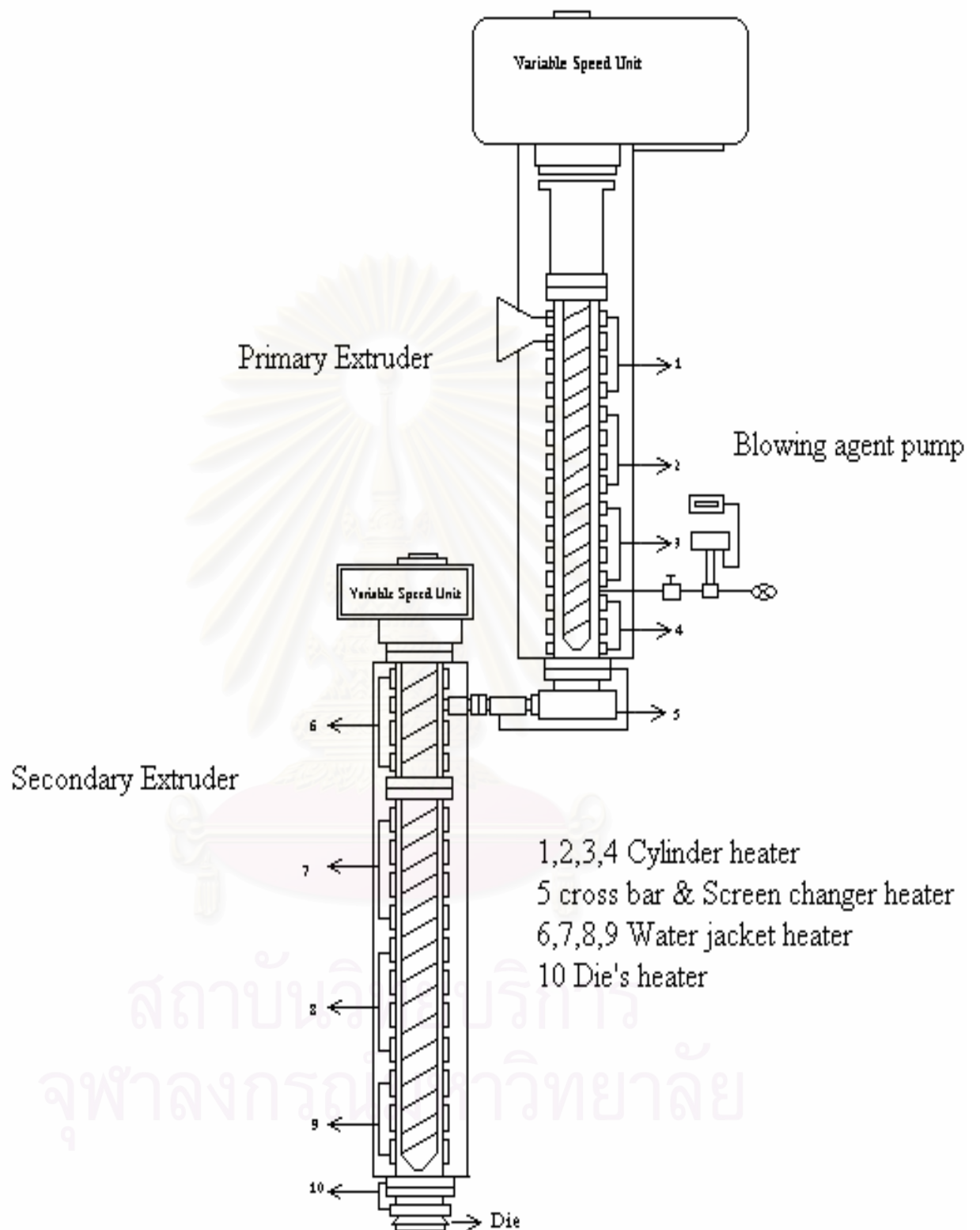


Figure 2 Schematic diagram of tandem extruder.

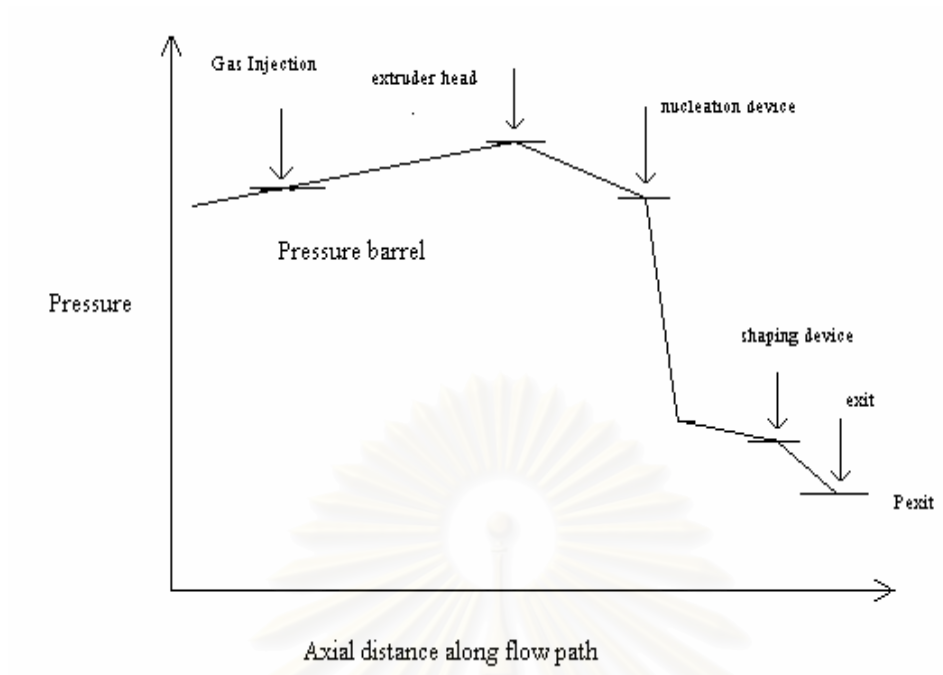


Figure 3 Pressure Vs Flow profile.

3.5 Rheological Properties

Blend preparation for rheological properties

The blend containing LDPE, EOC, Wax, Talc as shown in Table 3 is premixed in tumbler mister before feeding to twin screw extruder.

Table 3 : Composition of LDPE/EOC/Talc/Wax for Rheology

	Sample 1	Sample 2	Sample 3	Sample 4
LDPE	98.5 %	83.5 %	78.5 %	73.5 %
Elastomer	0 %	15 %	20 %	25 %
Talc	0.5 %	0.5 %	0.5 %	0.5 %
Wax	1.0 %	1.0 %	1.0 %	1.0 %

The pre-mixed compound were then fed in to a Collin ZK25 self wiping, co-rotating twin screw extruder operating at a screw speed of 70 rpm and a temperature profile of

Feed Zone : 80 °C

Zone 1 : 150 °C

Zone 2 : 160 °C

Zone 3 : 170 °C

Zone 4 : 185 °C

Die : 185 °C

The extrudate was cooled in the water and cut in to pellet form by planetrol 075D2 Pelletizer.

3.5.1 Rheological measurements

CEAST twin bore capillary rheometer, the dimension of instrument used was 9.95, 300 mm diameter and length of the barrel, the die series were 5/1, 10/1,10/2, and 30/2 mm of die length and diameter. The temperature used was 185 °C. The accuracy of the temperature was ± 0.5 °C, the hold on time and hold on pressure for stages 1, 2, and 3 were 200 second and 10, 20, 30 Pascal, respectively. The die swell measurement was measured by the laser analysis (KEYENSE VG036T) which included, a laser source directly light transfer to cover the extrudate diameters, the receiver accepts the signals and the data was analysed by computer program.

3.6 Characterization of foams

The volume expansion ratio and the cell population density were the structural foam parameters to be measured. The density of foam was determined by measuring the weight and the volume of the sample. The volume was measured accurately by volume displacement test.

The cell population density was calculated as the number of cells per unit area is calculated.

3.7 Mechanical Properties

3.7.1 Tensile Strength & Elongation (JIS K 6767)

The mechanical test of compression and tensile were carried out at room temperature using universal testing machine with a constant crosshead speed of 500 mm/min. For tensile test the sample was cut into dogbone shape specimen.

Temperature : $20 \pm 2^{\circ} \text{C}$

Relative Humidity : $65 \pm 5 \%$

3.7.2 Compression Test (UL Standard)

It was difficult to perform the compression test according to the standard test method because samples are very thin, specifically the foam samples were cut into square pieces with dimension of 4 inch * 4 inch. The thickness was accurately determined using a thickness gauge. The compression machine gently compressed the sample at the minimum rate of approximately 0.5 to the maximum of approximately 2 inches per minute was used. The machine equipped with a hand gauge to measure the deflection; and load required to compress the sample to 75 percent of the original thickness was found out.

3.7.3 Impact Strength (ASTM D 1709 – 01)

In this test the energy that cause to fail the specimen under specified conditions of impact of a free – falling dart. The energy expressed in terms of the weight (mass) of the missile falling from a specified height would result in 50 % failure of specimen test.

Dart size: 50.80 ± 0.13 mm diameter.

Height: 1.50 ± 0.03 m

Temperature: $23^{\circ} \pm 2^{\circ} \text{C}$

Relative Humidity: $50 \pm 5 \%$

3.7.4 Water Absorption (JIS K 6767)

Specimen Size: 120 mm * 120 mm

This test determines the amount of water absorbed by the specimen. In this test the specimen was positioned 50 mm beneath water by approximately. After immersing for 24 hrs, the sample was taken out and then immersed into alcohol of 95 % for 5 sec. the sample is then taken out and dried at 60⁰ C for few minutes and then cut into 100mm * 100mm along the marked lines, and the mass was measured. Then the sample was dried again for 24 hrs and the mass was again measured. The amount of water absorbed was then calculated.

$$Q_s = W_1 - W_2 / 2A$$

W1 is the mass of test piece immediately after cutting 100mm * 100mm.

W2 is the mass of specimen after drying for 24 hrs.

A is the area of test piece in cm²

3.7.5 Density (UL Standard)

The test method covers the determination of density of foam by calculation from the mass and the volume of a regularly shaped specimen. Samples of 12 inch * 12 inch are cut out. The weight of the foam sample is accurately measured using the analytical balance. The volume of the sample is calculated using volume displacement test. The density of foam is calculated by mass dividing the volume of the specimen.

3.7.6 Cell measurement (UL Standard)

In this method the number of cells per unit area (10 * 10 mm) was counted using the 4x microscope.

CHAPTER IV

RESULTS AND DISCUSSION

The research aimed to study the effect of ethylene octene copolymer on mechanical properties of extruded polyethylene foam. The foam was prepared by extrusion. Since talc is used as nucleating agent, variation of talc at 0.5 and 1.0% is studied. Changing the proportion of LDPE and EOC may lead to optimization in the properties of the foam for a given weight of material. Many foam industries are looking for an inexpensive material to reduce the cost and also to provide better functional characteristics than the current materials. Several attributes make this foam to satisfy the objective. Firstly, LDPE is the low cost material, blending with the elastomer in certain proportion may offer better resilience, flexibility, extensibility, durability and better chemical resistance than the normal LDPE foam. Secondly, at room temperature ethylene octene copolymer is above its glass transition temperature and below the melting point, of the blended foam may offer better impact strength. It also gives better water absorption capacity than the normal LDPE foam.

The advantages of this foam product would lead to number of uses, for example in insulation, packaging and marine products. The mechanical properties as well as rheological properties of the blended foam were thus investigated.

4.1 Preliminary study on LDPE/EOC blended foam preparation

Nucleating agents are required for generally a uniform fine cellular structure. Nucleating agents such as talc, calcium carbonate, silica gel are used as foaming aids. These nucleating agents are added to serve as seeds for the foam cells. The foam gas gathers around the nucleating agents to form cells.

Talc, calcium carbonate and metal powders function by providing many localized hot spots as a result of exothermic or endothermic reactions, and were termed as dynamic nucleators.

The hot spot formation to nucleate foam was due to the addition of talc to PE foam system, upon extrusion the PE swelled with resulting cooling, as it emerged from the die. The talc particles did not swell, of course, so were not cooled by this

effect. The talc particle remained hotter than the polymer, and thus provided hot spots that effectively nucleated the foam.

Since talc is needed in the preparation of foam, the appropriate range of talc in LDPE/EOC blended foam is determined, the foams were then prepared with talc 0.3% to 1.5%. In the foam containing 0.3%, the cell size was bigger than 0.5% and 1.0% which may not give the required properties. The density of the foam was lower than that of other talc proportion. In case of 1.5% talc the cell size was smaller than 0.5% and 1.0%, but the density of the foam was higher than that of other talc proportion.

4.2 Physical properties of blended foams.

As mentioned in section 3.4, two sets of blended foam were prepared. The first set consists of 0.5% talc and the second set consists of 1.0% talc. In both the sets, the proportion of elastomer was varied in steps of 5,10,15,20 and 25% by weight.

Physical properties such as density, cell density and water absorption are measured.

4.2.1 Density

Density is defined as mass per unit volume. In this process, the weight of the sample is accurately measured and the volume of the specimen is measured by the volume displacement test.

$$\text{Density} = \text{Weight of specimen} / \text{Volume of Specimen} = \text{kg} / \text{m}^3$$

Table 4.1 Density of blended foam containing 0.5% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Density (kg/m ³)
F11	98.5	0	33
F12	93.5	5	32
F13	88.5	10	33

F14	83.5	15	31
F15	78.5	20	31
F16	73.5	25	33

Table 4.2 Density of blended foam containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Density (kg/m ³)
F21	98.5	0	38
F22	93.5	5	40
F23	88.5	10	42
F24	83.5	15	41
F25	78.5	20	40
F26	73.5	25	43

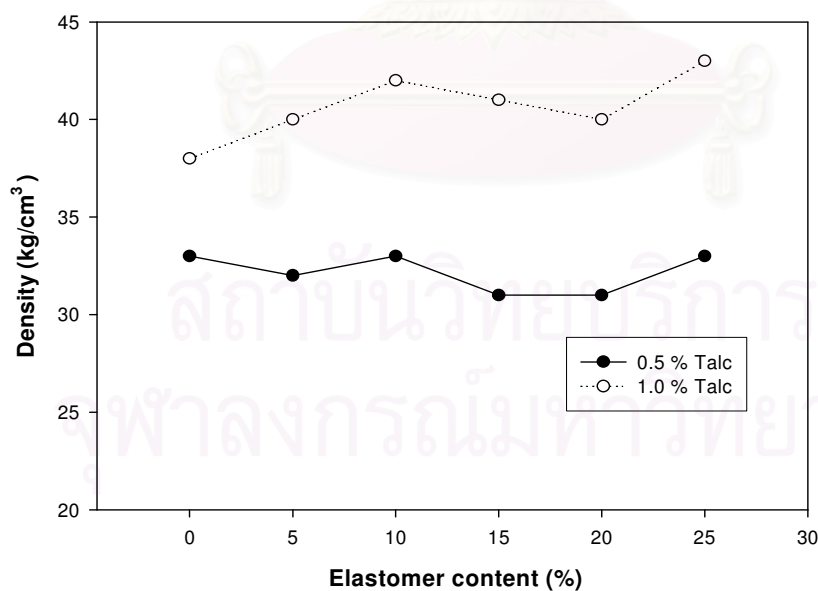


Figure 4.1 Comparison of density of the blended foams.

