ผลกระทบของน้ำมันแก๊สโซฮอล์ต่อวัสดุประกอบแต่งพอลิเอทิลีน
ชนิดความหนาแน่นสูงเสริมแรงด้วยเส้นใยแก้ว

นางสาววรพรรณ อักษรวงศ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาตรมหาบัณฑิต
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IMPACTS OF GASOHOLS ON GLASS FIBER REINFORCED HDPE COMPOSITE

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Chemical Engineering
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Field of Study	Chemical Engineering
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งานวิจัยนี้มุ่งศึกษาผลของปริมาณเส้นใยแก้วและปริมาณของเอทานอลในน้ำมันแก๊สโซฮอล์ต่อสมบัติทางกายภาพและทางกลของวัสดุประกอบแต่งพอลิเอทิลีนชนิดความหนาแน่นสูงเสริมแรงด้วยเส้นใยแก้ว โดยพอลิเอทิลีนชนิดความหนาแน่นสูงที่อัตราการไหล 6 g/10min ผสมกับเส้นใยแก้วแบบสั้นชนิด E ที่อัตราส่วน 0, 15, และ 30% โดยน้ำหนัก ในเครื่องอัดรีดแบบเกลียวคู่ หลังจากนั้นนำมาขึ้นรูปเป็นชิ้นงานโดยเครื่องอัดขึ้นรูปเพื่อทดสอบสมบัติทางกายภาพและฉีดขึ้นรูปเพื่อทดสอบสมบัติทางกล ชิ้นงานทดสอบถูกนำไปแช่ในน้ำมันทดสอบ 4 ชนิด คือ C(E0)$_A$, C(E20)$_A$, C(E85)$_A$, และ C(E100)$_A$ เป็นเวลา 16 สัปดาห์ โครงสร้าง ปริมาณการดูดซับน้ำ การเปลี่ยนแปลงด้านน้ำหนักและขนาด สมบัติด้านรับแรงดึง ด้านการบิดงอ ด้านการกดอัด และด้านการรับแรงกระแทกของชิ้นงานทดสอบถูกวัดด้วยกล้องจุลทัศน์อิเล็กตรอนแบบส่องกราด ตาชั่ง เครื่องทดสอบสมบัติเชิงกล และเครื่องทดสอบแรงกระแทก ตามลำดับ

ผลการทดลองที่ได้พบว่าพอลิเอทิลีนชนิดความหนาแน่นสูงสามารถยึดกับเส้นใยแก้วเสริมแรงได้ดี สมบัติเชิงกลและมวลของวัสดุประกอบแต่งพอลิเอทิลีนชนิดความหนาแน่นสูงเสริมแรงด้วยเส้นใยแก้วที่ไม่ได้แช่ในน้ำมันทดสอบมีค่าเพิ่มขึ้นตามปริมาณเส้นใยแก้วที่เพิ่มขึ้น น้ำมันทดสอบที่มีส่วนผสมของแอลกอฮอล์สูง ได้แก่ C(E85)$_A$ และ C(E100)$_A$ มีผลต่อสมบัติเชิงกายภาพและเชิงกลของวัสดุประกอบแต่งพอลิเอทิลีนชนิดความหนาแน่นสูงเสริมแรงด้วยเส้นใยแก้วน้อยกว่าน้ำมันทดสอบที่มีส่วนผสมของแอลกอฮอล์น้อยกว่า ได้แก่ C(E0)$_A$ และ C(E20)$_A$ เนื่องจากการดูดซับไอโซออกเทนและโทลูลีนจากน้ำมันทดสอบเข้าไปในพอลิเอทิลีนชนิดความหนาแน่นสูง แต่ไม่มีการดูดซับน้ำและแอลกอฮอล์จากน้ำมันทดสอบ ดังนั้นวัสดุประกอบแต่งพอลิเอทิลีนชนิดความหนาแน่นสูงเสริมแรงด้วยเส้นใยแก้วสามารถใช้ได้กับน้ำมันแก๊สโซฮอล์ โดยเฉพาะน้ำมันแก๊สโซฮอล์ที่มีปริมาณเอทานอลสูง

ภาควิชา วิศวกรรมเคมี	ลายมือชื่อนิสิต วรพรรณ อักษรวงศ์
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The effects of glass fiber content and ethanol concentration in gasohols on the physical and mechanical properties of HDPE/GF composites were studied. HDPE with MFI=6 g/10min were mixed with chopped E-glass fiber of 3 mm length at 0, 15, and 30 wt% using twin-screw extruder. Compression molded disk specimens were used for physical properties measurement and injection molded specimens were used for mechanical properties measurement. The specimens were immersed into 4 different test fuels, namely, $C(E0)_A$, $C(E20)_A$, $C(E85)_A$, and $C(E100)_A$ for 16 weeks. Morphology, water absorption, mass and dimension change, tensile, flexural, compressive and impact properties were examined by scanning electron microscope (SEM), balance, universal testing machine (INSTRON) and impact tester, respectively.

The experimental results showed that there were good bonding between the HDPE and reinforced glass fibers. Mechanical properties and mass of HDPE/GF composites of all unsoaked samples increased with increasing fiber content. Test fuels containing higher amount of ethanol, i.e. $C(E85)_A$, and $C(E100)_A$, had less effect on physical and mechanical properties of HDPE/GF composites than test fuels containing lower amount of ethanol, i.e. $C(E0)_A$, and $C(E20)_A$ due to absorption of iso-octane and toluene and not ethanol or water from test fuels into HDPE. Hence, HDPE/GF composites could be used with gasohols especially with fuels with high ethanol content.

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Finally, I would like to dedicate this thesis to my parents who give their unfailing love, understanding, and generous encouragement during my study.

CONTENTS

PAGE

CHAPTER

PAGE

CHAPTER

PAGE

CHAPTER

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

CHAPTER I

INTRODUCTION

1.1 General Introduction

Thailand relies mainly on imported oil from other countries to satisfy its energy demand. When the oil price fluctuates, Thailand has to pay more. However, Thailand has the potential for producing an energy substitute for oil, especially alcohol from plants, because of the prevalence of agricultural resources for example, rice, sweet corn, cassava root, sugarcane, sweet sorghum and others. This is therefore a good opportunity for Thailand to develop a fuel substitute in order to reduce the amount of imported oil, and also solve the problem of having low prices for agricultural products at the same time. Regarding the high oil price situation at present, the Ministry of Energy is promoting the serious use of gasohol. Gasohol is a mixture of gasoline and ethanol alcohol. It is widely used as an alternative fuel for gasoline. Gasohols with higher content of ethanol are more corrosive to materials than gasohols with lower ethanol content. Blends with different percentages of ethanol in gasoline are commonly used in various countries around the world, especially Australia (officially 10 vol%), Brazil (up to 25 vol%), Canada (10 vol%), Sweden (5 vol%) and the USA (up to 10 vol%) [1]. Hence, there is a need to develop material that is more compatible with gasohols. Polymers are widely used because of their ease of production, light weight and ductile nature. One common practice to improve their mechanical properties is to reinforce polymers with inclusions (fibers, whiskers, platelets or particles) to make composites. High-density polyethylene (HDPE) is a thermoplastic in family of polyethylene and one of the most popular polymers with good mechanical properties and chemical resistance to acid, alcohols, and hydrocarbons [2]. HDPE has been the resin of choice for plastic gas tanks, and production capacity has been on the increase. Glass fiber is used to reinforce HDPE to improve the mechanical properties of materials [2].

This work aims to study the effects of glass fiber content and 0 vol% aggressive ethanol-blended fuel C; $C(E0)_A$, 20 vol% aggressive ethanol-blended fuel C; $C(E20)_A$, 85 vol% aggressive ethanol-blended fuel C; $C(E85)_A$ and 100 vol% aggressive ethanol; $C(E100)_A$ on the physical and mechanical properties of HDPE/GF composites after immersion in 4 different test fuels for 16 weeks.

1.2 Objectives

1. To study the impacts of gasohols and glass fiber reinforced HDPE composite.
2. To study the effects of glass fiber content on physical and mechanical properties of glass fiber reinforced HDPE composite.
3. To study the impact of gasohols on physical and mechanical properties of glass fiber reinforced HDPE composite.

1.3 Scopes of work

1. High density polyethylene, trade name as InnoPlus HD2308J, is supplied by PTT Chemical.
2. E-Chopped strand glass fiber (ECS-401AD Chopped strand) with fiber length of 3 mm is purchased from Jushi Group Co., Ltd.
3. Preparation of polymer composites between HDPE and glass fibers at various weight ratios of HDPE and glass fibers are 100: 0, 85:15 and 70:30.
4. Four test fuels are prepared from Fuel C and aggressive ethanol at volume ratios of 100:0, 80:20, 15:85 and 0:100 to form $C(E0)_A$, $C(E20)_A$,$C(E85)_A$ and $C(E100)_A$ according to SAE (Standard J1681).

Note: ASTM Test Fuel C

- Test Fuel C is composed of 50 vol% toluene and 50 vol% iso-octane

Aggressive ethanol

- Synthetic ethanol 816.0 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g and glacial acetic acid 0.061 g

5. Determine physical and mechanical properties of specimens at beginning, four weeks, ten weeks and the end of experiment (about 16 weeks).

   Physical properties of the polymeric composite will be determined:

   - Mass change
   - Diameter change
   - Thickness change
   - Volume change
   - Water absorption
   - Morphology

   Mechanical properties of the polymeric composite will be determined:

- Tensile properties	(ASTM D638)
- Young's Modulus properties	(ASTM D638)
- Flexural properties	(ASTM D790)
- Compressive properties	(ASTM D695)
- Impact Properties	(ASTM D256)

1.4 Expected Benefits

1. To Gain insight into the compatibility between gasohol and glass fiber reinforced HDPE composite.
2. To Obtain information on effects of glass fiber content on mechanical properties of glass fiber reinforced HDPE composite.
3. To Obtain information on effects of gasohol on physical and mechanical properties of glass fiber reinforced HDPE composite.

CHAPTER II

THEORY

2.1 High Density Polyethylene (HDPE)

Polyethylene (PE) is the most widely used plastic throughout the world, and high density polyethylene (HDPE) is the most widely used type of PE [2]. HDPE is thermoplastic and can be produced in several ways, including radical polymerization of ethylene at extremely high pressure, coordination polymerization of ethylene, and polymerization of ethylene with supported metal-oxide catalysts [3]. Nowadays HDPE is still made almost entirely through chromium or Ziegler catalyst system. The two systems produce different types of polymer, which are useful for different applications [2].

Polymerization

The coordination polymerization of ethylene utilizes a catalyst prepared as a colloidal dispersion by reacting, typically, an aluminum alkyl and titanium tetrachloride in a solvent such as heptane. Ethylene is added to the reaction vessel under slight pressure, at temperature of 50-75 °C. Heat of polymerization is removed by cooling. Polymer forms as a powder or granules, insoluble in the reaction mixture. At the completion of the reaction, the catalyst is destroyed by the admission of water or alcohol, and the polymer is filtered or centrifuged off, washed, and dried [3].

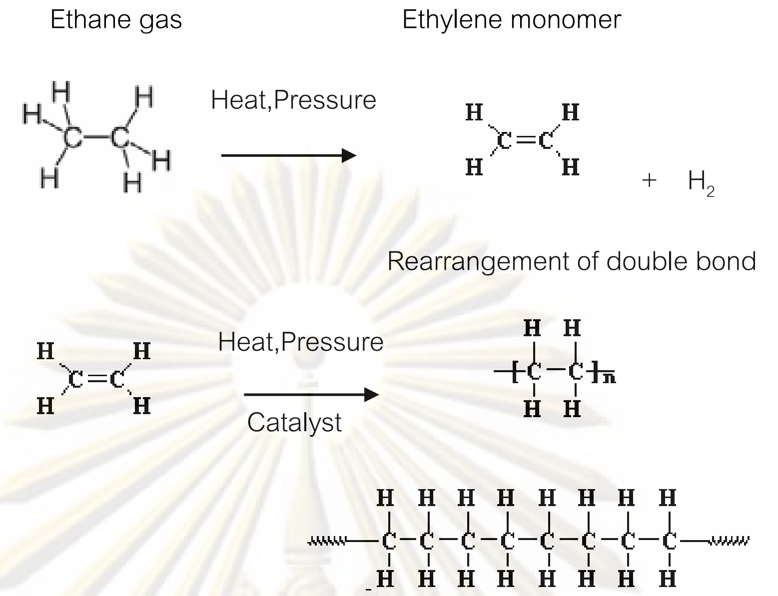


Figure 2.1 Polymerization of Polyethylene

Structure

Typical linear polyethylene are highly crystalline (over 90%) polymers. The weight average molecular weight of typical commercial HDPE grades can vary from 20,000 to over 1,000,000 depending on the application [2, 3].

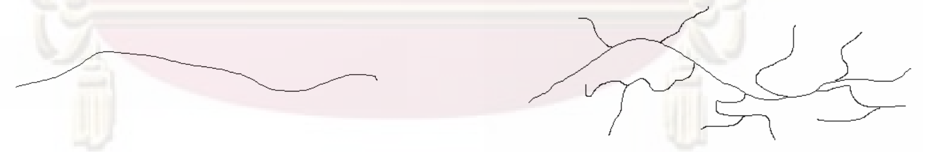


Figure 2.2 Linear Polyethylene or HDPE and
Branched Polyethylene or LDPE [4]

Properties

Most of the differences in properties between branched and linear polyethylene can be attributed to the higher crystallinity of the latter polymers. Linear polyethylene are decidedly stiffer than the branched materials (modulus of 100,000 versus 200,000 psi or

690 versus 1,379 MPa), and have a higher crystalline melting point and greater tensile strength and hardness. HDPE is not soluble in all common organic solvents at room temperature, more polar organic solvents even at elevated temperature and inorganic solvents. Linear polyethylene are soluble above 80 ºC in 1,2,4-trichlorobenzene, decalin, di-n-amyl ether, halogenated hydrocarbons, higher aliphatic esters and ketones, hydrocarbons and xylene [5,6].

Table 2.1 Properties of HDPE [2,7]

Properties	Metric
Density	0.95-0.97 g/cm^3
Melting Point	133-138 ºC
Water Absorption	0.0100 - 0.0200 %
Tensile Strength	11.7-44.0 MPa
Elongation at Break	200-400 %
Elongation at Yield	6.00 - 13.0 %
Flexural Modulus	0.179-2.62 GPa
Modulus of Elasticity	0.700 - 2.62 GPa
Izod Impact	32-850 J/m
Processing Temperature	157-271 ºC

Degradation

HDPE is relatively stable to heat because of the high bond energy of the single C-C bond. However, above about 290-300 ºC, chemical processes in an inert medium begin to result in breakage and cross-linking of chains. Oxygen is quite aggressive toward the C-H bonds of these macromolecules at the usual melt processing temperatures (200-300 ºC). This type of degradation is also a combination of radical reactions, resulting in a reduction of molecular weight, formation of oxygen-containing groups such as hydroxyl, carbonyl, and low molecular weight by products such as water, aldehydes, and ketones. Protection is also nearly always afforded by the addition of an antioxidant package. Exposure of the molded HDPE articles to sunlight and air also results in polymers being attacked over time, especially at wavelength less than 400 nm. Such exterior aging of the polymer results in development of surface cracks, brittleness, change in color, and a deterioration of mechanical and dielectrical properties. Photooxidation degradation is prevented by small amounts of light stabilizers. Chemical reactions of HDPE not involving oxidation include fluorination, chlorination and sulfonation. Sometimes molded articles, such as fuel tanks, are given such as surface treatment to increase diffusional resistance [2].

Application

Polyethylene products are made by injection, blow, extrusion and rotation molding. The production of bottles and other containers by blow molding accounts for about 40% of the linear polyethylene made. About 25% of the linear polyethylene produced is used in the injection molding of crates, pails, tubs, caps, closures and housewares. The higher stiffness and heat resistance of the linear material have led to its replacement of branched polyethylene in applications where these properties are important. Other major uses of linear polyethylene include film and sheet, wire and cable insulation, pipe, conduit and multilayer of fuel tanks [2,3,6].

2.2 Composite materials

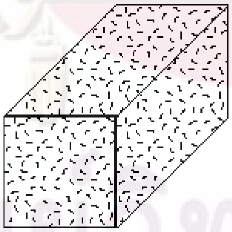
Materials consisting of more than a single phase can justifiably be described as composite materials [8]. In practice, most composites consist of a bulk material (the matrix), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This work aims to study the polymer matrix composites.

Polymer Matrix Composites (PMC) are materials brought about by combining materials differing in composition or form on a macroscale for the purpose of obtaining specific characteristics and properties. The constituents retain their identity such that they can be physically identified and they exhibit an interface between one another [11]. The first reinforced plastics were all based on thermoset polymers. These are versatile, inexpensive polymers, used extensively with glass-fiber reinforcement, often in substantial plastic components (such as storage tanks, pipes, boat hulls and seating for public places). Recent years, however, have seen rapid growth in the used of reinforced thermoplastics polymers. A major advantage of a thermoplastics matrix is that forming is possible by normal injection moulding or extrusion techniques. These are the most economical processes when cheap and precise manufacture of very large quantities of components is required. Allowance must be made for the effect of the reinforcing particles on the flow of molten plastic during forming; the viscosity, for example, is significantly increased. As a result, some modifications to tooling and process parameters are usually necessary [17].

2.2.1 Common Categories of Composite Materials.

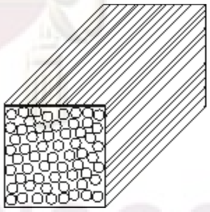
Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. Based on the form of reinforcement, common composite materials can be classified as follows: [15].

1. Fibers as the reinforcement (Fibrous Composites):



a. Random fiber (short fiber)

reinforced composites

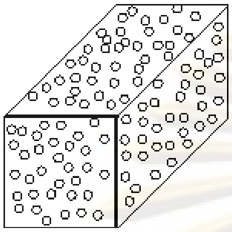


b. Continuous fiber (long fiber)

reinforced composites

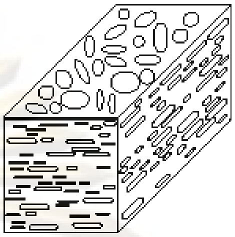
2. Particles as the reinforcement

(Particulate composites)

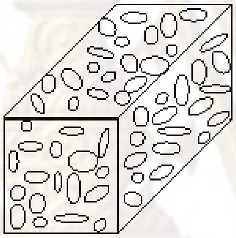


3. Flat flakes as the reinforcement

(Flake composites)



4. Fillers as the reinforcement (Filler composites):



In this work, the polymer composites, which comprise of high density polyethylene (HDPE) as polymer matrix and glass fibers as reinforcement are studied.

2.2.2 Reinforcement

Reinforced materials are referred to as composite or filled plastics. Filler materials or reinforcements can be glass, boron, graphite, alumina fibers, woven and unwoven textiles, sisal, wood flour and others. Fillers can be applied as a powder, pellet form in the shape of spheres or needles, granular form or can be fibrous in shape. The purpose of fillers are to enhance various properties to the plastics to which they are applied. They can reduce cost, provide body, minimize curing time, minimize shrinkage, improve thermal endurance, provide additional strength and mechanical properties and enhance electrical and chemical characteristics [9,10,12,13].

Polymer/glass fibers composites offer exceptionally high levels of strength, stiffness and impact strength, combined with a density substantially lower than those of structure metal and alloys. Strength and stiffness arise from the properties of the reinforcing fibers, which are very small in diameter and consequently substantially free from the flaws that normally reduce the strength of brittle materials from high theoretical values to the low practical values familiar in bulk samples [8,12,14].

2.3 Glass fibers

Although powdered glass or glass spheres can be used as fillers in polymer compositions, by far the largest usage of glass is in the form of continuous filament usually referred to as glass fiber. Glass fibers have been known for many years but they did not go into commercial production until 1938. It was 1942 when the first glass reinforced plastics were produced and used in the reinforced plastics industry in Britain [16].

Glass fibers are inorganic, amorphous (noncrystalline), isotropic (equal properties in all directions) and are a long, three-dimensional network of silicon, oxygen and other atoms arranged in a random fashion [10]. Glass fibers are strong, low in cost, nonflammable, nonconductive (electrically), and corrosion resistant. The disadvantages are relatively high specific gravity, sensitivity to abrasion with handling, relatively low fatigue resistance and high hardness. There are two main categories of glass fibers: E-glass and high-strength glass. High-strength glass can be further subdivided into the following categories: S-glass, S-2 glass and S-2 hollow glass fiber.

Another type known as C-glass, is used in chemical applications requiring greater corrosion resistance to acids than is provided by E-glass. A-glass which is a soda-lime-silica composition is more typically used for window panes and bottles [13].

Table 2.2 Composition (weight %) of Glass Fibers [16]

Oxide	A-Glass	E-Glass	S-Glass
SiO_2	72.0	54.3	64.3
Al_2O_3	0.6	15.0	24.8
Fe_2O_3	-	15.0	0.2
CaO	10.0	17.3	-
MgO	2.5	4.7	10.3
Na_2O	14.2	0.6	0.3
K_2O	-	0.6	-
Li_2O	-	-	-
SO_3	0.7	-	-
B_2O_3	-	8.0	-
F_2	-	0.1	-
BeO	-	-	-
TiO_2	-	-	-
ZrO_2	-	-	-
CeO_2	-	-	-

The additives for glass fibers is a mixture of lubricants, antistatic agent and a binder. The binder packs the filaments together into a strand. The additives may also contain small percentages of coupling agent that promotes adhesion between fibers and the specific matrix for which it is formulated. The basic commercial form of continuous glass fibers is a strand, which is a collection of parallel filaments. A roving is a group of untwisted parallel strands wound in a cylindrical forming package. Roving are used in continuous molding operations such as filament winding and pultrusion. They can also be preimpregnated with a thin layer of polymeric resin matrix to form prepregs. Prepregs are subsequently cut into required dimensions, stacked and cured into the final shape in batch molding operations such as compression molding and hand layup molding.

Chopped strands are produced by cutting continuous strands into short lengths. The ability of the individual filaments to hold together during or after the chopping process depends largely on the type and amount of additives applied during the fiber manufacturing operation [10].

Table 2.3 Typical Physical Properties of Representative Fibrous Reinforcements [13]

Property	E-Glass	Carbon (PAN)	Aramid	PET	Sisal	Stainless steel	Ceramic
Fiber diameter (in.)	0.0004	0.0003	0.0005	0.0009	0.010	0.0003	0.0002
Specific gravity	2.54	1.84	1.45	1.38	1.50	7.77	2.7
Modulus of elasticity (MPa)	72.4	359	131	10	16.5	193	103
Tensile strength (GPa)	3.45	3.79	2.76	1.03	0.52	0.59	1.72
Tensile elongation (%)	4.8	1.1	2.4	22	2-3	2.3	NA
Thermal conductivity (W/m°K)	1.01	8.65	0.50	0.25	NA	1.12	2.88
Approximate relative cost (by weight)	1	15	4	2	0.7	18	3

This work used chopped strand E-glass for reinforcement because E-glass has good resistance to heat and water, fair resistance to bases, low resistance to acids and has the lowest cost of all commercially available reinforcing fibers, which is the reason for its widespread use in the fiber-reinforced plastics industry [8,10,13].

2.4 Gasohols

Gasohol is a blending of unleaded gasoline and 99.5 % ethanol, mixed at different ratio. In the gasohol, the ethyl alcohol serves as an additive to enhance oxygenates value and octane number of gasoline which normally rendered by Methyl-Tertiary-Butyl-Ether (MTBE) [18]. Because of this make gasohol has higher octane, or antiknock, properties than gasoline and burns more slowly, coolly, and completely [20]. The ethanol is usually obtained by fermentation, followed by distillation, using crops, such as maize, wheat, potatoes, rice, corn, tapioca or sugar cane [22]. Combustion of gasohol produces lower levels of hydrocarbons, carbon monoxide and carbon dioxide than general 95 octane gasoline, and helps to reduce black smoke, aromatic hydrocarbon, benzene, and dust emission from exhaust pipes [23].

Mixing alcohol with gasoline produces gasohol. Advantages of fuel blends are that alcohol tends to increase the octane rating, which is particularly important in unleaded fuel, and reduce carbon monoxide (CO) emissions from the engine. The primary disadvantage of mixing methyl and ethyl alcohol with gasoline is that under certain conditions these alcohols may separate from the gasoline. An engine adjusted to burn gasoline efficiently will produce less power from alcohol should it separate from the gasoline. Separation is caused by the polar nature of the alcohol molecules and their tendency to absorb water, also a polar substance. Methyl alcohol is the most likely to separate, butyl alcohol the least likely. The tendency for separation increases as the temperature decreases, the quantity of water absorbed increases, and the quality of the gasoline decreases [21].

The proportion of ethanol used in Gasohol is generally 10 percent across the world, including Thailand because this proportion of mixture can be used in vehicles without engines modification. However, many countries are now trying to promote the use of ethanol by mixing it at a higher proportion with gasoline. Brazil is one such country, which embraces ethanol blend from 20 percent (E20) up to pure ethanol (E100). Besides Gasohol E5 or E10, the United States, Canada and Sweden also use Gasohol 85, which has only 15 percent of gasoline in its mixture. The gasoline content is kept in this formula because it helps engines to start easily during the cold weather. Gasohol with 85 percent concentration of ethanol has as high an octane rating as 105, which can boost the vehicle engine’s performances [18].

E10

E10, sometimes called gasohol, is a fuel mixture of 10 vol% ethanol and 90 vol% gasoline that can be used in the internal combustion engines of most modern automobiles. According the Philippine Department of Energy E10 is not harmful to cars' fuel systems. However, it is not allowed to be used in aircraft [19].

E15

E15 contains 15 vol% ethanol and 85 vol% gasoline. This is generally the greatest ratio of ethanol to gas that is recommended by auto manufacturers that sell vehicles in the United States, though it is possible that many vehicles can handle higher mixtures without trouble. Flexible-fuel vehicles (FFV) are designed to take higher concentrations, up to 96% v/v ethanol (and no gasoline) [19].

E20

E20 contains 20 vol% ethanol and 80 vol% gasoline. Since February 2006, this is the standard ethanol-gasoline mixture sold in Brazil, where concerns with the alcohol supply resulted in a drop in the ethanol percentage, previously at 25 vol%. Brazilian flexible-fuel cars are set up to run with gasoline in such concentration range and few will work properly with lower concentrations of ethanol. U.S. FFV can run below 20 vol% ethanol, but up to E85. This fuel is not yet widely used in Australia or the United States. It will be mandated by the U.S. state of Minnesota by 2013. Available also in Thailand with tax reductions for "E20" engine cars [19].

E85

E85 is a mixture of 85 vol% ethanol and 15 vol% gasoline, and is generally the highest ethanol fuel mixture found in the United States. It is common in Sweden, and there are more than 1000 public E85 fuel pumps in the U.S. as of 2006, mostly concentrated in the Midwest, with over half of those in Minnesota. This mixture has an octane rating of about 105. This is down significantly from pure ethanol but still much higher than normal gasoline 87 octane. The addition of a small amount of gasoline helps a conventional engine start when using this fuel under cold conditions. E85 does not always contain exactly 85 vol% ethanol. In winter, especially in colder climates, additional gasoline is added (to facilitate cold start). E85 contains approximately 27% less energy per gallon than conventional gasoline, although ethanol typically burns more efficiently. This results in a fuel economy loss of less than the energy content would imply [19].

E95

E95 designates a blend of 95 vol% ethanol and 5 vol% ignition improver and is used in some diesel engines where high compression is used to ignite the fuel, as opposed to the operation of gasoline engines where spark plugs are used. Because of the high ignition temperatures of pure ethanol, the addition of ignition improver is necessary for successful diesel engine operation. This fuel has been used with success in many Swedish busses since the 1980's [19].

E100

E100 is ethanol with up to 4 vol% water, which is most widely used in Brazil and Argentina. Operation in ambient temperatures below 15 °C (59 °F) causes problems with pure, or so-called neat, ethanol for starting engines. The most common cold weather solution is to add an additional small gasoline reservoir to increase the gasoline content momentarily to permit starting the engine. Once started, the engine is then switched back to neat ethanol. Ethanol used as a fuel in Brazil is the azeotrope (the highest concentration of ethanol that can be achieved via distillation) and contains 4 vol% of water [19].

2.4.1 Engines for Gasohol

Gasohol, which contains ethanol less than 10 percent can be used in vehicles without engine modification. However, vehicles which use Gasohol at higher ratio of ethanol must have a specially designed engine as specified in the following. Vehicles, which are all to use Gasohol E20, need to have their fuel systems and fuel injection functions modified. These types of vehicles can use gasohol up to 20 percent of ethanol or use normal gasoline. This technology was developed and has been used in the United States, Europe and Brazil for more than 10 years. There are over one million vehicles worldwide which use this type of engine.

The Flexible Fuel Vehicle (FFV) – The vehicles come with an engine that can use fuel which contains ethanol in different ratios and with high efficiency. This type of vehicle is designed to include a sensor system for checking the ratio of ethanol and gasoline in order to control the fuel combustion system in line with the type of fuel used. The materials used in the fuel system of this type of vehicle, such as the fuel tank, fuel pipe and fuel injection, is reinforced to possess resistance to high erosion caused by ethanol. Other than this, the engine is not different from other vehicles [18].

2.4.2 Disadvantages of Alcohol

There are many disadvantages to using alcohols, particularly methyl and ethyl alcohol. Although these alcohols, when used near their stoichiometric air-fuel ratios, produce more power, a larger quantity of fuel is required to produce a specified power output. For example, in an automobile, more fuel is required for each mile driven. The relatively low boiling points and high vapor pressures of methyl and ethyl alcohol indicate that vapor lock could be a serious problem, particularly at high altitudes on warm summer days. Butyl alcohol, because of its low vapor pressure, is the least likely of the alcohols to cause vapor lock. The relatively high latent heats of methyl and ethyl alcohol cause problems in mixing these alcohols with air and transporting them through the intake manifold of the engine. Heating the intake manifold may be necessary in cold weather or before the engine reaches operating temperatures. Without external heat to more completely vaporize the fuel, the engine may be difficult to start and sluggish for a considerable time after starting. Butyl alcohol is the least likely to cause starting difficulties or problems during warm-up. Note that its latent heat is almost the same as the latent heat of octane. All of the alcohols are soluble in water, but butyl alcohol is relatively insoluble compared to methyl and ethyl alcohol. Less engine power is produced as the water content of an alcohol increases. Further, vapor lock, fuel mixing and starting problems increase with water.

Alcohols may be corrosive to certain materials used in engines. Generally, methyl alcohol is the most corrosive and butyl alcohol is least corrosive. Alcohols also can cause injury or physical harm if not used properly. People who use alcohol in motor fuels should observe warning labels and follow precautions to avoid problems [21].

2.4.3 Gasohol vs. Gasoline

Many studies have been carried out to compare gasohol and gasoline as automotive fuels. In almost all studies gasohol has shown itself to be comparable in performance, but to have major environmental advantages. Some of these are as follows:

(a) 10% alcohol boosts the octane of lead free gasolines. This is particularly important when octane enhancers, such as MMT (methyl cyclo pentadienyl manganese tricarbonyl) and lead are under restrictions.

(b) Gasohol has been shown by studies in Purdue School of Technology to produce more horsepower for each lb. of fuel burned.

(c) The exhaust pollution from gasohol is reduced 50-60% compared to regular gasoline (measured as unburned hydrocarbons)

(d) The carbon monoxide emitted when using gasohol is often so low it cannot be measured.

(e) Carbon build-up is reduced.

More and more oil companies are using alcohol to boost octane “super unleaded gasoline” without any reference to gasohol [25].

The addition of ethanol to gasoline results in changes to the properties of the fuel. When fuel properties change they can affect engine performance in many ways. This includes exhaust and evaporative emissions, fuel economy, operability, full load performance (power) and durability. The extent to which changes in fuel composition affects these engine performance qualities are very dependent on the engine itself, including engine design, fuel system and control system, as well as emissions control equipment. Table 2 summaries the some of the major properties of gasoline, ethanol, and mixtures of 10% and 20% (by volume) ethanol with gasoline. This is assuming splash blending of the components with no special blend stock for the gasoline component.

Table 2.4 Properties of Gasoline, Ethanol and Gasoline/Ethanol Blends [38]

Property	Gasoline	Ethanol	10% Ethanol / Gasoline Blend	20% Ethanol / Gasoline Blend[2]
Specific Gravity @ 15.5 °C	0.72-0.75	0.79	0.73-0.76	0.735-0.765
Heating Value				
(MJ/kg)	43.5	27	41.9	40
(BTU/lb)	18,700	11,600	18,000	17,200
Heating Value				
(MJ/litre)	32	21.3	30.9	29.9
(BTU/gal)	117,000	76,000	112,900	109,000
Approx Reid Vapour Pressure @ 37.8ºC (kPa)[1]	59.5	17	64	63.4
Stoichiometric Air/ Fuel Ratio	14.6	9	14	13.5
Oxygen Content (% by weight)	0	35	3.5	7

Volatility

Fuel volatility can be described by vapour pressure, each of which is important in understanding what is required from the fuel in terms of satisfying engine operability requirements. When small amounts of ethanol are added to gasoline, the vapour pressure of the mixture is greater than the vapour pressure of either the gasoline or alcohol alone. The molecules of pure alcohol are strongly hydrogen-bonded, but with small amounts of alcohol in a non-polar material (i.e. gasoline) the hydrogen bonding is much less extensive and the alcohol molecules behave in a manner more in keeping with their low molecular weight. Thus the alcohol becomes more volatile [38].