It can be seen from Figure 4.1 and Table 4.1 that the density of the first set of samples, F11 to F16, containing 0.5% talc is in the range of 31-33 kg/m³, while in the second set of samples, F21 to F26 in Table 4.2, containing talc 1 % has density in the range of 38 – 43 kg/m³.

At a lower concentration of nucleating agent, the number of nucleation sites are less, and hence, the total void volume is less, resulting in an increase in absolute melt viscosities. This effectively leads to a suppression of bubble growth and hence there is an increase in cell size. Since the concentration of the nucleating agent is 0.5 %, the excessive blowing agent will not diffuse in the polymer matrix and undesirable large bubbles will be formed(7,8). This existence of large bubbles prohibits a large number of nuclei because the gas molecules prefer to diffuse into larger cells. On the other hand, at higher concentration of nucleating agent, there is a decrease in melt viscosities, resulting in increased bubble growth and cell size. Due to a decrease in melt viscosities there is greater tendency of gas to escape to atmosphere through the hot skin layer of the foam after extruding from die during expansion because of the high diffusivity of the gas, leading to the increase in density of foam or lower expansion ratio(5).

At each blending ratio of LDPE and EOC, the blended foam with 1% talc has higher density than the one with 0.5% talc. It clearly indicates that talc play an important role in determining the density of the foam. The blends having higher talc content has higher density compared to the blends at low talc composition. It was also found that varying the composition of elastomer has no effect on the density of the foam.

4.2.2 Cell Density

It is defined as the number of cells per particular area of the specimen. The surface area of the foam is marked and the numbers of cells were counted using a microscope whose magnification ratio is about 4x.

Table 4.3 Cell density of blended foam containing 0.5% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Cell Density (number of cells)	Thickness (mm)	Gas injection pressure (kg/cm ³)
F11	98.5	0	56	5.0	90-100
F12	93.5	5	48	5.1	90-100
F13	88.5	10	56	4.9	90-100
F14	83.5	15	50	5.1	90-100
F15	78.5	20	48	4.9	90-100
F16	73.5	25	50	4.9	90-100

Table 4.4 Cell density of blended foam containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Cell Density (number of cells)	Thickness (mm)	Gas injection pressure (kg/cm ³)
F21	98.5	0	100	4.5	80-90
F22	93.5	5	110	4.4	70-80
F23	88.5	10	100	4.6	70-80
F24	83.5	15	104	4.4	70-80
F25	78.5	20	108	4.4	70-80
F26	73.5	25	100	4.3	70-80

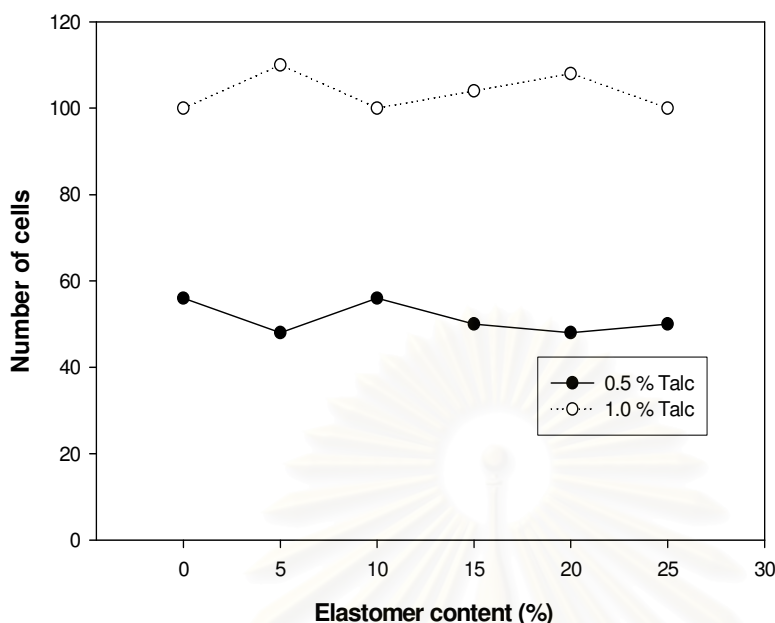


Figure 4.2 Comparison of cell density of the blended foams.

As talc acts as nucleating agent, it gets dispersed in the polymer matrix to provide heterogeneous nucleation sites and control the number density and/or size distribution of bubbles in the final foam(31).

There is direct relationship between density and the proportion of the cell in polymer foam. In blended polymer foam, composition as the proportion of the cell increases, that is as the cell size decreases the density of the foamed plastic increases, because increase in cell size means decrease in the thickness of foam sheet.

From Figure 4.2 and Table 4.3, it can be observed that the cell density for the first set of samples is in the range of 48 – 56 cells, while in the second set in Table 4.4 is in the range of 100 –110 cells. It can be observed that there is proportional increase in the cell numbers with increase in the talc content. Since the value of cell density are almost in the same range for each talc composition, it can be confirmed that addition of elastomer has no effect on the cell density and is only depended on content of talc in the formulation.

Increase in the concentration of the talc in the polymer matrix results in higher cell density. This result is expected because the higher the concentration of the nucleating agent in the polymer matrix, a greater driving force is needed to nucleate bubbles. As a result, a thermodynamic instability would be induced in the polymer

melt, and the melt viscosities decreases. Then there is rapid drop in the pressure of extrusion barrel, when the melt is extruded from the die and solubility drops. As a consequence, a higher cell population density is observed in the extruded foam. Similar things were observed when there is decrease in melt viscosities due to increase in blowing agent(7).

An increase in nucleating agent also leads to decrease in pressure in the extrusion barrel due to more number of nucleating sites which are produced in the polymer matrix. The pressure in the extrusion barrel at the gas injection point can be seen from Table 4.3 and Table 4.4 for 0.5% talc and 1.0% talc, respectively. As a result, more amount of heat is generated which may lead to increase injection of the blowing agent in the polymer matrix. Such phenomenon which leads to greater thermodynamic instability in the polymer melt as it exits from the die because of the solubility drop. As a consequence, a higher cell population density was developed in the extruded foams(7).

It was mentioned that 10 fold increase in nucleating agent concentration caused a 1000 fold increase in the number of bubbles. The efficiency of gas utilization increased from about 15% to 90% by increasing the amount of nucleating agents(9,34).

It can be concluded that varying the composition of the elastomer has no influence on the cell density. Talc is the only influencing factor which controls the cell density of the foam.

4.2.3 Water Absorption

Cellular foams may be used in the application where it may contact with water. The water absorption in cellular plastics is directly linked to the presence of open cells in the volume, i.e. the more open cells are, the higher the water absorption. The higher the water absorption the more prone a material becomes to experience the negative effects caused by water (i.e. fungi growth, increase of dynamic stiffness, decrease of static stiffness etc).

Table 4.5 Water absorption of blended foam containing 0.5% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Water Absorption (%)
F11	98.5	0	4.7
F12	93.5	5	3.6
F13	88.5	10	2.2
F14	83.5	15	2.0
F15	78.5	20	3.4
F16	73.5	25	2.1

Table 4.6 Water absorption of blended foam containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Water Absorption (%)
F21	98.5	0	4.9
F22	93.5	5	3.7
F23	88.5	10	2.1
F24	83.5	15	2.1
F25	78.5	20	3.8
F26	73.5	25	2.3

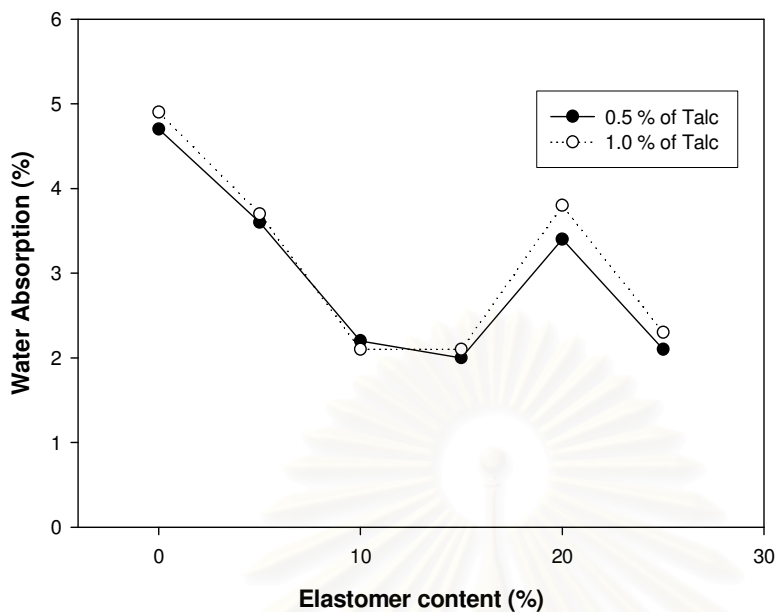


Figure 4.3 Water absorption of blended foams.

It can be observed from Table 4.5 that there is gradual decrease in water absorption capacity of the blended foams F11 to F16 from 4.7% to 2.1% except there is an increase to 3.4% for sample F15. Table 4.6 indicates water absorption capacity for the second set of samples and it can be observed that the increase in percentage of elastomer from F21 to F26 the water absorption capacity decreases but there is an increase in value to 3.8 for sample F25.

From Figure 4.3 it can be concluded that varying the percentage of talc does not much affect much on the water absorption capacity of the blended foam and is dependent only on the addition of elastomer.

Since water absorption depends on the open cell content of the foam, the decrease in the values can be attributed to the decrease in the open cell content. Immersion studies of closed cell foam at room temperature indicated the cells are sufficiently strong enough to withstand hydrostatic pressures.

But for samples F15 and F25, there is the increases in values of water absorption which may be attributed to weak cell walls which are not strong to withstand the hydrostatic pressure. This can be confirmed from the compression test, whose values are shown in Table 4.6 and 4.7. It can be observed from the Figure 4.4 that there is a drop in the compression values for samples F12, F15, F22 and samples

F25. This indicates that cell walls must be quite weak as compared to the other blend ratio, due to higher water absorption comparing to other blends..

4.3 Mechanical properties of blended foam

4.3.1 Elongation

Tensile and elongation is defined as the measurement of the ability of a material to withstand tension forces that tend to pull it apart and to determine to what extent the material stretches before breaking.

Table 4.7 Elongation of blended foams containing 0.5 % talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Elongation (%)
F11	98.5	0	62
F12	93.5	5	86
F13	88.5	10	93
F14	83.5	15	105
F15	78.5	20	89
F16	73.5	25	123

Table 4.8 Elongation of blended foams containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Elongation (%)
F21	98.5	0	65
F22	93.5	5	78
F23	88.5	10	91
F24	83.5	15	100

F25	78.5	20	80
F26	73.5	25	128

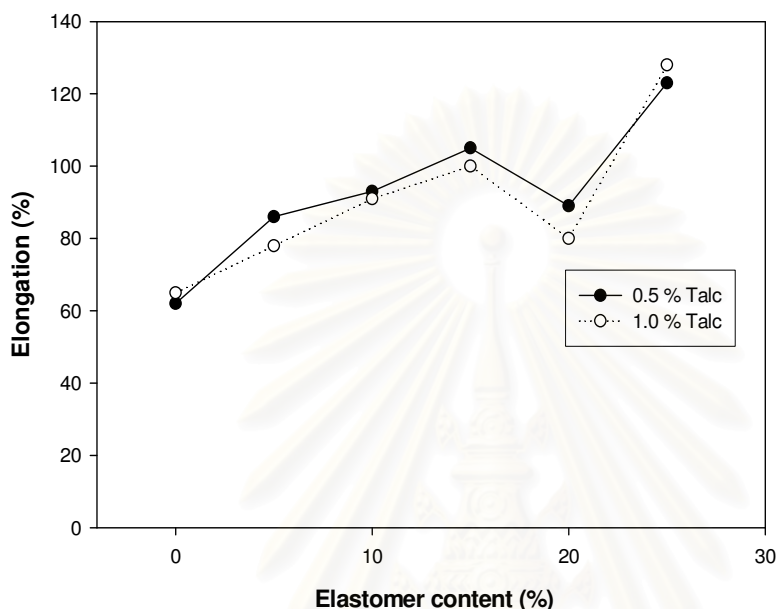


Figure 4.4 Comparison of elongation of blended foams.

The variation in mechanical properties such as elongation can be seen from Tables 4.7 and 4.8 and Figure 4.4. It can be seen that elongation rate increases for sample F11 to F16 except there is a decrease in the elongation for sample F15 containing 20% elastomer.

Similar results were observed in the samples of second set, and the values are shown in Table 4.5. In this set the elongation also increases for sample F21 to F26 and there is a decrease in the value for sample F25 containing 20% elastomer.

The increase in elongation must be due to an increase in the elastomer component in which the deformation is recoverable. There is no permanent displacement of the molecules relative to each other. It can be said that the deformation may be similar to straightening out of coiled portion of the molecular chains. There is no intermolecular slippage and the deformation may be recoverable ultimately so there is increase in elongation, impact strength and compression strength for the test samples. Due to elastomer, there are long chains and

interpenetrating coil structure and restricted molecular mobility, the molecules take more sufficient energy and time to slip to new position (33).

For sample F15 and F25 where the components might be compatible and the displaced molecules cannot slip back to their original positions, and permanent deformation occurs or it can be said that there may be disorientation of macromolecular chains in the cell during foaming so deformation occurs at a value different from the other composition (33).

The decrease in the elongation values for samples containing 1.0% talc composition may be due to an increase in density of the foam which can be seen from Figure 4.1 due to which the phase of the foam changes to hard and strong from soft and tough leading to a decrease in elongation values of foam.