Reid Vapour Pressure

The RVP is a measure of the vapour pressure of a liquid as measured by the ASTM D 323 procedure and is commonly applied to automotive fuels. For automotive fuels, the Reid Vapour Pressure (RVP) measured at 37.8 deg C is used to define the fuel volatility [38]. Figure 5 shows RVP of the fuel for different ethanol blend content. The RVP only drops consistently below the gasoline RVP with blends of ethanol greater than 30%.

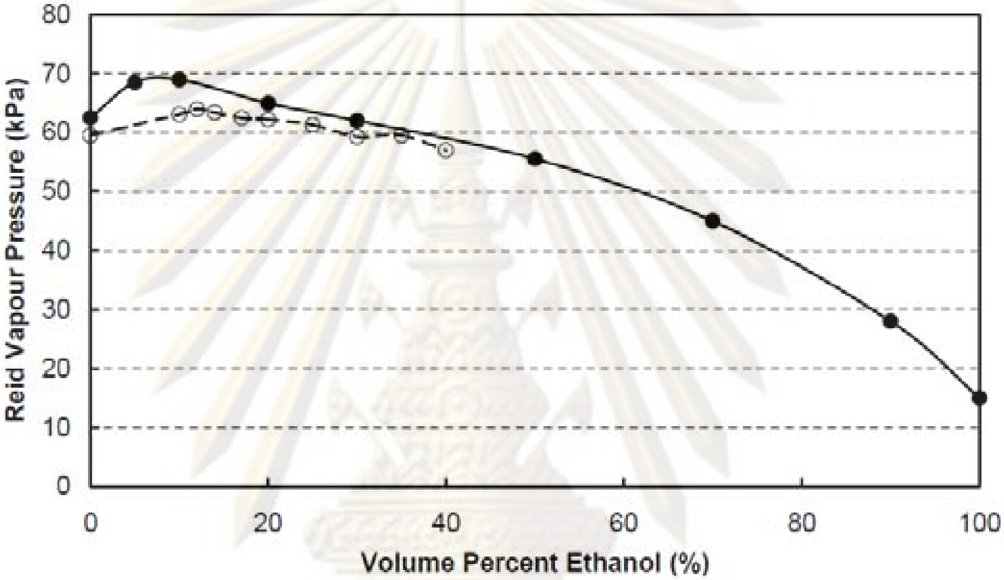


Figure 2.3 Reid Vapour Pressure with High Blend Ethanol [38]

Table 3 shows the change effect of an addition of 10% and 20% ethanol on the RVP of the base gasoline fuel using data from Owen & Coley.

Table 2.5 Increase in RVP with ethanol addition [38]

Volume % Ethanol added	RVP (kPa)
0	62
10	67.3
20	69

2.5 Polymer Solubility

The question of whether a chemical is harmful to a specific polymeric material needs to be addressed if the polymer component is to be placed in a possibly threatening environment. Similar to polymer solutions, a chemical reaction between a polymer and another substance is governed by Gibbs free energy equation. If the change in enthalpy, ΔH, is negative, a chemical reaction will occur between the polymer and the solvent [3].

The Solution Process

Dissolving a polymer is a slow process that occurs in two stages. First, solvent molecules slowly diffuse into the polymer to produce a swollen gel. This may be all that happens-if, for example, the polymer-polymer intermolecular forces are high because of crosslinking, crystallinity, or strong hydrogen bonding. But if this forces can be overcome by the introduction of strong polymer-solvent interactions, the second stage of solution can take place. Here the gel gradually disintegrates into a true solution. Only this stage can be materially speeded by agitation. Even so, the solution process can be quite slow (days or a weeks) for materials of very high molecular weight [3].

Polymer Texture and Solubility

From what has already been said, it is clear that the topology of the polymer is highly important in determining its solubility. Crosslinked polymers do not dissolve, but only swell if indeed they interact with the solvent at all. In part, at least, the degree of this interaction is determined by the extent of crosslinking: Lightly crosslinked rubbers swell extensively in solvents in which the unvulcanized material would dissolve, but hard rubbers, like many thermosetting resins, may not swell appreciably in contact with any solvent. The absorbance of solubility does not imply crosslinking, however. Other features may give rise to sufficiently high intermolecular forces to prevent solubility. The presence of crystallinity is the common example. Many crystalline polymers, particularly nopolar ones, do not dissolve except at temperatures near their crystalline melting points. Because crystallinity decreases as the melting point is approached and the melting point is itself depressed by the presence of the solvent, solubility can often be achieved at temperatures significantly below the melting point. Thus linear polyethylene, with crystalline melting point T_m = 135 °C, is soluble in many liquids at temperature above 100 °C, while even polytetrafluoroethylene, T_m = 325 °C, is soluble in some of the few liquids that exist above 300 °C. More polar crystalline polymers, such as nylon-66, T_m = 265 °C, can dissolve at room temperature in solvent that interact strongly with them (for example, to form hydrogen bonds).

There is little quantitative information about the influence of branching on solubility; in general, branched species appear to be more readily soluble than their linear counterparts of the same chemical type and molecular weight.

Of all these systems, the theory of the solubility, based on the thermodynamics of polymer solutions, is highly developed only for linear polymers in the absence of crystallinity. Here the chemical nature of the polymer is by far the most important determinant of solubility, as is elucidated in the remainder of this section. The influence of molecular weight (within the polymer range) is far less, but it is of great importance to fractionation processes, which yield information about the distribution of molecular weights in polymer samples.

Solubility Parameters

Solubility occurs when the free energy of mixing is negative. It was long thought that.

$$\Delta G = \Delta H - T\Delta S$$

the entropy of mixing ΔS was always positive, and therefore the sign of ΔG was determined by the sign and magnitude of the heat of mixing ΔH. For reasonably nonpolar molecules and in the absence of hydrogen bonding, ΔH is positive and was assumed to be the same as that derived for the mixing of small molecules. For this case, the heat of mixing per unit volume can be approximated (Hildebrand 1950) as

$$\Delta H = v_1 v_2 (\delta_1 - \delta_2)^2$$

Where ν is volume fraction and subscripts 1 and 2 refer to solvent and polymer, respectively. The quantitative δ^2 is the cohesive energy density or, for small molecules, the energy of vaporization per unit volume. The quantitative δ is known as the *solubility parameter*. (This expression for the heat of mixing is one of several alternatives used in theories of the thermodynamics of polymer solutions)

The value of the solubility-parameter approach is that δ can be calculated for interactions such as hydrogen bondings, solubility can be excepted if δ_1-δ_2 is less than 3.5-4.0, but not if it is appreciably larger. This approach to polymer solubility, pioneered by Burrell (1955). Has been extensively used, particularly in the paint industry. A few typical values of δ_1 and δ_2 are given in Table 2.6; for polymers. Extensive tabulations has been published. Perhaps the easiest way to determine δ_2 for a polymer of known structure is by the molar-attraction constants *E* of Table 2.7,

$$\delta_2 = \frac{\rho \sum E}{M}$$

where values of *E* are summed over the structural configuration of the repeating unit in the polymer chain, with repeat molecular weight *M* and density ρ.

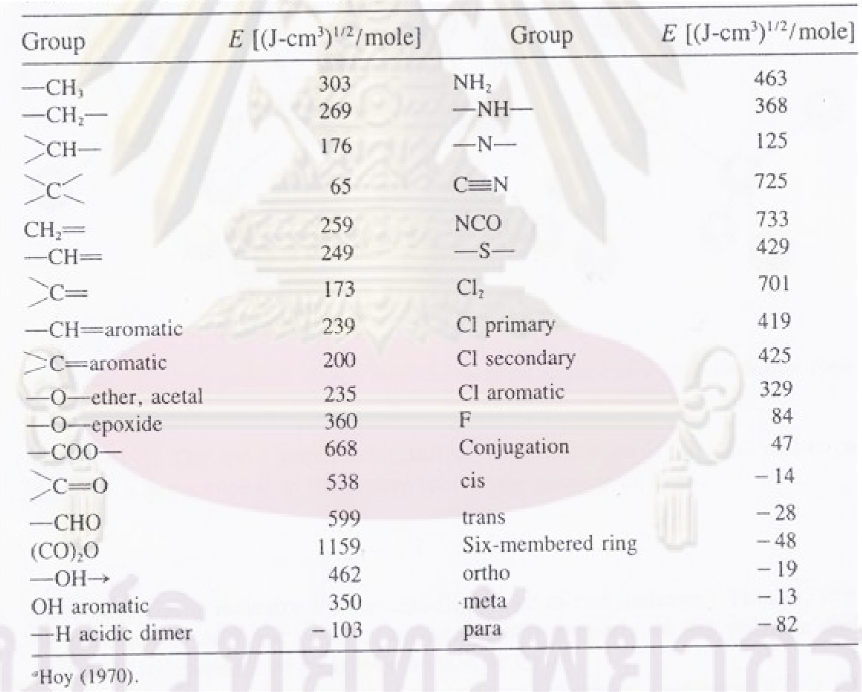
The original solubility-parameter approach was developed for nonpolar systems. Modifications to include polarity and hydrogen bonding have led to three-dimensional solubility-parameter schemes, which lack the simplicity of the single-parameter method but are more widely applicable. Despite its shortcomings, the concept is nevertheless still extremely useful and should not be abandoned without test.

In contrast to the above considerations of the thermodynamics of dissolution of polymers, the rate of this step depends primarily on how rapidly the polymer and the solvent diffuse into one another. Solvents that promote rapid solubility are usually small, compact molecules, but these kinetically good solvents need not be thermodynamically good as well. Mixtures of a kinetically good and liquid are often very powerful and rapid polymer solvents.

Table 2.6 Typical values of the solubility parameter δ for some common polymers and solvents [3]

Solvent	δ_1 [(J/cm^3)$^{1/2}$]	Polymer	δ_2 [(J/cm^3)$^{1/2}$]
n-Hexane	14.8	Polyethylene	16.2
Toluene	18.3	Polypropylene	16.6
Benzene	18.7	Nylon-66	27.8
Acetone	19.9	Poly(vinyl chloride)	19.4
Methanol	29.7	Polystyrene	17.6
Water	47.9	Polyacrylonitrile	31.5

Table 2.7 Molar attraction constants *E* [3]



Group	E [(J-cm^3)$^{1/2}$/mole]	Group	E [(J-cm^3)$^{1/2}$/mole]
—CH$_3$	303	NH$_2$	463
—CH$_2$—	269	—NH—	368
>CH—	176	—N—	125
>C<	65	C≡N	725
CH$_2$=	259	NCO	733
—CH=	249	—S—	429
>C=	173	Cl$_2$	701
—CH=aromatic	239	Cl primary	419
>C=aromatic	200	Cl secondary	425
—O—ether, acetal	235	Cl aromatic	329
—O—epoxide	360	F	84
—COO—	668	Conjugation	47
>C=O	538	cis	− 14
—CHO	599	trans	− 28
(CO)$_2$O	1159	Six-membered ring	− 48
—OH→	462	ortho	− 19
OH aromatic	350	meta	− 13
—H acidic dimer	− 103	para	− 82

[a] Hoy (1970).

2.6 Processing Techniques

2.6.1 Processing of HDPE/Glass fibers

Extruder

Extruders are the most common machines in the plastics processing industry. Extruders are used not only in extrusion operations, but also in most molding operations, for instance injection molding and blow molding. Essentially every plastic part has gone through an extruder at one point or another; in many cases, more than once [2].

The screw of an extruder is divided into several sections, each with a specific purpose. The feed section picks up the finely divided polymer from a hopper and propels it into the main part of the extruder. In the compression section, the loosely packed feed is compacted, melted, and formed into a continuous stream of molten plastic. Some external heat must be applied, but much is generated by friction. The metering section contributes to uniform flow rate, required to produce uniform dimensions in the finished product, and builds up sufficient pressure in the polymer melt to force the plastic through the rest of the extruder and out of the die [3,26,27].

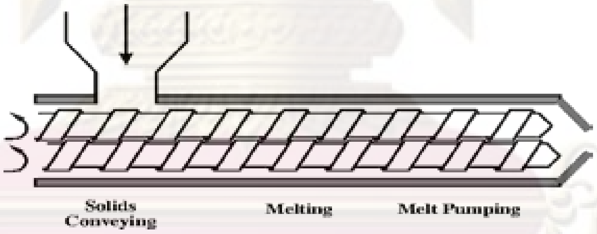


Figure 2.4 Co-rotating of Twin Screw Extruder [28]

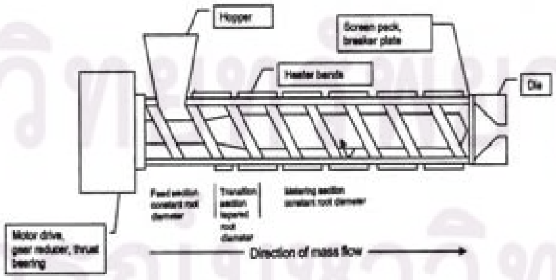


Figure 2.5 Diagram of a Plastics Extruder [29]

2.6.2 Preparation of specimens

Compression Molding

In compression molding, the polymer is put between stationary and movable members of a mold. The mold is closed, and heat and pressure are applied so that the materials becomes plastic, flows to fill the mold, and becomes a homogeneous mass. The necessary pressure and temperature vary considerably depending upon the thermal and rheological properties of the polymer. For a typical compression-molding material they may be near 150 ºC and 1,000-3,000 psi. A slight excess of material is usually placed in the mold to insure it is being completely filled. The rest of the polymer is squeezed out between the mating surfaces of the mold in a thin, easily removed sheet [3].

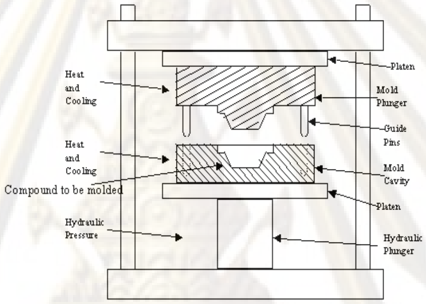


Figure 2.6 Diagram of a Compression-molding Press and Mold [28]

Advanced composite thermoplastics can also be compression molded with unidirectional tapes, woven fabrics, randomly orientated fiber mat or chopped strand. The advantage of compression molding is its ability to mold large, fairly intricate parts. Also, it is one of the lowest cost molding methods compared with other methods such as transfer molding and injection molding. Moreover it wastes relatively little material, giving it an advantage when working with expensive compounds. However, compression molding often provides poor product consistency and difficulty in controlling flashing, and it is not suitable for some types of parts [29].

Injection Molding

Injection molding is a forming process. Material (plastic, metal, ceramic, wax, etc.) is fed into a hopper which delivers it to the feed section of the barrel and screw.

The material is melted usually via a screw that melts or blends the material and then pushes liquefied material into the mold, which forms the part.

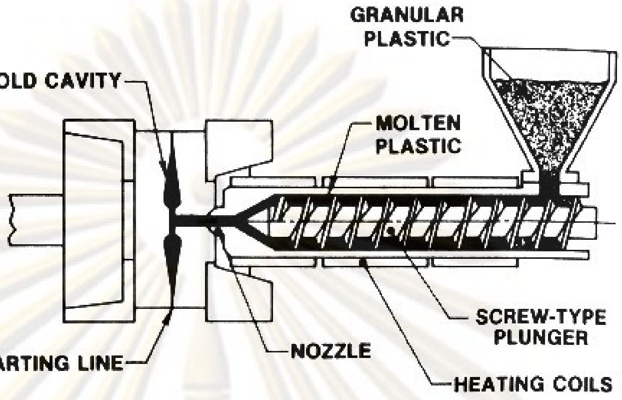


Figure 2.7 Diagram of an Injection Molding [30]

Advances in injection molding machinery continue with the evolution of hydraulic circuits and advanced computer numerically control system (CNC) [2]. Injection molding is widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars. Injection molding is the most common method of production, with some commonly made items including bottle caps and outdoor furniture [30].

2.7 Property Testing

2.7.1 Physical Properties

While all polymers absorb water to some degree, some are sufficiently hydrophilic that they absorb large enough quantities of water to significantly affect their performance. Water will case the polymer to swell and serves as a plasticizer, consequently lowering its performance, such as in electrical and mechanical behavior. The standard tests ISO 62 and ASTM D570 are used to measure the water absorption of polymers. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environment. Mass change, diameter change, thickness change and volume change are determined under specified conditions.

Specimen size

Diameter disks, 50.8 mm and 3.175 mm in thick. Shown in Figure 2.8.

Data: Water absorption is expressed as increase in weight percent.

Percent water absorption = [(Wet weight – Dry weight)/ Dry weight] × 100

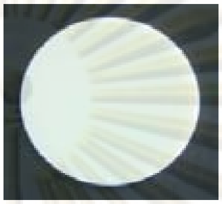


Figure 2.8 Specimen (disk) for Water Absorption, Mass Change, Diameter Change, Thickness change and Volume change

2.7.2 Morphology Characterization

The morphology of the composites were examined by Scanning Electron Microscope (SEM). The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.The composite samples were broken in liquid nitrogen and then coated with gold palladium alloy under vacuum [44].

Figure 2.9 Scanning Electron Microscope (SEM) [45]

2.7.3 Tensile Test

The tensile test is performed to characterize stress-strain behavior of material. However, standardized tests such as DIN 53457 and ASTM D638 are available to evaluate the stress-strain behavior of polymeric materials [39]. The ASTM D638 test also uses one rate of deformation per material to measure the modulus; a slow speed for brittle materials and fast speed for ductile ones. The relationship between the applied force, or load, and the elongation the specimen exhibits is linear. In this linear region, the line obeys the relationship defined as "Hooke's Law" where the ratio of stress to strain is a constant, or

$$E = \frac{\sigma}{\varepsilon}$$

E is the slope of the line in this region where stress (σ) is proportional to strain (ε) and is called the "Modulus of Elasticity" or "Young's Modulus"[39]. By its basic definition the uniaxial stress is given by:

$$\sigma = \frac{F}{A}$$

where F = Load applied [N], A = Area [m^2]

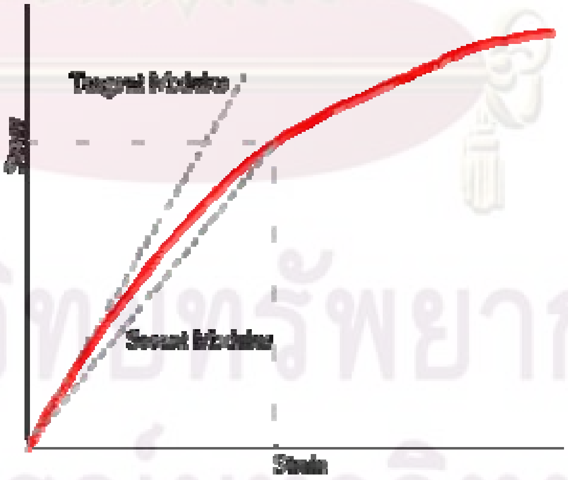


Figure 2.10 Illustration of Tensile Modulus [31]

The general factors, affecting the toughness of a material are: temperature, strain rate, relationship between the strength and ductility of the material and presence of stress concentration (notch) on the specimen surface. Fracture toughness is indicated by the area below the curve on strain-stress diagram (see the figure):

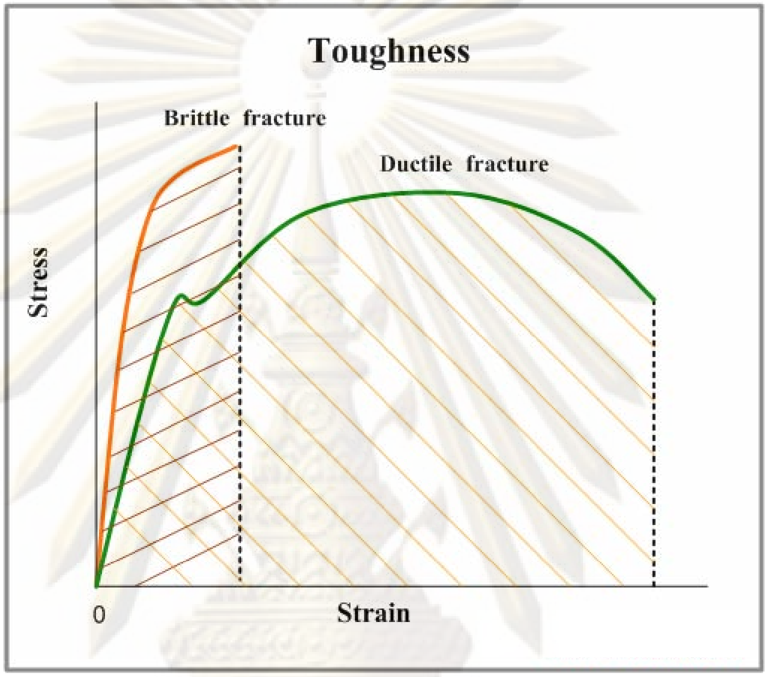


Figure 2.11 Toughness of the Ductile and Brittle of Materials [40]

Specimen size

The dog-bone shape specimens are were prepared for tensile testing following ASTM D638 (or ISO 527). The appearance and the dimension of sample are shown in Figure 2.12.

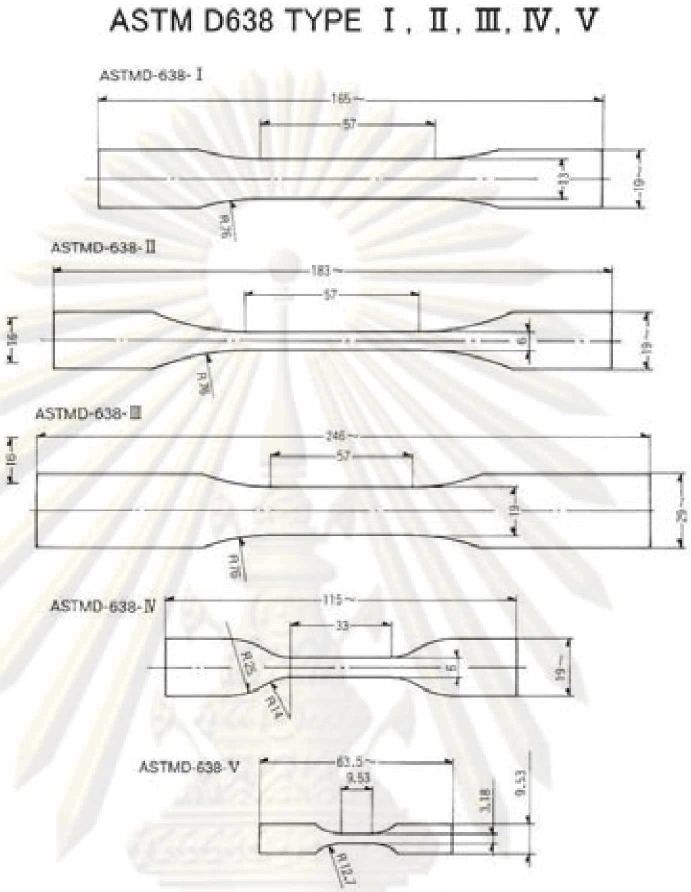


Figure 2.12 Dog-bone Shape Specimen for Tensile Test

This work was used type IV for tensile test.

W-Width of narrow section = 6 mm.

L-Length of narrow section = 33 mm.

WO-Width overall = 19 mm.

LO-Length overall = 115 mm.

G-Gage length = 25 mm.

Distance between grips = 65 mm.

R-Radius of fillet = 14 mm.

RO-Outer radius = 25 mm.

T-Thickness = 3.2 mm.

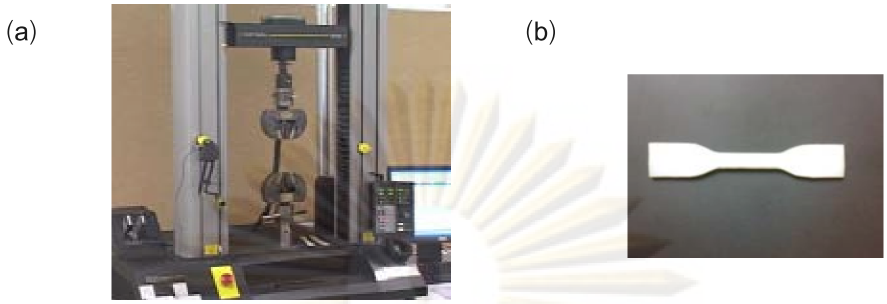


Figure 2.13 Universal Testing Machines (a); Dog-bone Shape Specimen for Tensile Test (b) [31]

2.7.4 Izod Impact Test

Notched izod impact is a single point test that measures a materials resistance to impact from a swinging pendulum. In the notched impact test, a notch is cut into the specimen. By notching, a stress concentration as well as an increase in crack propagation rate is achieved at the front of the crack tip. In this way, a break can be achieved even on tough plastics that do not break when unnotched specimens are used. Izod impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. Izod specimens are notched to prevent deformation of the specimen upon impact. For the test, pendulum hammers are used with nominal impact energies of 0.5 J to 50 J and impact velocities of 3.5 ms-1 in Izod configuration [41]. ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy in J by the thickness of the specimen [32].

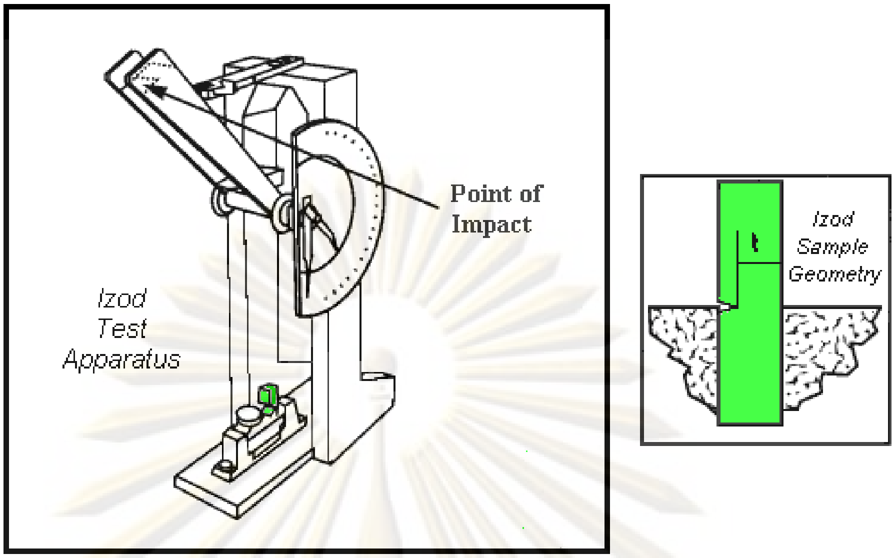


Figure 2.14 A pendulum swings on its track and strikes a notched plastic sample [42]

Specimen size

The bar shape specimens are prepared for Izod impact strength testing following ASTM D256 (or ISO 180). The standard specimen for ASTM is 12.7 mm x 64 mm x 3.2 mm as shown in Figure 2.15 (b). The depth under the notch of the specimen is 10.2 mm [31].

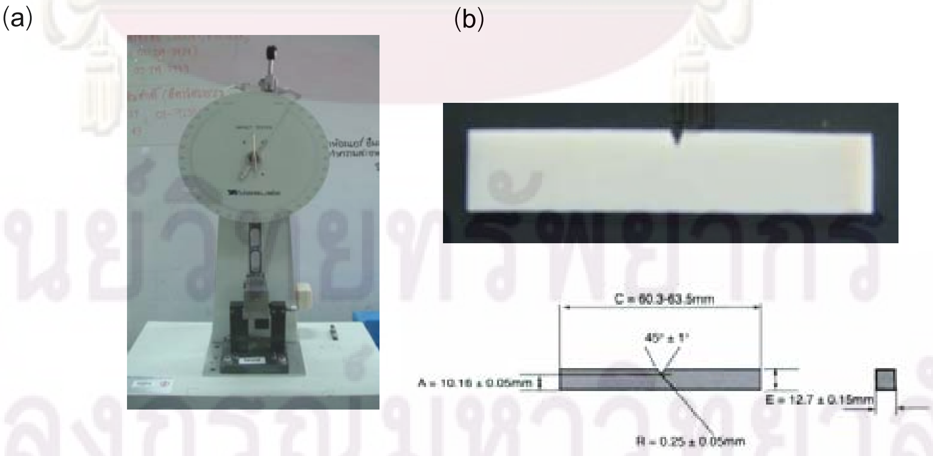

(a) (b)

Figure 2.15 Impact Tester (a); and Bar Shape Specimen for Izod Impact Strength Evaluation (b)

2.7.5 Flexural Test

The flexure test according to ASTM D790 serves determining strength and form change properties under bending loading. The 3-point flexure test is the most common for polymers shown in Figure 2.16. Results are plotted in a stress-strain diagram. Flexural strength is defined as the maximum stress in the outermost fiber. This is calculated at the surface of the specimen on the convex or tension side. Flexural modulus is calculated from the slope of the stress vs. deflection curve. If the curve has no linear region, a secant line is fitted to the curve to determine slope [32].

Three-Point Bend Test

In the three-point bend test, maximum flexural stress at break σ_f is calculated from fracture load F: [41].

$$\sigma_f = \frac{6M}{Bd^2} = \frac{3FL}{2Bd^2}$$

M	is maximum bending moment
F	is the load (force) at the fracture point
L	is the length of the support span
B	is width of specimen
D	is thickness of specimen

Specimen size

A variety of specimen shapes can be used for this test, but the most commonly used specimen size is 12.7mm x 12.5mm x 3.2mm for ASTM.

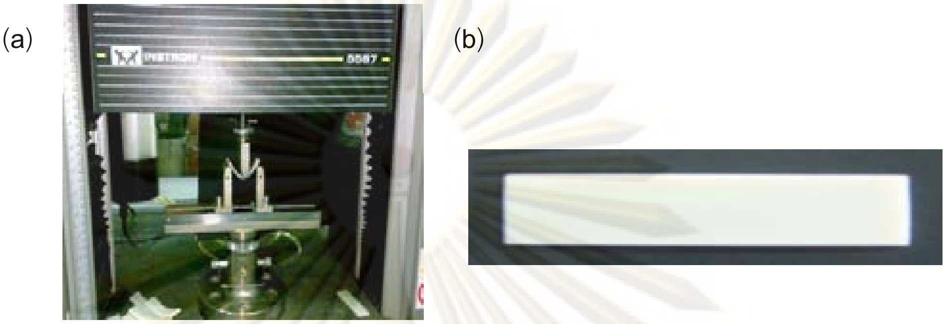


Figure 2.16 Universal Testing Machines for Flexural Test (a); Specimen Bar for Flexural Test (b) [31]

2.7.6 Compression Test

A compression test determines behavior of materials under crushing loads. The specimen is compressed and deformation at various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram [39]. A large number of relatively complex loading direction and specimen configurations were developed to measure the compression strength of composite materials [41]. The compressive strength of the material would correspond to the stress at the red point shown on the curve.

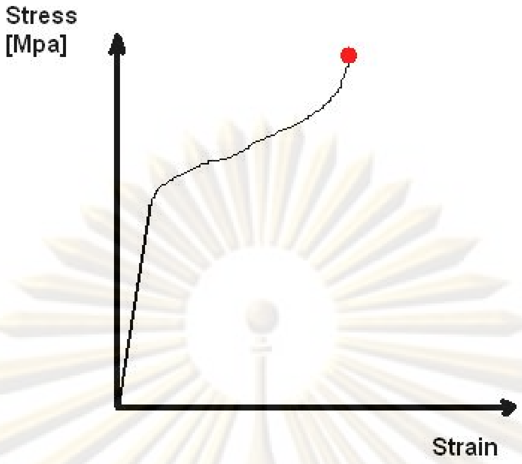


Figure 2.17 Stress-Strain Curve for Compressive Strength [43]

Even in a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region [43]:

$$\sigma = E\varepsilon$$

where this time E refers to the Young's Modulus for compression. There is a difference between the engineering stress and the true stress. By its basic definition the uniaxial stress is given by:

$$\sigma = \frac{F}{A}$$

where, F = Load applied [N], A = Area [m^2]

Specimen size

Specimens can either be blocks following ASTM D695 and ISO 604; the typical blocks are 10 mm x 10 mm x 4 mm shown in Figure 2.18 (b).

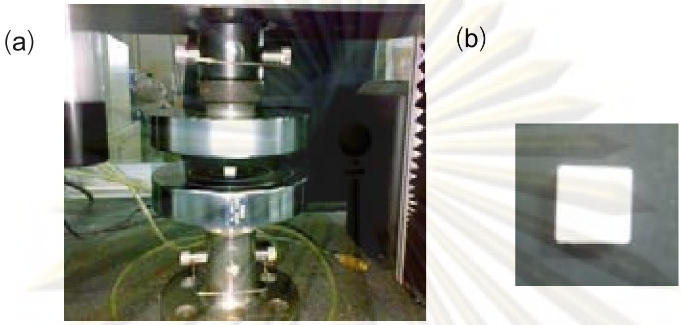


Figure 2.18 Universal Testing Machines for Compressive Test (a); Specimen Block for Compressive Test (b) [31]

CHAPTER III

LITERATURE REVIEWS

Orbital Engine Company, 2003 [33] focussed on conducting materials/component compatibility testing to assess the impact of gasoline containing 10% and 20% by volume ethanol (E10 and E20) for 2,000 hr following as closely as possible the relevant SAE standards J1748 (polymeric material) and J1747 (metallic material). SAE standard J1681 was followed as closely as possible in defining the test fluids utilised for material/component immersion testing. The testing and experimental design was not an attempt to fulfil the requirements for material qualification, actual product or process validation for the materials or components. The impact of the results obtained during materials compatibility testing can be summary as follows:

- For metallic base engine components that have exhibited corrosion when in contact with E20 fuel.