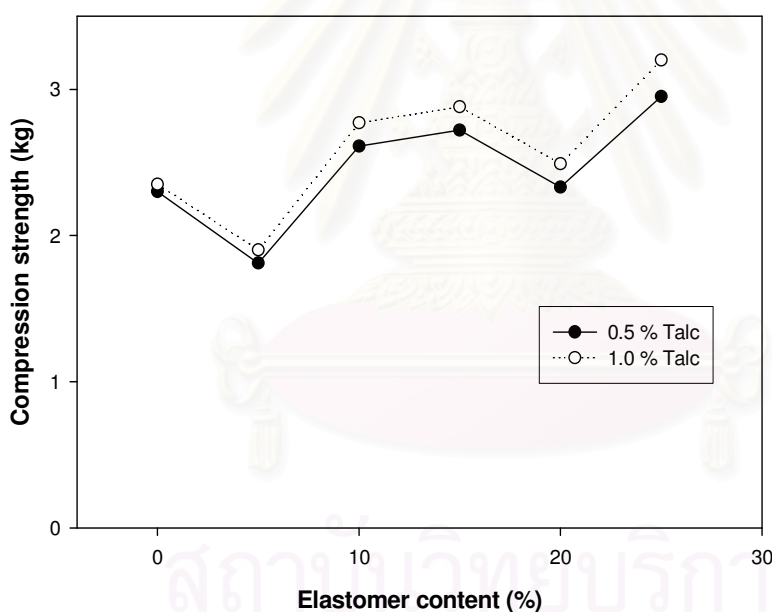
4.3.2 Compression

Table 4.9 Compression of blended foam containing 0.5 % talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Compression (kg)	Compression (psi)
F11	98.5	0	2.3	5.06
F12	93.5	5	1.81	3.98
F13	88.5	10	2.61	5.74
F14	83.5	15	2.72	5.98
F15	78.5	20	2.33	5.12
F16	73.5	25	2.95	6.49

Table 4.10 Compression of blended foam containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Compression (kg)	Compression (psi)
F21	98.5	0	2.35	5.17
F22	93.5	5	1.90	4.18
F23	88.5	10	2.77	6.09
F24	83.5	15	2.88	6.33
F25	78.5	20	2.49	5.47
F26	73.5	25	3.2	7.04

**Figure 4.5** Comparison of compression strength of blended foams.

The value of compression strength is shown in Table 4.9. It can be observed that there is an increase in compression strength from sample F12 to F16, and conversely there is a drop for sample F25 containing 20% elastomer. Similar trend can be observed in Table 4.10 for the samples containing 1.0% talc.

For samples F12, F15, F22 and F25, the cell wall may not be sufficiently strong enough to withstand the compression force. The energy required is thus less

compared to other blend formulations and this can be proved by the water absorption values from Figure 4.6.

By increasing the concentration of elastomer the deformation of cells, which are caused by compression, are recoverable so the energy require is high as compared to others.

In case of 20 % elastomer composition for samples F15 and F25 where the blends might be compatible the displaced molecules cannot slip back to their original positions, therefore a permanent deformation occurs at a value different from the other composition. The decrease in the properties at 20 % blend composition may also be due to disorientation of macromolecular chains in the cell walls during foaming.

Samples containing 1% talc shows higher values of compression strength than samples containing 0.5% talc at the same percentage of elastomer, This may be due to increase in the density of the foam and also due to large amount of cells in the structure of the foam. This may require higher compressive energy as compared to 0.5% talc.

The drop in the values for 20% concentration of elastomer was reconfirmed and the values can be seen in Table 4.11.

Table 4.11 Compression strength of blended foam.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Talc Content (%)	Compression (kg)	Compression (psi)
F15(1)	78.5	0	0.5%	2.35	5.17
F25(2)	78.5	5	1.0%	2.49	5.47
F15(1)	78.5	0	0.5%	2.33	5.12
F25(2)	78.5	5	1.0%	2.44	5.36

4.3.3 Tensile Strength

Table 4.12 Tensile strength of blended foam containing 0.5% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Tensile Strength (kg/mm ²)	Tensile Strength (MPa)
F11	98.5	0	27.1	265.76
F12	93.5	5	30.6	300.08
F13	88.5	10	32.2	315.77
F14	83.5	15	52	509.94
F15	78.5	20	41.6	407.95
F16	73.5	25	37.6	368.74

Table 4.13 Tensile strength of blended foam containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Tensile Strength (kg/mm ²)	Tensile Strength (MPa)
F21	98.5	0	32.5	318.71
F22	93.5	5	36.2	355.00
F23	88.5	10	41.6	407.95
F24	83.5	15	62.1	608.99
F25	78.5	20	57.4	562.90
F26	73.5	25	38.3	375.59

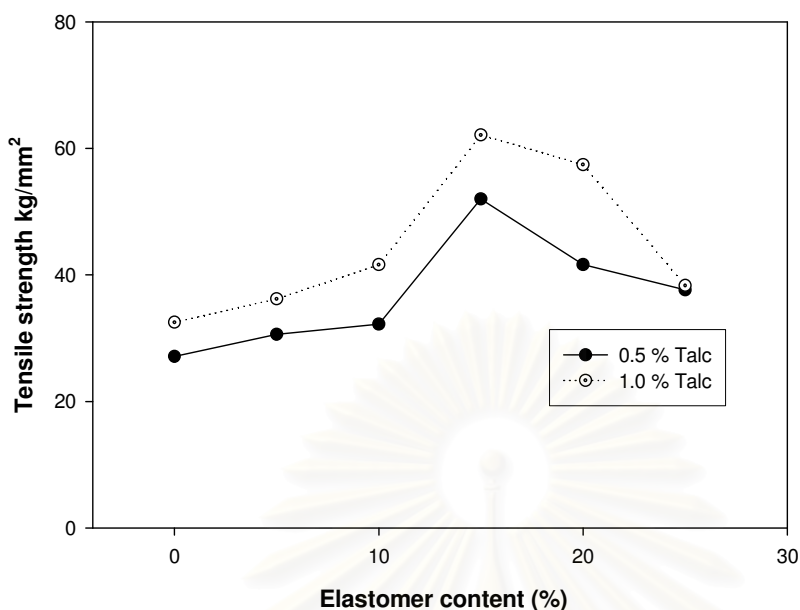


Figure 4.6 Comparison of tensile strength of blended foams.

Tensile strength of the blends containing 0.5% talc and 1.0% talc is shown in Tables 4.12 and 4.13. It is observed that there is gradual increase in tensile strength for samples F11 to F14 while there is decrease in the values for samples F15 and F16 containing 20% and 25% elastomer respectively.

Similar trend can be observed in Table 4.13 where there is increase in tensile strength with increase in the percentage of elastomer for sample F21 to F24 and hence after there is decrease in values for sample F25 and F26.

The reason for this can be discussed as follows. The polymer blend which contains 5 % to 15 % is simple mixture of thermoplastic polymer with compatible elastomeric polymer. Each of the polymeric components has its own phase, but the interaction between the phases is quite weak. So the properties of the blend are approximately those predicted directly from the properties of the component in major proportion.

But in the blend composition of 20 % to 25 % the soft elastomeric phase dominates the hard thermoplastic phase and there is decrease in the tensile strength (31).

From the Figure 4.6 it can be seen that tensile strength for 1.0% talc is higher than that of 0.5% talc for the same composition of elastomer which can be

attributed due to smaller cell size which leads to increase in overall cross sectional area as a result there is increase in tensile strength(32).

4.3.4 Impact Strength

Impact strength can be defined as the ability of the polymer to absorb applied energy. Or in other words it is the ability of a material to resist breaking under a shock loading or the ability to resist the fracture under stress applied at high speed.

Table 4.14 Impact strength of blended foam containing 0.5% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Impact Strength (gf)
F11	98.5	0	220
F12	93.5	5	242
F13	88.5	10	350
F14	83.5	15	411
F15	78.5	20	356
F16	73.5	25	416

Table 4.15 Impact strength of blended foam containing 1.0% talc and 1% wax.

Sample Code	LDPE Content (%)	Elastomer Content (%)	Impact Strength (gf)
F21	98.5	0	197
F22	93.5	5	308
F23	88.5	10	385

F24	83.5	15	450
F25	78.5	20	350
F26	73.5	25	467

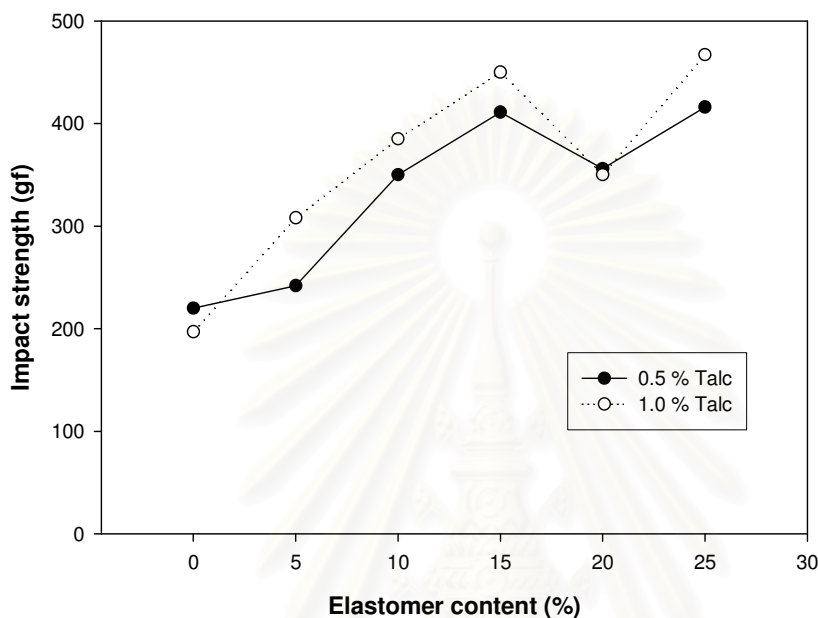


Figure 4.7 Impact strength of blended foams.

There is an increase in the impact strength from 220 gf for 0.5% talc sample F11 to 416 gf for sample F16, except there is decrease in impact strength for sample F15 to 356 gf as shown in Table 4.14.

Similar trend can be seen for samples F21 to F26 containing 1% talc except there is decrease in value to 356 gf for sample F25 as shown in Table 4.15. The increase in impact strength as the percentage of elastomer increases is due to the fact the elastomer has more % to absorb energy attributed by its elastic behavior as compared to rigid plastics.

It was stated that phase morphology played an important role in examining the impact properties. The phase morphology after etching of the blends of different composition reveal small spherical domains dispersed in LDPE matrix. As the concentration of EOC in the blends increased the number of domain increased but the average diameter decreased. For all the blends having up to 15% EOC loading the diameters of the domains never exceeded than 1 μm . The smallest average domain

diameter, between 0.15 and 0.60 μm was seen for 15% EOC blend. This diameter is in the range required to toughen blends. As the concentration of EOC was increased the dispersed phase has transformed from spherical like domain to more elongated feature. The optimum impact properties obtained from the blend may arise as a consequence of the spherical and slightly elongated phase morphology of elastomeric EOC being well dispersed in LDPE matrix(22).

Lower impact strength at for samples F15, F25 seemed due to certain degree of miscibility between LDPE and elastomer phases in the blends(22).

From the Figure 4.8 it is observed that samples with 1.0% talc has higher impact strength than the samples with 0.5% talc. This clearly indicates that talc plays an important role in the impact strength.

The density of foam samples in set 2 is higher than set 1 that can be observed from Figure 4.1 so the foam can be described as hard and strong this may lead to increase in impact strength.

It was reported that there is increase in strength and elongation with increase in amount of cell. It was also suggested that decrease in the cell size leads to increase in cross sectional area, and the energy required to rupture the cells is quite high(32).

4.4 Rheological Properties.

4.4.1 Effect of elastomer content added on the matrix

The effect of shear rate on real shear stress of the blend was investigated at 185 $^{\circ}\text{C}$. Figure 5a-5d shows the results on various die dimensions. All of the sample exhibited the pseudo plastic behavior, as the relation between shear stress on shear rate is non linear. Similar, relationship was influenced all of die series.

Increase in amount of EOC, at the same shear rate, leads to increase in real shear stress. The relation between viscosity on the real shear rate has been reported on Figure 6a-6d, in which there is decrease in viscosity non linearly with increased shear rate, which focus on the die series, 10/1 and 10/2 (Figure 6b and 6c), respectively, The large die size shows clearly show the value of viscosity at the same shear rate for all composition, and this can be confirmed by the results in Figure. 6a and 6d. The residence time of both system has been effective on elastomer and the LDPE matrix. The discussion of the residence time will be examine on the later paragraph.

Figures 7a and 7b show dependence tensile stress on the elongational rate instantaneous the melt flow pass through the die, the Cogswell's method widely accepted (8,16,7) to determine the elongational components on the real works, the flow properties of the polymer melt passed the channel, have both properties of shear component and elongational component. The relationship of tensile stress and elongational rate was non linear manner, and the trend of them carried out as the tensile stress increased with increasing the elongational rate with increasing the elastomer content, due to the stretching of the chains. While comparing the percentage concentration of the elastomer component (see Figures 7a and 7b), the tensile stress was influenced by the amount of EOC content, interestingly EOC 20% wt show lower values than 15% and 25% of EOC. The possible ways for the lower tensile stress may be, the component of rubbery and rigid plastic were balanced, loosening the chain entanglement on the matrix, and making the rubbery state on the matrix less effective. Similarly, the result has been confirmed on the Figures 7b, 7c, 7d where the results of experiment present the same manner.

Figure 8 shows dependence of elongational viscosity on the elongational rate, the elongational viscosity was greater than shear viscosity, by approximate values of 3 times(17), and increasing the elongational rate, elongational viscosity decreased. According to Figure 8a to 8d the result strongly confirm that the rubber component on 20% EOC was less effective on the LDPE matrix phases.

The die swell of the blends was investigated and the results are shown in Figures 9a and 9b. On comparing both Figures, the die swell on short die was greater than longer die in all range of sample. The decrease in the length of the die decreased the residence time and there is roughness in the curve. The result on Figure 9b indicates, as the residence time increased, the smoothness of curve occurred.

Effect of die design, L/D ratio

Figure 10 illustrates the relationship between real shear stress and real shear rate, comparison with neat LDPE and 25% of EOC on 10/2 and 30/2 L/D ratios, both samples exhibited pseudo plastic materials. Observing to L/D ratio, the greater the L/D ratio, the real shear stress was low, but on increasing the EOC content to 25% the effect of L/D ratio was not clearly differentiated. Figure 11a and 11b shows the

dependence of real shear stress on real shear rate on L/D 5/1 and 10/1 respectively, this materials exhibited similar result as that of die series with L/D 10/2 and 30/2.

Table 5 shows the residence time of polymer from the entrance of die to the end of it. Comparing at same shear rate, the residence time for long die is high, so the effect of the residence time can be analysis on the homo polymer and not for polymer blends. At the same time the viscosity on real shear rate was analyzed, the results are shown in Figure 12, at lower shear rate, the viscosity of neat LDPE distinguish various L/D ratio, and on high rate, the effect is more effective, while the blends of EOC have equal values at all shear rates.

The extrudate swell of the sample was carried on the real shear rate as shown on Figure 13. Neat LDPE exhibited an increasing extrudate swell, while the real shear rate increased, but, with increasing amount of elastomer to 25% EOC, the extrudate swell was insignificant. This may be due to addition of elastomer, the deformation changed the plastic matrix more over elastomer, so that the conformation of elastomer part does not effect where the melts passed through the die.