  - This is considered a concern since the potential exists for the oxide to dislodge and become trapped in between moving engine components. This situation would most likely result in accelerated wear of these components surfaces.
  - The potential exists, depending upon the severity of the oxidation and the actual final location of the dislodged oxide, to cause engine failure.

- For all the brass fuel system components that were tarnished indicating an oxidation process had occurred.

  - This is considered a concern since the oxidation of brass fuel and air metering jets or fuel control devices in the engine carburettor has the potential to lead to the loss of the intended nominal air metering and /or fuel metering, or control.
  - The potential exists, depending upon the severity of the loss of metering and/or control, to result in the degradation or loss of engine function.

- For polymeric materials found to have significant changes in appearance due to contact with E20 fuel.

- This is considered as unacceptable since the changes have the potential to result in fuel leakage.

B.Jones et al. 2008 [34] compared the effects of E20 versus E10 and gasoline on plastic materials found in automotive and small engine fuel system components. Plastics included in the study were acrylonitrile butadiene styrene (ABS), polyamide 6 (PA6), polyamide 66 (PA66), polybutylene terephthalate (PBT), polyethylene terephthalate (PET), polyetherimide (PEI), polyurethane (PUR) and polyvinyl chloride (PVC) were immersed in test fuels at an elevated temperature of 55 °C for 3,024 hours. Test fuels were prepared using SAE and ASTM standards and composed to blends of ASTM Fuel C; 90 vol% Fuel C and 10 vol% aggressive ethanol (E10); and 80 vol% Fuel C with 20 vol% aggressive ethanol (E20). The fuel was changed in weekly intervals for the 18-week study. The study found that four of the materials PA6, PA66, PET, and PEI, were compatible with the three test fuels. The other four materials, ABS, PUR, PVC, and PBT, were affected by all three fuels to varying degrees. The ABS specimens failed after less than one week of immersion in all three fuels. The specimens turned to a jelly-like mass in the bottom of the jars. This material was not compatible with any of the fuels. PVC demonstrated significant changes in mass and volume in all three fuels but to a higher degree in ethanol fuels. The PBT changes in impact resistance in all three fuels but to a greater extent in the ethanol blends. PUR was deemed incompatible with both E10 and E20 due to cracking and changes in mass, volume, tensile strength, and elongation. The mechanical properties of plastics were shown in Figure 3.1 and Figure 3.2.

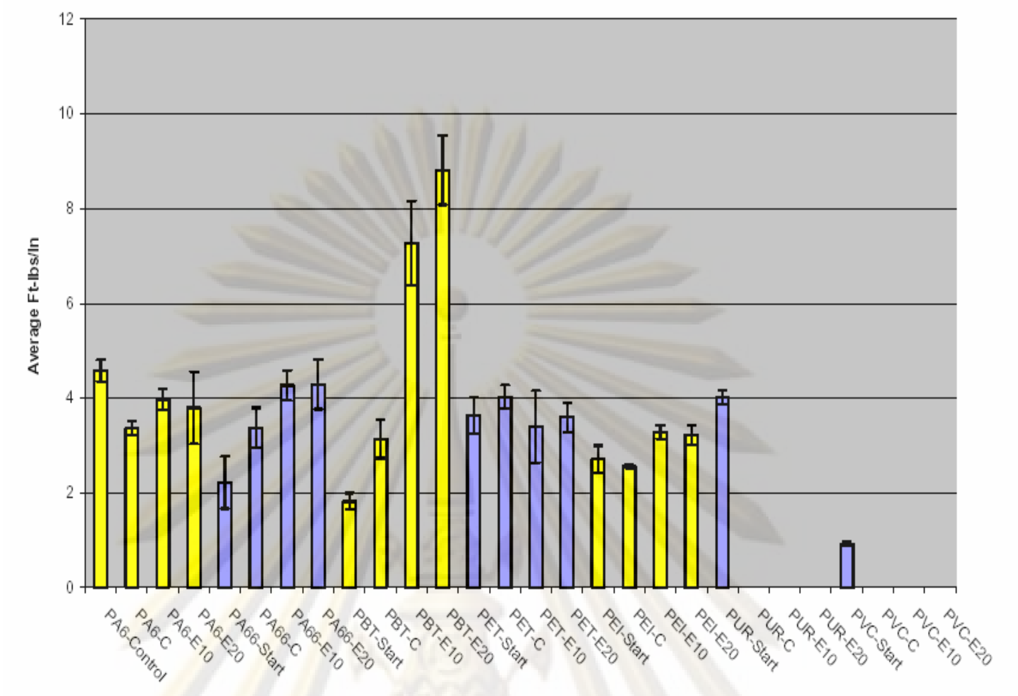


Figure 3.1 Results of Izod Impact of Plastic Samples in Three Test Fuels [34]

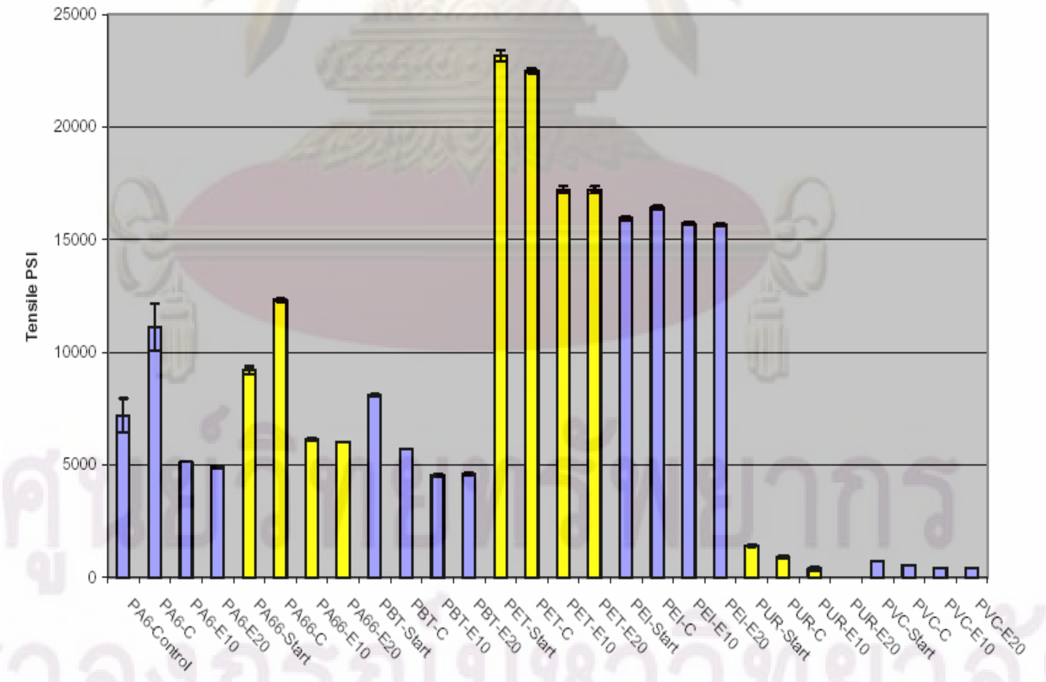


Figure 3.2 Results of Tensile Strength of Plastic Samples in Three Test Fuels [34]

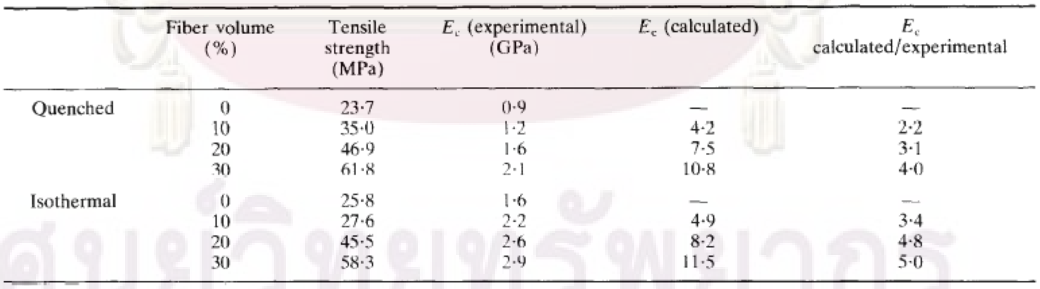
Jonn A. Foulk, et al. 2004 [35] studied the mechanical properties of different fiber composites. The source of materials included virgin HDPE, recycled HDPE, carbon fiber, glass fiber, thermal mechanical pulp (TMP), and three levels of enzyme-retted flax fiber. All HDPE/fiber composites were mixed to contain 30% fiber by weight. The controls were formed using only virgin HDPE or recycled HDPE. Glass and carbon fibers have fiber strengths from 2000 to 3750 MPa and tensile strength between 28 and 30 MPa. The addition of glass or carbon fibers to the recycled HDPE significantly gave high mechanical properties but the natural fibers reduced the tensile strength. Natural fibers have a lower strength, modulus of elasticity and cost than glass or carbon fibers as shown in Table 3.1.

Table 3.1 Composite Mechanical Properties

Sample	Tensile Strength (MPa)	Percent elongation (%)	Modulus of elasticity (MPa)	Toughness (MPa)
Virgin HDPE	25.74	10.13	917.8	2.98
Recycle HDPE	25.61	9.33	738.0	4.36
TMP	20.24	2.26	1774.0	0.33
Flax	23.11	2.81	2220.7	0.54
Glass	28.14	2.93	2636.8	0.82
Carbon	29.52	1.13	3148.2	0.32

T.Stern et al. 1996 [36] focused on the preparation and characterization of single-polymer composites reinforced with randomly oriented chopped polyethylene fibers, stressing the effect of a transcrystalline interphase on the properties of the composites. Two different composite preparation methods were used and compared in their work. For the first method designated as system A, fibers were manually dispersed and placed between two Petrothane sheets, which were then processed in a closed 3.5 cm X 8 cm mold in a laboratory press (Carver, model 2518). The samples were first heated to 134°C for a period of 15 min under a pressure of 0.75 MPa and then either ice-water quenched or isothermally treated at 127°C under minimum pressure for a period of 1.5 h, followed by water cooling under the same molding. For the second method designated as system B, the fibers were weighed according to the desired ratio and dispersed in ethanol at room temperature. The dispersion was poured into a closed 3.5 cm X 8 cm mold, over a high-density polyethylene film after which the ethanol was evaporated at 50°C. An additional HDPE film was placed on top and the closed mold was inserted in the press at 136°C. An initial pressure of 220 atm was applied for 5 s, after which the pressure was released and the composites were further processed with practically no applied pressure, in order to prevent melt flow and eventual fiber orientation. The temperature cycle comprised of 136°C for 20 min, followed by two isothermal crystallization steps at 125°C for 2 h and subsequently at 121°C for two additional hours, and finally ice-water quenching. (The two-step isothermal crystallization process was chosen to separate the favorable conditions for transcrystallization and bulk crystallization, respectively.) An alternative thermal cycle comprised of 136°C for 20 min, followed by ice-water quenching. In system B, a significant increase in both the tensile strength and the Young's modulus of the composites were observed with increasing fiber volume, in the ice-water-quenched as well as in the isothermally treated samples.

Table 3.2 Effect of Fiber Volume and Thermal Treatment on the Tensile Properties of System B [36]



	Fiber volume (%)	Tensile strength (MPa)	E_c (experimental) (GPa)	E_c (calculated)	E_c calculated/experimental
Quenched	0	23·7	0·9	—	—
	10	35·0	1·2	4·2	2·2
	20	46·9	1·6	7·5	3·1
	30	61·8	2·1	10·8	4·0
Isothermal	0	25·8	1·6	—	—
	10	27·6	2·2	4·9	3·4
	20	45·5	2·6	8·2	4·8
	30	58·3	2·9	11·5	5·0

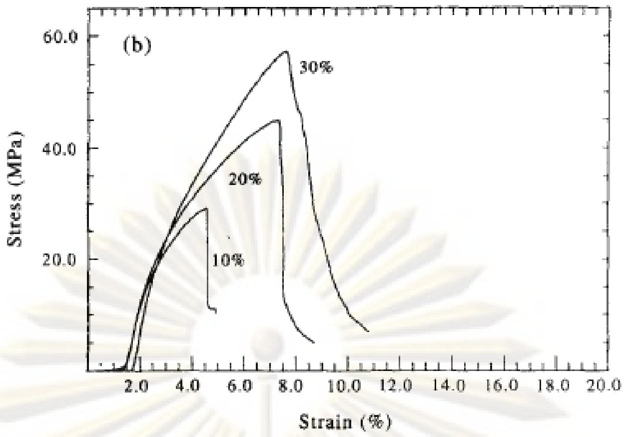


Figure 3.3 The Stress/Strain Curves of Isothermally Treated Composites of Different Fiber Volume Fractions [36]

It was seen that there was a significant increase in both the tensile strength and the elastic modulus of the composites, with increasing fiber volume fraction. This indicated that the increase in modulus was probably due to bulk crystallization in the matrix and no significant change in the tensile strength with thermal treatment.

V. Radojevi et al. [37] described a feasible process to reuse glass fibers separated from a wasted glass mat as reinforcement in high density polyethylene (HDPE). Glass fibers were recovered by pyrolysis, chopped and surface was treated by silane as adhesion promoters for increased composite interfacial strength before compounding. The silane coupling agents used in the study were 3 – methacryloxypropyltrimethoxy silane (MEMO), 3-aminopropyltriethoxy silane (AMEO), and 3-glycidoxypropyltrimethoxy silane (GLYMO), and supplied by Dynasilan, Germany.

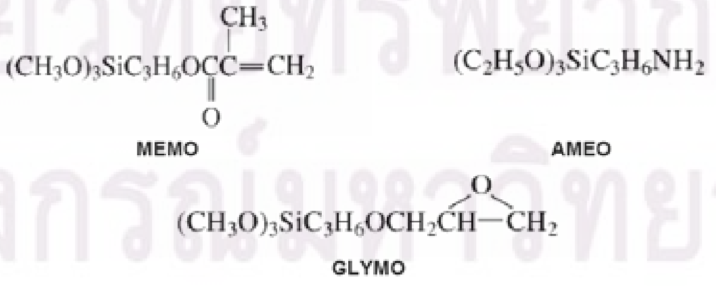


Figure 3.4 Chemical Structures of the Silane Coupling Agents [37]

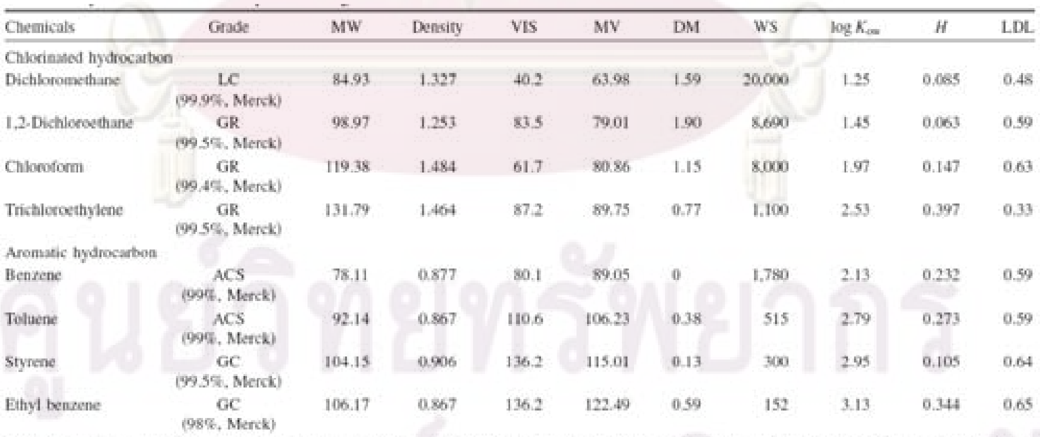
Four series of samples were processed by compression molding (pressure 41.38 MPa, temperature 160-170ºC, time 26 min):

I- HDPE- glass fibers as received after heat treatment (10; 20; 30 and 40 vol. %)
II- HDPE-glass fibers treated by MEMO silane (10; 20; 30 and 40 vol. %)
III- HDPE-glass fibers treated by AMEO silane (10; 20; 30 and 40 vol. %)
IV- HDPE-glass fibers treated by GLYMO silane (10; 20; 30 and 40 vol. %)

The best improvement of interfacial strength was obtained with MEMO silane. It was seen that there was a significant increase in both the compressive strength and hardness of the composite, with increasing fiber volume fraction.

Keh-Ping Chao, et al. 2006 [46] focussed on the permeation of several chlorinated and aromatic hydrocarbons through high-density polyethylene (HDPE) geomembranes were conducted using the ASTM F-739 standard test method. Eight organic solvents used for study were chlorinated hydrocarbons (dichloromethane, 1,2-dichloroethane, chloroform,and trichloroethylene) and aromatic hydrocarbons (benzene, toluene, styrene, and ethyl benzene). As shown in Table 3.3.

Table 3.3 Physical and Chemical Properties of Organic Chemicals [46]



Chemicals	Grade	MW	Density	VIS	MV	DM	WS	log K_{ow}	H	LDL
Chlorinated hydrocarbon										
Dichloromethane	LC (99.9%, Merck)	84.93	1.327	40.2	63.98	1.59	20,000	1.25	0.085	0.48
1,2-Dichloroethane	GR (99.5%, Merck)	98.97	1.253	83.5	79.01	1.90	8,690	1.45	0.063	0.59
Chloroform	GR (99.4%, Merck)	119.38	1.484	61.7	80.86	1.15	8,000	1.97	0.147	0.63
Trichloroethylene	GR (99.5%, Merck)	131.79	1.464	87.2	89.75	0.77	1,100	2.53	0.397	0.33
Aromatic hydrocarbon										
Benzene	ACS (99%, Merck)	78.11	0.877	80.1	89.05	0	1,780	2.13	0.232	0.59
Toluene	ACS (99%, Merck)	92.14	0.867	110.6	106.23	0.38	515	2.79	0.273	0.59
Styrene	GC (99.5%, Merck)	104.15	0.906	136.2	115.01	0.13	300	2.95	0.105	0.64
Ethyl benzene	GC (98%, Merck)	106.17	0.867	136.2	122.49	0.59	152	3.13	0.344	0.65

Note: Properties are at 25°C and abbreviations are as follows: MW=molecular weight (g/mol) (Lide 1994); density (g/cm^3); VIS=viscosity (cp) (Lide 1994); MV=molar volume (cm^3)=(MW/density); DM=dipole moment (debye) (Lide 1994); WS=water solubility (mg/L) at 20°C (LaGrega et al. 1994); K_{ow}=octanol-water partition coefficient (LaGrega et al. 1994); H=Henry's constant (LaGrega et al. 1994); and LDL=limit detection level (mg/L).

The study was conducted using a 0.5 mm thick HDPE geomembrane. Before experimentation, a HDPE sample(diameter=8 cm) was rinsed with deionized water and air dried for 24 h at 25±1°C and a relative humidity of 50±20%. The average thickness of each sample was determined by measuring at four random locations using a dial thickness gauge to an accuracy of 0.001 cm.

At the end of the permeation experiments, the HDPE geomembrane samples were found to increase in average thickness by less than 12 and 10% for aromatic and chlorinated hydrocarbons, respectively. As shown in Fig.3.5, it was found that the average thickness of HDPE geomembrane increased with increasing molecular weight and molar volume for chlorinated hydrocarbons. On the other hand, the increase in average thickness for HDPE was found to be inversely proportional to the molecular weight and molar volume of aromatic hydrocarbons.

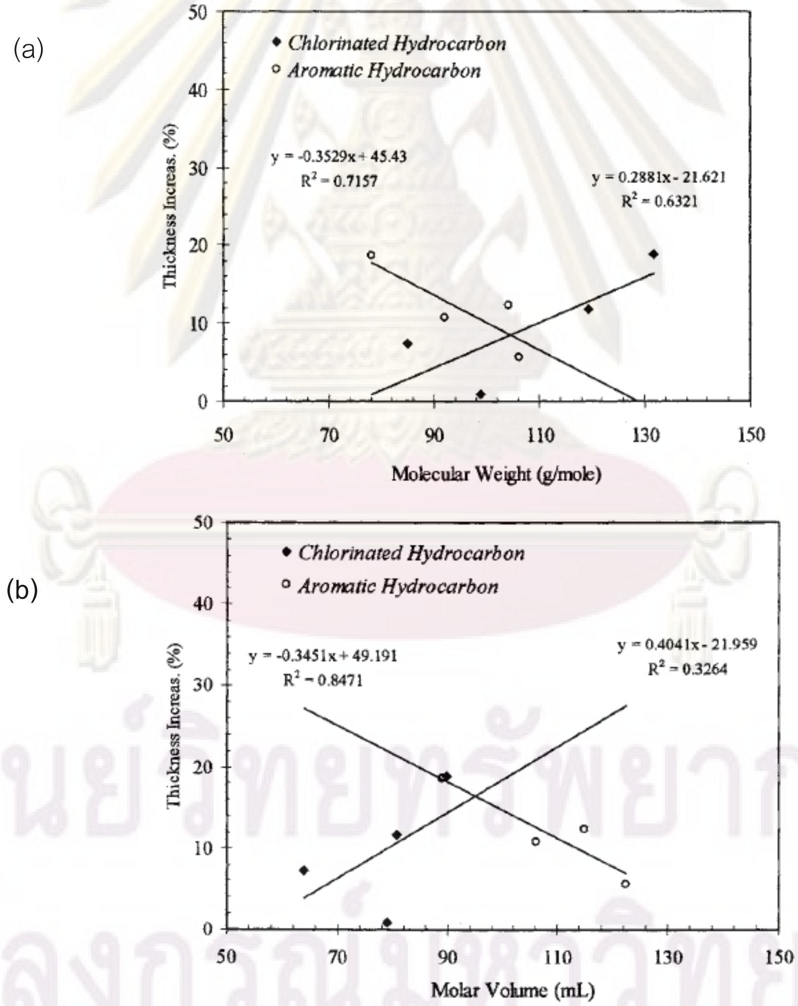
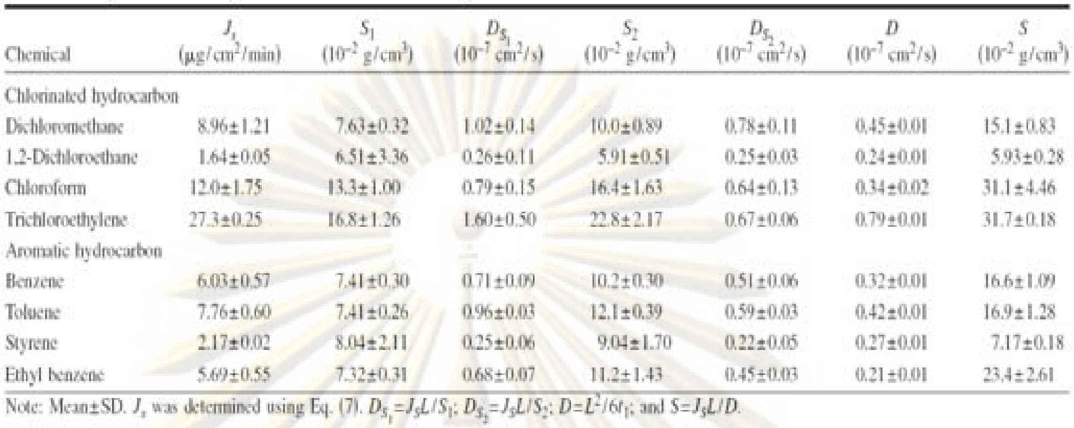


Figure 3.5 Correlation of increase in average thickness of HDPE samples with molecular weight (a); and molar volume (b)

Table 3.4 Comparisons of Steady State Permeation Rate, Solubility and Diffusion Coefficients [46]



Chemical	J_s (μg/cm^2/min)	S_1 (10^{-2} g/cm^3)	D_{S_1} (10^{-7} cm^2/s)	S_2 (10^{-2} g/cm^3)	D_{S_2} (10^{-7} cm^2/s)	D (10^{-7} cm^2/s)	S (10^{-2} g/cm^3)
Chlorinated hydrocarbon							
Dichloromethane	8.96±1.21	7.63±0.32	1.02±0.14	10.0±0.89	0.78±0.11	0.45±0.01	15.1±0.83
1,2-Dichloroethane	1.64±0.05	6.51±3.36	0.26±0.11	5.91±0.51	0.25±0.03	0.24±0.01	5.93±0.28
Chloroform	12.0±1.75	13.3±1.00	0.79±0.15	16.4±1.63	0.64±0.13	0.34±0.02	31.1±4.46
Trichloroethylene	27.3±0.25	16.8±1.26	1.60±0.50	22.8±2.17	0.67±0.06	0.79±0.01	31.7±0.18
Aromatic hydrocarbon							
Benzene	6.03±0.57	7.41±0.30	0.71±0.09	10.2±0.30	0.51±0.06	0.32±0.01	16.6±1.09
Toluene	7.76±0.60	7.41±0.26	0.96±0.03	12.1±0.39	0.59±0.03	0.42±0.01	16.9±1.28
Styrene	2.17±0.02	8.04±2.11	0.25±0.06	9.04±1.70	0.22±0.05	0.27±0.01	7.17±0.18
Ethyl benzene	5.69±0.55	7.32±0.31	0.68±0.07	11.2±1.43	0.45±0.03	0.21±0.01	23.4±2.61

Note: Mean±SD. J_s was determined using Eq. (7). $D_{S_1}=J_SL/S_1$; $D_{S_2}=J_SL/S_2$; $D=L^2/6t_1$; and $S=J_SL/D$.

The solubilities of solvents in HDPE obtained by immersion test were found to be inappropriate in the simulation of organic solvents permeation through HDPE geomembrane. For organic solvents with similar structure, the diffusion coefficients correlated well with their molecular weights, and the solubilities were correlated well to their polarity.

CHAPTER IV

EXPERIMENTS

4.1 Materials, Chemicals and Equipment

Materials

- High density polyethylene, HDPE with the trade name of InnoPlus HD2308J is supplied by PTT Chemical.
- E-Chopped strand (ECS) glass fiber with 3 mm. fiber length and treated with silane under the trade name of ECS-401AD Chopped strand is purchased by Jushi Group Co., Ltd.

Table 4.1 The Physical and Mechanical Properties of HDPE (InnoPlus HD2308J)

Physical and Mechanical Properties	Testing Method	HD2308J
Melt Flow Rate	ASTM D1238	6 (g/10 min)
Melting Point	ASTM D2117	131 °C
Density	ASTM D1505	0.962 g/cm^3
Tensile Strength at Yield	ASTM D638	29.42 MPa
Tensile Strength at Break	ASTM D638	21.57 MPa
Elongation at Break	ASTM D638	750%
Izod Impact Strength	ASTM D256	4 kg.cm/cm

Table 4.2 The Mechanical Properties of Glass Fiber (ECS-401ADChopped strand)

Physical and Mechanical Properties	Testing Method	ECS-401AD
Tensile Strength	ASTM D638	47.6 MPa
Flexural Strength	ASTM D790	108.1 MPa
Flexural Modulus	ASTM D790	10.3 GPa
Izod Impact Strength	ASTM D256	5.2 ft-lbs/in.
Unnotched Impact Strength	ASTM D256	6.8 ft-lbs/in.
Compressive Strength	ASTM D695	140 MPa

Chemicals

- Toluene
- Iso-octane
- Synthetic ethanol
- Sulfuric acid
- De-ionized water
- Glacial acetic acid
- Sodium chloride

Equipments

- Twin screw extruder
- Compression molding
- Injection molding
- Digital vernier calipers
- Cutting machine
- Universal testing machine
- Impact tester
- Oven
- Notching machine

4.2 Processing Techniques

4.2.1 Preparation of glass fibers reinforced HDPE (ratios of glass fibers is 0 wt%, 15 wt% and 30 wt%) by twin screw extruder.

Table 4.3 Condition of Twin Screw Extruder

Parameter	Setting
Temperature 1 (TS-E1), (ºC)	160
Temperature 2 (TS-E2), (ºC)	160
Temperature 3 (TS-E3), (ºC)	170
Temperature 4 (TS-E4), (ºC)	170
Temperature 5 (TS-D1), (ºC)	175
Temperature 6 (TS-D2), (ºC)	180
Screw speed (rpm)	60

4.2.2 Preparation of Specimens condition of specimens made by compression and injection molding.

Table 4.4 Condition for Compression Molding

Parameter	Setting
Temperature (ºC)	170-180
Pressure (bars)	50-80
Time (min)	5-7
Cooling time (min)	5

Table 4.5 Condition for Injection Molding

Parameter		Setting
Pressure (bars)	Mould open	40
	Mould close	40
	Mould safety	10
	Mould clamping	50
	Carriage forward 1	40
	Carriage forward 2	40
	Carriage back	40
	Spure break	38
	Injection forward 1	70-135
	Injection forward 2	70-135
	Injection forward 3	70-135
	Holding	55-120
	Metering	50
	Decompression	50
	Ejector Raise	30
	Ejector Lower	40
Times (sec)	Mould safety check	1
	Mould clamp pressure	1
	Carriage forward delay	1
	Injection delay	1
	Holding pressure	10
	Screw back delay	1
	Spure break delay	1
	Cooling	2
	Mould open delay	1

Parameter		Setting
Temperature (°C)	Nozzle	190
	Zone 1	200
	Zone 2	190
	Molding	70

The specimens will be tested 4 times during experiment:

- Beginning (Before soaking in test fuels)
- 4 weeks after soaking
- 10 weeks after soaking
- 16 weeks after soaking

4.3 Preparation of test fuels

$C(E0)_A$ = Fuel C 100 vol% + Aggressive ethanol 0 vol%
$C(E20)_A$ = Fuel C 80 vol% + Aggressive ethanol 20 vol%
$C(E85)_A$ = Fuel C 15 vol% + Aggressive ethanol 85 vol%
$C(E100)_A$ = Fuel C 0 vol% + Aggressive ethanol 100 vol%
Fuel C = Toluene 50 vol% + Iso-octane 50 vol%

Formulation of Aggressive ethanol are:

- synthetic ethanol 816.00 g
- de-ionized water 8.103 g
- sodium chloride 0.004 g
- sulfuric acid 0.021 g
- glacial acetic acid 0.061 g

The specimens are soaked in each test fuels until the end of experiment at room temperature and fuels are changed every three weeks.

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 The Effects of Glass Fiber Content on Physical and Mechanical Properties

5.1.1 Physical Properties

The glass fiber reinforced HDPE composites with glass fiber 0, 15 and 30 wt% were measured according to procedures described in Chapter II. The experimental data are showed in Table 5.1.

Table 5.1 Physical properties of glass fiber reinforced HDPE composites at 0, 15 and 30 wt% of Glass Fiber

Glass Fiber content (wt%)	%Water Absorption	Mass (g)	Diameter (mm.)	Thickness (mm.)	Volume (cm^3)
0	0.0370	5.45 ± 0.03	49.41 ± 0.11	3.26 ± 0.02	6.24 ± 0.06
15	0.0826	6.00 ± 0.03	49.48 ± 0.07	3.26 ± 0.04	6.27 ± 0.09
30	0.3018	6.05 ± 0.07	49.44 ± 0.04	3.25 ± 0.02	6.24 ± 0.03

5.1.2 Mechanical Properties

The glass fiber reinforced HDPE composites with glass fiber 0, 15 and 30 wt% were measured according to procedures described in Chapter II. The experimental data are showed in Table 5.2.

Table 5.2 Mechanical properties of glass fiber reinforced HDPE composites at 0, 15 and 30 wt% of Glass Fiber

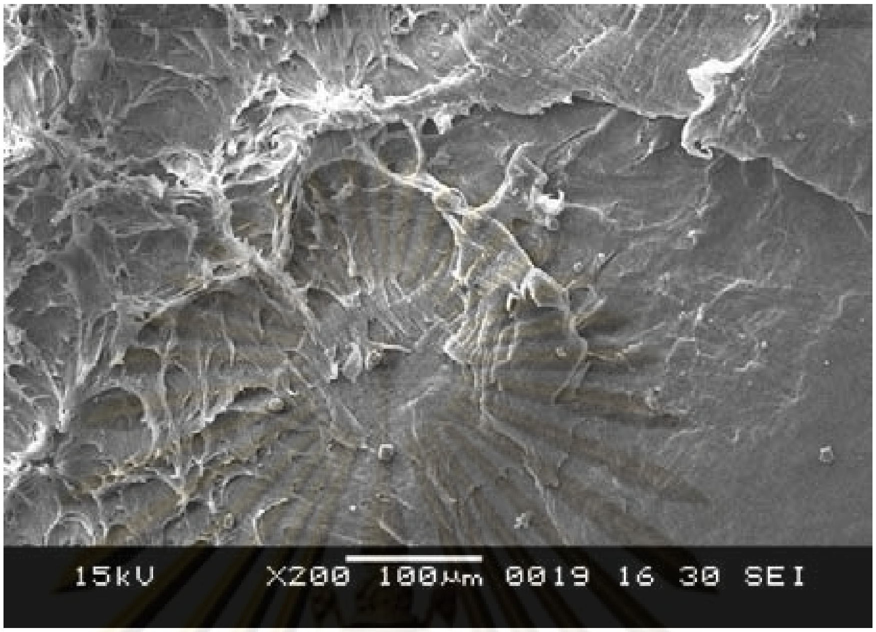
Glass Fiber (wt%)	Tensile Strength (MPa)	Young's Modulus (GPa)	Flexural Strength (MPa)	Compressive Strength (MPa)	Impact Strength (kJ/m^2)
0	26.28 ± 0.24	0.68 ± 0.02	26.99 ± 2.04	104.86 ± 4.22	14.30 ± 0.35
15	28.60 ± 0.26	1.95 ± 0.26	35.77 ± 0.34	123.56 ± 2.75	16.38 ± 0.39
30	34.03 ± 1.13	3.97 ± 0.17	39.35 ± 4.00	139.38 ± 4.36	18.04 ± 1.35

For the composite of glass fiber, it could be seen from the experimental result that the tensile strength, young's modulus, flexural strength, compressive strength and impact strength of all samples were a significant increase with increasing fiber content from 0 to 30 wt% confirming the previous report by Foulk et al., 2004 [35] and Stern et al., 1996 [36].

5.1.3 Scanning Electron Microscope (SEM) of glass fiber reinforced HDPE Composites

To gain more insight of the distribution and orientation of glass fiber in glass fiber reinforced HDPE composites prepared in this work, two types of images were taken for each sample - one at low magnification (200x) and the other at randomly selected area of the sample at high magnification (2000x).

Figs. 5.1 –5.3 (a) show the low magnification (200x) SEM image of glass fiber 0, 15, 30 wt% reinforced HDPE composites (b) show the 2000x magnification SEM image of the sample at some randomly selected surface areas.



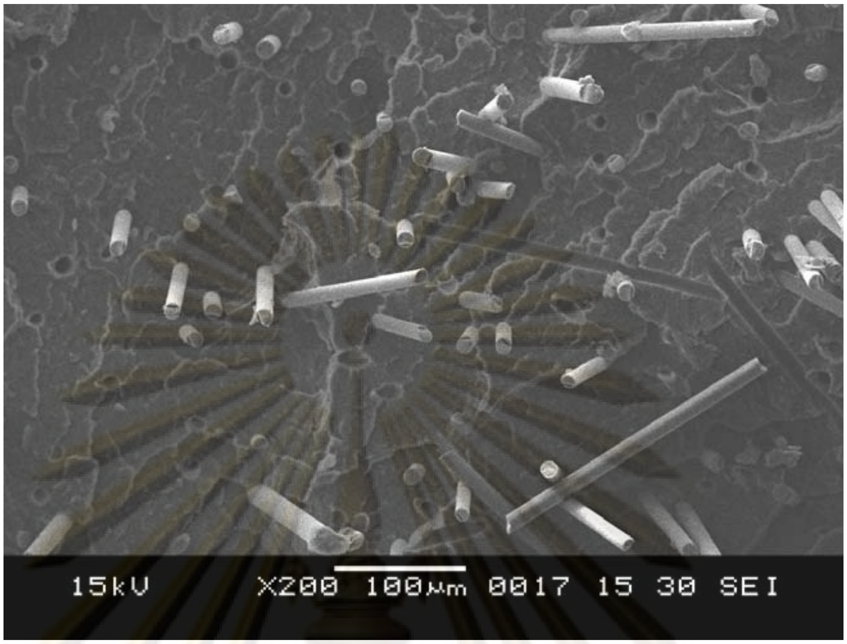
(a)

(b)

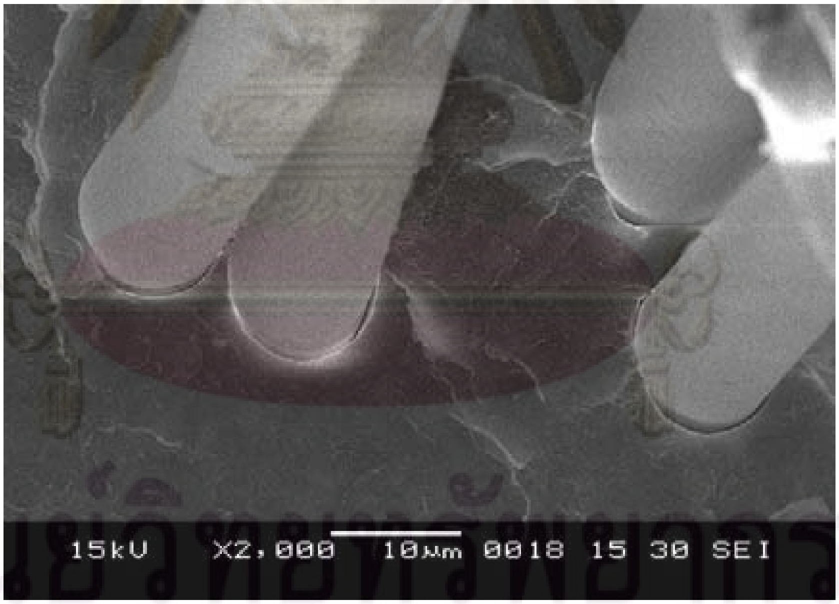
Figure 5.1 SEM Image of glass fiber 0 wt% reinforced HDPE composites

(a) 200x Magnification

(b) 2000x Magnification (continued)



(a)



(b)

Figure 5.2 SEM Image of glass fiber 15 wt% reinforced HDPE composites

(a) 200x Magnification

(b) 2000x Magnification (continued)

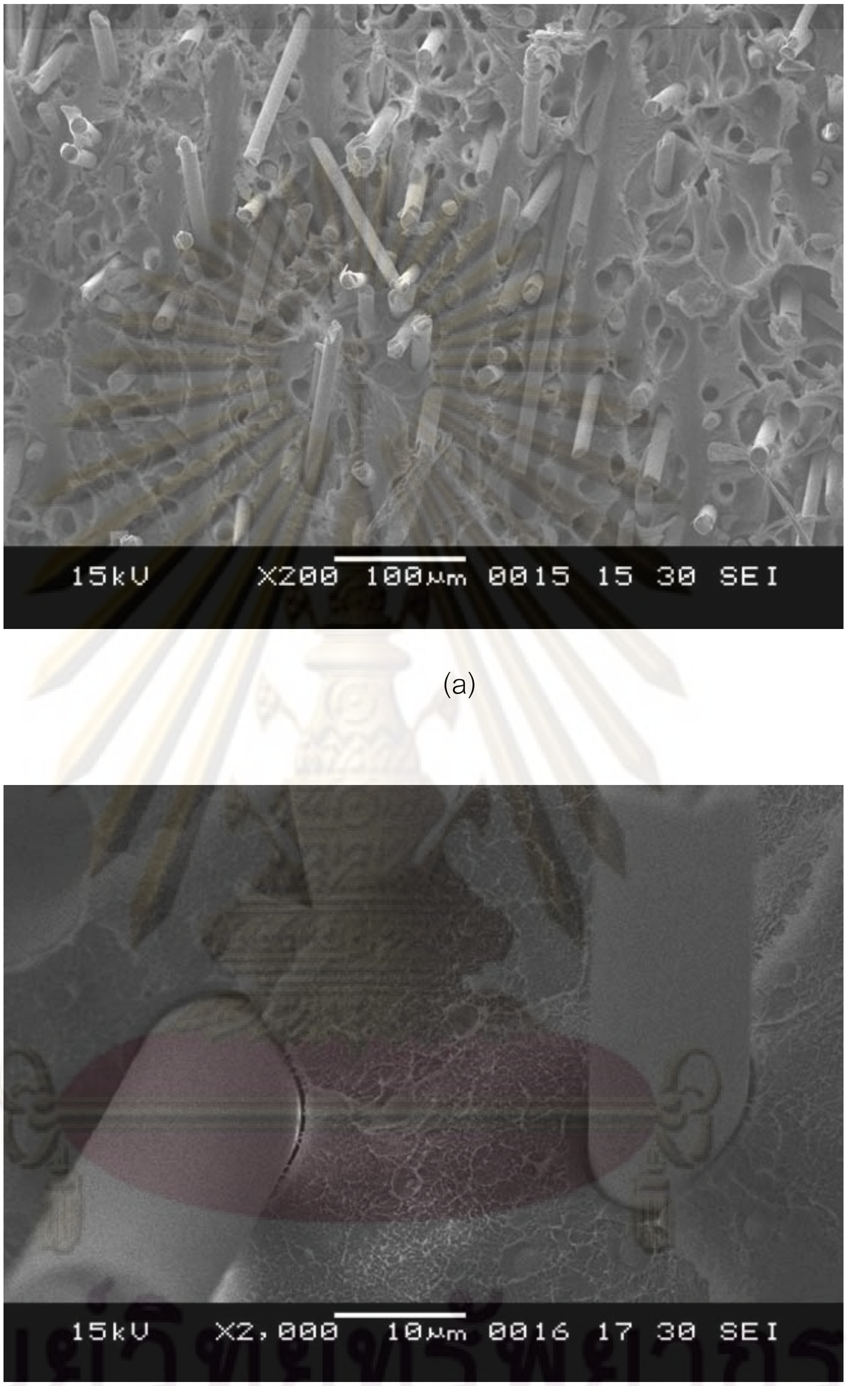


Figure 5.3 SEM Image of glass fiber 30 wt% reinforced HDPE composites

(a) 200x Magnification

(b) 2000x Magnification (continued

Fig. 5.1(a-b) shows the surface of neat HDPE, figure 5.2 and 5.3 (a-b) show the surface of glass fiber reinforced HDPE composites at 15 and 30 wt% that clearly demonstrate the polymer adhered to the fiber surface. In these pictures, the fibers are coated by the polyethylene layer, thus, improving interfacial adhesion with the matrix and at the proximity of fibers there are good bonding between the polymer and fibers.

5.2 The Effects of Gasohols on Physical Properties

5.2.1 Mass Change

The mass of experimental data after being soaking in each test fuels are showed in Table 5.3.

Table 5.3 Mass (g) of HDPE/GF composites in each test fuels

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
0%GF				
0	5.45 ± 0.03	5.50 ± 0.05	5.48 ± 0.02	5.45 ± 0.05
2	5.63 ± 0.04	5.58 ± 0.08	5.59 ± 0.13	5.50 ± 0.08
4	5.70 ± 0.14	5.66 ± 0.02	5.56 ± 0.07	5.48 ± 0.06
7	5.63 ± 0.03	5.66 ± 0.03	5.56 ± 0.07	5.48 ± 0.05
10	5.62 ± 0.04	5.64 ± 0.03	5.55 ± 0.06	5.47 ± 0.05
13	5.62 ± 0.04	5.65 ± 0.03	5.55 ± 0.06	5.47 ± 0.05
16	5.61 ± 0.04	5.65 ± 0.03	5.53 ± 0.06	5.47 ± 0.05

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
15%GF				
0	6.00 ± 0.03	6.05 ± 0.07	6.06 ± 0.05	6.00 ± 0.04
2	6.17 ± 0.03	6.20 ± 0.07	6.12 ± 0.05	6.01 ± 0.04
4	6.04 ± 0.03	6.20 ± 0.07	6.14 ± 0.05	6.02 ± 0.04
7	6.16 ± 0.03	6.21 ± 0.07	6.15 ± 0.05	6.02 ± 0.04
10	6.14 ± 0.03	6.19 ± 0.07	6.13 ± 0.05	6.02 ± 0.04
13	6.14 ± 0.03	6.19 ± 0.07	6.13 ± 0.05	6.02 ± 0.04
16	6.14 ± 0.03	6.19 ± 0.07	6.11 ± 0.05	6.02 ± 0.04
30%GF				
0	6.72 ± 0.10	6.59 ± 0.06	6.65 ± 0.08	6.65 ± 0.08
2	6.86 ± 0.11	6.71 ± 0.06	6.72 ± 0.08	6.67 ± 0.08
4	6.75 ± 0.11	6.71 ± 0.06	6.73 ± 0.08	6.68 ± 0.08
7	6.86 ± 0.11	6.72 ± 0.06	6.73 ± 0.08	6.68 ± 0.08
10	6.84 ± 0.11	6.71 ± 0.06	6.72 ± 0.08	6.67 ± 0.08
13	6.83 ± 0.11	6.69 ± 0.06	6.71 ± 0.08	6.67 ± 0.08
16	6.83 ± 0.11	6.69 ± 0.06	6.70 ± 0.08	6.67 ± 0.08

The mass changed of HDPE/GF composites after being soaking in each test fuels were shown in Figs.5.4 – 5.10.

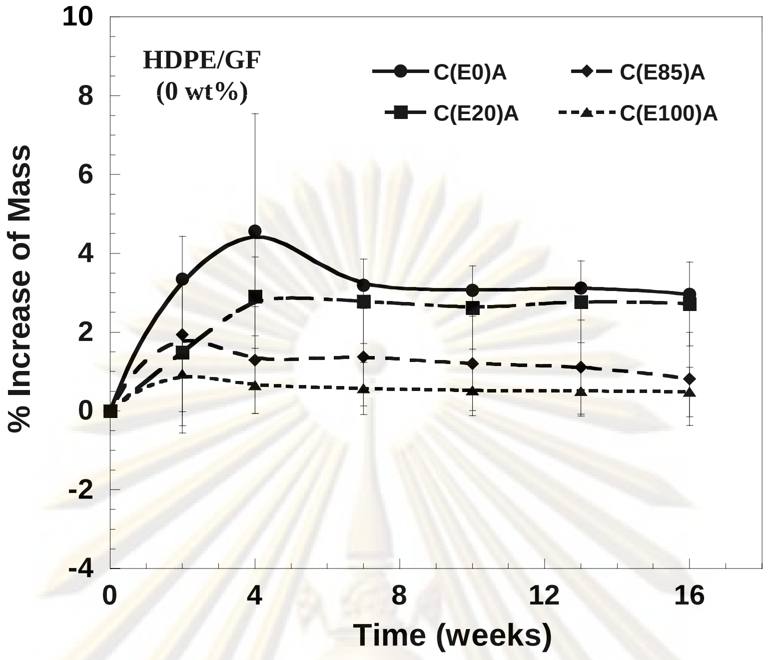


Figure. 5.4 Effect of gasohols on mass change of HDPE/GF (0 wt%) composites

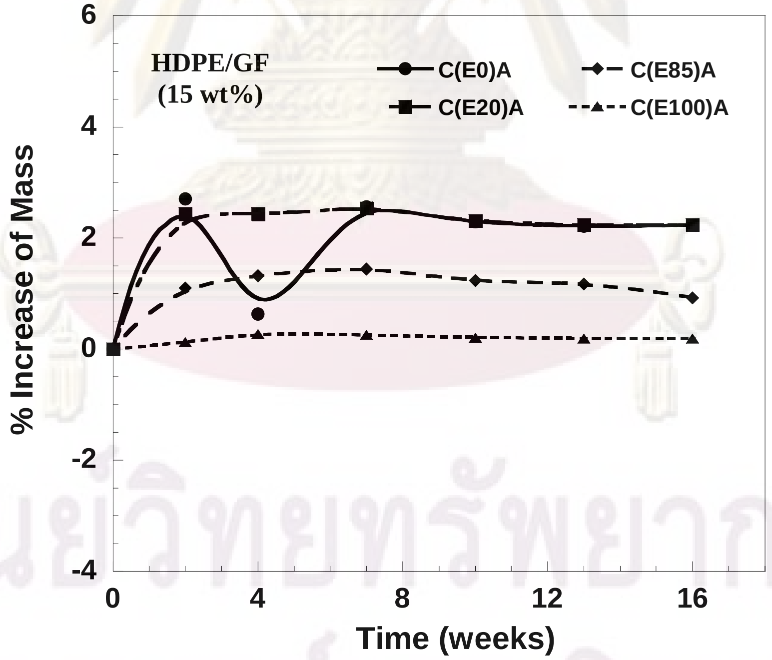


Figure. 5.5 Effect of gasohols on mass change of HDPE/GF (15 wt%) composites

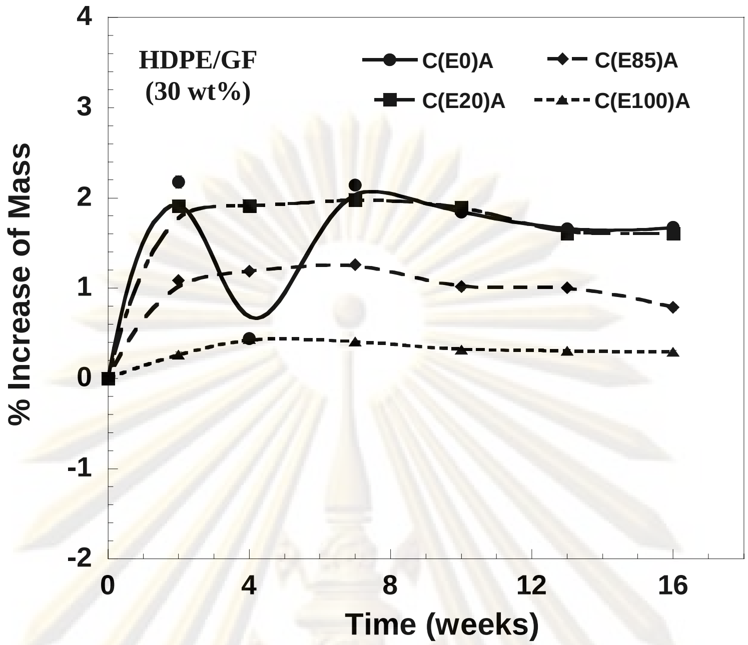


Figure 5.6 Effect of gasohols on mass change of HDPE/GF (30 wt%) composites

Fig. 5.4, mass of HDPE/GF (0 wt%) increased by about 3-4.5% after 4 weeks of immersion in C(E0)$_A$ and C(E20)$_A$ test fuels and leveled off after that. The mass of HDPE/GF (0 wt%) immersed in C(E85)$_A$ and C(E100)$_A$ test fuels were increased only about 1-1.5%. Figs. 5.5-5-6, mass of HDPE/GF at 15 and 30 wt% were increased about 2-3% after 4 weeks of immersion in C(E0)$_A$ and C(E20)$_A$ test fuels and leveled off after that. However, the mass of HDPE/GF at 15 and 30 wt% immersed in C(E85)$_A$ and C(E100)$_A$ test fuels were increased only about 0.5-1%.

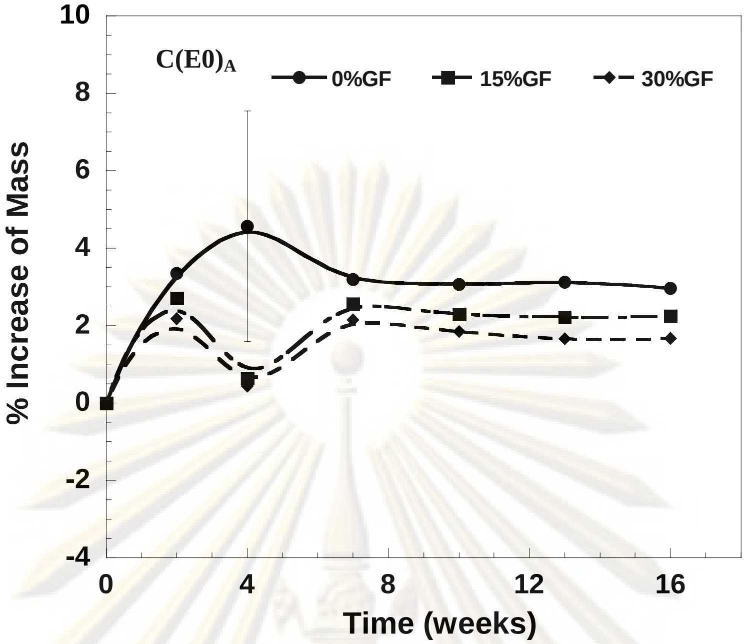


Figure. 5.7 Effect of C(E0)$_A$ on mass change of HDPE/GF composites

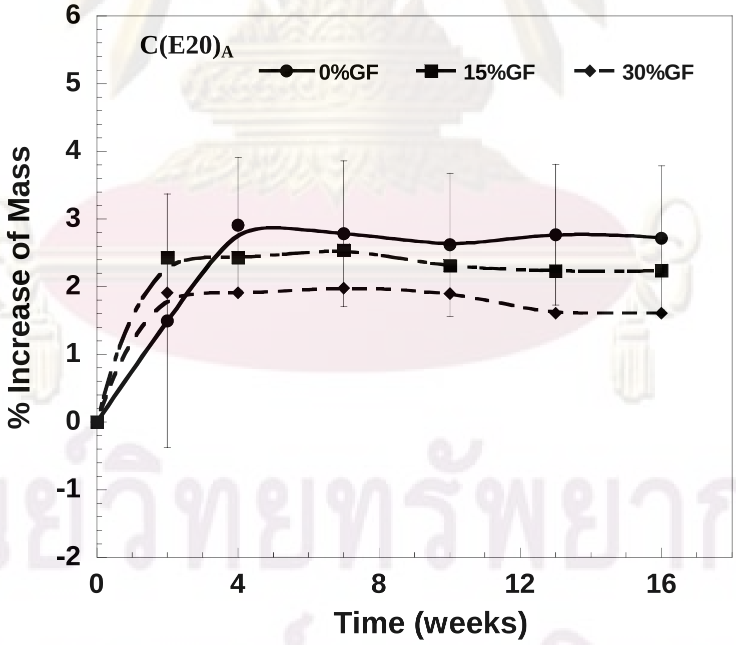


Figure. 5.8 Effect of C(E20)$_A$ on mass change of HDPE/GF composites

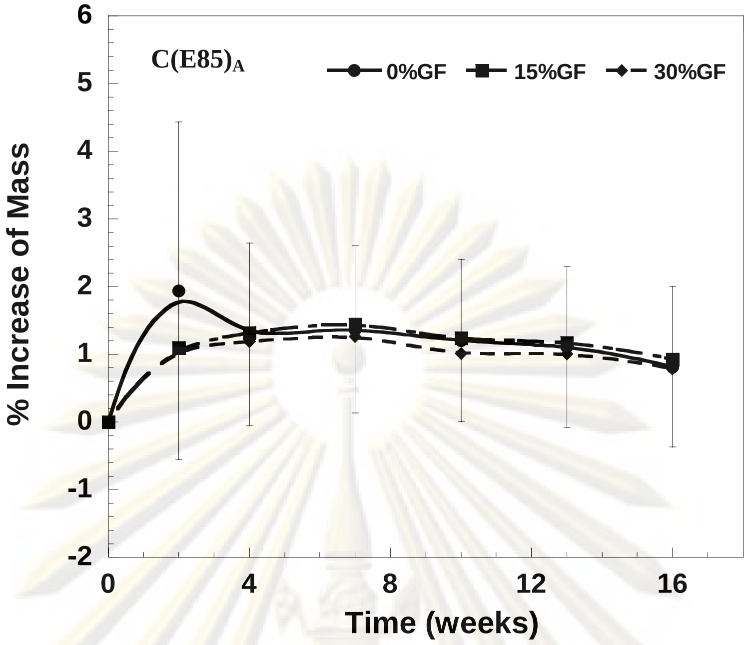


Figure. 5.9 Effect of C(E85)$_A$ on mass change of HDPE/GF composites

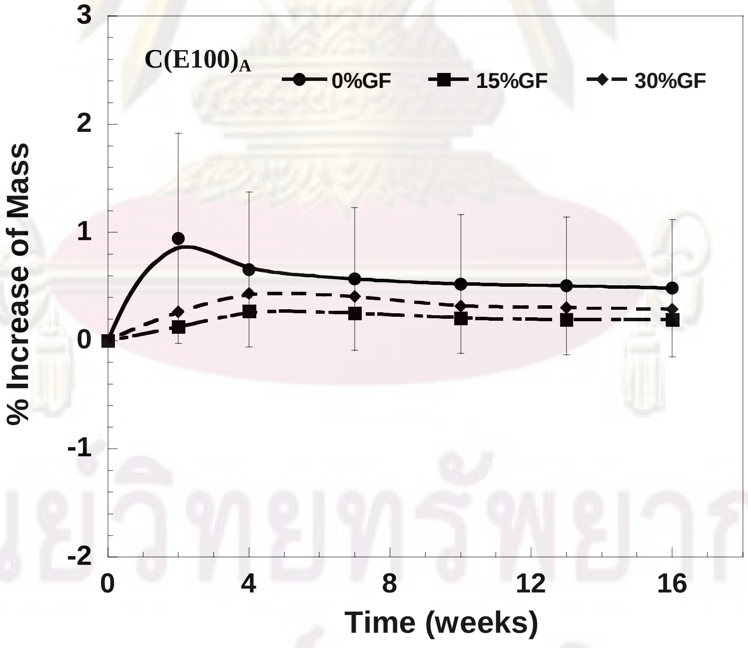


Figure. 5.10 Effect of C(E100)$_A$ on mass change of HDPE/GF composites

Figs. 5.7-5-10 show mass change of HDPE/GF composites in each test fuels. Mass of all HDPE/GF composites were increased after immersion in $C(E0)_A$ and $C(E20)_A$ test fuels. These were mainly due to the absorption of fuel C into specimens. Test fuels $C(E0)_A$ and $C(E20)_A$ clearly had more fuel C than in $C(E85)_A$ and $C(E100)_A$ test fuels. The percentage increase of mass of HDPE/GF composites were higher in HDPE/GF (0 wt%) than HDPE/GF (15 wt%) and HDPE/GF (30 wt%) composites. The reasons for mass increase in HDPE/GF composites were that the structure of HDPE samples softened by the solvent and the molecular chains were subjected to large molecular forces and toluene has high solubility value for HDPE (Keh-Ping Chao et al., 2006 [46]). Iso-octane represents the alkane group can swelling in polymer (Jones et al., 2008 [34]).

5.2.2 Diameter Change

The diameter of experimental data after being soaking in each test fuels are showed in Table 5.4.

Table 5.4 Diameter (mm.) of HDPE/GF composites in each test fuels

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
	0%GF			
0	49.41 ± 0.11	49.48 ± 0.07	49.44 ± 0.04	49.42 ± 0.08
2	50.07 ± 0.12	49.81 ± 0.29	49.85 ± 0.39	49.56 ± 0.11
4	50.11 ± 0.10	50.12 ± 0.03	49.75 ± 0.16	49.51 ± 0.07
7	50.12 ± 0.07	50.13 ± 0.02	49.76 ± 0.12	49.51 ± 0.05
10	49.90 ± 0.09	49.90 ± 0.04	49.70 ± 0.08	49.46 ± 0.05
13	50.02 ± 0.11	50.05 ± 0.03	49.66 ± 0.09	49.45 ± 0.04
16	50.01 ± 0.11	50.06 ± 0.02	49.63 ± 0.12	49.46 ± 0.06

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
15%GF				
0	49.98 ± 0.06	50.01 ± 0.05	50.01 ± 0.08	50.03 ± 0.06
2	50.43 ± 0.07	50.49 ± 0.08	50.16 ± 0.05	50.02 ± 0.05
4	50.44 ± 0.04	50.47 ± 0.09	50.20 ± 0.07	50.04 ± 0.04
7	50.47 ± 0.06	50.51 ± 0.05	50.27 ± 0.07	50.04 ± 0.07
10	50.27 ± 0.07	50.36 ± 0.05	50.16 ± 0.08	50.00 ± 0.02
13	50.36 ± 0.06	50.42 ± 0.06	50.15 ± 0.09	50.00 ± 0.06
16	50.39 ± 0.08	50.43 ± 0.06	50.14 ± 0.06	50.01 ± 0.04
30%GF				
0	50.15 ± 0.08	50.15 ± 0.11	50.22 ± 0.06	50.20 ± 0.06
2	50.51 ± 0.06	50.53 ± 0.04	50.32 ± 0.11	50.19 ± 0.11
4	50.51 ± 0.05	50.50 ± 0.05	50.36 ± 0.06	50.18 ± 0.07
7	50.52 ± 0.06	50.55 ± 0.05	50.37 ± 0.04	50.20 ± 0.08
10	50.39 ± 0.07	50.46 ± 0.07	50.32 ± 0.04	50.14 ± 0.07
13	50.42 ± 0.05	50.45 ± 0.07	50.31 ± 0.07	50.13 ± 0.10
16	50.43 ± 0.07	50.25 ± 0.06	50.29 ± 0.07	50.14 ± 0.09

The diameter changed of HDPE/GF composites after being soaking in each test fuels were shown in Figs.5.11 – 5.17.

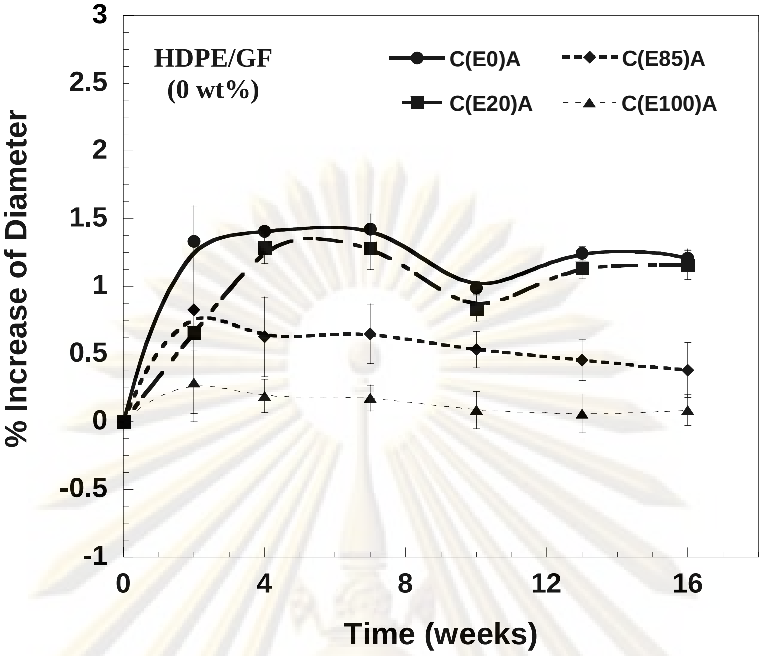


Figure. 5.11 Effect of gasohols on diameter change of HDPE/GF (0 wt%) composites

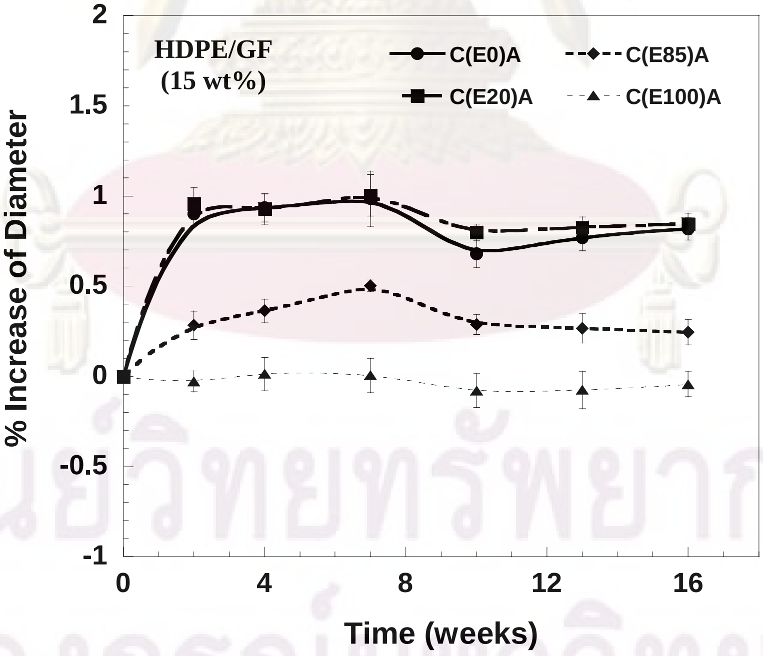


Figure. 5.12 Effect of gasohols on diameter change of HDPE/GF (15 wt%) composites

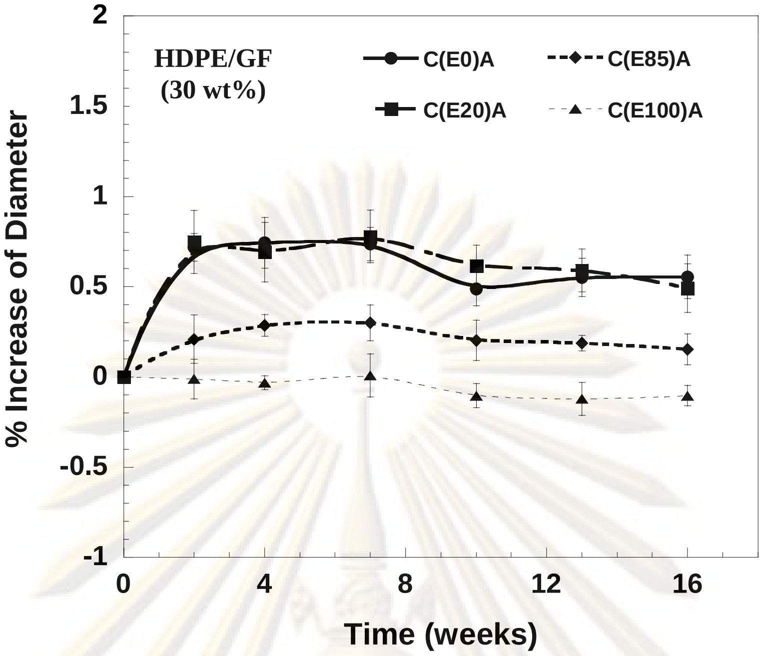


Figure. 5.13 Effect of gasohols on diameter change of HDPE/GF (30 wt%) composites

From Figs. 5.11-5.13, diameter changed of all HDPE/GF composites increased by about 0.5-1.5% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels and leveled off after that. However, the diameter of HDPE/GF composites immersed in $C(E85)_A$ and $C(E100)_A$ test fuels were increased only about 0-0.5%.