Figure 14 describes the extrudate swell on the real shear stress. The percentage of extrudate swell was linear as a function of shear stress on 10/2 and 30/2 L/D series, following the literatures (17,28), but exhibited non linear function at 25% EOC. These results confirmed that, the shear deformation depend strongly on the LDPE matrix, while on addition of elastomer the relationship changes. In this case since, EOC and LDPE were miscible, the interaction between both molecules was strong, so it mat exhibit non linear behavior.

In addition, the dependence tensile stress on the elongational rate was show in Figure 15. It was found that the tensile stress increased with increasing L/D ratio except in case of neat LDPE. This may be due to the stretching force of LDPE chains is not sufficient and no rearrangement takes place, while the EOC chains use more force to arrange, if the die length increased, the enhancement of force was occurred. Moreover, various elongational rate, elongational viscosity as shown on Figure 16, it can be seen that EOC contents has effect on L/D ratio. On the other hand, at low elongational rate, neat LDPE shows clear difference due to the difference in the resident time.

4.5 Economic Consideration

Table 4.16 Comparison of properties of crosslinked, blended and polyethylene foam.

Properties	Crosslinked Foam	Blended Foam	Polyethylene Foam
Density (kg/mm ²) UL standard	23 – 50	33 - 45	26 - 35
Cell structure UL standard	80 - 150	56 - 100	56 – 100
Water absorption (%) JIS K 6767	0.4 – 0.5	2 – 3.6	4.7 – 4.9
Compression strength (kg) UL standard	1.6 – 3.5	1.9 – 3.2	2.2 – 2.3
Elongation % JIS K 6767	90 - 150	86 - 123	55 – 65
Impact strength (gf) ASTM - 1709 – 01	190 - 500	242 - 467	190 – 220
Tensile strength (kg/mm ²) JIS K 6767	22 - 65	30 - 62	24 – 32
Recycle	No	Yes	Yes
Cost	High	Medium	Low

It is found that properties of blended foam are in between the crosslinked foam and normal PE foam.

Since the properties of the crosslinked foam has better properties than the blended and normal polyethylene foam. Higher manufacturing cost and nonrecyclable are the main disadvantage of the crosslinked foam.

Comparing mechanical properties of the crosslinked foam with the blended foam, it is found that they are in the same range and the values are quite comparable.

Water absorption have higher values as compared to crosslinked foam but lower than normal polyethylene foam.

The products manufactured from the blended foam is ideally suitable for products requiring shock absorption, insulating, barrier or buoyancy component, and as a material for cushioning components in packaging application.



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CHAPTER V

CONCLUSION AND SUGGESTION

5.1 Conclusion

Mechanical properties of EOC blended LDPE foam were tested by varying composition of the elastomer from 5%, 10%, 15%, 20% and 25%. It was found that the mechanical properties of blended foams of LDPE and EOC were improved. Increase in elongation, compression, impact are achieved with the increase of elastomer composition of elastomer but there was a drop when the elastomer composition was 20%.

By increasing the talc from 0.5% to 1.0% the density and the cell size change and as a result tensile strength, compression strength, elongation and impact strength show higher values.

At 25% elastomer blend the properties were similar to 15% elastomer blended composition, so seeing that at the cost of the latter is more cost effective than 25%.

The rheology of LDPE and EOC blend was observed using a capillary rheometer for the EOC composition of 0, 15, 20, and 25%. The shear and elongational behavior were analyzed in term of elastomer amount and effect of die geometry on L/D ratios. It was found that an increase amount of EOC on the blended matrix, the real shear stress and the viscosity increase at the same shear rate. On the other hand, the tensile stress on the elongational rate exhibited non linear increase manner. On the result of 20% EOC content, the lower tensile stress than 15% and 25% of EOC was occurred. It is possible that both component of plastic and elastic of the blends were balanced, and concrete the result on the elongational viscosity. Focusing on the L/D ratio, the residence time can be described on the homopolymer, not suitable for polymer blends as the elastomer part. The tensile stress on the elongational rate of high filled elastomer was increased with increasing L/D ratio due to the stretching of EOC chains on the blends, while the homo polymer exhibited less sensitive on the L/D ratio. For all the samples die swell increased with decreasing the L/D ratio. The percentage of extrudate swell on real shear stress exhibited non linear manner on the addition of EOC elastomer at all %.

5.2 Suggestion

- 1) Blending the foam with higher percentage of elastomer.
- 2) Use of other nucleating agent such as sodium bicarbonate, citric acid and sodium citrate and comparing their properties.
- 3) Use of different blowing agent such as carbon dioxide and to study the effect on cell size.



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Appendices

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Appendix A

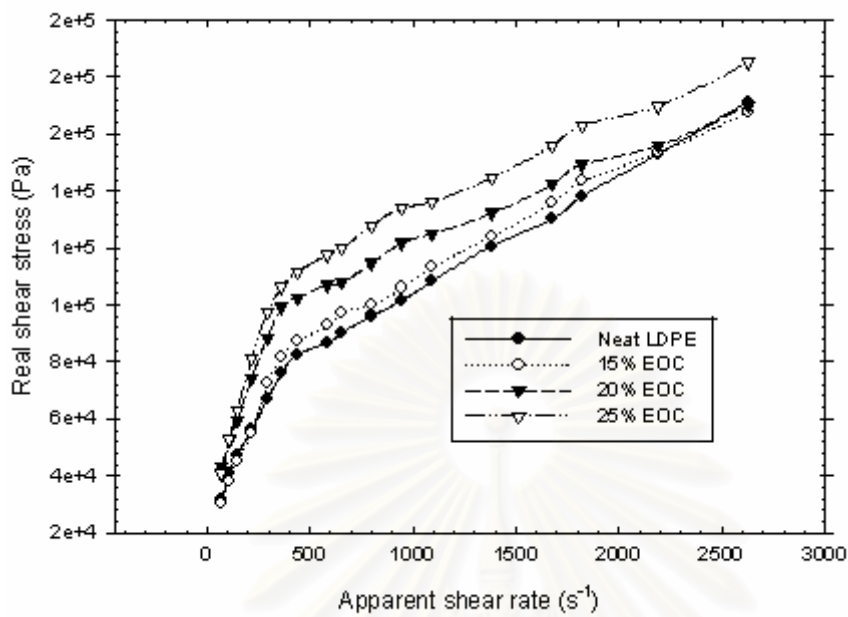


Figure 5a : Real shear stress as a function of apparent shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 5/1.

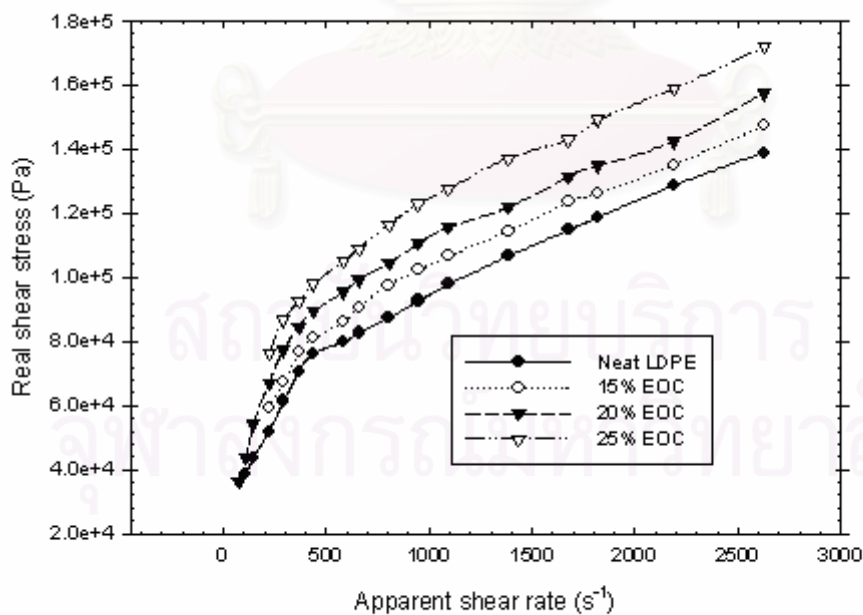


Figure 5b : Real shear stress as a function of apparent shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/1.

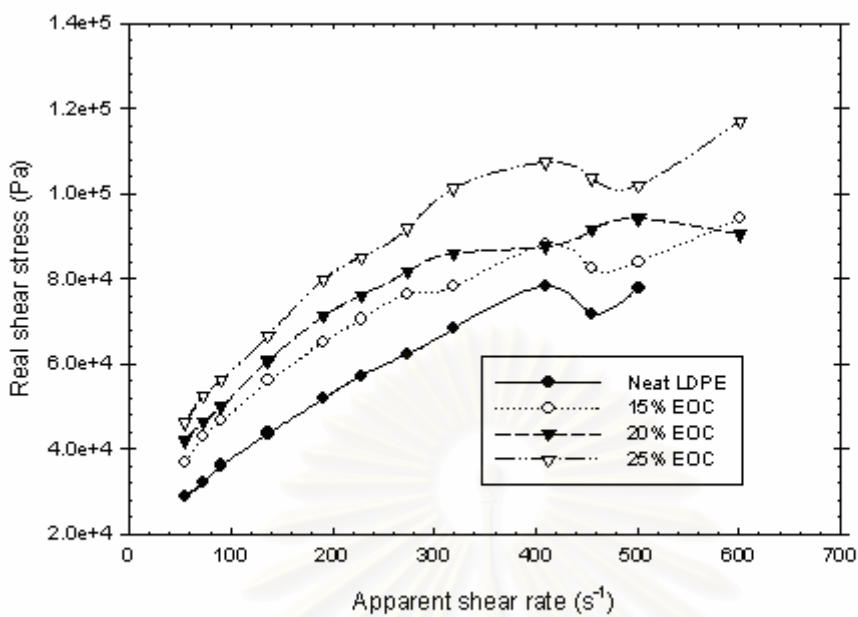


Figure 5c : Real shear stress as a function of apparent shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/2.

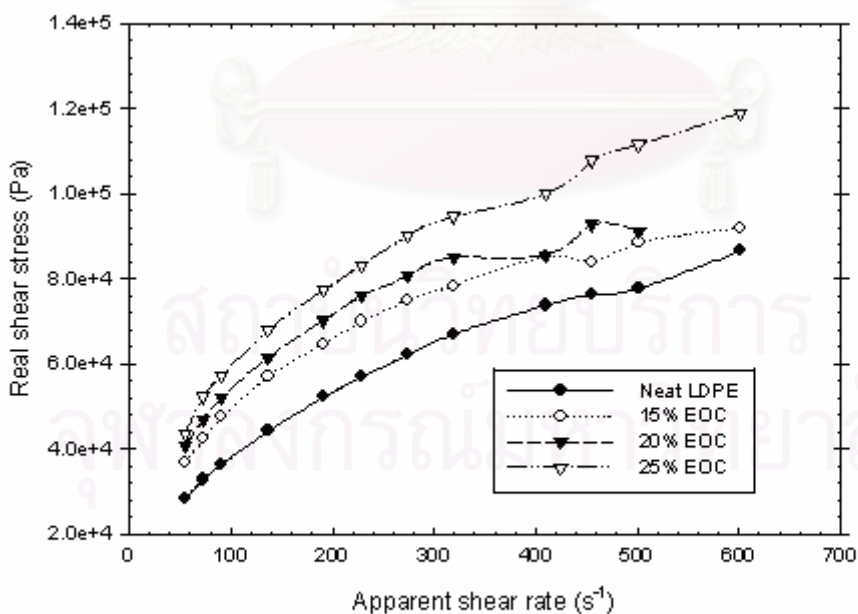


Figure 5d : Real shear stress as a function of apparent shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 30/2.

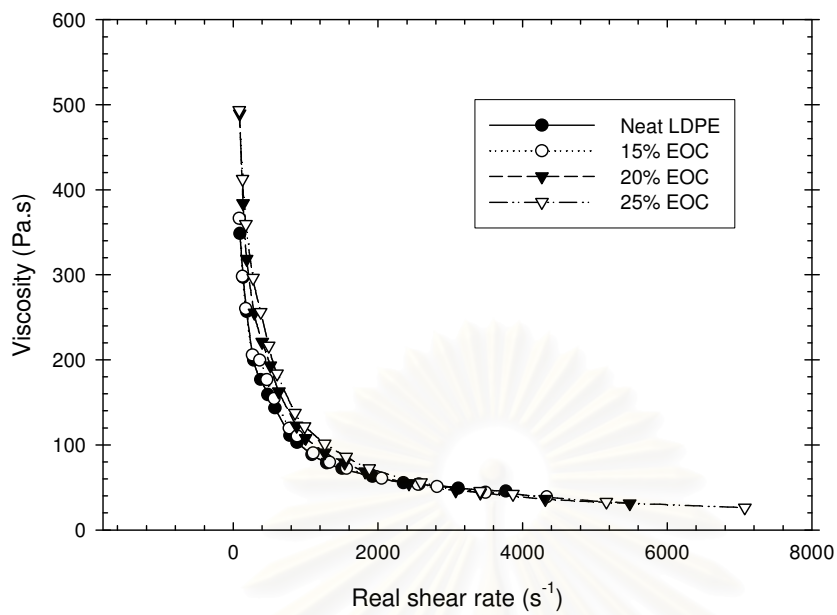


Figure 6a : Shear viscosity as a function of real shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 5/1.

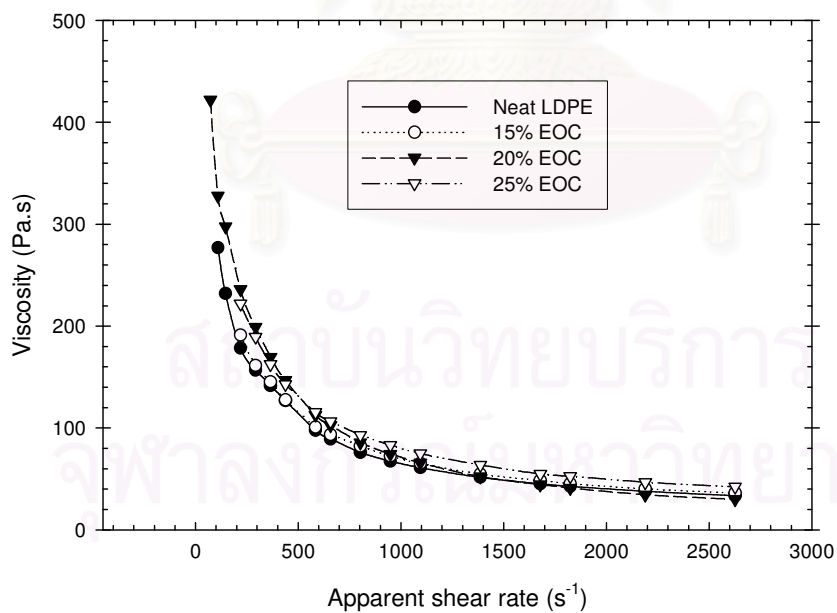


Figure 6b : Shear viscosity as a function of real shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/1.