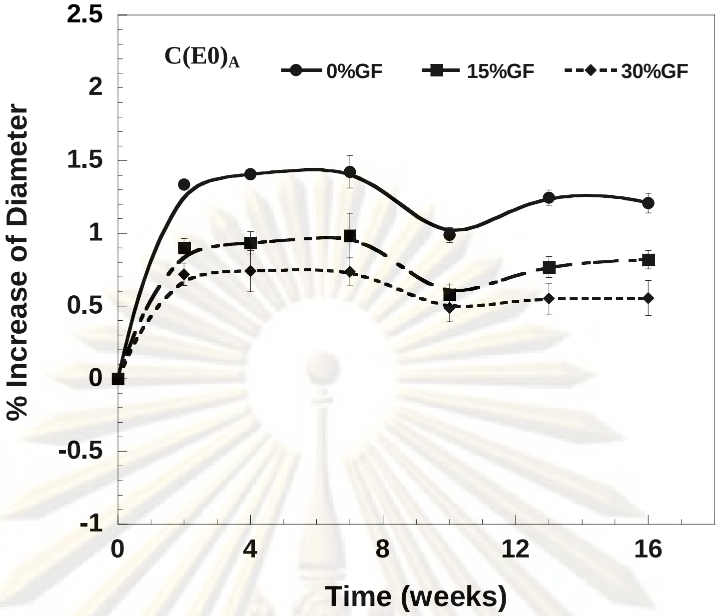


Figure. 5.14 Effect of C(E0)$_A$ on diameter change of HDPE/GF composites

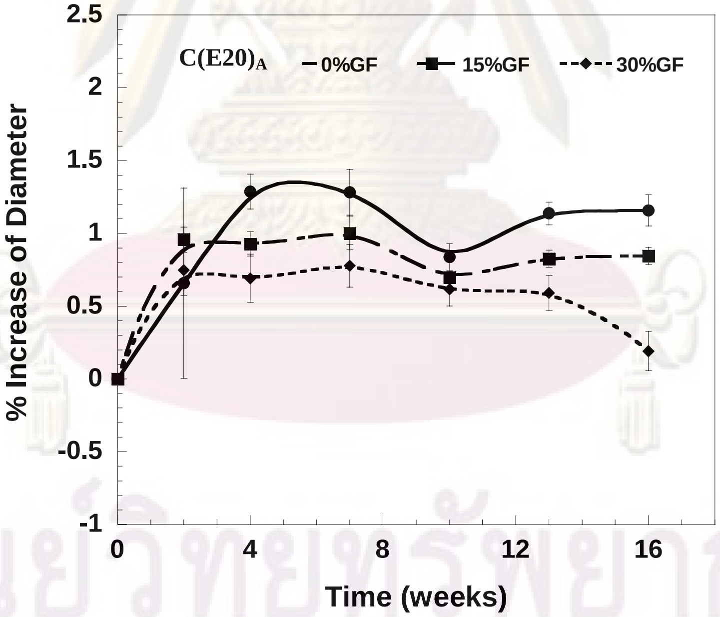


Figure. 5.15 Effect of C(E20)$_A$ on diameter change of HDPE/GF composites

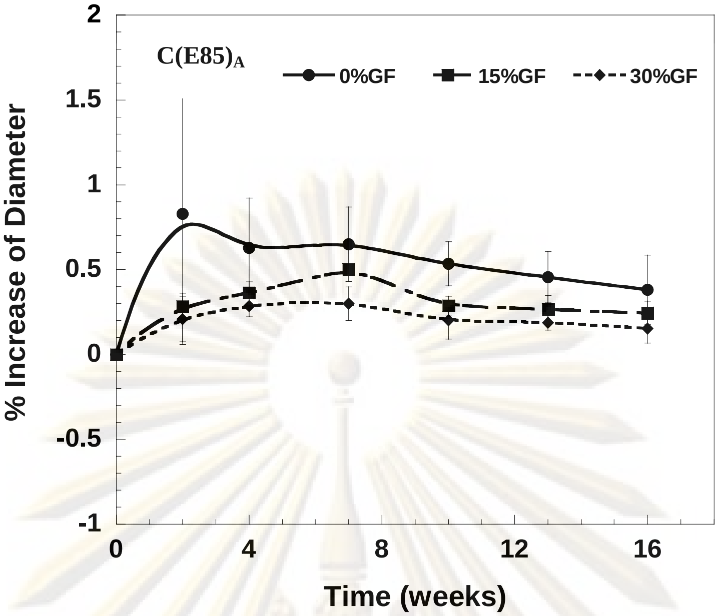


Figure. 5.16 Effect of C(E85)$_A$ on diameter change of HDPE/GF composites

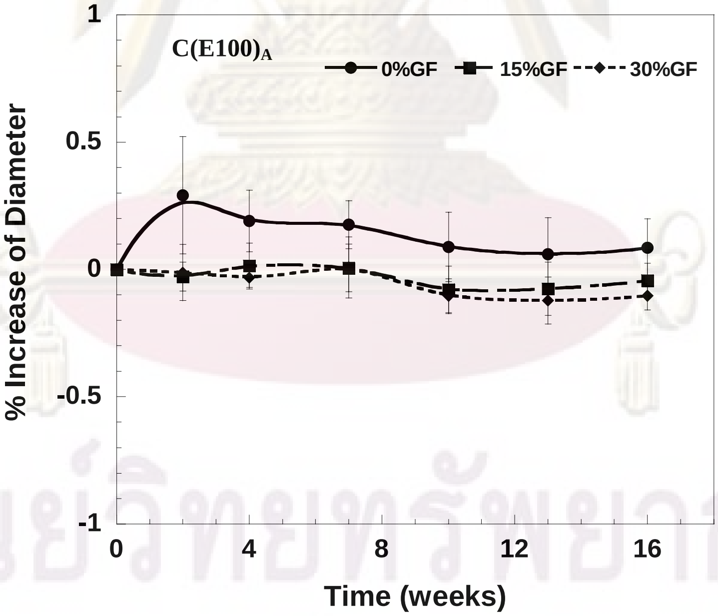


Figure. 5.17 Effect of C(E100)$_A$ on diameter change of HDPE/GF composites

Figs. 5.14-5.17 show diameter change of HDPE/GF composites in each test fuels. Diameter of all HDPE/GF composites were increased after immersion in $C(E0)_A$ and $C(E20)_A$ test fuels. These are mainly due to the absorption of fuel C into specimens. Test fuels $C(E0)_A$ and $C(E20)_A$ clearly had more fuel C than in $C(E85)_A$ and $C(E100)_A$ test fuels. The reasons for diameter increase in HDPE/GF composites are that the structure of HDPE samples softened by the solvent and the molecular chains are subjected to large molecular forces and toluene has high solubility value for HDPE (Keh-Ping Chao et al., 2006 [46]). Iso-octane represents the alkane group can swelling in polymer (Jones et al., 2008 [34]).

5.2.3 Thickness Change

The thickness of experimental data after being soaking in each test fuels are showed in Table 5.5.

Table 5.5 Thickness (mm.) of HDPE/GF composites in each test fuels

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
0%GF				
0	3.26 ± 0.02	3.26 ± 0.04	3.25 ± 0.02	3.24 ± 0.04
2	3.27 ± 0.01	3.26 ± 0.02	3.27 ± 0.04	3.27 ± 0.04
4	3.28 ± 0.02	3.29 ± 0.02	3.27 ± 0.04	3.26 ± 0.05
7	3.28 ± 0.02	3.28 ± 0.01	3.29 ± 0.04	3.26 ± 0.04
10	3.28 ± 0.01	3.28 ± 0.03	3.28 ± 0.03	3.27 ± 0.04
13	3.26 ± 0.01	3.29 ± 0.01	3.27 ± 0.05	3.26 ± 0.04
16	3.27 ± 0.02	3.29 ± 0.01	3.28 ± 0.03	3.27 ± 0.04

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
15%GF				
0	3.28 ± 0.03	3.27 ± 0.01	3.28 ± 0.03	3.28 ± 0.03
2	3.27 ± 0.02	3.29 ± 0.01	3.31 ± 0.02	3.29 ± 0.04
4	3.27 ± 0.03	3.29 ± 0.02	3.31 ± 0.03	3.27 ± 0.03
7	3.30 ± 0.02	3.31 ± 0.03	3.31 ± 0.03	3.29 ± 0.03
10	3.30 ± 0.02	3.30 ± 0.02	3.31 ± 0.02	3.29 ± 0.03
13	3.28 ± 0.02	3.30 ± 0.01	3.30 ± 0.02	3.28 ± 0.02
16	3.30 ± 0.03	3.30 ± 0.02	3.30 ± 0.02	3.29 ± 0.02
30%GF				
0	3.25 ± 0.04	3.21 ± 0.03	3.22 ± 0.01	3.23 ± 0.02
2	3.25 ± 0.04	3.24 ± 0.01	3.22 ± 0.01	3.22 ± 0.01
4	3.23 ± 0.02	3.25 ± 0.01	3.23 ± 0.02	3.23 ± 0.01
7	3.27 ± 0.03	3.25 ± 0.01	3.24 ± 0.02	3.23 ± 0.01
10	3.26 ± 0.03	3.24 ± 0.03	3.23 ± 0.01	3.23 ± 0.04
13	3.23 ± 0.03	3.23 ± 0.02	3.22 ± 0.02	3.23 ± 0.02
16	3.27 ± 0.03	3.26 ± 0.03	3.23 ± 0.02	3.23 ± 0.01

The thickness change of HDPE/GF composites after being soaking in each test fuels were shown in Figs.5.18 – 5.20.

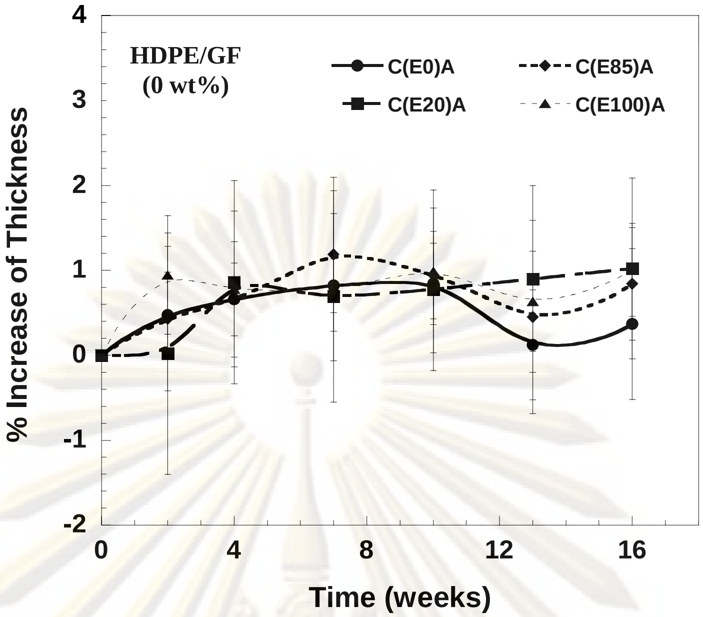


Figure. 5.18 Effect of gasohols on thickness change of HDPE/GF (0 wt%) composites

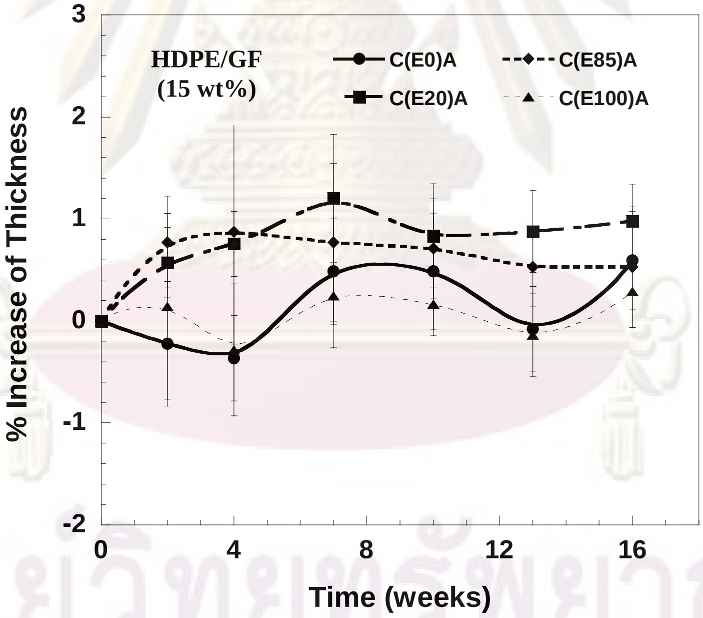


Figure. 5.19 Effect of gasohols on thickness change of HDPE/GF (15 wt%) composites

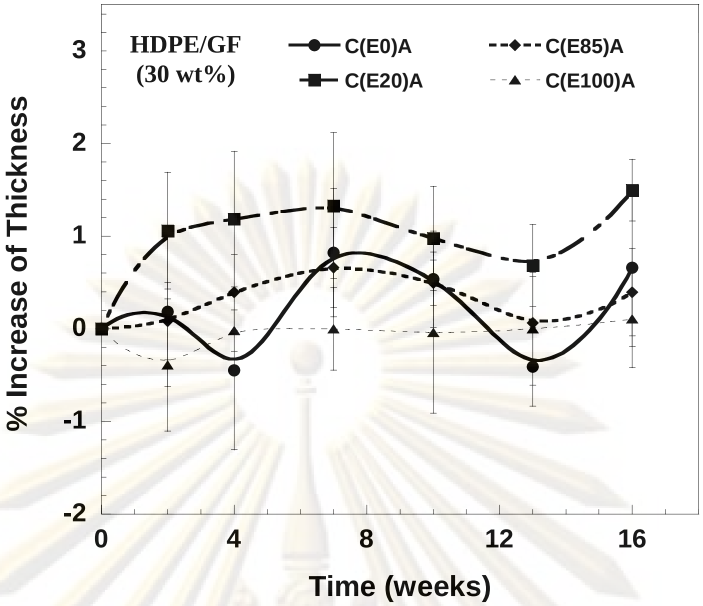


Figure. 5.20 Effect of gasohols on thickness change of HDPE/GF (30 wt%) composites

Figs. 5.18-5.20, thickness change of HDPE/GF composites at 0, 15 and 30 wt% increased by about 0-1% after 4 weeks of immersion in all test fuels and leveled off after that. Figs. 5.21-5.24 show thickness change of HDPE/GF composites in each test fuels. The reasons for thickness increase in HDPE/GF composites were that the structure of HDPE samples softened by the solvent and the molecular chains are subjected to large molecular forces (Keh-Ping Chao et al., 2006 [46]).

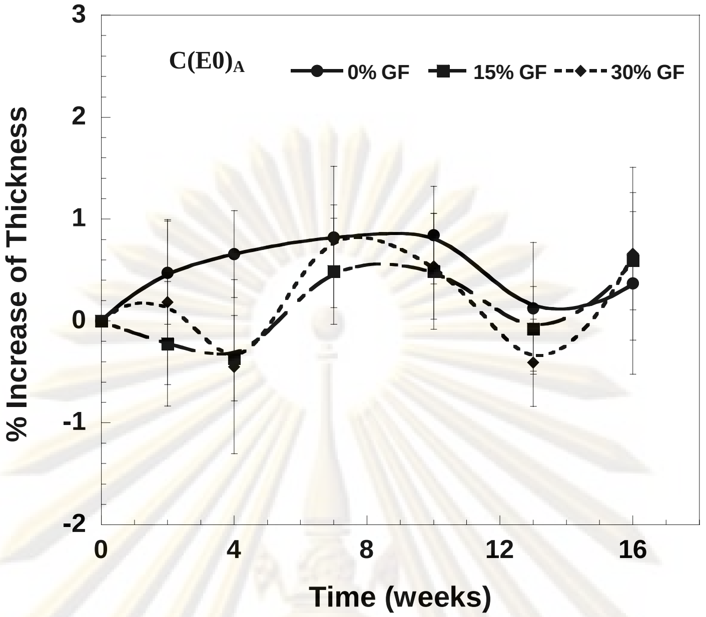


Figure. 5.21 Effect of C(E0)$_A$ on thickness change of HDPE/GF composites

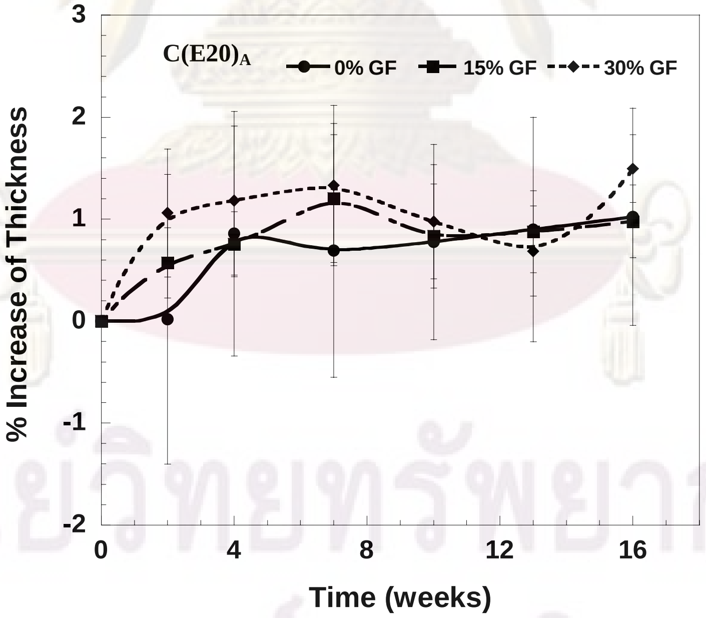


Figure. 5.22 Effect of C(E20)$_A$ on thickness change of HDPE/GF composites

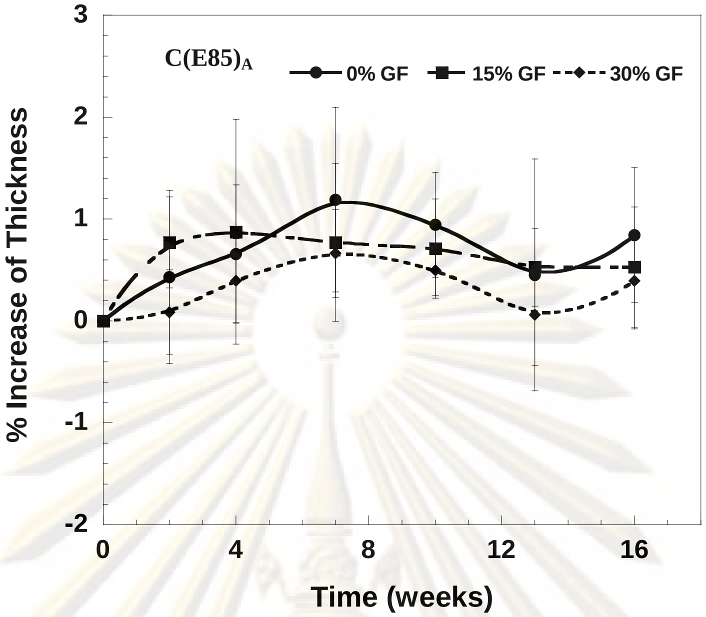


Figure. 5.23 Effect of C(E85)$_A$ on thickness change of HDPE/GF composites

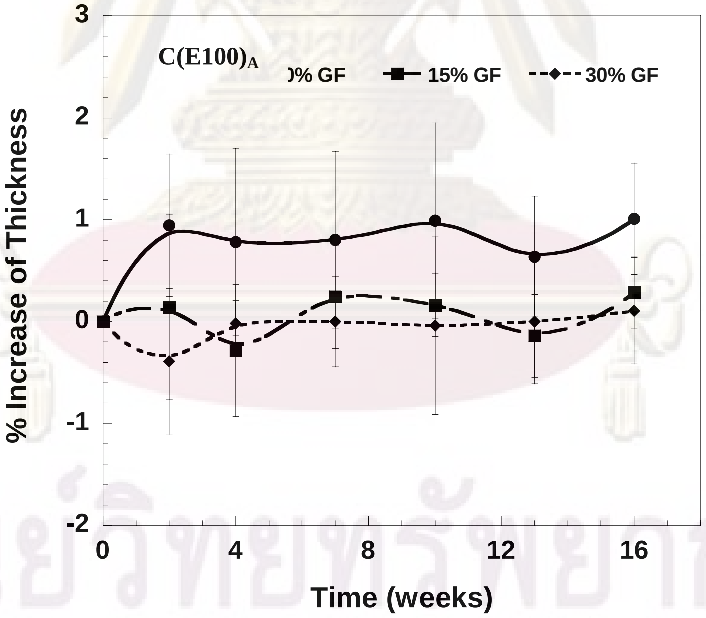


Figure. 5.24 Effect of C(E100)$_A$ on thickness change of HDPE/GF composites

5.2.4 Volume Change

The volume of HDPE/GF composites had a positive correlation to the diameter and thickness result. Refer to Appendix B for the data of diameter and Appendix C for thickness.

The experimental data after being soaking in each test fuels are showed in Table 5.6.

Table 5.6 Volume (cm^3.) of HDPE/GF composites in each test fuels

Time (weeks)	Test Fuel			
	$C(E0)_A$	$C(E20)_A$	$C(E85)_A$	$C(E100)_A$
0%GF				
0	6.24 ± 0.06	6.27 ± 0.09	6.24 ± 0.03	6.21 ± 0.07
2	6.44 ± 0.04	6.35 ± 0.11	6.38 ± 0.16	6.31 ± 0.10
4	6.46 ± 0.05	6.49 ± 0.04	6.36 ± 0.10	6.28 ± 0.10
7	6.48 ± 0.04	6.48 ± 0.02	6.40 ± 0.10	6.28 ± 0.08
10	6.42 ± 0.04	6.42 ± 0.06	6.37 ± 0.07	6.28 ± 0.08
13	6.41 ± 0.03	6.47 ± 0.03	6.33 ± 0.11	6.26 ± 0.06
16	6.42 ± 0.04	6.48 ± 0.02	6.35 ± 0.07	6.28 ± 0.08
15%GF				
0	6.44 ± 0.05	6.43 ± 0.03	6.45 ± 0.06	6.46 ± 0.05
2	6.54 ± 0.03	6.59 ± 0.04	6.54 ± 0.04	6.46 ± 0.08
4	6.45 ± 0.07	6.59 ± 0.06	6.55 ± 0.06	6.44 ± 0.05
7	6.60 ± 0.04	6.64 ± 0.06	6.57 ± 0.06	6.48 ± 0.05
10	6.55 ± 0.05	6.57 ± 0.05	6.53 ± 0.05	6.46 ± 0.04
13	6.53 ± 0.04	6.59 ± 0.03	6.52 ± 0.05	6.44 ± 0.05
16	6.58 ± 0.05	6.60 ± 0.04	6.52 ± 0.04	6.47 ± 0.03

Time (weeks)	Test Fuel			
	C(E0)$_A$	C(E20)$_A$	C(E85)$_A$	C(E100)$_A$
30%GF				
0	6.41 ± 0.08	6.34 ± 0.08	6.37 ± 0.02	6.40 ± 0.05
2	6.52 ± 0.07	6.50 ± 0.03	6.40 ± 0.01	6.37 ± 0.03
4	6.40 ± 0.03	6.50 ± 0.04	6.43 ± 0.04	6.39 ± 0.04
7	6.56 ± 0.04	6.53 ± 0.03	6.45 ± 0.03	6.40 ± 0.03
10	6.51 ± 0.05	6.48 ± 0.06	6.43 ± 0.03	6.38 ± 0.09
13	6.46 ± 0.06	6.46 ± 0.06	6.40 ± 0.03	6.38 ± 0.03
16	6.53 ± 0.05	6.46 ± 0.07	6.42 ± 0.04	6.39 ± 0.03

The volume change of HDPE/GF composites after being soaking in each test fuels are showed in Figs.5.25 – 5.27.

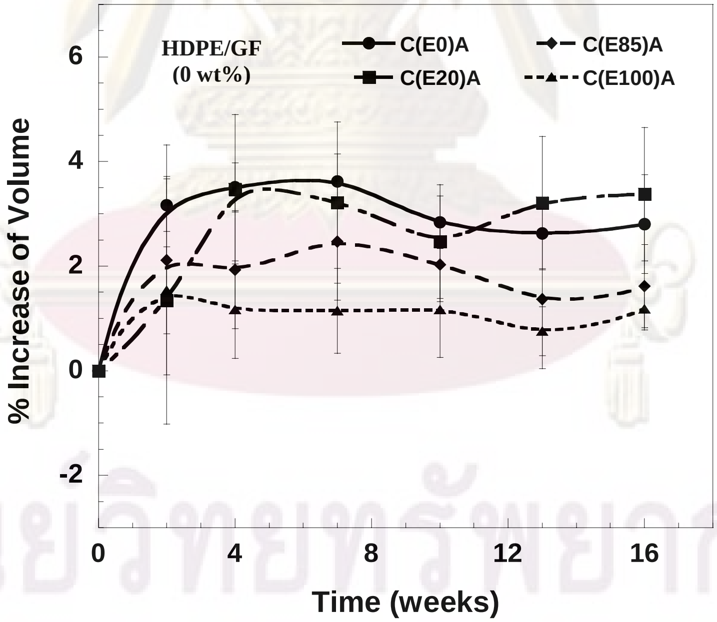


Figure. 5.25 Effect of gasohols on volume change of HDPE/GF (0 wt%) composites

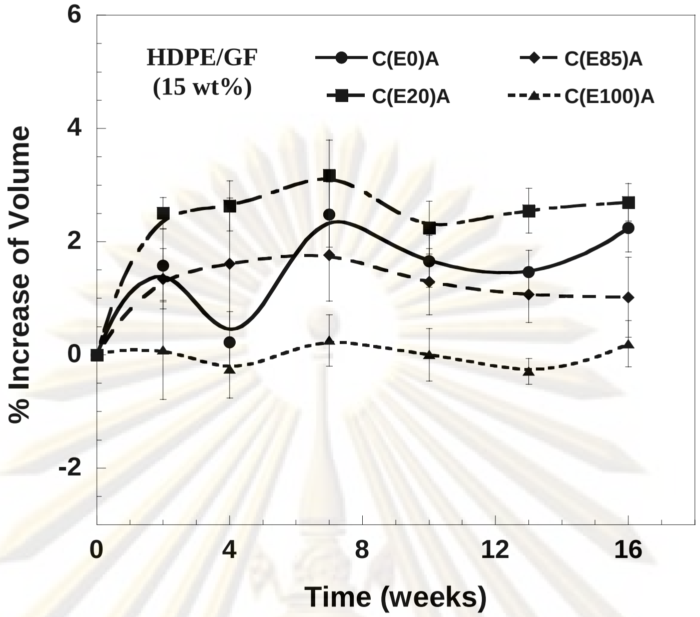


Figure. 5.26 Effect of gasohols on volume change of HDPE/GF (15 wt%) composites

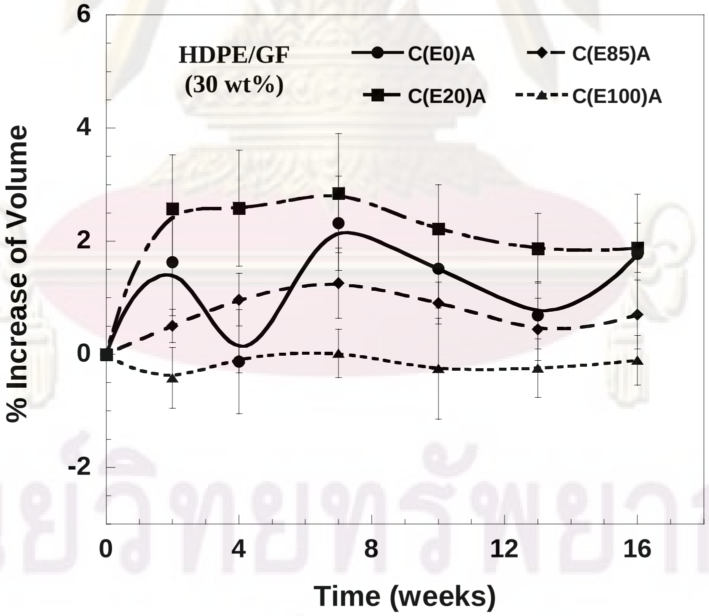


Figure. 5.27 Effect of gasohols on volume change of HDPE/GF (30 wt%) composites

Figs. 5.25-5.27, volume change of all HDPE/GF composites increased by about 1-3% after 4 weeks of immersion in $C(E0)_A$,$C(E20)_A$ and $C(E85)_A$ test fuels. However, the volume of all HDPE/GF composites immersed in $C(E100)_A$ test fuels were increased only about 0-1%.

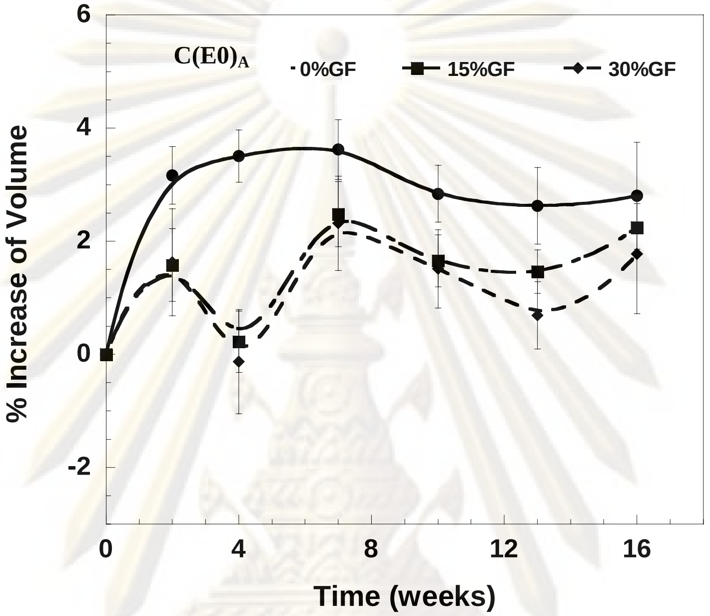


Figure. 5.28 Effect of $C(E0)_A$ on volume change of HDPE/GF composites

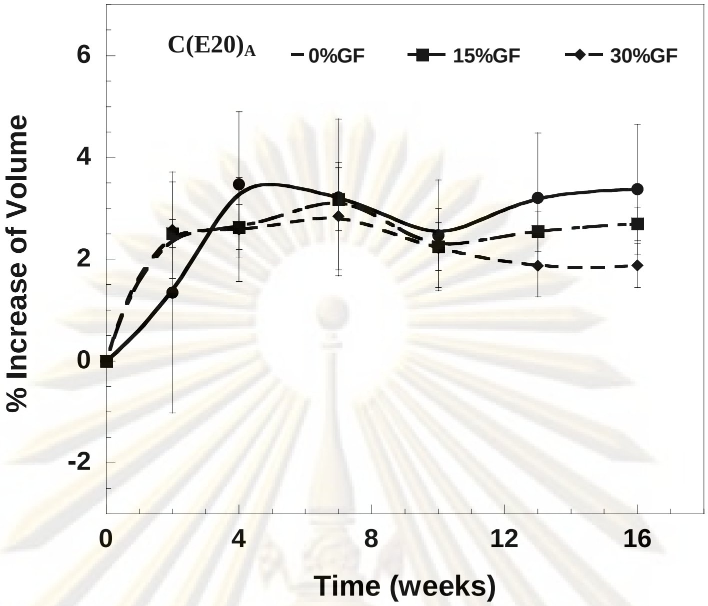


Figure. 5.29 Effect of C(E20)$_A$ on volume change of HDPE/GF composites

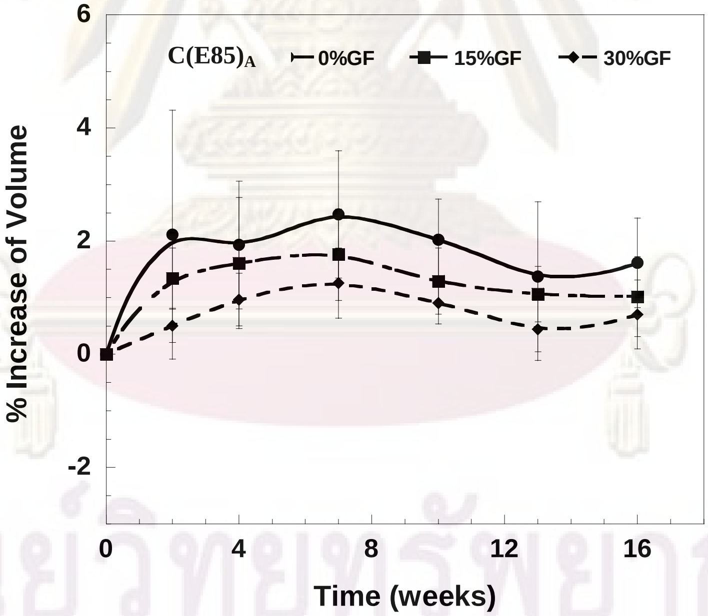


Figure. 5.30 Effect of C(E85)$_A$ on volume change of HDPE/GF composites

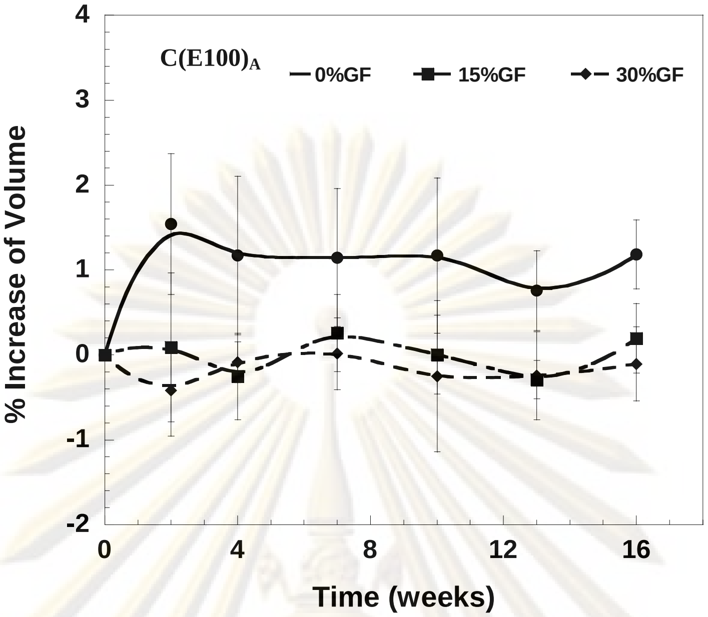


Figure. 5.31 Effect of C(E100)$_A$ on volume change of HDPE/GF composites

Figs. 5.28-5.31, show volume change of HDPE/GF composites at 0, 15 and 30 wt% in each test fuels. The reasons for volume increase in HDPE/GF composites were depended on diameter and thickness. The percentage increased of volume of HDPE/GF composites were higher in HDPE/GF (0 wt%) than HDPE/GF (15 wt%) and HDPE/GF (30 wt%) composites. However, that the structure of HDPE samples softened by the solvent and the molecular chains are subjected to large molecular forces (Keh-Ping Chao et al., 2006 [46]).

5.2.5 Water Absorption

The water absorption of HDPE/GF composites after being soaking in water are showed in Table 5.7 and Fig.5.32.

Table 5.7 Water absorption of HDPE/GF composites in water

Time (days)	HDPE/GF (0 wt%)		HDPE/GF (15 wt%)		HDPE/GF (30 wt%)	
	Average (g)	%Increase	Average (g)	%Increase	Average (g)	%Increase
0	5.402	0.000	5.978	0.000	6.607	0.000
1	5.403	0.018	5.979	0.019	6.612	0.068
2	5.403	0.020	5.980	0.024	6.614	0.098
3	5.403	0.021	5.980	0.030	6.615	0.121
4	5.403	0.020	5.980	0.032	6.615	0.125
5	5.403	0.021	5.980	0.036	6.616	0.141
6	5.403	0.022	5.980	0.037	6.618	0.166
7	5.403	0.024	5.980	0.039	6.619	0.178
8	5.403	0.026	5.981	0.040	6.618	0.169
9	5.403	0.026	5.981	0.044	6.620	0.194
10	5.403	0.028	5.981	0.049	6.620	0.202
11	5.403	0.030	5.981	0.056	6.621	0.212
12	5.403	0.031	5.982	0.057	6.622	0.221
13	5.403	0.030	5.982	0.057	6.622	0.232
14	5.403	0.031	5.982	0.060	6.622	0.233
16	5.404	0.033	5.982	0.066	6.624	0.254
18	5.404	0.033	5.982	0.067	6.624	0.262
20	5.404	0.034	5.982	0.072	6.625	0.269
22	5.404	0.035	5.983	0.075	6.626	0.282
24	5.404	0.035	5.983	0.076	6.626	0.286
26	5.404	0.035	5.983	0.076	6.626	0.286
28	5.404	0.037	5.983	0.083	6.627	0.302

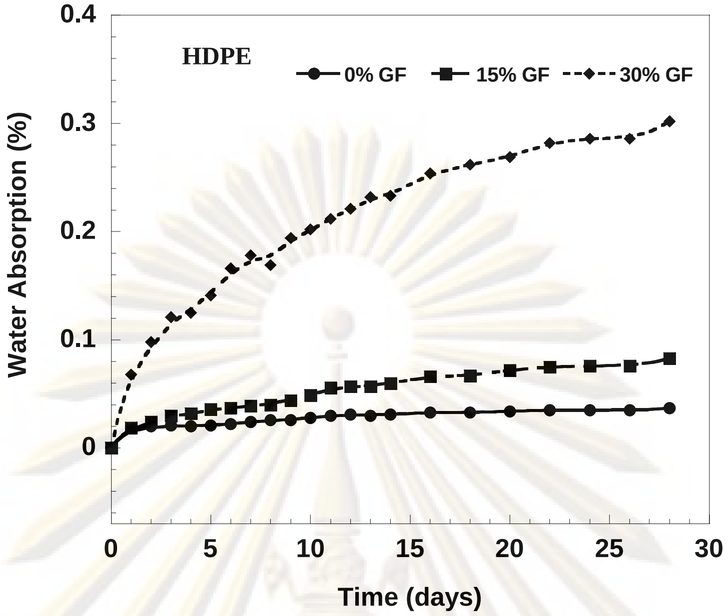


Figure. 5.32 Water Absorption of HDPE/GF composites

Fig. 5.32, shows percentage water absorption of HDPE/GF composites. At 0 wt% increased about 0.037% , 15 wt% increased about 0.083% and 30 wt% increased about 0.302% . Glass considered a hydrophilic fiber that absorbs water. The percentage water absorption of HDPE/GF composites were increased with increasing glass fiber content from 0 to 30 wt% (Foulk et al., 2004 [35]). These were mainly due to HDPE no absorption of water but glass fiber can absorption of water into specimens.

5.3 The Effects of Gasohols on Mechanical Properties

5.3.1 Tensile Properties

The results on comparison of the tensile strength of the HDPE/GF composites at 0, 15 and 30 wt% after being soaking in each test fuels for 0, 4, 10 and 16 weeks are showed in Table 5.8.

Table 5.8 Tensile strength (MPa) of HDPE/GF composites in each test fuels

Test Fuel	Time (weeks)			
	0	4	10	16
0%GF				
$C(E0)_A$	26.28 ± 0.24	21.98 ± 0.07	21.19 ± 0.48	17.86 ± 0.13
$C(E20)_A$	26.28 ± 0.24	21.60 ± 0.24	20.50 ± 0.26	17.95 ± 0.23
$C(E85)_A$	26.28 ± 0.24	22.64 ± 0.27	22.86 ± 0.47	20.47 ± 0.29
$C(E100)_A$	26.28 ± 0.24	24.43 ± 0.10	24.95 ± 0.81	22.76 ± 0.40
15%GF				
$C(E0)_A$	28.60 ± 0.26	21.90 ± 0.14	21.82 ± 0.66	15.52 ± 0.38
$C(E20)_A$	28.60 ± 0.26	22.00 ± 0.19	22.48 ± 0.40	16.96 ± 0.18
$C(E85)_A$	28.60 ± 0.26	23.35 ± 0.13	22.03 ± 0.34	16.59 ± 1.44
$C(E100)_A$	28.60 ± 0.26	25.21 ± 0.13	25.74 ± 0.15	17.70 ± 0.55
30%GF				
$C(E0)_A$	34.03 ± 1.13	21.04 ± 0.11	24.16 ± 0.33	17.23 ± 0.86
$C(E20)_A$	34.03 ± 1.13	20.74 ± 0.59	23.18 ± 0.45	19.52 ± 0.47
$C(E85)_A$	34.03 ± 1.13	22.94 ± 0.35	24.10 ± 0.26	22.45 ± 0.25
$C(E100)_A$	34.03 ± 1.13	24.51 ± 0.14	24.87 ± 0.49	23.66 ± 0.17

The percentage reduction of tensile strength of HDPE/GF composites after being soaking in each test fuels are showed in Figs.5.33-5.35.

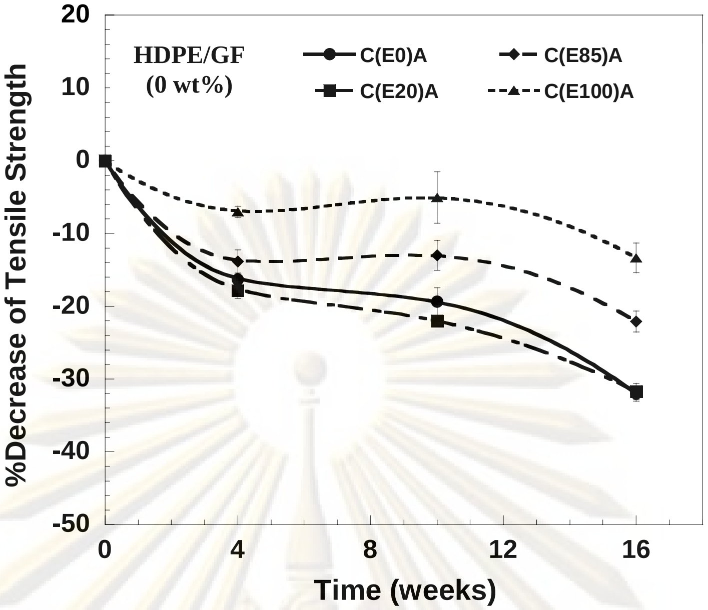


Figure. 5.33 Effect of gasohols on %decrease of tensile strength of HDPE/GF (0 wt%) composites

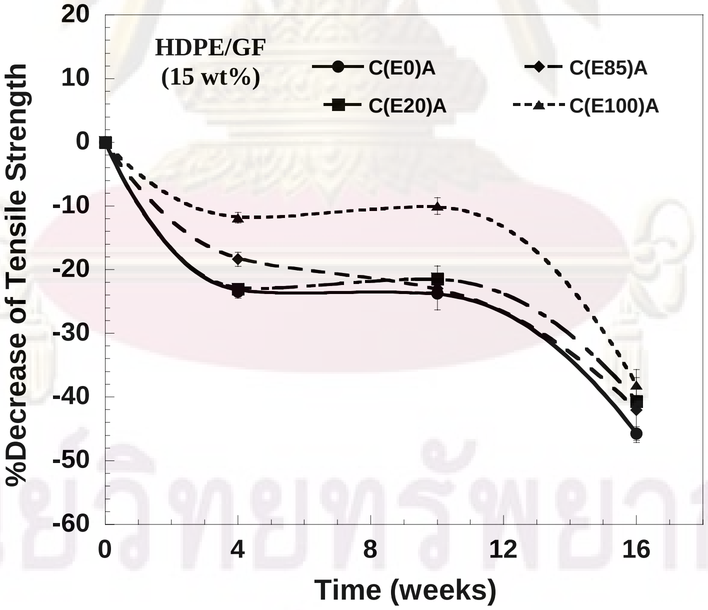


Figure. 5.34 Effect of gasohols on %decrease of tensile strength of HDPE/GF (15 wt%) composites

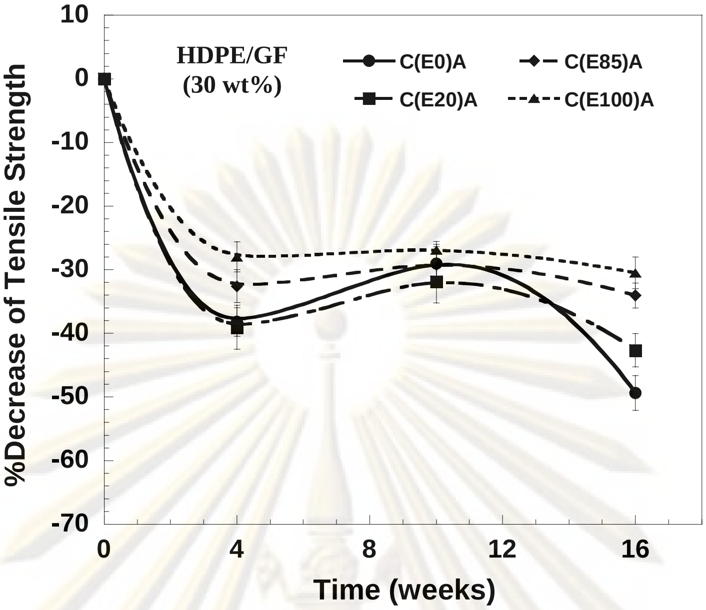


Figure. 5.35 Effect of gasohols on %decrease of tensile strength of HDPE/GF (30 wt%) composites

As expected, the tensile strength of all unsoaked samples were increased with increasing fiber content from 0 to 30 wt%. After immersion in each test fuel, the tensile strength were clearly decreased during the first 4 weeks. Fig. 5.33 shows the reduction of about 15-33% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for tensile strength of HDPE/GF (0 wt%) composites. The reduction of about 5-22% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Fig. 5.34 shows the reduction of about 20-45% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for tensile strength of HDPE/GF (15 wt%) composites. The reduction of about 10-42% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Fig. 5.35 shows the reduction of about 30-50% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for tensile strength of HDPE/GF (30 wt%) composites. The reduction of about 27-34% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Test fuels $C(E0)_A$ and $C(E20)_A$ clearly had more fuel C than in $C(E85)_A$ and $C(E100)_A$ test fuels. These were mainly due to the absorption of fuel C into specimens and fuel C has high solubility value for HDPE

(Barrett et al., 1999 [47]).The percentage reduction of tensile strength of HDPE/GF composites were higher in C(E0)$_A$ and C(E20)$_A$ than C(E85)$_A$ and C(E100)$_A$.

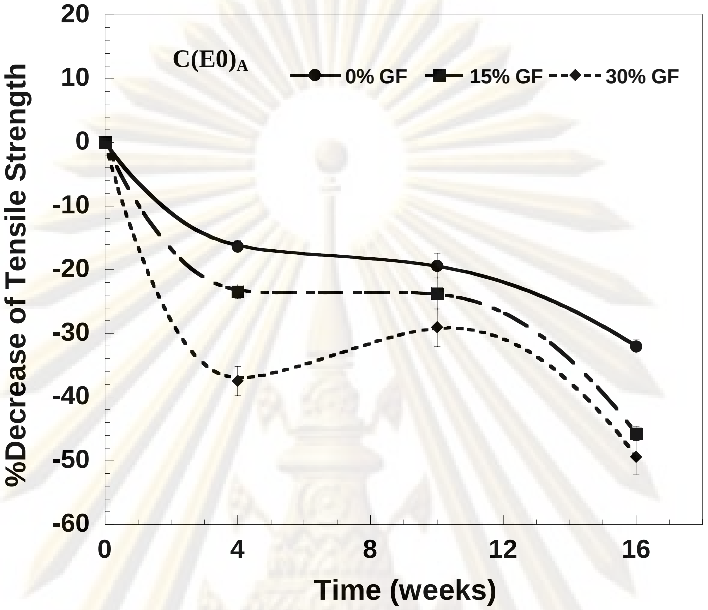


Figure. 5.36 Effect of C(E0)$_A$ on %decrease of tensile strength of HDPE/GF composites

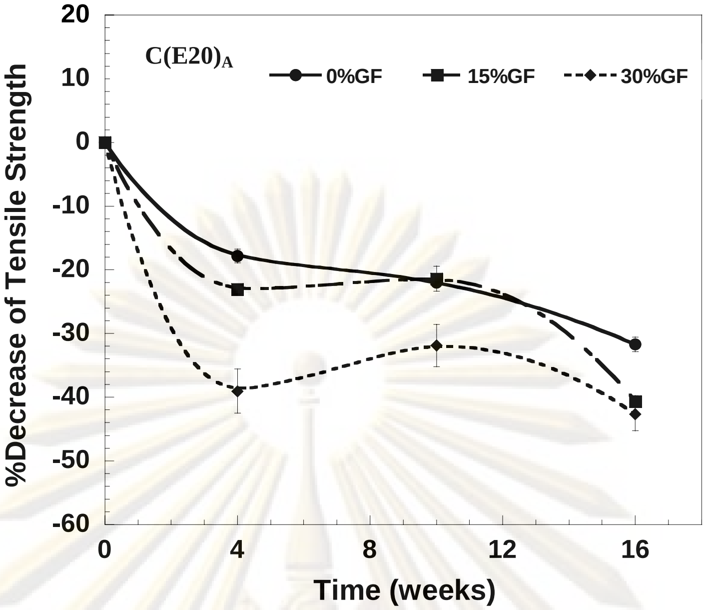


Figure. 5.37 Effect of C(E20)$_A$ on %decrease of tensile strength of HDPE/GF composites

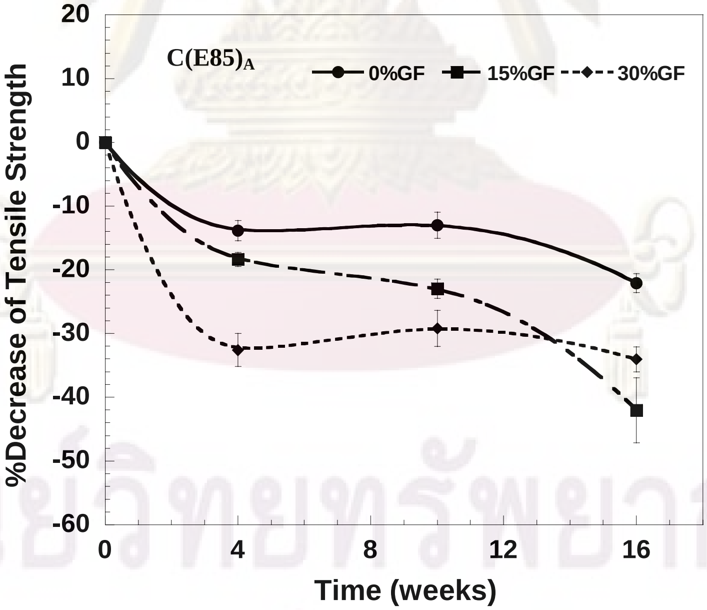


Figure. 5.38 Effect of C(E85)$_A$ on %decrease of tensile strength of HDPE/GF composites

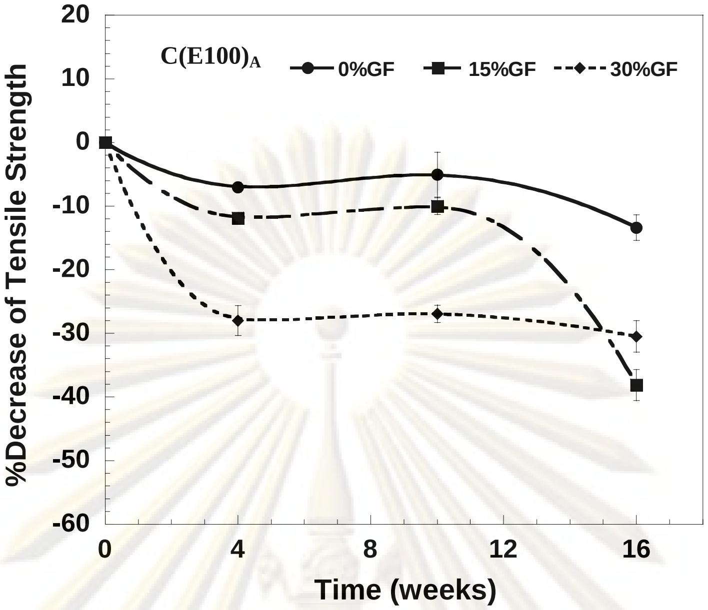


Figure. 5.39 Effect of C(E100)$_A$ on %decrease of tensile strength of HDPE/GF composites

Figs. 5.36-5.39, show the percentage reduction of tensile strength of HDPE/GF composites in each test fuel. The decrease was mainly due to the swelling and plasticizing effects of iso-octane i.e., the alkane group which can swell polymer and elastomer (Jones et al., 2008 [34]) and toluene absorbed into specimens (Keh-Ping Chao et al., 2006 [46] and Aminabhavi et al., 1998 [48]). The percentage reduction of tensile strength of HDPE/GF composites were higher in HDPE/GF (30 wt%) and HDPE/GF (15 wt%) than HDPE/GF (0 wt%) composites, but the actual values of tensile strength of HDPE/GF (30 wt%) and HDPE/GF (15 wt%) were higher than HDPE/GF (0 wt%) composites. Hence, the GF still served as reinforcing filler in these composites after immersion in gasohols.

5.3.2 Young’s Modulus Properties

The results on comparison of the young’s modulus of the HDPE/GF composites at 0,15 and 30 wt% after being soaking in each test fuels for 0, 4, 10 and 16 weeks are showed in Table 5.9.

Table 5.9 Young’s modulus (GPa) of HDPE/GF composites in each test fuels

Test Fuel	Time (weeks)			
	0	4	10	16
0%GF				
$C(E0)_A$	0.68 ± 0.02	0.37 ± 0.01	0.35 ± 0.02	0.32 ± 0.02
$C(E20)_A$	0.68 ± 0.02	0.35 ± 0.02	0.34 ± 0.01	0.33 ± 0.01
$C(E85)_A$	0.68 ± 0.02	0.44 ± 0.03	0.42 ± 0.01	0.42 ± 0.01
$C(E100)_A$	0.68 ± 0.02	0.60 ± 0.01	0.66 ± 0.01	0.64 ± 0.02
15%GF				
$C(E0)_A$	1.95 ± 0.26	0.37 ± 0.01	0.36 ± 0.03	0.32 ± 0.01
$C(E20)_A$	1.95 ± 0.26	0.36 ± 0.01	0.33 ± 0.03	0.32 ± 0.01
$C(E85)_A$	1.95 ± 0.26	0.49 ± 0.02	0.47 ± 0.02	0.44 ± 0.02
$C(E100)_A$	1.95 ± 0.26	0.90 ± 0.01	0.71 ± 0.05	0.65 ± 0.01
30%GF				
$C(E0)_A$	3.97 ± 0.17	0.66 ± 0.05	0.68 ± 0.09	0.49 ± 0.01
$C(E20)_A$	3.97 ± 0.17	0.66 ± 0.05	0.59 ± 0.06	0.49 ± 0.01
$C(E85)_A$	3.97 ± 0.17	0.90 ± 0.10	0.70 ± 0.05	0.51 ± 0.05
$C(E100)_A$	3.97 ± 0.17	1.65 ± 0.19	1.10 ± 0.09	0.67 ± 0.01

The percentage reduction of young’s modulus of HDPE/GF composites after being soaking in each test fuels are showed in Figs.5.40-5.42.

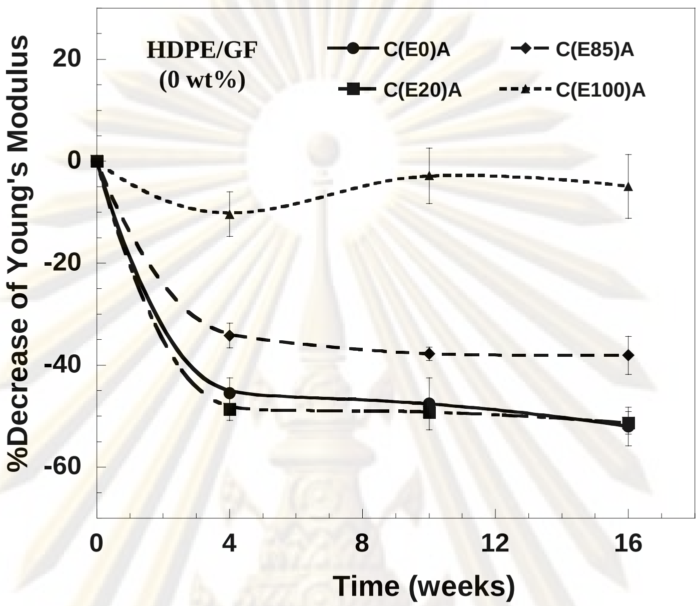


Figure. 5.40 Effect of gasohols on %decrease of young’s modulus of HDPE/GF (0 wt%) composites

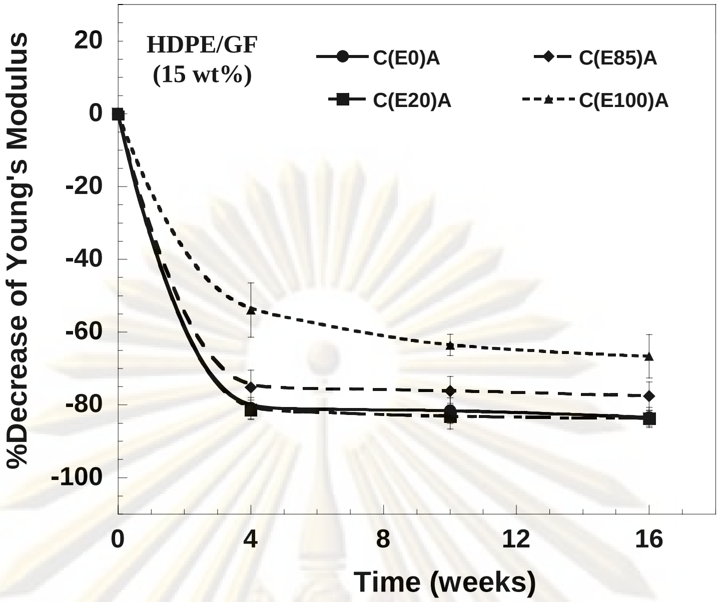


Figure. 5.41 Effect of gasohols on %decrease of young's modulus of HDPE/GF (15 wt%) composites

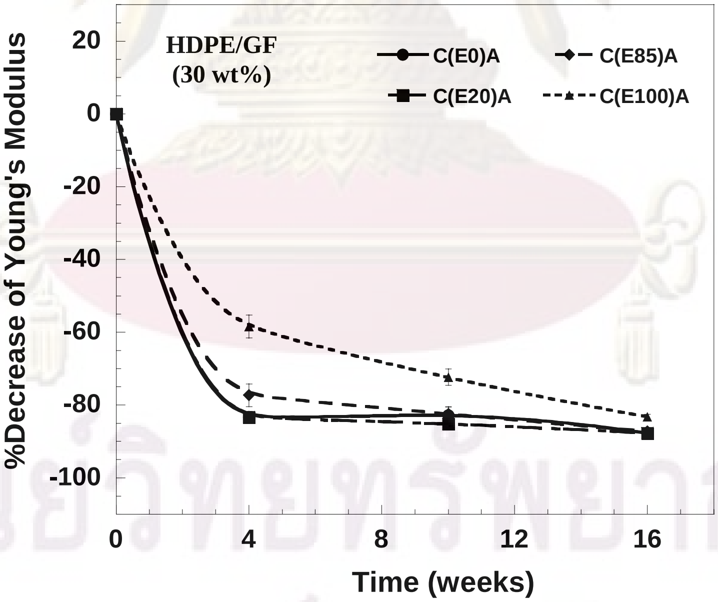


Figure. 5.42 Effect of gasohols on %decrease of young's modulus of HDPE/GF (30 wt%) composites

As expected, the young's modulus of all unsoaked samples were increased with increasing fiber content from 0 to 30 wt%. After immersion in each test fuel, the young's modulus were clearly decreased during the first 4 weeks. Fig. 5.40 shows the reduction of about 45-52% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for the young's modulus of HDPE/GF (0 wt%) composites. The reduction of about 3-38% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Fig. 5.41 shows the reduction of about 80-84% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for young's modulus of HDPE/GF (15 wt%) composites. The reduction of about 54-78% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Fig. 5.42 shows the reduction of about 82-88% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for young's modulus of HDPE/GF (30 wt%) composites. The reduction of about 58-87% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Test fuels $C(E0)_A$ and $C(E20)_A$ clearly had more fuel C than in $C(E85)_A$ and $C(E100)_A$ test fuels. These were mainly due to the absorption of fuel C into specimens and fuel C has high solubility value for HDPE (Barrett et al., 1999 [47]). The percentage reduction of young's modulus of HDPE/GF composites were higher in $C(E0)_A$ and $C(E20)_A$ than $C(E85)_A$ and $C(E100)_A$.

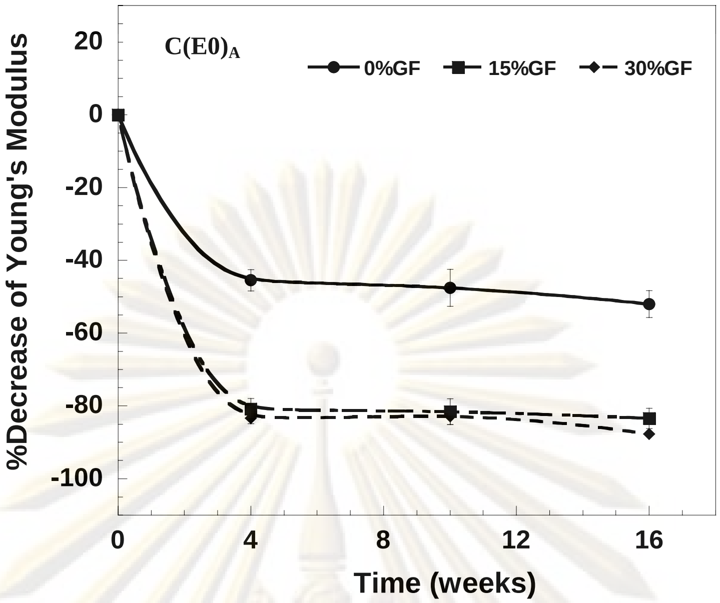


Figure. 5.43 Effect of C(E0)$_A$ on %decrease of young's modulus of HDPE/GF composites

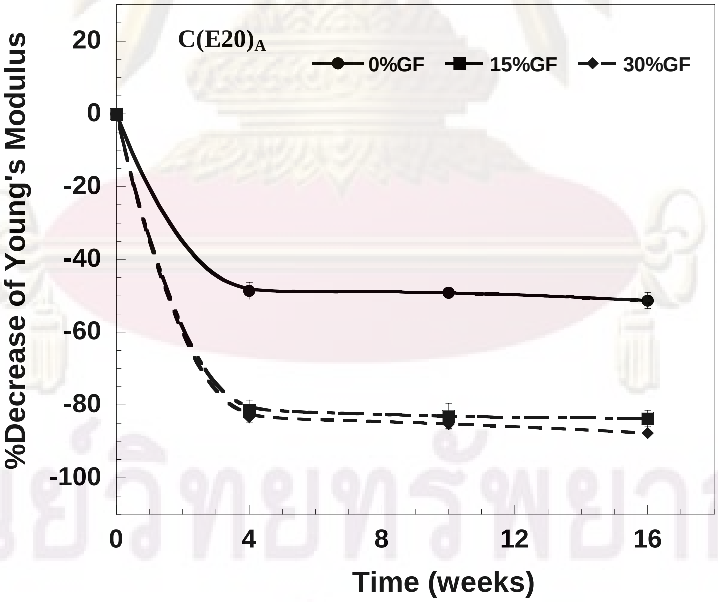


Figure. 5.44 Effect of C(E20)$_A$ on %decrease of young's modulus of HDPE/GF composites

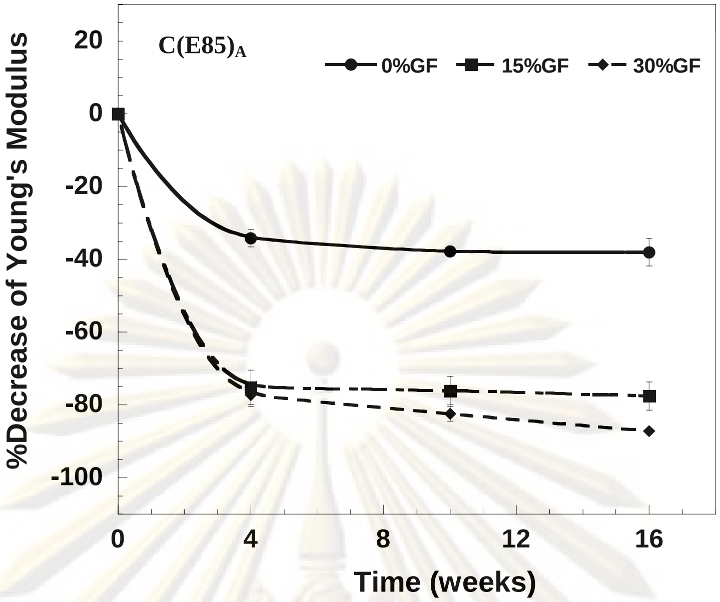


Figure. 5.45 Effect of C(E85)$_A$ on %decrease of young's modulus of HDPE/GF composites

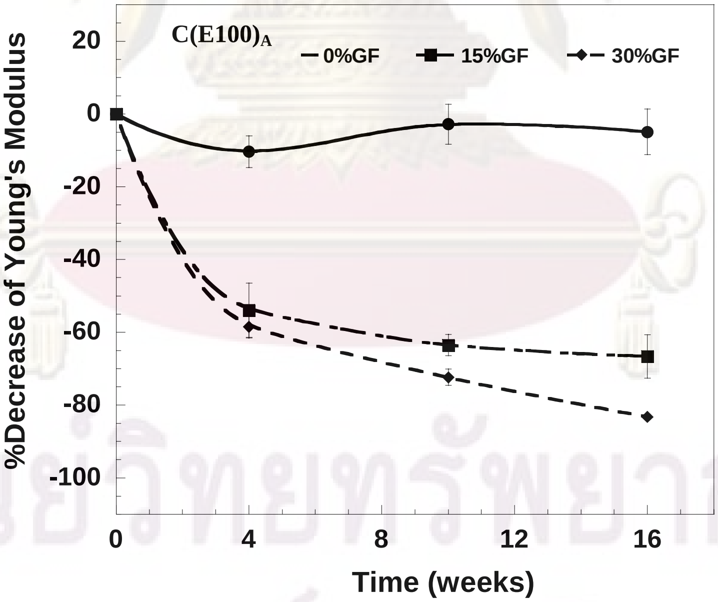


Figure. 5.46 Effect of C(E100)$_A$ on %decrease of young's modulus of HDPE/GF composites

Figs. 5.43-5.46, show the percentage reduction of young's modulus of HDPE/GF composites in each test fuel. The decrease was mainly due to the swelling and plasticizing effects of iso-octane i.e., the alkane group which can swell polymer and elastomer (Jones et al., 2008 [34]) and toluene absorbed into specimens (Keh-Ping Chao et al., 2006 [46] and Aminabhavi et al., 1998 [48]). The percentage reduction of young's modulus of HDPE/GF composites were higher in HDPE/GF (30 wt%) and HDPE/GF (15 wt%) than HDPE/GF (0 wt%) composites, but the actual values of young's modulus of HDPE/GF (30 wt%) and HDPE/GF (15 wt%) were higher than HDPE/GF (0 wt%) composites. Hence, the GF still served as reinforcing filler in these composites after immersion in gasohols.