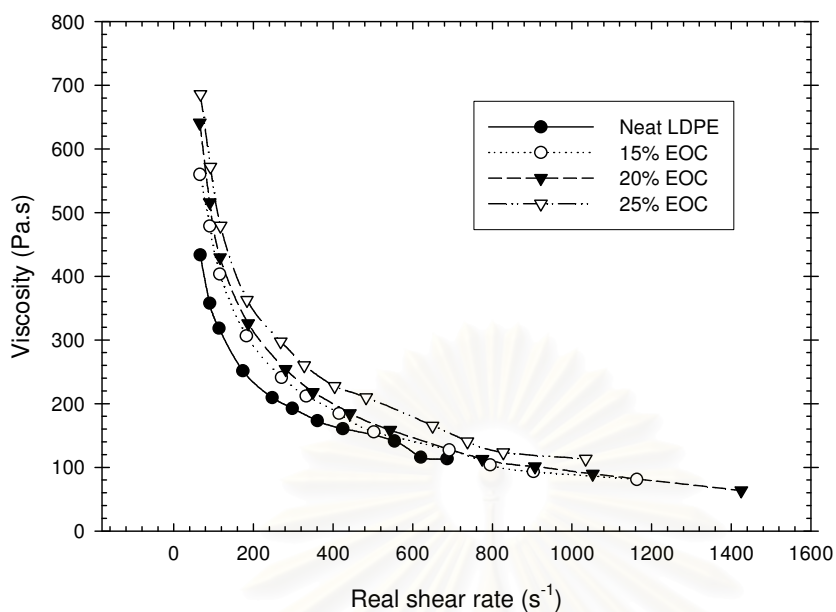


Figure 6c : Shear viscosity as a function of real shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/2.

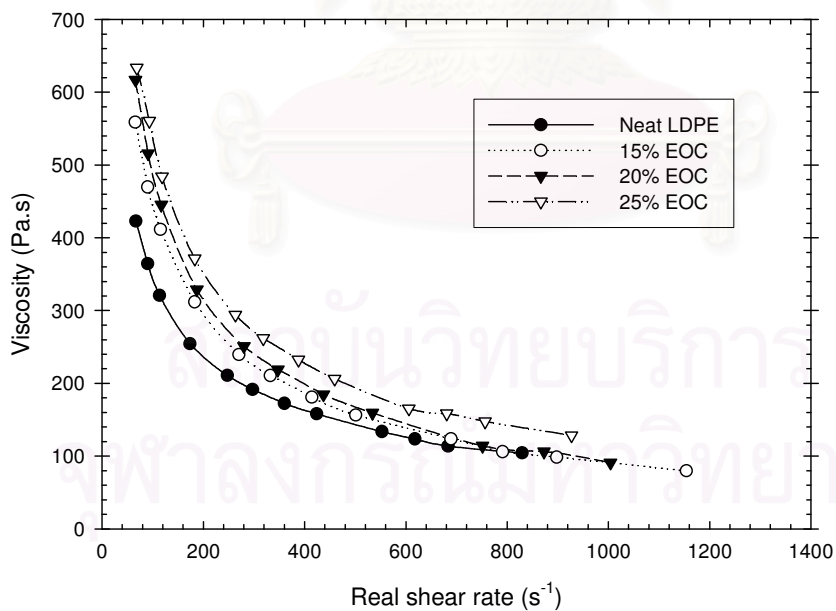


Figure 6d : Shear viscosity as a function of real shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 30/2.

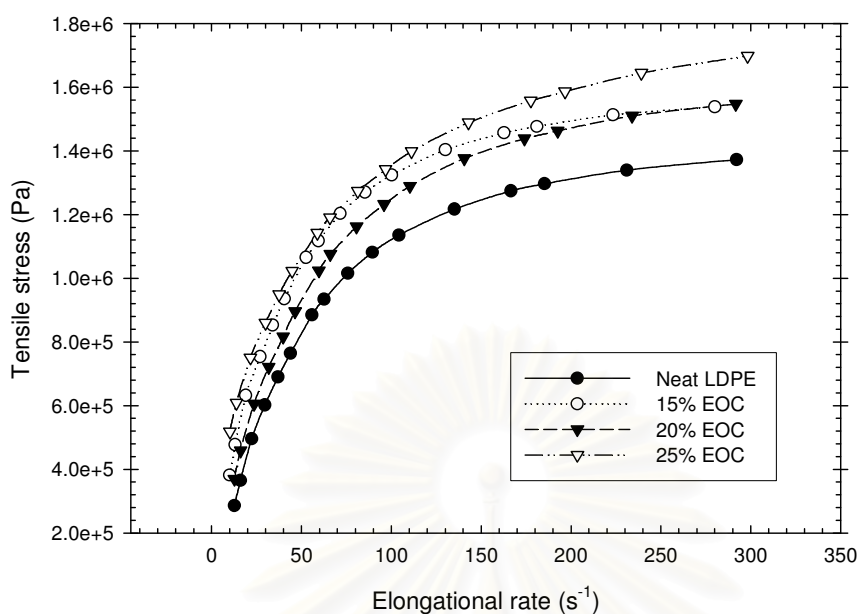


Figure 7a : Tensile stress as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 5/1.

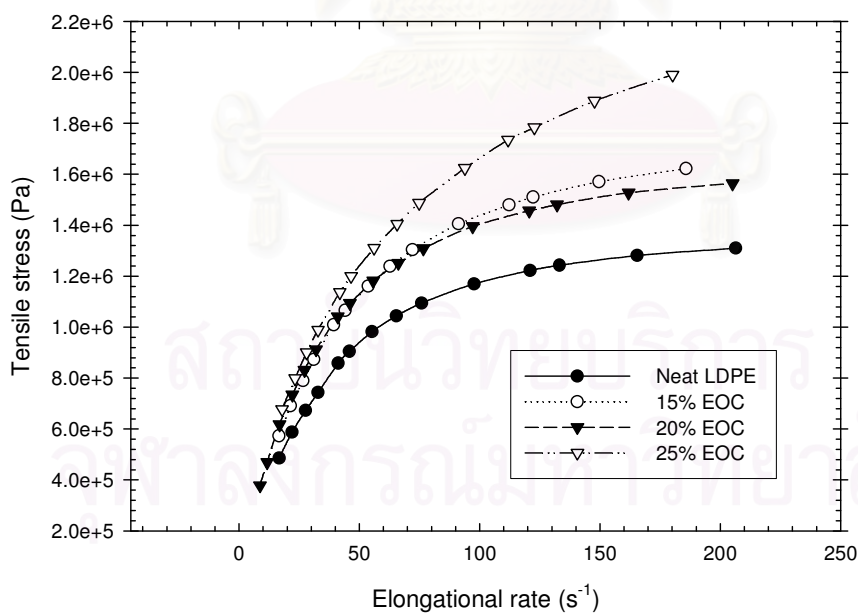


Figure 7b : Tensile stress as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/1.

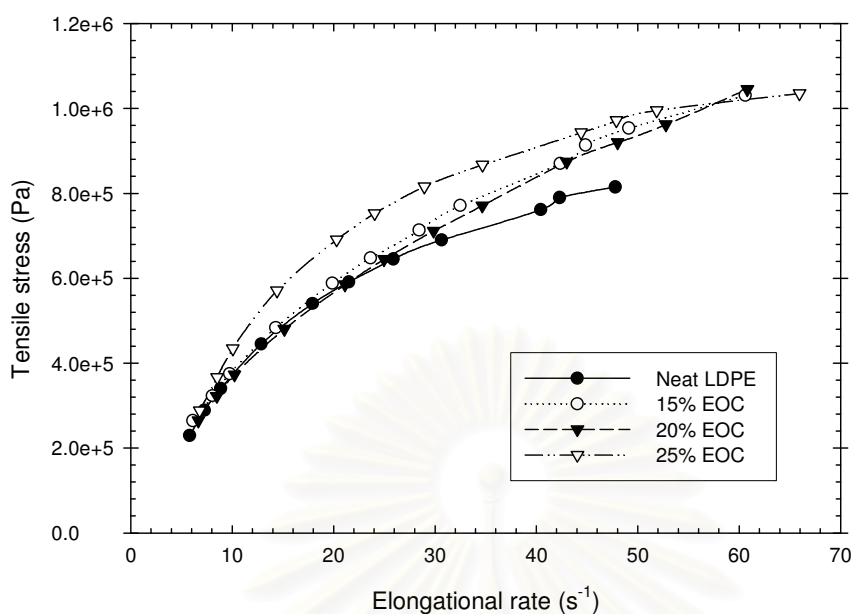


Figure 7c : Tensile stress as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/2.

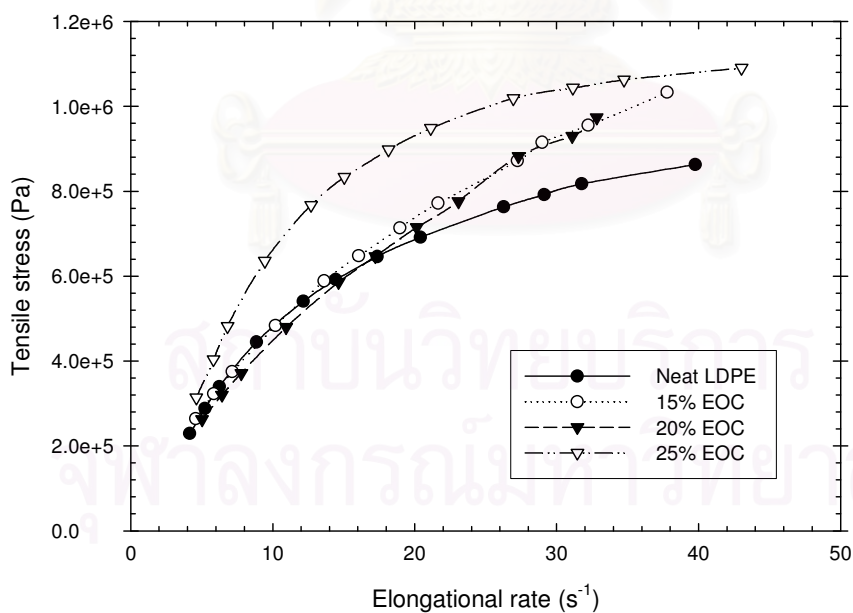


Figure 7d : Tensile stress as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 30/2.

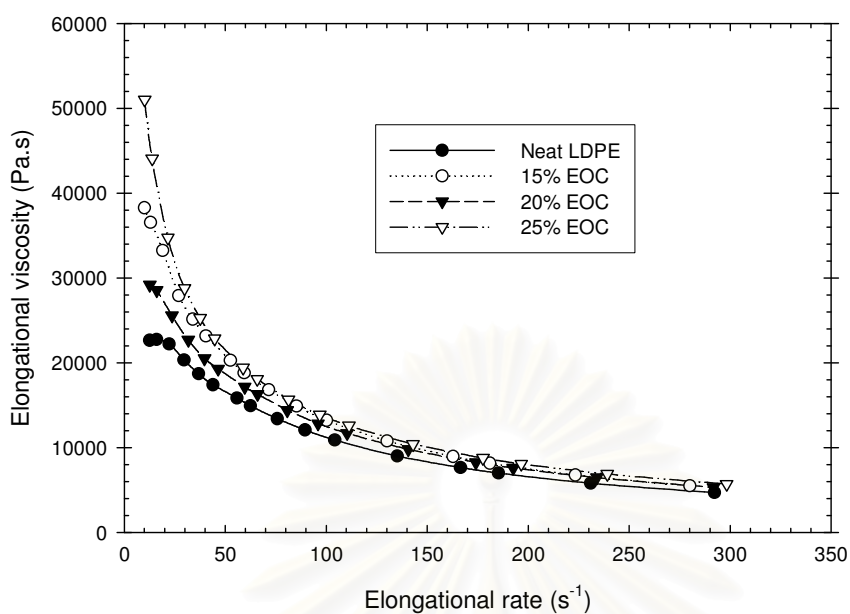


Figure 8a : Elongational viscosity as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 5/1.

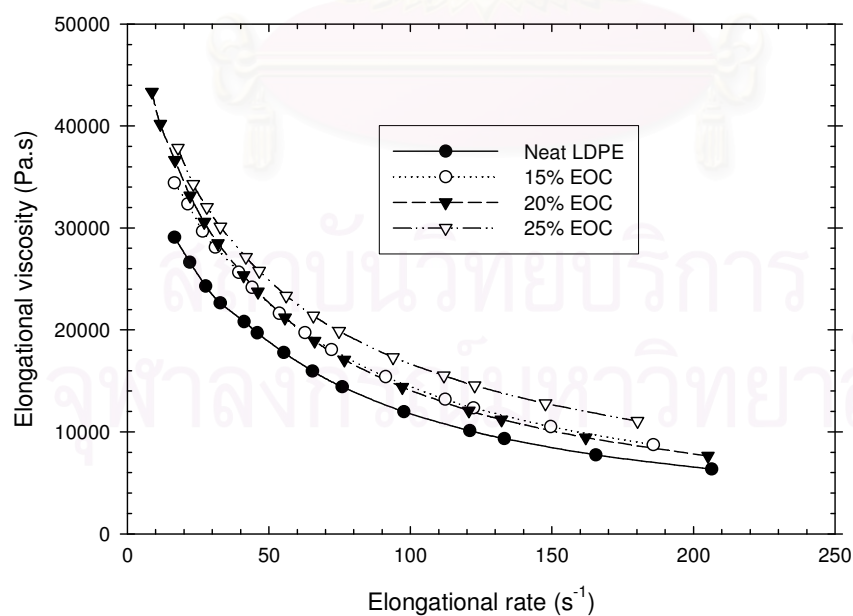


Figure 8b : Elongational viscosity as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/1.

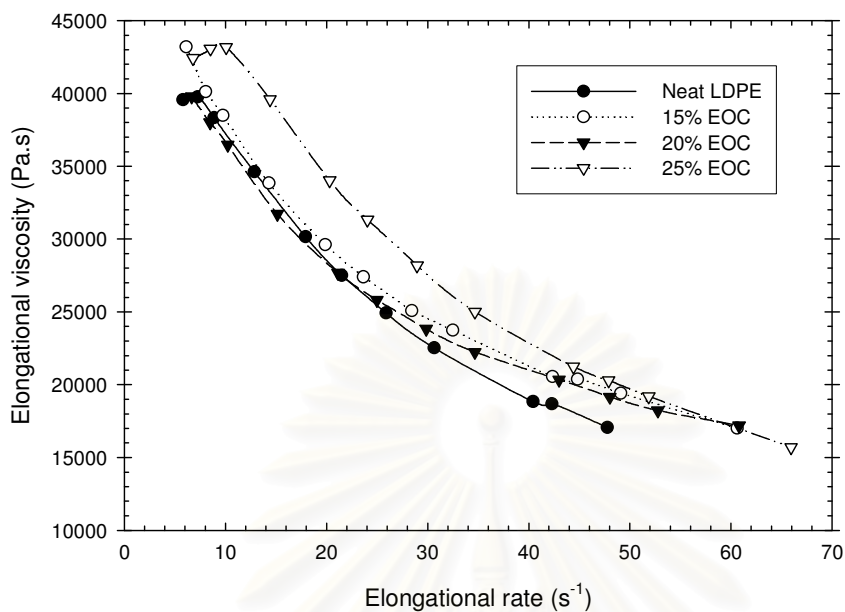


Figure 8c : Elongational viscosity as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/2.

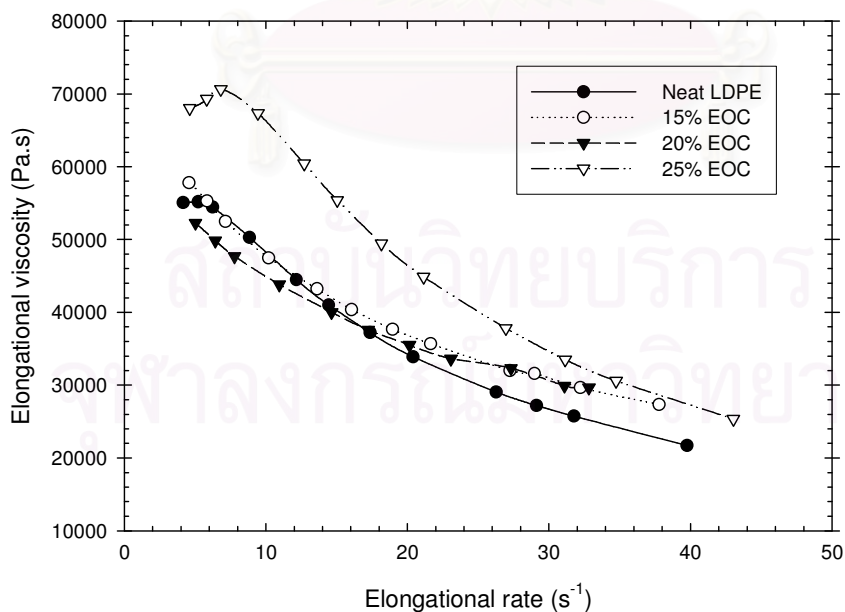


Figure 8d : Elongational viscosity as a function of elongational rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 30/2.

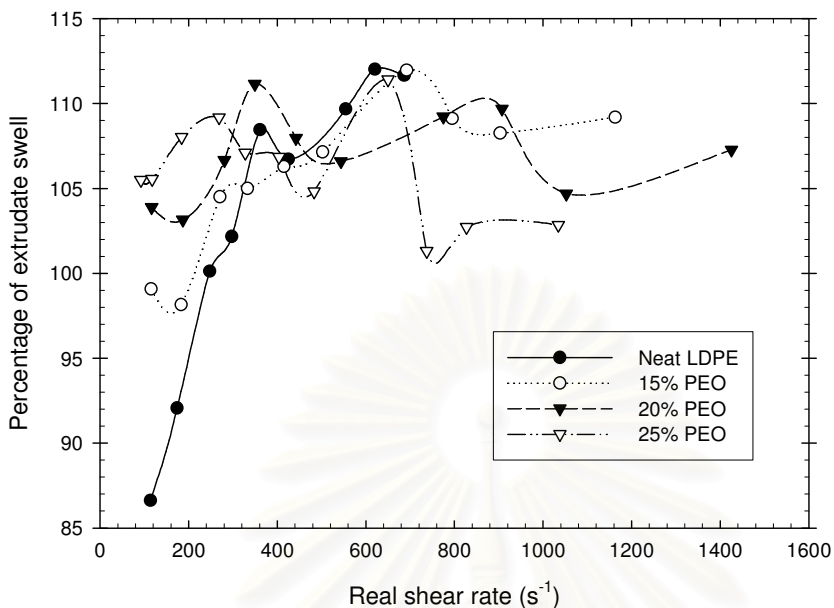


Figure 9a : Percentage of extrudate swell as a function of real shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 10/2.

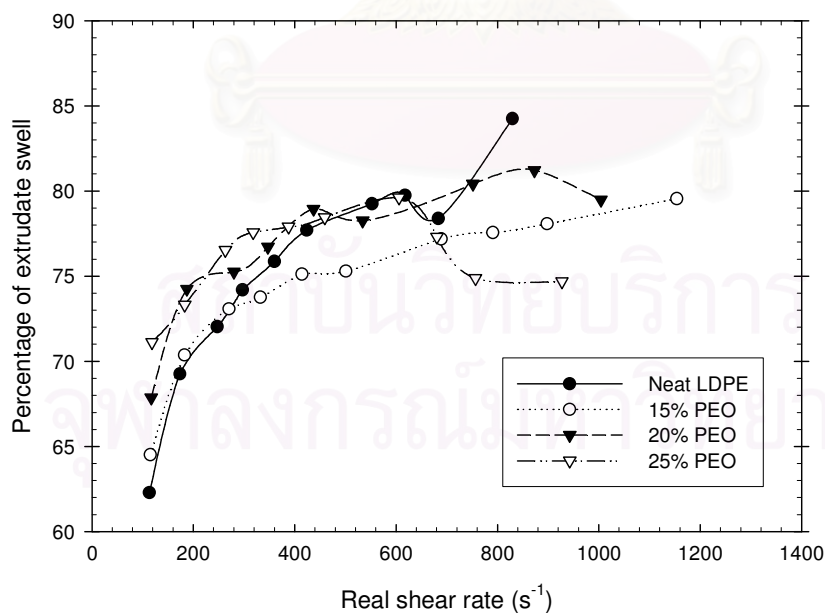


Figure 9b : Percentage of extrudate swell as a function of real shear rate for neat LDPE and LDPE/EOC blends on 15%wt., 20%wt., and 25%wt. of EOC with L/D ratio on 30/2.

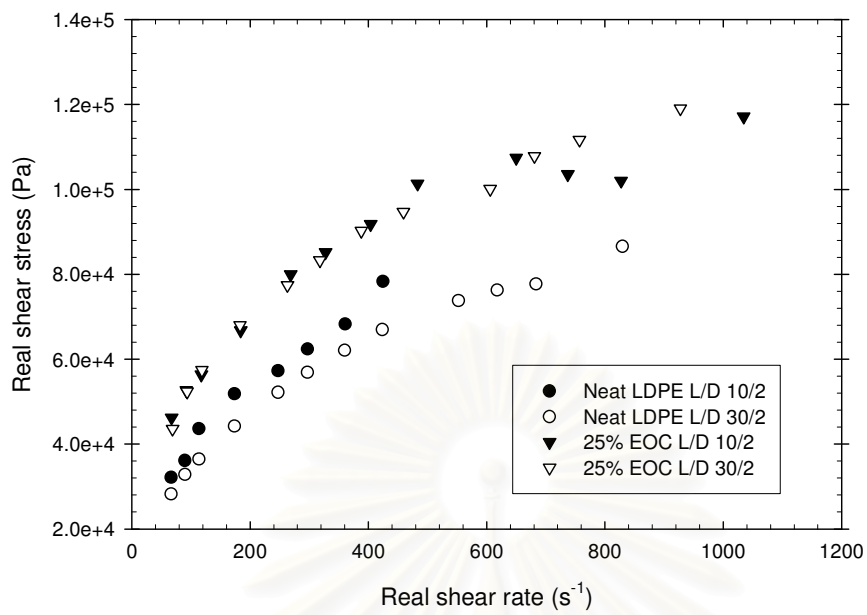


Figure 10 : Real shear stress as a function of real shear rate for neat LDPE and LDPE/EOC blends on 25%wt. of EOC with L/D ratio on 10/2, and 30/2.

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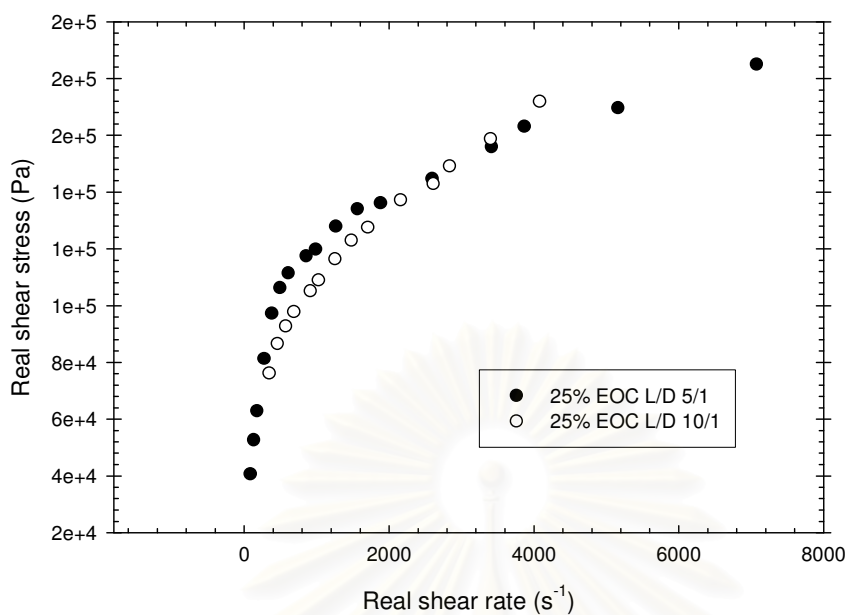


Figure 11a : Real shear stress as a function of real shear rate for (a) neat LDPE and (b) LDPE/EOC blends on 25%wt. of EOC with L/D ratio on 5/1.

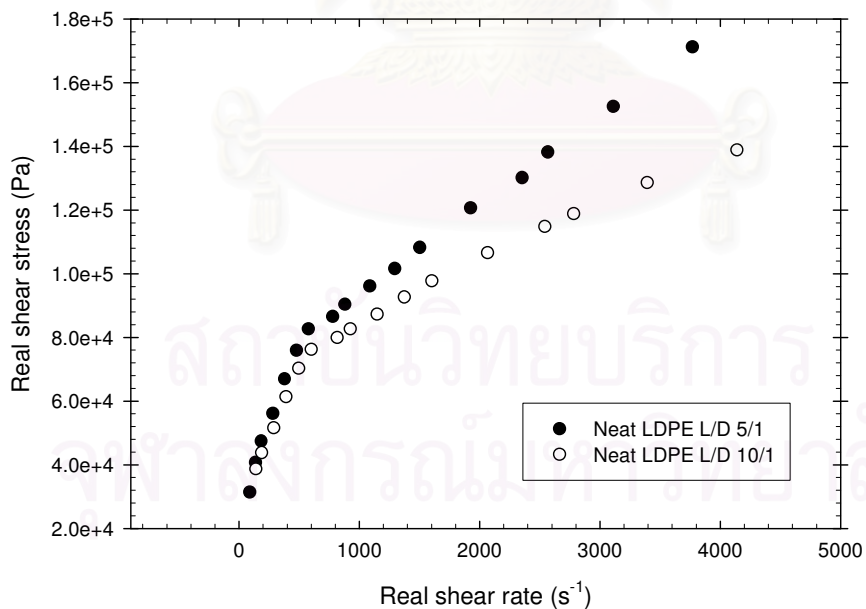


Figure 11b : Real shear stress as a function of real shear rate for (a) neat LDPE and (b) LDPE/EOC blends on 25%wt. of EOC with L/D and 10/1.

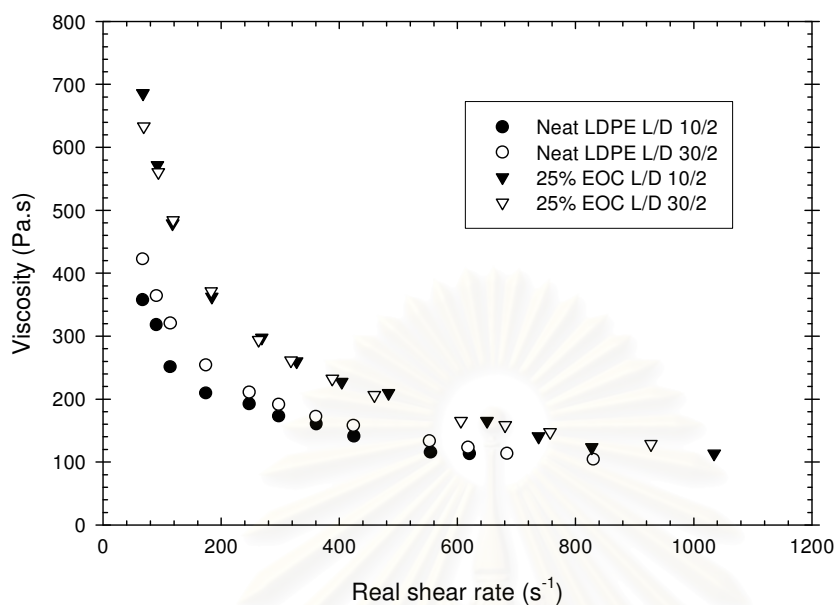


Figure 12 : Shear viscosity as a function of real shear rate for neat LDPE and LDPE/EOC blends on 25%wt. of EOC with L/D ratio 10/2.

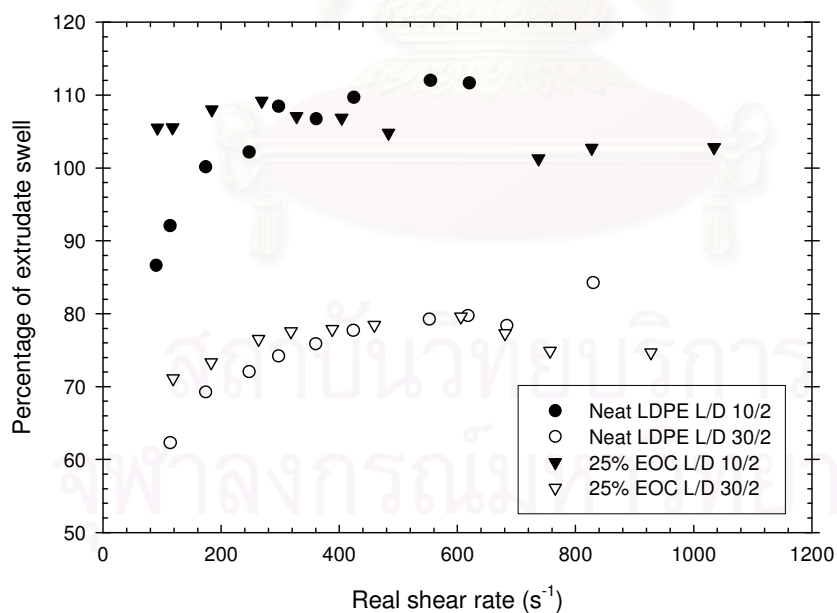


Figure 13 : Percentage extrudate swell as a function of Real shear rate for neat LDPE and LDPE/EOC blends on 25%wt. of EOC with L/D ratio 10/2 and 30/2.