5.3.3 Impact Properties

The results on comparison of the impact strength of the HDPE/GF composites at 0, 15 and 30 wt% after being soaking in each test fuels for 0, 4, 10 and 16 weeks are showed in Table 5.10.

Table 5.10 Impact strength (kJ/m^2) of HDPE/GF composites in each test fuels

Test Fuel	Time (weeks)			
	0	4	10	16
	0%GF			
C(E0)$_A$	14.30 ± 0.35	20.88 ± 0.75	20.55 ± 1.52	20.71 ± 0.62
C(E20)$_A$	14.30 ± 0.35	20.49 ± 0.37	18.69 ± 0.53	20.72 ± 0.42
C(E85)$_A$	14.30 ± 0.35	14.24 ± 0.74	15.53 ± 0.91	15.22 ± 0.33
C(E100)$_A$	14.30 ± 0.35	12.64 ± 0.92	12.98 ± 0.20	12.51 ± 0.61

Test Fuel	Time (weeks)			
	0	4	10	16
15%GF				
C(E0)$_A$	16.38 ± 0.39	19.99 ± 1.53	21.03 ± 1.45	21.23 ± 0.67
C(E20)$_A$	16.38 ± 0.39	21.60 ± 0.89	20.73 ± 1.82	21.26 ± 0.94
C(E85)$_A$	16.38 ± 0.39	17.21 ± 0.74	17.76 ± 0.45	17.36 ± 0.96
C(E100)$_A$	16.38 ± 0.39	16.65 ± 0.59	16.20 ± 1.06	16.49 ± 0.78
30%GF				
C(E0)$_A$	18.04 ± 1.35	20.97 ± 1.05	21.69 ± 0.63	22.80 ± 1.12
C(E20)$_A$	18.04 ± 1.35	20.11 ± 0.95	22.89 ± 1.93	22.04 ± 2.30
C(E85)$_A$	18.04 ± 1.35	18.80 ± 0.71	20.23 ± 0.94	19.92 ± 0.81
C(E100)$_A$	18.04 ± 1.35	17.52 ± 1.10	18.21 ± 1.16	18.06 ± 0.91

The impact strength change of HDPE/GF composites after being soaking in each test fuels are showed in Figs.5.47-5.49.

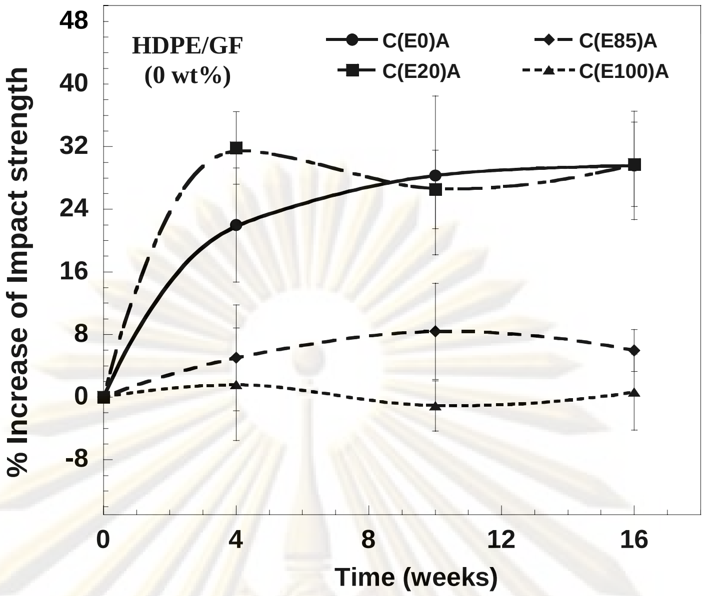


Figure. 5.47 Effect of gasohols on %increase of impact strength of HDPE/GF (0 wt%) composites

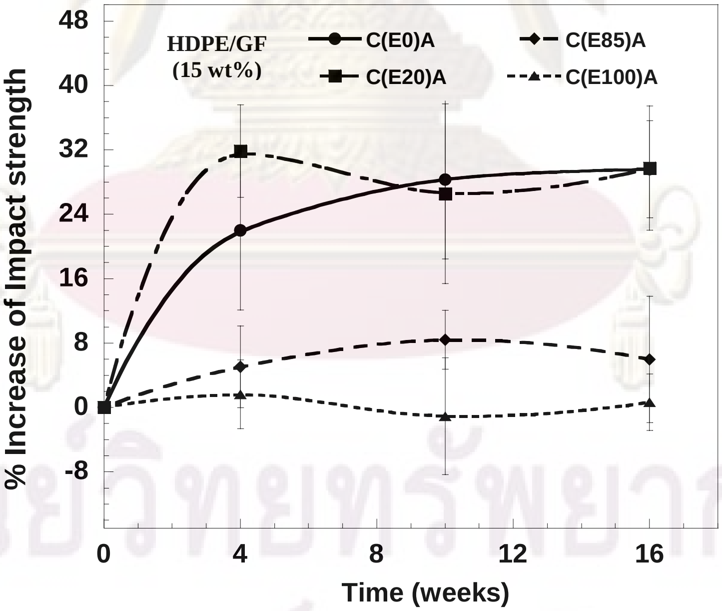


Figure. 5.48 Effect of gasohols on %increase of impact strength of HDPE/GF (15 wt%) composites

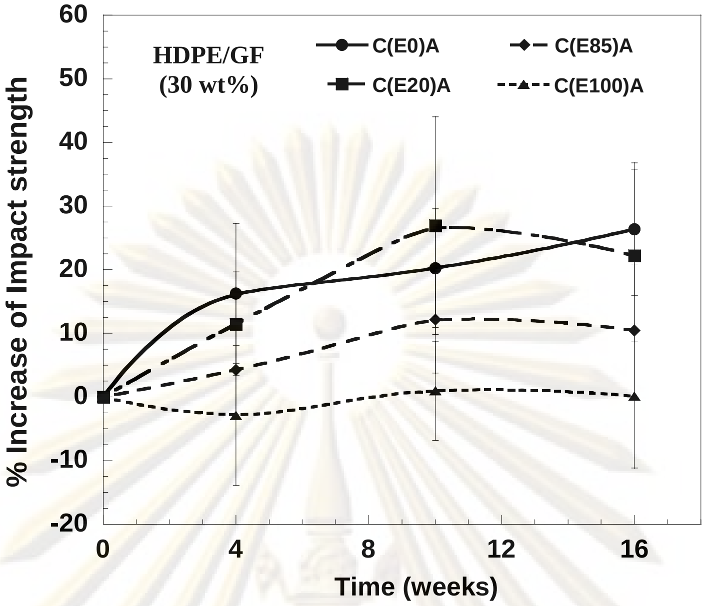


Figure. 5.49 Effect of gasohols on %increase of impact strength of HDPE/GF (30 wt%) composites

As expected, the impact strength of all unsoaked samples were increased with increasing fiber content from 0 to 30 wt%. After immersion in each test fuel, impact strength were clearly increased during the first 4 weeks. Fig. 5.47 shows the percentage increased about 30-45% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for the impact strength. The increased about 6-8% after 4 weeks of immersion in $C(E85)_A$ and reduction of about 9-12% in $C(E100)_A$ test fuels of HDPE/GF (0 wt%) composites. Fig. 5.48 shows the percentage increased about 22-32% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for the impact strength. The increased about 5-8% after 4 weeks of immersion in $C(E85)_A$ and reduction of about 0-1% in $C(E100)_A$ test fuels of HDPE/GF (15 wt%) composites. Fig. 5.49 shows the percentage increased about 11-27% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for the impact strength. The increased about 4-12% after 4 weeks of immersion in $C(E85)_A$ and reduction of about 0-3% in $C(E100)_A$ test fuels of HDPE/GF (30 wt%) composites. The increase of impact strength was mainly due to the specimens were tough and required high energy to break. Test fuels $C(E0)_A$ and $C(E20)_A$ clearly had more fuel C than in $C(E85)_A$ and

$C(E100)_A$ test fuels and fuel C has high solubility value for HDPE (Barrett et al., 1999 [47]). The impact strength of specimens were increased in $C(E0)_A$ and $C(E20)_A$ test fuels.

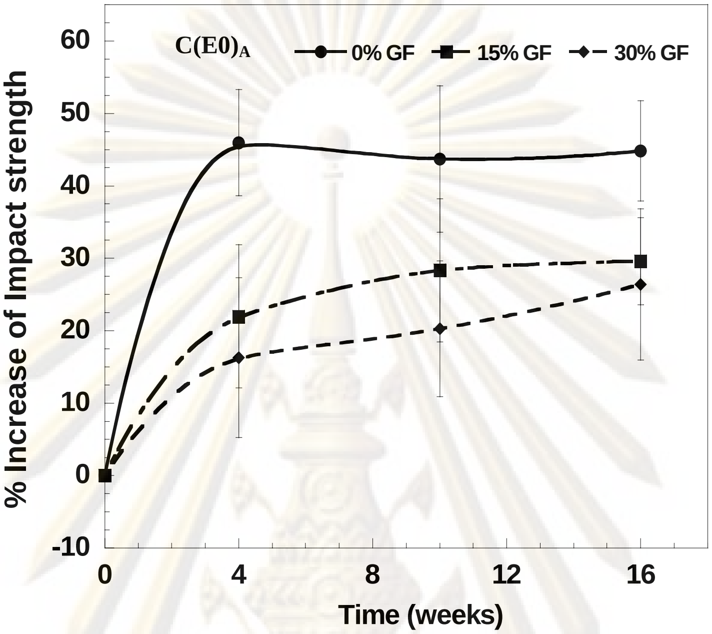


Figure. 5.50 Effect of $C(E0)_A$ on %increase of impact strength of HDPE/GF composites

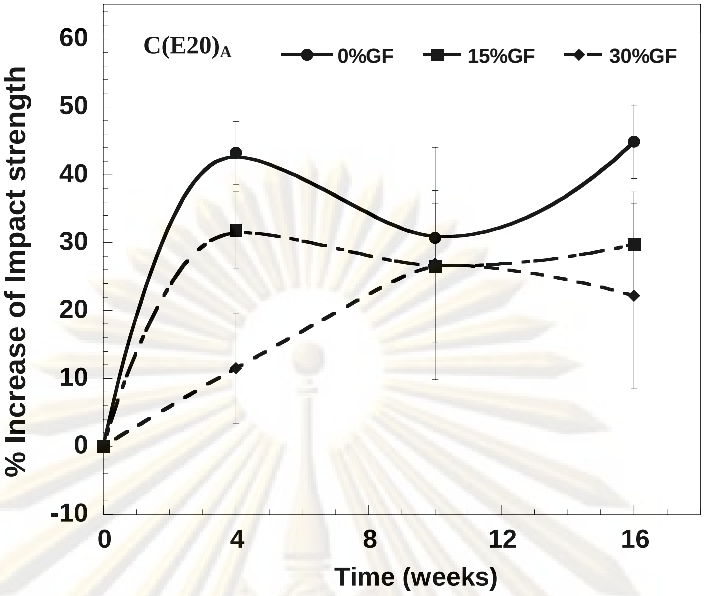


Figure. 5.51 Effect of C(E20)$_A$ on %increase of impact strength of HDPE/GF composites

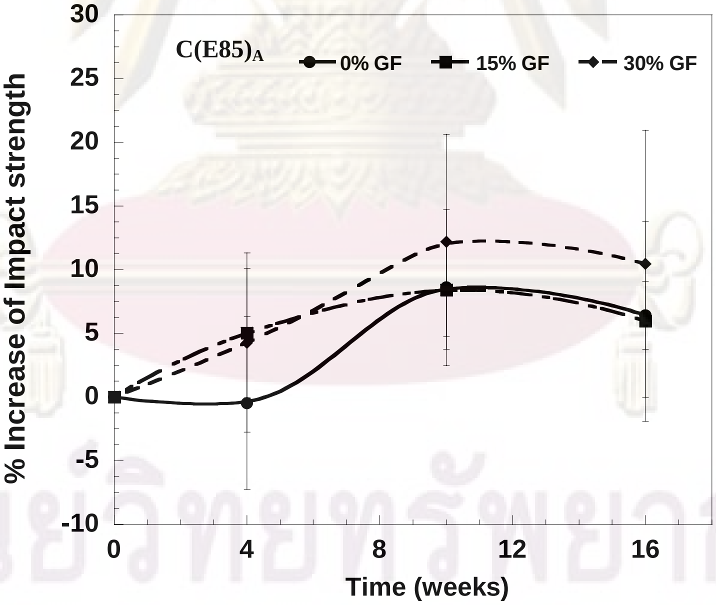


Figure. 5.52 Effect of C(E85)$_A$ on %increase of impact strength of HDPE/GF composites

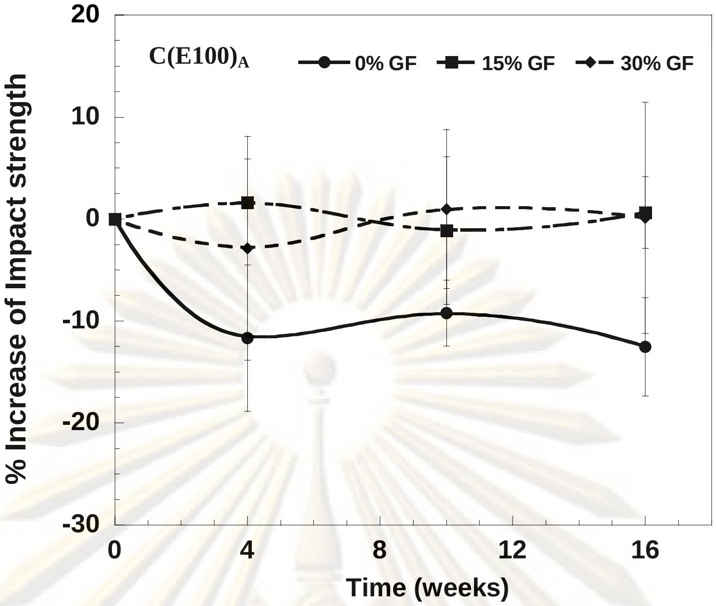


Figure. 5.53 Effect of C(E100)$_A$ on %increase of impact strength of HDPE/GF composites

Figs. 5.50-5.53, show the percentage increased and reduction of impact strength of HDPE/GF composites in each test fuel. The increase of impact strength was mainly due to the swelling and plasticizing effects of iso-octane i.e., the alkane group which can swell polymer and elastomer (Jones et al., 2008 [34]) and toluene absorbed into specimens (Keh-Ping Chao et al., 2006 [46] and Aminabhavi et al., 1998 [48]). The specimens were tough and required high energy to break. Test fuels C(E0)$_A$ and C(E20)$_A$ clearly had more fuel C than in C(E85)$_A$ and C(E100)$_A$ test fuels. The impact strength of specimens were increased in C(E0)$_A$ and C(E20)$_A$ test fuels. The percentage reduction of impact strength of HDPE/GF composites in C(E85)$_A$ and C(E100)$_A$ test fuels were higher in HDPE/GF (0 wt%) than HDPE/GF (15 wt%) and HDPE/GF (30 wt%) composites, and the actual values of impact strength of HDPE/GF (30 wt%) and HDPE/GF (15 wt%) were higher than HDPE/GF (0 wt%) composites. Hence, the GF still served as reinforcing filler in these composites after immersion in gasohols.

5.3.4 Flexural Properties

The results on comparison of the flexural strength of the HDPE/GF composites at 0, 15 and 30 wt% after being soaking in each test fuels for 0, 4, 10 and 16 weeks are showed in Table 5.11.

Table 5.11 Flexural strength (MPa) of HDPE/GF composites in each test fuels

Test Fuel	Time (weeks)			
	0	4	10	16
0%GF				
$C(E0)_A$	26.99 ± 2.04	21.06 ± 1.72	20.04 ± 1.59	18.92 ± 2.67
$C(E20)_A$	26.99 ± 2.04	20.18 ± 1.15	18.80 ± 1.47	18.95 ± 3.86
$C(E85)_A$	26.99 ± 2.04	22.26 ± 1.29	20.40 ± 1.96	20.31 ± 1.69
$C(E100)_A$	26.99 ± 2.04	24.20 ± 2.11	20.09 ± 3.34	21.52 ± 2.25
15%GF				
$C(E0)_A$	35.77 ± 0.34	25.25 ± 2.35	21.84 ± 1.54	20.12 ± 2.04
$C(E20)_A$	35.77 ± 0.34	18.65 ± 0.35	21.29 ± 1.04	18.68 ± 0.67
$C(E85)_A$	35.77 ± 0.34	24.83 ± 1.27	23.21 ± 1.92	21.33 ± 0.54
$C(E100)_A$	35.77 ± 0.34	27.17 ± 2.46	27.54 ± 2.32	20.78 ± 0.63
30%GF				
$C(E0)_A$	39.35 ± 4.00	18.32 ± 0.62	25.46 ± 1.62	18.97 ± 0.44
$C(E20)_A$	39.35 ± 4.00	25.72 ± 1.95	25.41 ± 1.11	19.39 ± 0.39
$C(E85)_A$	39.35 ± 4.00	27.88 ± 2.71	26.36 ± 0.71	20.94 ± 0.38
$C(E100)_A$	39.35 ± 4.00	24.36 ± 1.58	29.57 ± 0.75	21.96 ± 0.33

The percentage reduction of flexural strength of HDPE/GF composites after being soaking in each test fuels are showed in Figs.5.54-5.56.

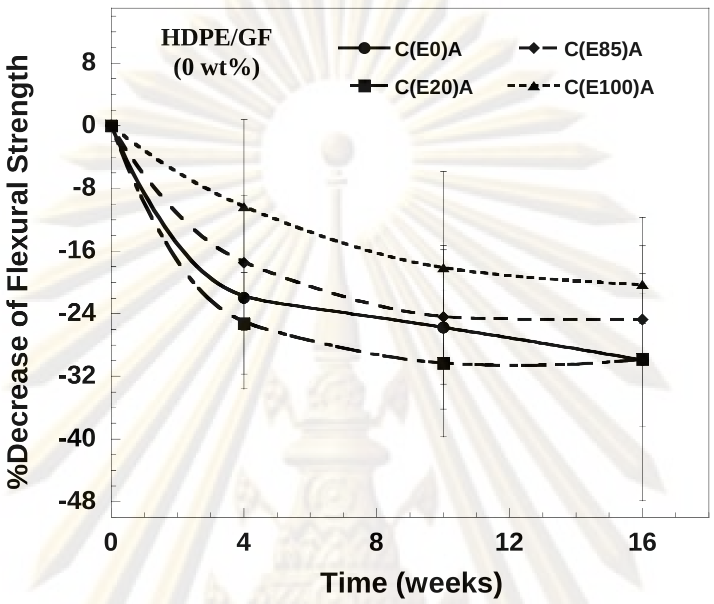


Figure. 5.54 Effect of gasohols on %decrease of flexural strength of HDPE/GF (0 wt%) composites

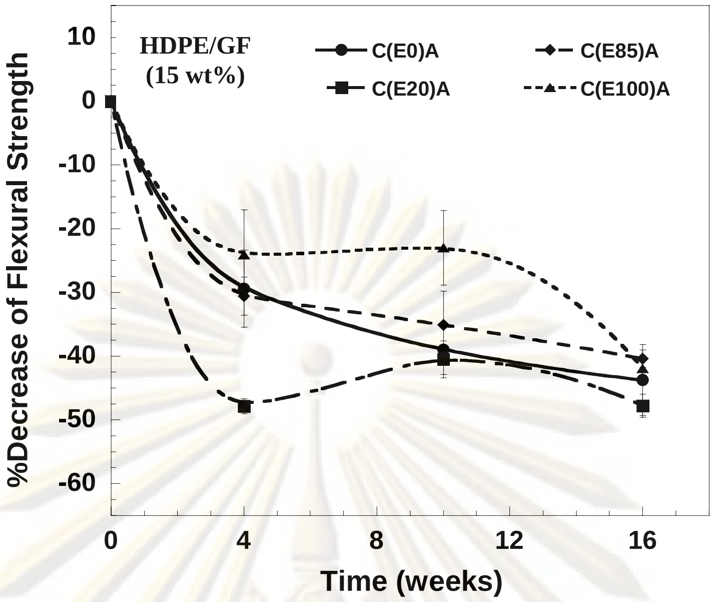


Figure. 5.55 Effect of gasohols on %decrease of flexural strength of HDPE/GF (15 wt%) composites

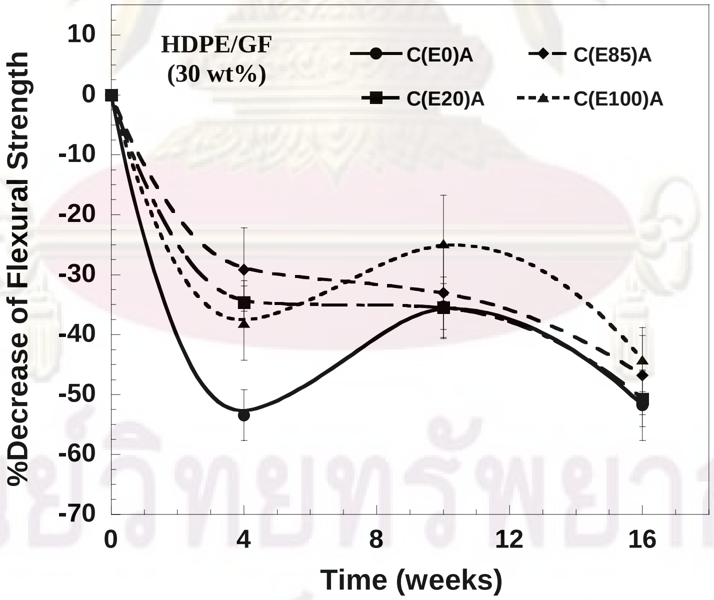


Figure. 5.56 Effect of gasohols on %decrease of flexural strength of HDPE/GF (30 wt%) composites

As expected, the flexural strength of all unsoaked samples were increased with increasing fiber content from 0 to 30 wt%. After immersion in each test fuel, the flexural strength were clearly decreased during the first 4 weeks. Fig. 5.54 shows the reduction of about 22-30% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for flexural strength of HDPE/GF (0 wt%) composites. The reduction of about 10-25% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Fig. 5.55 shows the reduction of about 30-48% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for flexural strength of HDPE/GF (15 wt%) composites. The reduction of about 23-42% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Fig. 5.56 shows the reduction of about 35-54% after 4 weeks of immersion in $C(E0)_A$ and $C(E20)_A$ test fuels for flexural strength of HDPE/GF (30 wt%) composites. The reduction of about 25-47% after 4 weeks of immersion in $C(E85)_A$ and $C(E100)_A$ test fuels. Test fuels $C(E0)_A$ and $C(E20)_A$ clearly had more fuel C than in $C(E85)_A$ and $C(E100)_A$ test fuels. These were mainly due to the absorption of fuel C into specimens and fuel C has high solubility value for HDPE (Barrett et al., 1999 [47]). The percentage reduction of flexural strength of HDPE/GF composites were higher in $C(E0)_A$ and $C(E20)_A$ than $C(E85)_A$ and $C(E100)_A$.

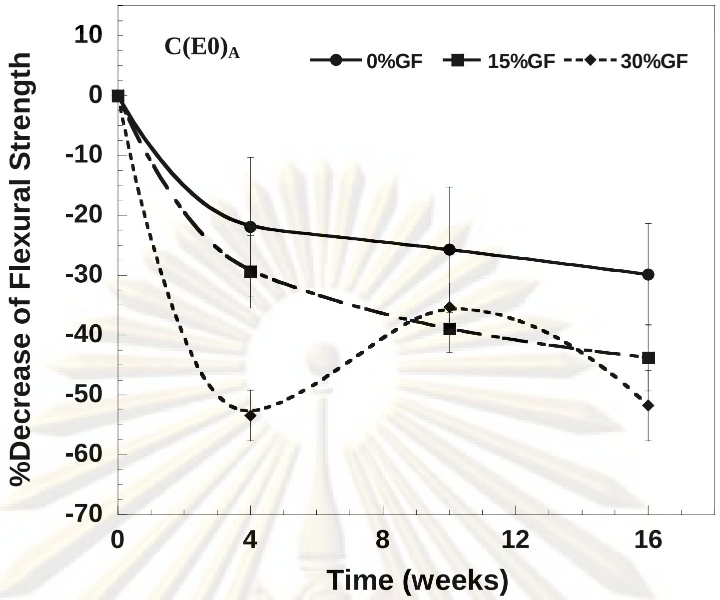


Figure. 5.57 Effect of C(E0)$_A$ on %decrease of flexural strength of HDPE/GF composites

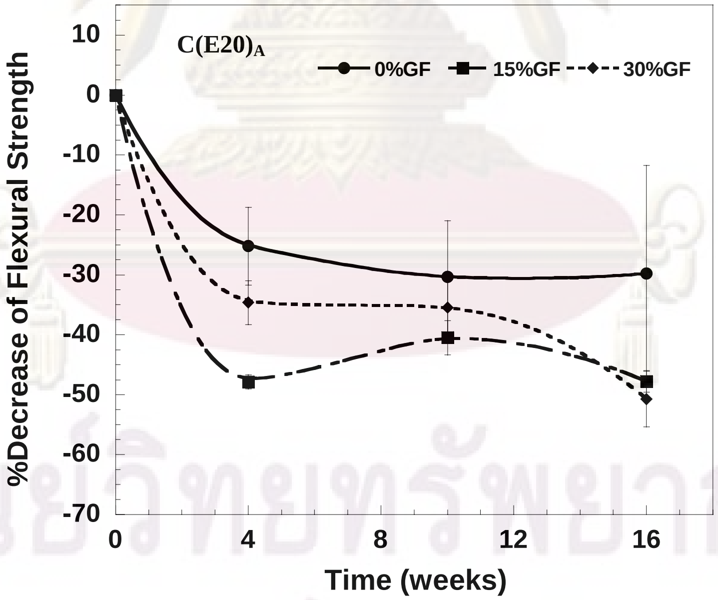


Figure. 5.58 Effect of C(E20)$_A$ on %decrease of flexural strength of HDPE/GF composites

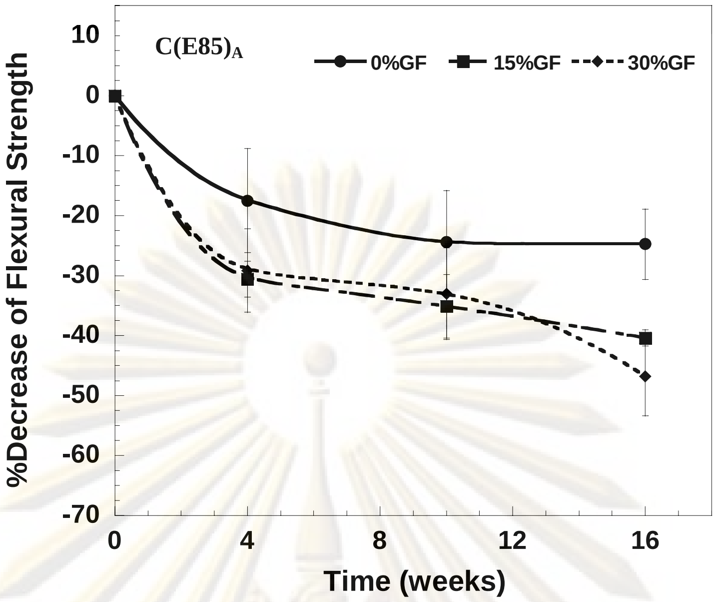


Figure. 5.59 Effect of C(E85)$_A$ on %decrease of flexural strength of HDPE/GF composites

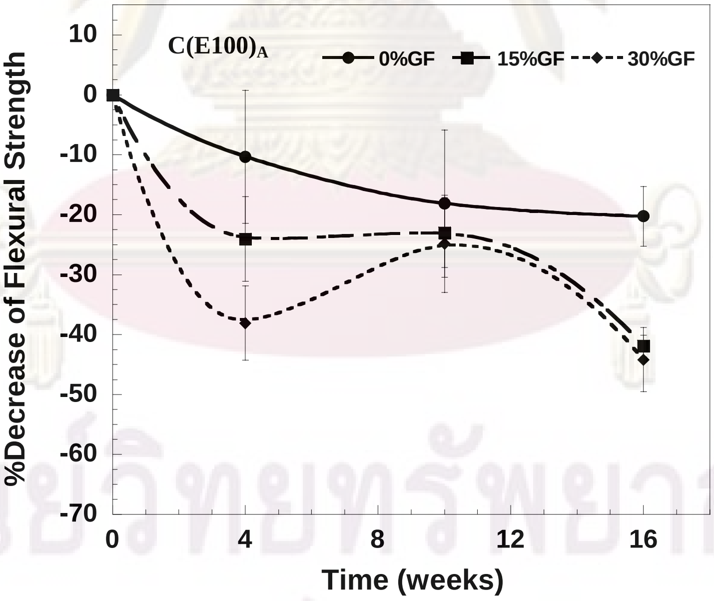


Figure. 5.60 Effect of C(E100)$_A$ on %decrease of flexural strength of HDPE/GF composites

Figs. 5.57-5.60, show the percentage reduction of flexural strength of HDPE/GF composites in each test fuel. The decrease was mainly due to the swelling and plasticizing effects of iso-octane i.e., the alkane group which can swell polymer and elastomer (Jones et al., 2008 [34]) and toluene absorbed into specimens (Keh-Ping Chao et al., 2006 [46] and Aminabhavi et al., 1998 [48]). The percentage reduction of flexural strength of HDPE/GF composites were higher in HDPE/GF (30 wt%) and HDPE/GF (15 wt%) than HDPE/GF (0 wt%) composites, but the actual values of flexural strength of HDPE/GF (30 wt%) and HDPE/GF (15 wt%) were higher than HDPE/GF (0 wt%) composites. Hence, the GF still served as reinforcing filler in these composites after immersion in gasohols.

5.3.5 Compression Properties

The results on comparison of the compressive strength of the HDPE/GF composites at 0, 15 and 30 wt% after being soaking in each test fuels for 0, 4, 10 and 16 weeks are showed in Table 5.12.

Table 5.12 Compressive strength (MPa) of HDPE/GF composites in each test fuels

Test Fuel	Time (weeks)			
	0	4	10	16
	0%GF			
$C(E0)_A$	104.86 ± 4.22	101.89 ± 4.61	112.29 ± 1.62	110.97 ± 2.65
$C(E20)_A$	104.89 ± 4.22	113.68 ± 1.34	104.90 ± 2.55	115.85 ± 1.59
$C(E85)_A$	104.86 ± 4.22	120.72 ± 1.74	117.01 ± 1.54	128.41 ± 7.26
$C(E100)_A$	104.89 ± 4.22	127.90 ± 1.71	119.09 ± 4.76	122.03 ± 4.72

Test Fuel	Time (weeks)			
	0	4	10	16
15%GF				
$C(E0)_A$	123.56 ± 2.75	111.77 ± 9.98	111.92 ± 6.33	133.64 ± 4.19
$C(E20)_A$	123.56 ± 2.75	112.14 ± 9.98	115.21 ± 7.59	128.59 ± 8.11
$C(E85)_A$	123.56 ± 2.75	127.81 ± 1.83	118.83 ± 4.10	117.03 ± 3.72
$C(E100)_A$	123.56 ± 2.75	136.86 ± 1.96	121.28 ± 11.29	128.29 ± 7.55
30%GF				
$C(E0)_A$	139.38 ± 4.36	138.81 ± 2.68	141.55 ± 2.38	144.27 ± 2.29
$C(E20)_A$	139.38 ± 4.36	137.00 ± 10.24	147.59 ± 2.51	151.40 ± 11.22
$C(E85)_A$	139.38 ± 4.36	142.18 ± 1.85	149.33 ± 12.96	157.05 ± 11.33
$C(E100)_A$	139.38 ± 4.36	134.37 ± 15.95	147.77 ± 14.36	160.72 ± 1.39

The percentage reduction of compressive strength of HDPE/GF composites after being soaking in each test fuels are showed in Figs.5.61-5.63.