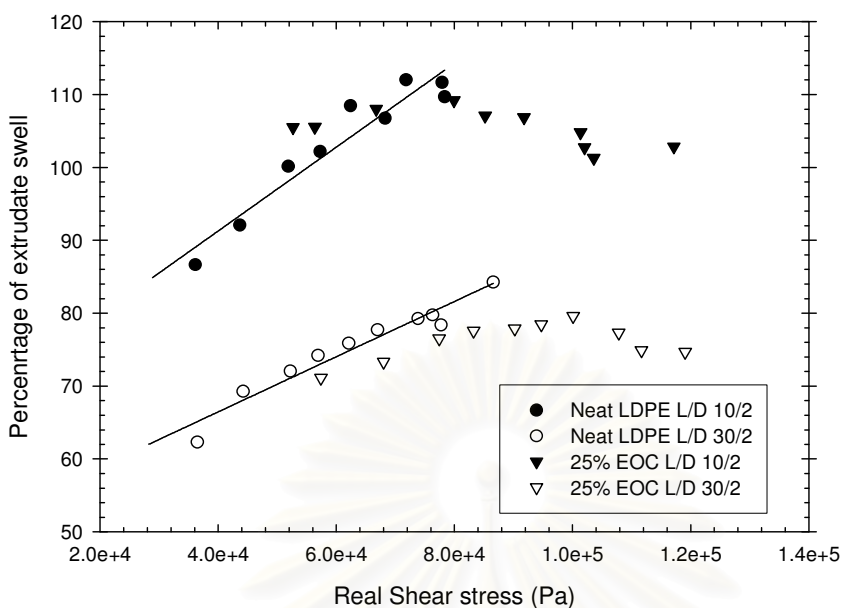


Figure 14 : Percentage of extrudate swell as a function of real shear stress for neat LDPE and LDPE/EOC blends on 25%wt. of EOC with L/D ratio on 10/2 and 30/2.

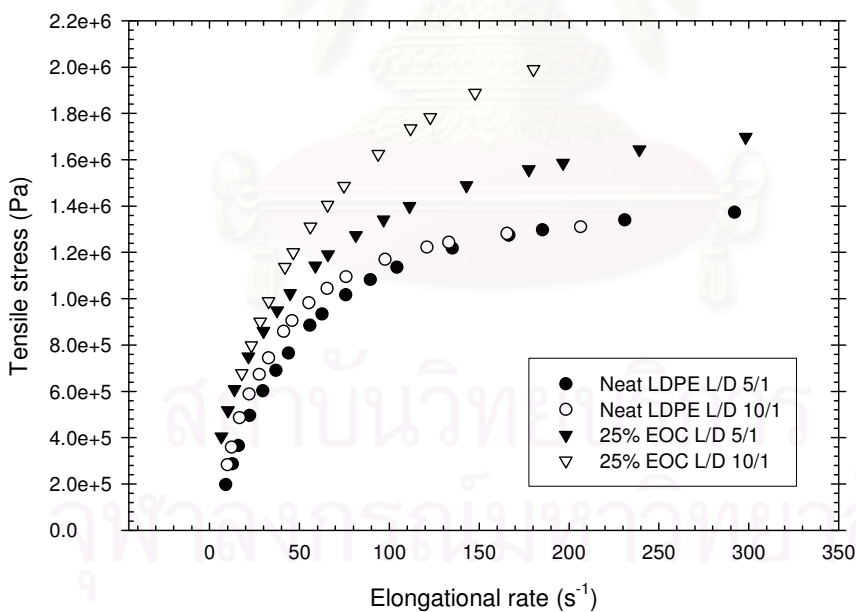


Figure 15 : Tensile stress as a function of elongational rate for neat LDPE and LDPE/EOC blends on 25%wt. of EOC with L/D ratio on 5/1, and 10/1.

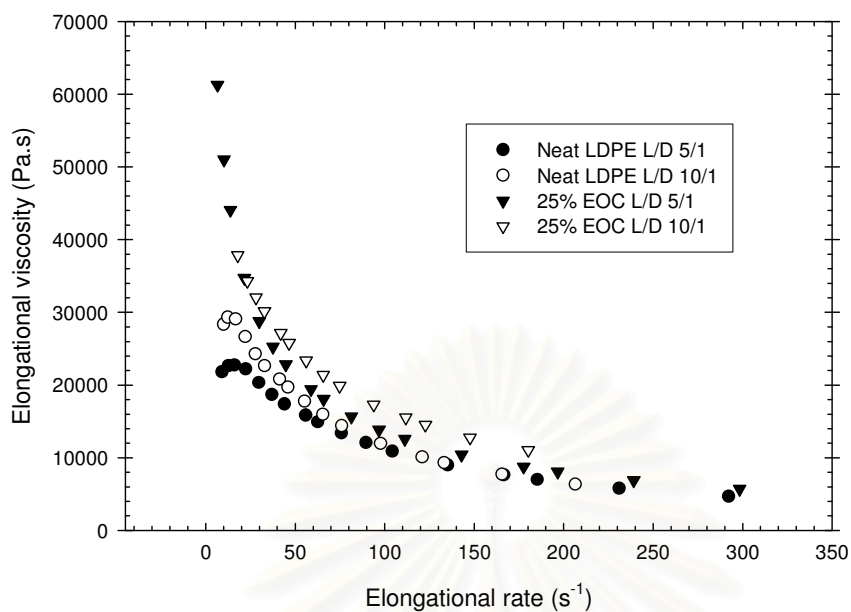


Figure 16 : Elongational viscosity as a function of elongational rate for neat LDPE and LDPE/EOC blends on 25%wt. of EOC with L/D ratio on 5/1, and 10/1.

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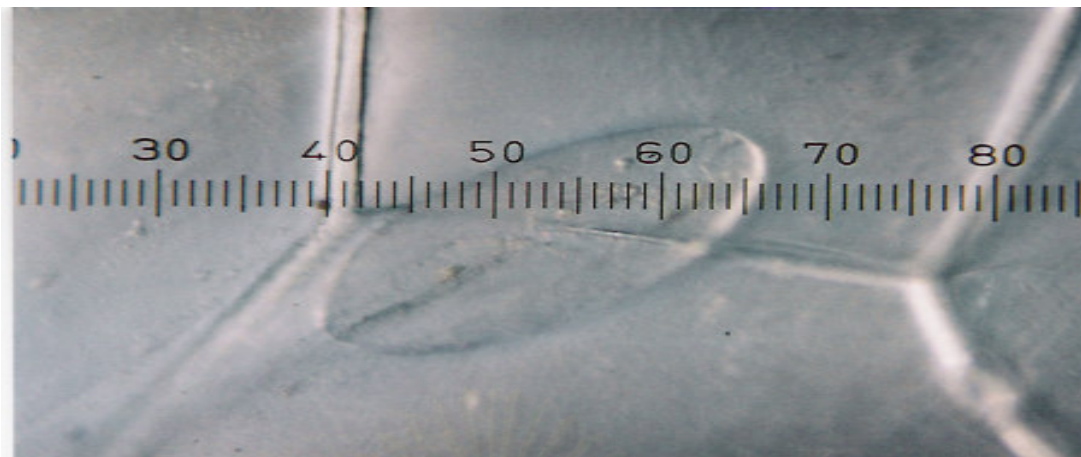


Figure 17 : Cell Structure for foam sample F21.

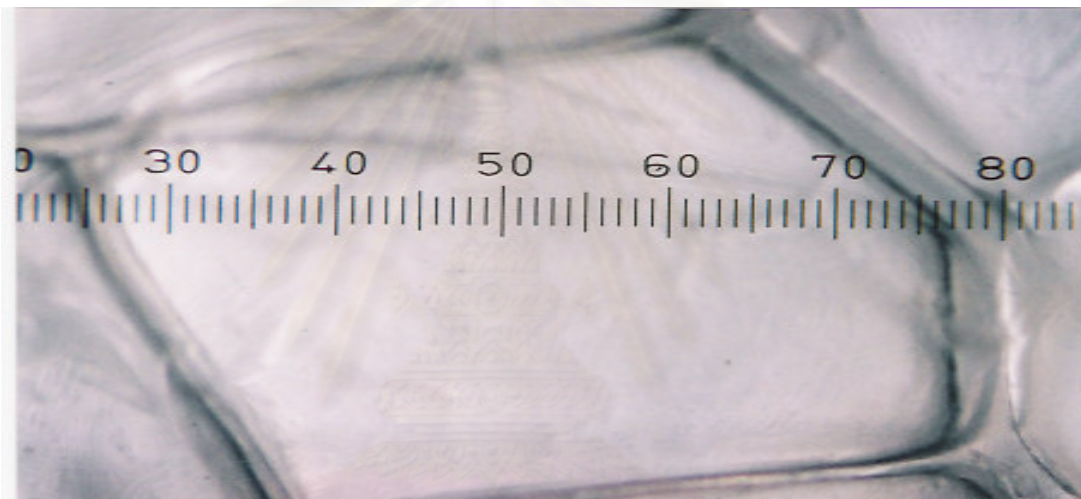


Figure 18 : Cell Structure for foam sample F22.

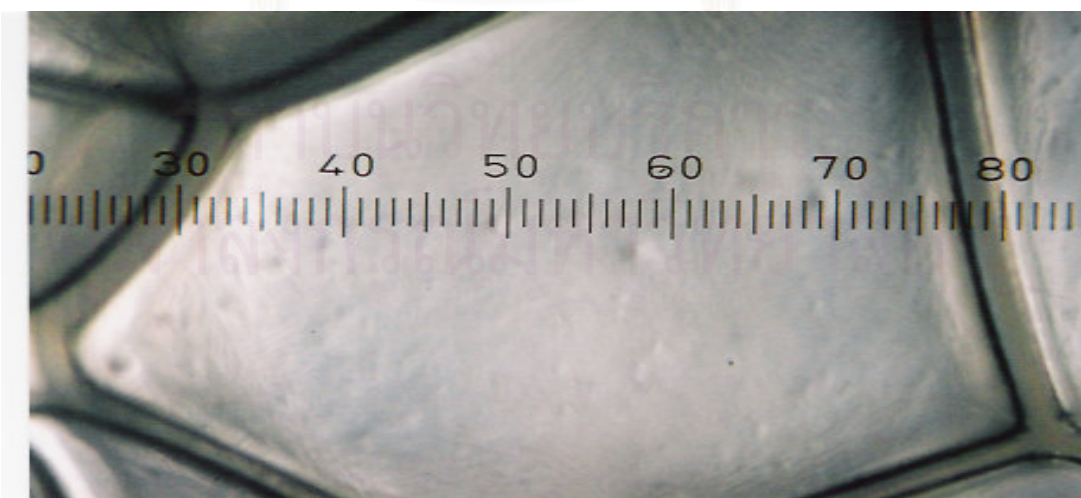


Figure 19 : Cell Structure for foam sample F23.

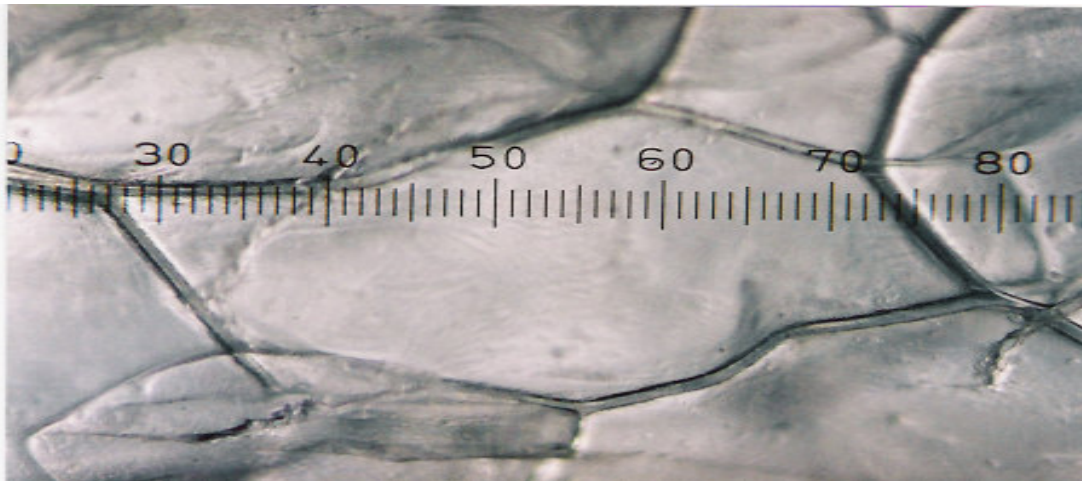


Figure 20 : Cell Structure for foam sample F24.

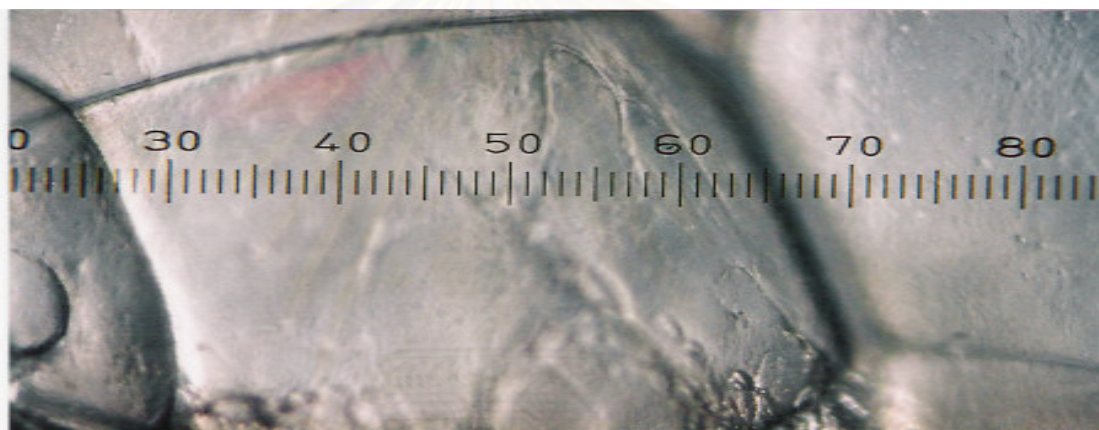


Figure 21 : Cell Structure for foam sample F25.

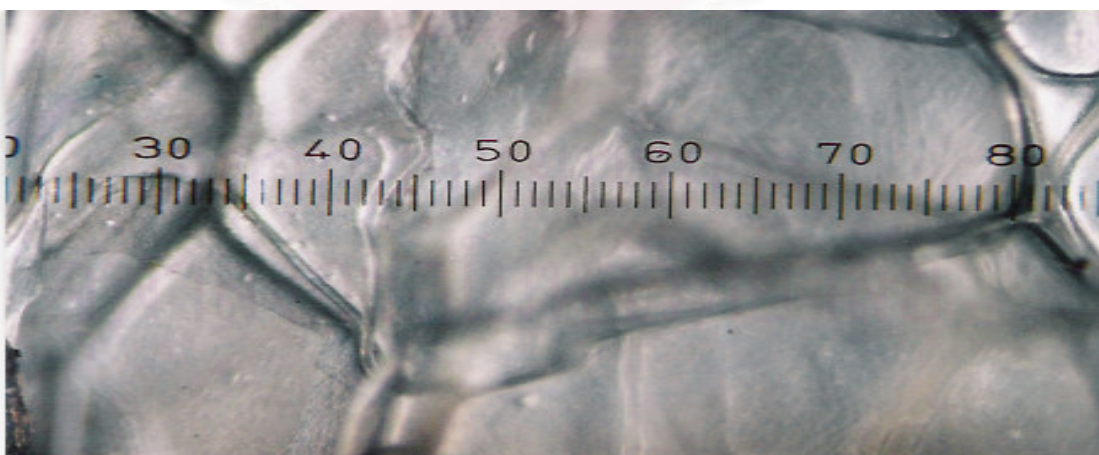


Figure 22 : Cell Structure for foam sample F26.

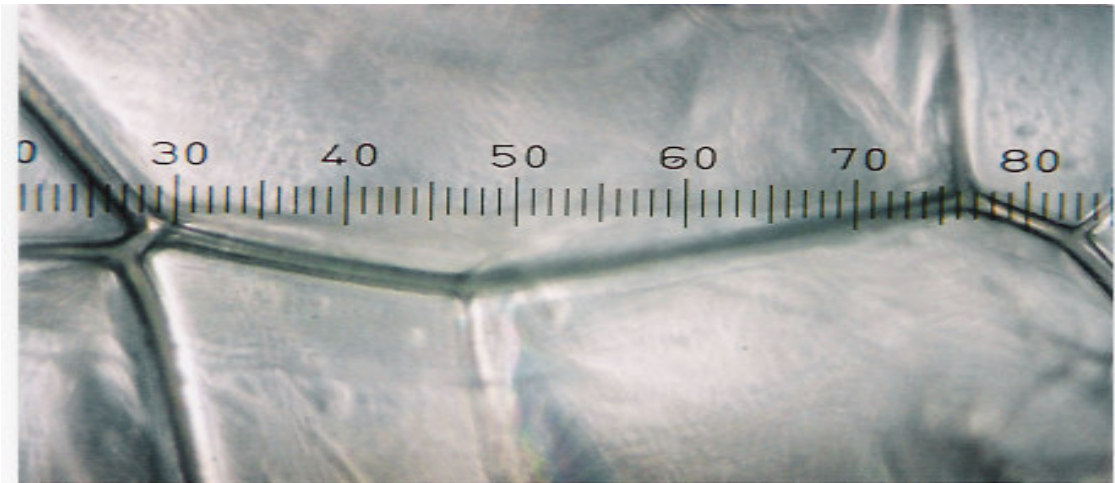


Figure 23 : Cell Structure for foam sample F11.

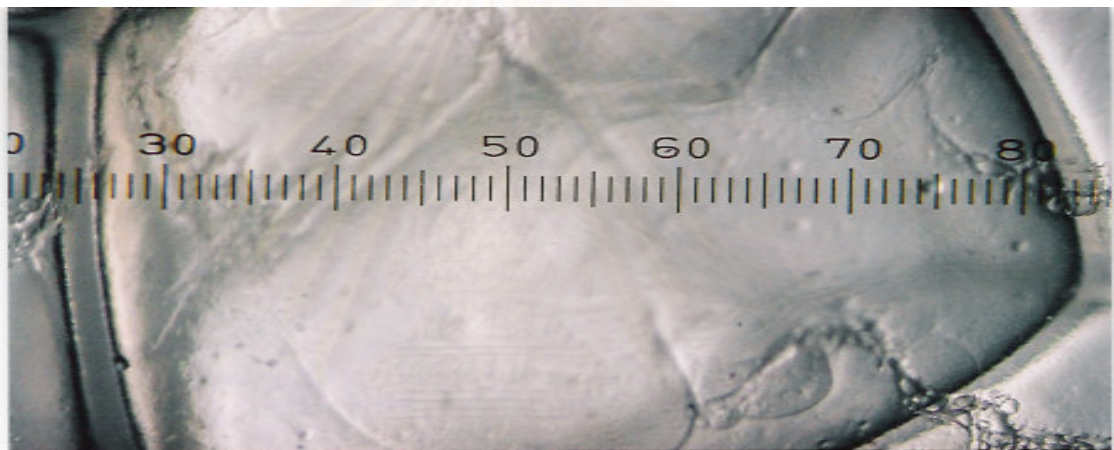


Figure 24: Cell Structure for foam sample F12.

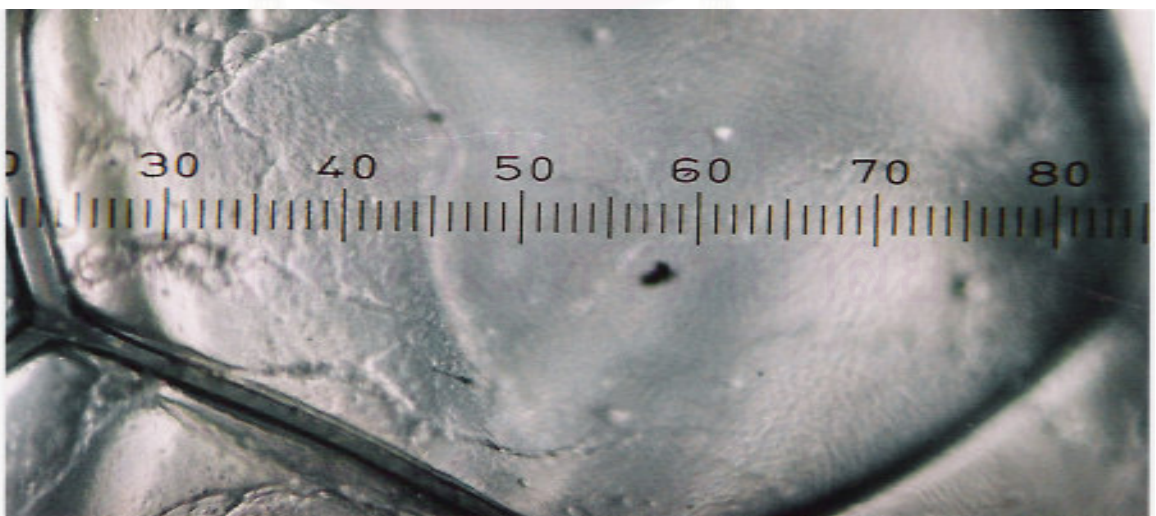


Figure 25 : Cell Structure for foam sample F13.

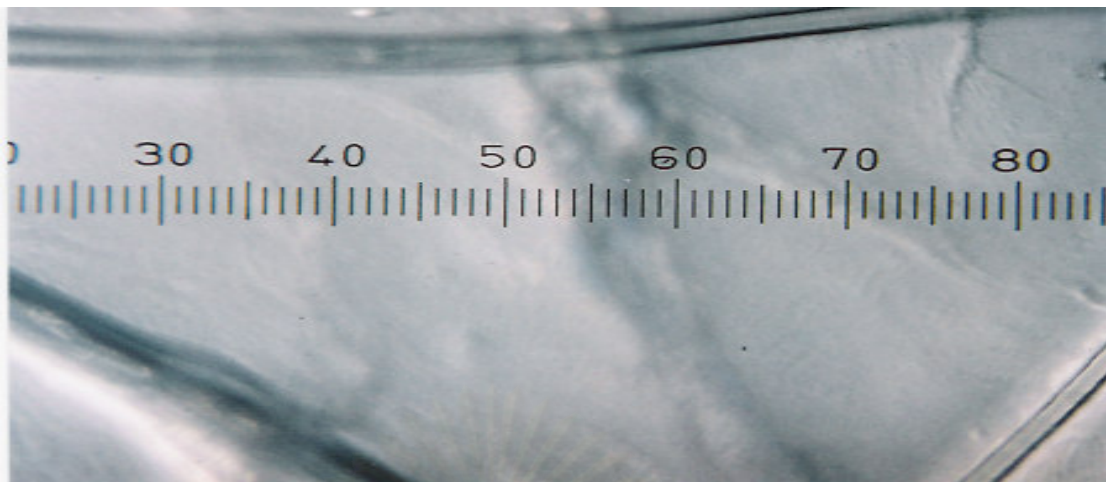


Figure 26 : Cell Structure for foam sample F14.



Figure 27 : Cell Structure for foam sample F15.

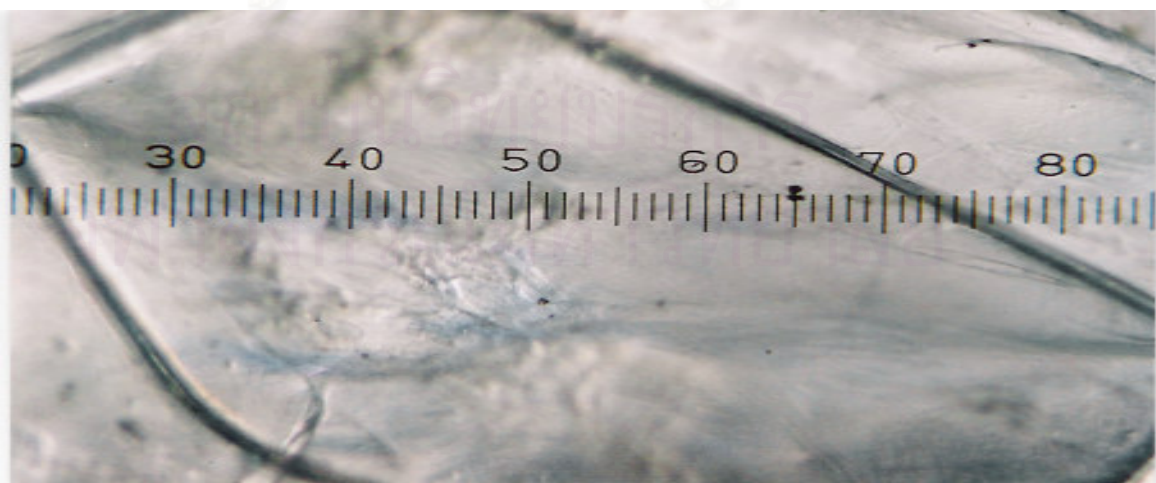


Figure 28 : Cell Structure for foam sample F16.

Table 5 Residence times as a function of apparent shear rate various L/D ratios.

Apparent shear rate (sec ⁻¹)	Residence time (sec)		Apparent shear rate (sec ⁻¹)	Residence time (sec)	
	L/D 5/1	L/D 10/1		L/D 10/2	L/D 30/1
72.96	0.548	1.096	54.72	0.731	2.193
109.44	0.365	0.731	72.96	0.548	1.645
145.92	0.274	0.548	91.20	0.439	1.316
218.89	0.183	0.365	136.80	0.292	0.877
291.85	0.137	0.274	191.53	0.209	0.627
364.81	0.110	0.219	228.01	0.175	0.526
437.77	0.091	0.183	273.61	0.146	0.439
583.70	0.069	0.137	319.21	0.125	0.376
656.66	0.061	0.122	410.41	0.097	0.292
802.58	0.050	0.100	456.01	0.088	0.263
948.51	0.042	0.084	501.61	0.080	0.239
1094.43	0.037	0.073	601.94	0.066	0.199
1386.28	0.029	0.058			
1678.13	0.024	0.048			
1824.05	0.022	0.044			
2188.86	0.018	0.037			
2626.63	0.015	0.030			

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Appendix B

Statistic of Mechanical Properties Data

The sampling distribution of mechanical properties data were calculated by standard deviation (SD).

$$SD = \frac{\sum (x_i - x_a)^2}{n-1}$$

Where n is the number of sample

x_i is the sample.

x_a is the sample mean.

Table B1.1 Density of blended foam containing 0.5% talc and 1.0% wax.

Sample Code	F11	F12	F13	F14	F15	F16
Density (kg/m ³)	33	31	33	30	31	35
	34	32	31	30	33	30
	31	33	34	33	30	33
	33	30	35	32	30	34
	34	34	32	30	31	33
Mean	33	32	33	31	31	33
SD	1.22	1.58	1.58	1.41	1.22	1.87

Table B1.2 Density of blended foam containing 1.0% talc and 1.0% wax.

Sample Code	F21	F22	F23	F24	F25	F26
Density (kg/m ³)	40	40	44	39	38	44
	36	43	40	42	42	43
	38	40	38	42	42	42
	39	38	44	40	38	43
	37	39	44	42	40	43
Mean	38	40	42	41	40	43
SD	1.58	1.87	2.82	1.41	2.0	0.707

Table B1.3 Cell density of blended foam containing 0.5% talc and 1.0% wax.

Sample Code	F11	F12	F13	F14	F15	F16
Cell Density	60	46	58	48	52	52
	54	52	58	52	48	48
	58	50	62	54	52	50
	52	45	50	47	44	54
	56	47	52	49	44	46
Mean	56	48	56	50	48	50
SD	3.16	2.91	4.89	2.91	4.0	3.16

Table B1.4 Cell density of blended foam containing 1.0% talc and 1.0% wax.

Sample Code	F21	F22	F23	F24	F25	F26
Cell Density	98	104	98	108	110	98
	102	114	100	102	106	102
	100	112	96	103	107	104
	96	108	104	105	110	96
	104	111	102	102	107	100
Mean	100	110	100	104	108	100
SD	3.16	4.0	3.16	2.54	1.87	3.16

Table B1.5 Compression strength of blended foam containing 0.5% talc and 1.0% wax.

Sample Code	F11	F12	F13	F14	F15	F16
Compression Strength (kg)	2.28	1.79	2.63	2.75	2.35	2.97
	2.32	1.81	2.59	2.73	2.32	2.93
	2.29	1.83	2.62	2.69	2.36	2.96
	2.32	1.82	2.59	2.73	2.30	2.94
	2.29	1.80	2.62	2.71	2.32	2.95
Mean	2.30	1.81	2.61	2.72	2.33	2.95
SD	0.01	0.01	0.01	0.02	0.02	0.01

Table B1.6 Compression strength of blended foam containing 1.0% talc and 1.0% wax.

Sample Code	F21	F22	F23	F24	F25	F26
Compression Strength (kg)	2.33	1.88	2.73	2.90	2.52	2.28
	2.37	1.92	2.81	2.86	2.46	2.34
	2.36	1.90	2.79	2.87	2.48	2.30
	2.33	1.88	2.75	2.89	2.50	2.32
	2.36	1.92	2.77	2.88	2.49	2.36
Mean	2.35	1.90	2.77	2.88	2.49	2.32
SD	0.01	0.02	0.03	0.01	0.02	0.03

VITA

Satyen S. Desai was born on 7th September 1976 in Santrampur, India. He completed Post Graduate Diploma in Plastic testing and Conversion technology from Central Institute of Plastic Engineering and Technology, India in 1998. He continues his Master's degree in Petrochemistry and Polymer Science, Faculty of Science at Chulalongkorn University in 2003 and finished in 2005.



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