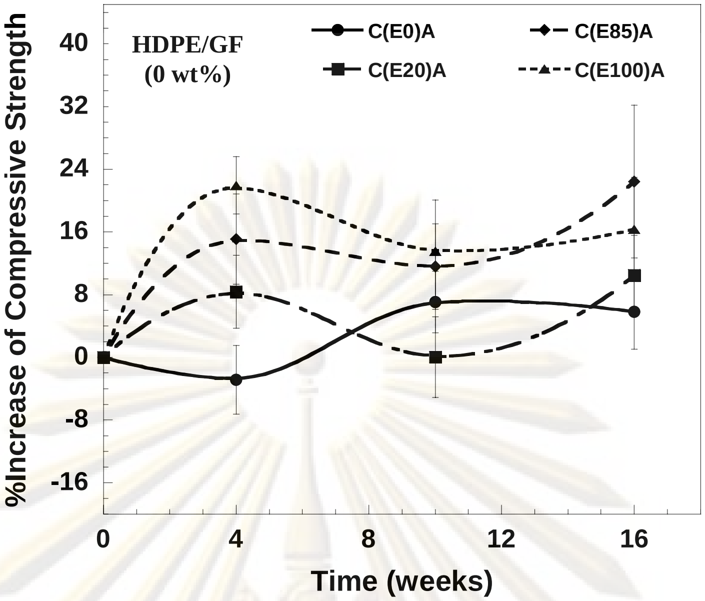


Figure. 5.61 Effect of gasohols on %increase of compressive strength of HDPE/GF (0 wt%) composites

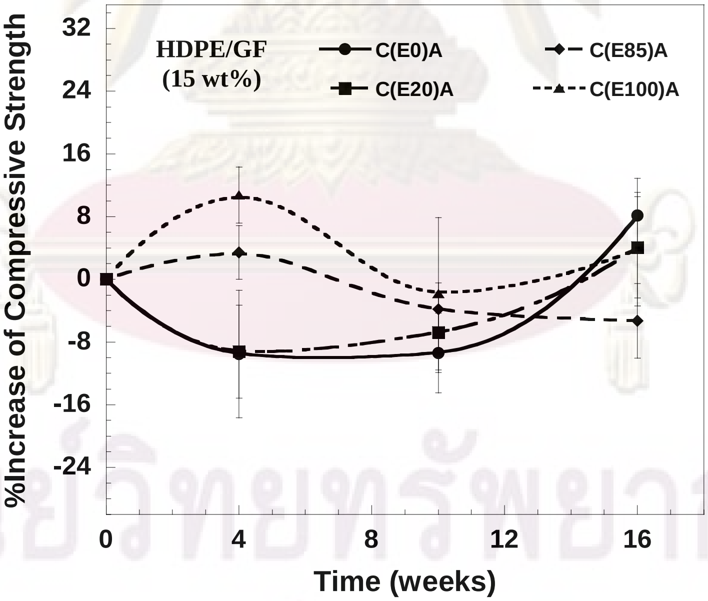


Figure. 5.62 Effect of gasohols on %increase of compressive strength of HDPE/GF (15 wt%) composites

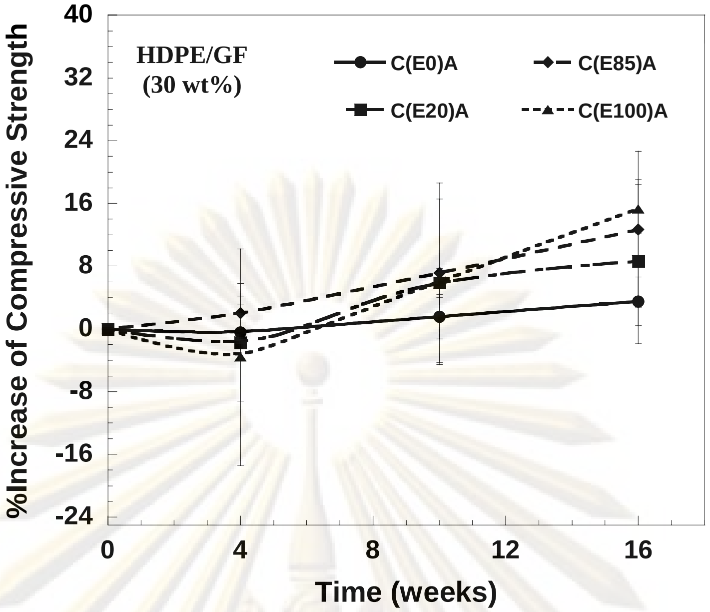


Figure. 5.63 Effect of gasohols on %increase of compressive strength of HDPE/GF (30 wt%) composites

Figs. 5.61-5.63, compressive strength of HDPE/GF composites at 0, 15 and 30 wt% were no trend of change. Figs. 5.64-5.67 were shown compressive strength of HDPE/GF composites in each test fuels. The reasons for compressive strength no trend of change were that the specimens for test.

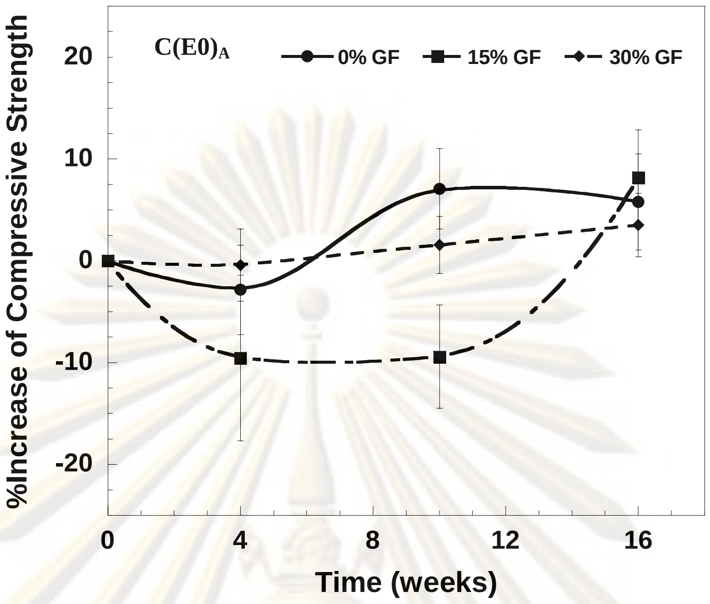


Figure. 5.64 Effect of C(E0)$_A$ on %increase of compressive strength of HDPE/GF composites

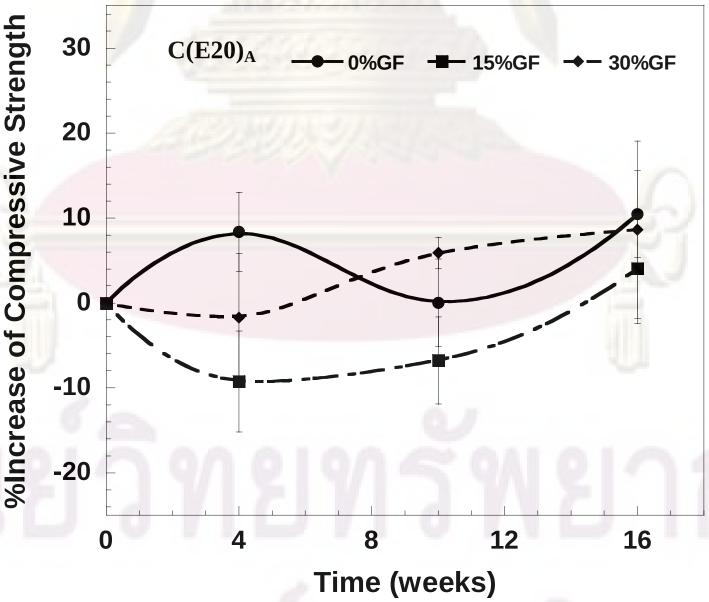


Figure. 5.65 Effect of C(E20)$_A$ on %increase of compressive strength of HDPE/GF composites

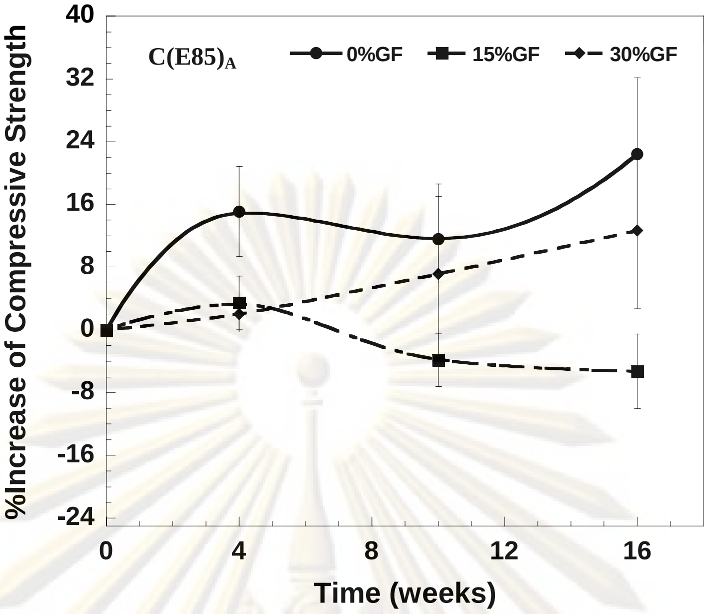


Figure. 5.66 Effect of $C(E85)_A$ on %increase of compressive strength of HDPE/GF composites

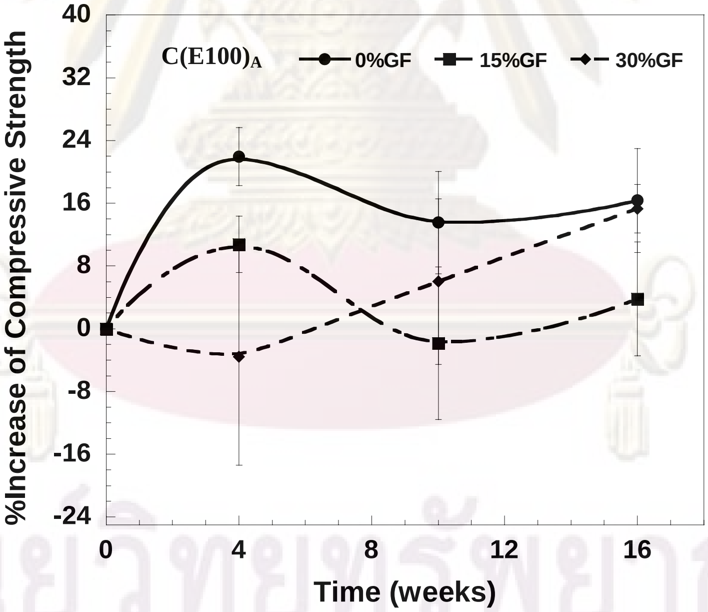


Figure. 5.67 Effect of $C(E100)_A$ on %increase of compressive strength of HDPE/GF composites

CHAPTER VI

CONCLUSIONS

The results obtained from this work can be concluded as the followings:

1. The morphology of HDPE/GF composites showed that there were good bonding between the HDPE and reinforced glass fibers.

2. Mechanical properties and mass of HDPE/GF composites of all unsoaked samples increased with increasing fiber content from 0 to 30 wt%.

3. The main reasons for mass increase in HDPE/GF composites were due to absorption of iso-octane and toluene and not ethanol or water from test fuels into HDPE.

4. Test fuels containing higher amount of ethanol, i.e. $C(E85)_A$, and $C(E100)_A$, had less effect on physical properties of HDPE/GF composites than test fuels containing lower amount of ethanol, i.e. $C(E0)_A$, and $C(E20)_A$. Also, the effects of higher content of ethanol in test fuels were less on mechanical properties of HDPE/GF composites.

5. HDPE/GF composites could be used with gasohols especially with fuels with high ethanol content.

REFERENCES

[1] Study performed by Stockholm University, ATRAX AB, Autoemission KEE Consultant AB,AVL MTC AB.Financed. Blending of ethanol in gasoline for spark ignition engines. 2004-2005.

[2] Mark, H.F. Encyclopedia of polymer science and technology. third edition. Wiley – Interscience, 2007.

[3] Billmeyer, Fred W.JR. Textbook of polymer science. third edition. New York : 1984.

[4] Available from: http://www.pslc.ws/macrog/pe.html [2008, September 20]

[5] Brandrup J., Lammergut E.H., and Grulke E.A. Polymer handbook. fourth edition. 1999.

[6] Frederick W.John. Plastics. New York, London : Reinhold publishing coporetion, 1967.

[7] Available from: http:// www.matweb.com [2008, September 28]

[8] Packham, D.E.. Handbook of Adhesion. second edition. WILEY, 2005.

[9] Shalin, R.E. Polymer Matrix Composite. 1st edition. UK : Chapman&Hall, 1995.

[10] Schwartz, Mel M. Composite Materials, volume II Processing, Fabrication and Application. 1997.

[11] Schwartz, Mel M. Composite Materials volume I. 1996.

[12] Cheremisinoff, Nicholas P. and Cheremisinoff, Paul N. Fiber glass Reinforced Plastics. 1978.

[13] Roger F.Jones with contributions from Michell R.Jones and Donald V.Rosato. Guide to short fiber Reinforced Plastics.1998.

[14] Charles A.Harper. Handbook of plastics and Elastomer. Editor-in-chief. 1975.

[15] Available from: http:// www.efunda.com [2008, September 26]

[16] Wake, William C. Ph.D.,D.Sc.,F.R.I.C.,F.I.R.I.. Filler for plastics. Co-ordinating Editor. The city university London, 1971.

[17] McCrum N.G., Buckley C.P., and Bucknall C.B. Principles of polymer engineering. 1988.

[18] Available from: http:// www.pttplc.com [2008, September 26]

[19] Common ethanol fuel mixtures. Available from: http://www.en.wikipedia.org/wiki/Gasohol [2008, September 26]

[20] The Columbia Encyclopedia. Gasohol. Sixth Edition. 2007.

[21] Smith, J.L. and Workman, J.P. Alcohol for Motor Fuels. Available from: http://www.ext.colostate.edu/pubs/farmmgt/05010.html [2008, September 23]

[22] Available from: http:// www.encyclopedia.farlex.com/gasohol [2008,September 26]

[23] Available from: http:// www.energy.go.th [2008,September 26]

[24] Cheremisinoff, Nicholas P. Gasohol for Energy Production. 1979.

[25] Alltech, Lyons T.P.Inc. A Step to Energy Independence. 1981.

[26] D.H. Morton-Jones. Polymer Processing. London, 1989.

[27] Chris Rauwendaal with contributions from Paul J.Gramann, Bruce A.Davis and Tim A. Osswald. Polymer extrusion. fourth edition. 2001.

[28] Available from: http:// www.polymerprocessing.com [2008,September 26]

[29] Available from: http:// www.ijpr-online.com [2008,September 26]

[30] Available from: http:// www.en.wikipedia.org [2008,September 30]

[31] Available from: http:// www.instron.us/wa/applications.co.th [2008, October 18]

[32] Available from: http:// www.ptli.com [2008, October 18]

[33] Orbital Engine Company. A Testing Based Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines 2000 hrs Material Compatibility Testing. Report to Environment Australia (2003).

[34] Jones B., Mead G., and Steevens P.The Effects of E20 on Plastic Automotive Fuel System Components. Minnesota Center for Automotive Research (2008).

[35] Foulk Jonn A., Chao Wayne Y., Akin Danny E., Dodd Roy B., and Layton Patricia A. Enzyme-Retted Flax Fiber and Recycled Polyethylene Composites. Journal of Polymers and the Environment Vol.12, No.3 (2004): 165-171.

[36] Stern T., Teishev A., and Marom G. Composites of Polyethlene Reinforced with Chopped Polyethylene Fibers: Effect of Transcrystalline Interphase. Composites Science and Technobgy (1997) : 1009-1015.

[37] V. Radojevic V., Stojanovic D., Trifunovic D., Perisic M., and Aleksic R. Influence of silane coupling agents on the mechanical properties of recycled glass fiber-reinforced composites.

[38] Orbital Engine Company. A Literature Review Based Assessment on the Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines. 2002.

[39] Alberto Naranjo, Maria del Pilar Narie ga, Tim Osswald, Alejandro Roldan-Alzate, Juan Diego sierra. Plastics Testing and Characterization. 2008.

[40] Available from: http://www.substech.com/dokuwiki/doku.php?i=fracture_toughness [2008, June 18]

[41] Wolfgang Grellmann, sabine seidler (Eds). Polymer Testing. 2007.

[42] Available from: http://www.matweb.com/reference/izod-impact.aspx [2008, July 24]

[43] Available from: http://www.instron.co.th/wa/applications/test/compression.aspx [2008, July 24]

[44] Mahmound Rajabian, Charles Dubois. Polymerization Compounding of HDPE/Kevlar Composite. I.Morphology and Mechanical Properties. Society of Plastics Engineers. (2006): 129-137.

[45] Available from: http://en.wikipedia.org/wiki/Scanning_electron_microscope [2008, July 24]

[46] Keh-Ping Chao, Ping Wang and Chia-huei Lin. Estimation of Diffusion Coefficients and Solubilities for Organic Solvents Permeation through High-Density Polyethylene Geomembrane. Journal of Environmental Engineering (2006) : 519-526.

[47] Barrett, William Martin and Stessel, Richard Ian. Correlating Solubility of Chemicals and Mixtures with Strength of Exposed High-Density Polyethylene Geomembrane. Journal of Environmental Science & Technology (1999) : 1274-1279.

[48] Aminabhavi, T.M. and Naik, H.G.. Sorptionrdesorption, diffusion, permeation and swelling of high density polyethylene geomembrane in the presence of hazardous organic liquids. Journal of Hazardous Materials (1999) : 251-262.

APPENDICES

APPENDIX A

Mass of HDPE/GF Composites

Appendix A-1 Mass of HDPE/GF 0 wt% (g)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
C(E0)$_A$	1	5.50	5.69	5.69	5.68	5.68	5.67	5.67
	2	5.45	5.64	5.63	5.63	5.62	5.62	5.62
	3	5.44	5.62	5.62	5.63	5.61	5.61	5.60
	4	5.41	5.60	5.95	5.60	5.58	5.58	5.57
	5	5.44	5.62	5.61	5.62	5.61	5.61	5.60
Average		5.45	5.63	5.70	5.63	5.62	5.62	5.61
Stdev		0.03	0.04	0.14	0.03	0.04	0.03	0.04
%Stdev		0.61	0.64	2.51	0.55	0.63	0.60	0.64
C(E20)$_A$	1	5.56	5.52	5.68	5.68	5.67	5.68	5.67
	2	5.50	5.67	5.67	5.68	5.66	5.67	5.67
	3	5.49	5.66	5.65	5.66	5.65	5.66	5.65
	4	5.52	5.51	5.62	5.61	5.59	5.60	5.60
	5	5.42	5.55	5.66	5.66	5.64	5.65	5.65
Average		5.50	5.58	5.66	5.66	5.64	5.65	5.65
Stdev		0.05	0.08	0.02	0.03	0.03	0.03	0.03
%Stdev		0.94	1.43	0.42	0.54	0.55	0.54	0.53

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E85)_A$	1	5.51	5.74	5.65	5.65	5.63	5.63	5.61
	2	5.48	5.42	5.47	5.49	5.49	5.48	5.47
	3	5.49	5.50	5.55	5.57	5.57	5.56	5.55
	4	5.44	5.69	5.60	5.59	5.58	5.57	5.56
	5	5.49	5.59	5.50	5.50	5.48	5.48	5.46
Average		5.48	5.59	5.56	5.56	5.55	5.55	5.53
Stdev		0.02	0.13	0.07	0.07	0.06	0.06	0.06
%Stdev		0.45	2.37	1.27	1.17	1.14	1.14	1.13
$C(E100)_A$	1	5.50	5.57	5.54	5.53	5.53	5.53	5.52
	2	5.41	5.54	5.51	5.50	5.50	5.50	5.50
	3	5.49	5.55	5.52	5.51	5.51	5.51	5.51
	4	5.42	5.42	5.42	5.42	5.42	5.42	5.42
	5	5.41	5.41	5.41	5.41	5.41	5.41	5.41
Average		5.45	5.50	5.48	5.48	5.47	5.47	5.47
Stdev		0.05	0.08	0.06	0.05	0.05	0.05	0.05
%Stdev		0.87	1.41	1.09	1.00	0.98	0.97	0.96

Appendix A-2 Mass of HDPE/GF 15 wt% (g)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
C(E0)$_A$	1	5.97	6.13	6.01	6.13	6.11	6.10	6.11
	2	5.99	6.16	6.03	6.15	6.13	6.13	6.13
	3	6.01	6.17	6.05	6.16	6.15	6.14	6.15
	4	6.00	6.16	6.04	6.15	6.14	6.13	6.13
	5	6.04	6.20	6.08	6.20	6.18	6.18	6.18
Average		6.00	6.17	6.04	6.16	6.14	6.14	6.14
Stdev		0.03	0.03	0.03	0.03	0.03	0.03	0.03
%Stdev		0.43	0.42	0.42	0.44	0.41	0.43	0.41
C(E20)$_A$	1	5.98	6.12	6.12	6.13	6.12	6.11	6.11
	2	6.09	6.23	6.23	6.24	6.23	6.22	6.22
	3	6.08	6.23	6.23	6.24	6.22	6.22	6.22
	4	6.13	6.28	6.28	6.29	6.28	6.27	6.27
	5	5.98	6.12	6.12	6.13	6.12	6.11	6.11
Average		6.05	6.20	6.20	6.21	6.19	6.19	6.19
Stdev		0.07	0.07	0.07	0.07	0.07	0.07	0.07
%Stdev		1.14	1.16	1.18	1.15	1.15	1.16	1.15
C(E85)$_A$	1	6.09	6.16	6.17	6.18	6.17	6.16	6.15
	2	6.05	6.12	6.14	6.14	6.13	6.12	6.11
	3	6.09	6.15	6.17	6.17	6.16	6.16	6.14
	4	6.08	6.14	6.16	6.17	6.15	6.15	6.13
	5	5.98	6.04	6.06	6.07	6.05	6.05	6.03
Average		6.06	6.12	6.14	6.15	6.13	6.13	6.11
Stdev		0.05	0.05	0.05	0.05	0.05	0.05	0.05
%Stdev		0.77	0.77	0.76	0.77	0.77	0.77	0.77

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E100)_A$	1	6.01	6.02	6.03	6.03	6.02	6.02	6.02
	2	6.03	6.03	6.04	6.04	6.04	6.04	6.04
	3	6.00	6.01	6.02	6.02	6.01	6.01	6.01
	4	5.94	5.94	5.95	5.95	5.95	5.95	5.95
	5	6.05	6.06	6.07	6.07	6.06	6.06	6.06
Average		6.00	6.01	6.02	6.02	6.02	6.02	6.02
Stdev		0.04	0.04	0.04	0.04	0.04	0.04	0.04
%Stdev		0.72	0.71	0.71	0.72	0.72	0.72	0.72

Appendix A-3 Mass of HDPE/GF 30 wt% (g)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	6.75	6.90	6.78	6.90	6.88	6.86	6.86
	2	6.88	7.04	6.92	7.03	7.01	7.00	7.00
	3	6.66	6.80	6.69	6.81	6.78	6.77	6.77
	4	6.64	6.79	6.67	6.78	6.76	6.75	6.75
	5	6.64	6.78	6.67	6.79	6.76	6.75	6.75
Average		6.72	6.86	6.75	6.86	6.84	6.83	6.83
Stdev		0.10	0.11	0.11	0.11	0.11	0.11	0.11
%Stdev		1.56	1.60	1.58	1.58	1.58	1.59	1.59

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E20)_A$	1	6.57	6.69	6.69	6.70	6.69	6.67	6.67
	2	6.56	6.68	6.68	6.69	6.68	6.66	6.66
	3	6.59	6.71	6.71	6.73	6.71	6.69	6.70
	4	6.53	6.65	6.65	6.66	6.65	6.63	6.63
	5	6.69	6.82	6.82	6.82	6.82	6.79	6.79
Average		6.59	6.71	6.71	6.72	6.71	6.69	6.69
Stdev		0.06	0.06	0.06	0.06	0.06	0.06	0.06
%Stdev		0.93	0.95	0.96	0.93	0.95	0.93	0.92
$C(E85)_A$	1	6.63	6.70	6.71	6.71	6.70	6.70	6.68
	2	6.77	6.84	6.85	6.86	6.84	6.84	6.83
	3	6.56	6.64	6.64	6.65	6.63	6.63	6.61
	4	6.64	6.71	6.72	6.72	6.71	6.71	6.69
	5	6.63	6.70	6.71	6.72	6.70	6.70	6.68
Average		6.65	6.72	6.73	6.73	6.72	6.71	6.70
Stdev		0.08	0.08	0.08	0.08	0.08	0.08	0.08
%Stdev		1.14	1.13	1.15	1.16	1.17	1.17	1.17
$C(E100)_A$	1	6.77	6.78	6.79	6.79	6.79	6.79	6.79
	2	6.60	6.62	6.63	6.62	6.62	6.62	6.62
	3	6.71	6.72	6.73	6.73	6.73	6.73	6.73
	4	6.56	6.58	6.59	6.59	6.58	6.58	6.58
	5	6.63	6.65	6.66	6.66	6.66	6.66	6.66
Average		6.65	6.67	6.68	6.68	6.67	6.67	6.67
Stdev		0.08	0.08	0.08	0.08	0.08	0.08	0.08
%Stdev		1.25	1.22	1.21	1.24	1.25	1.25	1.25

Appendix A-4 %Increase of Mass on HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	5.45	0.00	5.50	0.00	5.48	0.00	5.45	0.00
2	5.63	3.35	5.58	1.50	5.59	1.94	5.50	0.95
4	5.70	4.56	5.66	2.91	5.56	1.29	5.48	0.66
7	5.63	3.19	5.66	2.79	5.56	1.37	5.48	0.57
10	5.62	3.07	5.64	2.62	5.55	1.21	5.47	0.52
13	5.62	3.12	5.65	2.77	5.55	1.11	5.47	0.51
16	5.61	2.96	5.65	2.72	5.53	0.82	5.47	0.48

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.00	0.00	6.05	0.00	6.06	0.00	6.00	0.00
2	6.17	2.70	6.20	2.43	6.12	1.10	6.01	0.13
4	6.04	0.63	6.20	2.43	6.14	1.32	6.02	0.27
7	6.16	2.56	6.21	2.54	6.15	1.44	6.02	0.26
10	6.14	2.29	6.19	2.31	6.13	1.24	6.02	0.21
13	6.14	2.22	6.19	2.24	6.13	1.17	6.02	0.19
16	6.14	2.24	6.19	2.24	6.11	0.93	6.02	0.19

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.72	0.00	6.59	0.00	6.65	0.00	6.65	0.00
2	6.86	2.18	6.71	1.91	6.72	1.09	6.67	0.26
4	6.75	0.44	6.71	1.91	6.73	1.19	6.68	0.44
7	6.86	2.14	6.72	1.98	6.73	1.26	6.68	0.41
10	6.84	1.84	6.71	1.90	6.72	1.02	6.67	0.32
13	6.83	1.66	6.69	1.61	6.71	1.00	6.67	0.31
16	6.83	1.67	6.69	1.61	6.70	0.79	6.67	0.29

Appendix A-5 %Increase of Mass on HDPE/GF composites (Base on Polymer Matrix)

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	5.45	0.00	5.50	0.00	5.48	0.00	5.45	0.00
2	5.63	3.35	5.58	1.50	5.59	1.94	5.50	0.95
4	5.70	4.56	5.66	2.91	5.56	1.29	5.48	0.66
7	5.63	3.19	5.66	2.79	5.56	1.37	5.48	0.57
10	5.62	3.07	5.64	2.62	5.55	1.21	5.47	0.52
13	5.62	3.12	5.65	2.77	5.55	1.11	5.47	0.51
16	5.61	2.96	5.65	2.72	5.53	0.82	5.47	0.48

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.00	0.00	6.05	0.00	6.06	0.00	6.00	0.00
2	6.17	3.18	6.20	2.86	6.12	1.29	6.01	0.15
4	6.04	0.74	6.20	2.86	6.14	1.55	6.02	0.32
7	6.16	3.02	6.21	2.99	6.15	1.70	6.02	0.30
10	6.14	2.70	6.19	2.72	6.13	1.45	6.02	0.25
13	6.14	2.61	6.19	2.63	6.13	1.38	6.02	0.23
16	6.14	2.64	6.19	2.63	6.11	1.09	6.02	0.23

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.72	0.00	6.59	0.00	6.65	0.00	6.65	0.00
2	6.86	3.11	6.71	2.73	6.72	1.55	6.67	0.38
4	6.75	0.63	6.71	2.73	6.73	1.70	6.68	0.62
7	6.86	3.06	6.72	2.83	6.73	1.80	6.68	0.58
10	6.84	2.63	6.71	2.71	6.72	1.45	6.67	0.46
13	6.83	2.37	6.69	2.30	6.71	1.44	6.67	0.44
16	6.83	2.39	6.69	2.30	6.70	1.12	6.67	0.42

APPENDIX B

Diameter of HDPE/GF Composites

Appendix B-1 Diameter of HDPE/GF 0 wt% (mm.)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	49.53	50.18	50.21	50.16	49.98	50.12	50.12
	2	49.40	50.03	50.10	50.10	49.91	49.98	50.03
	3	49.52	50.20	50.20	50.23	49.99	50.16	50.09
	4	49.29	49.94	49.99	50.05	49.79	49.91	49.84
	5	49.32	49.99	50.03	50.07	49.82	49.96	49.95
Average		49.41	50.07	50.11	50.12	49.90	50.02	50.01
Stdev		0.11	0.12	0.10	0.07	0.09	0.11	0.11
%Stdev		0.22	0.24	0.19	0.14	0.19	0.21	0.23
$C(E20)_A$	1	49.58	49.48	50.13	50.13	49.92	50.09	50.07
	2	49.51	50.14	50.13	50.09	49.92	50.07	50.08
	3	49.43	50.10	50.08	50.12	49.86	50.01	50.04
	4	49.49	49.69	50.16	50.15	49.93	50.04	50.06
	5	49.41	49.64	50.11	50.15	49.86	50.02	50.03
Average		49.48	49.81	50.12	50.13	49.90	50.05	50.06
Stdev		0.07	0.29	0.03	0.02	0.04	0.03	0.02
%Stdev		0.14	0.59	0.06	0.05	0.07	0.07	0.04

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E85)_A$	1	49.44	50.19	49.94	49.94	49.81	49.78	49.78
	2	49.48	49.50	49.69	49.77	49.70	49.68	49.61
	3	49.38	49.35	49.51	49.59	49.60	49.53	49.46
	4	49.46	50.13	49.85	49.74	49.72	49.70	49.68
	5	49.44	50.08	49.76	49.76	49.68	49.63	49.62
Average		49.44	49.85	49.75	49.76	49.70	49.66	49.63
Stdev		0.04	0.39	0.16	0.12	0.08	0.09	0.12
%Stdev		0.07	0.79	0.33	0.25	0.15	0.19	0.24
$C(E100)_A$	1	49.51	49.64	49.56	49.56	49.45	49.45	49.49
	2	49.45	49.69	49.61	49.57	49.54	49.51	49.54
	3	49.31	49.59	49.47	49.46	49.40	49.40	49.40
	4	49.46	49.46	49.48	49.49	49.46	49.43	49.45
	5	49.37	49.44	49.45	49.46	49.46	49.46	49.43
Average		49.42	49.56	49.51	49.51	49.46	49.45	49.46
Stdev		0.08	0.11	0.07	0.05	0.05	0.04	0.06
%Stdev		0.16	0.22	0.14	0.11	0.10	0.08	0.11

Appendix B-2 Diameter of HDPE/GF 15 wt% (mm.)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	50.05	50.47	50.47	50.46	50.31	50.39	50.46
	2	49.92	50.34	50.43	50.38	50.19	50.28	50.29
	3	50.00	50.47	50.43	50.52	50.35	50.42	50.45
	4	50.01	50.49	50.49	50.49	50.28	50.39	50.42
	5	49.90	50.36	50.38	50.51	50.20	50.32	50.31
Average		49.98	50.43	50.44	50.44	50.27	50.36	50.39
Stdev		0.06	0.07	0.04	0.04	0.07	0.06	0.08
%Stdev		0.13	0.14	0.08	0.08	0.14	0.12	0.17
$C(E20)_A$	1	49.94	50.35	50.37	50.53	50.29	50.32	50.32
	2	50.03	50.51	50.49	50.55	50.35	50.42	50.45
	3	50.04	50.54	50.54	50.56	50.41	50.46	50.48
	4	50.05	50.54	50.57	50.51	50.40	50.47	50.48
	5	49.98	50.49	50.40	50.42	50.34	50.43	50.43
Average		50.01	50.49	50.47	50.51	50.36	50.42	50.43
Stdev		0.05	0.08	0.09	0.05	0.05	0.06	0.06
%Stdev		0.09	0.16	0.17	0.11	0.10	0.12	0.13

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E85)_A$	1	50.02	50.17	50.17	50.27	50.17	50.11	50.13
	2	50.08	50.18	50.27	50.30	50.22	50.18	50.17
	3	50.01	50.19	50.22	50.26	50.19	50.18	50.18
	4	50.08	50.18	50.23	50.34	50.19	50.26	50.17
	5	49.89	50.07	50.10	50.16	50.02	50.01	50.03
Average		50.01	50.16	50.20	50.27	50.16	50.15	50.14
Stdev		0.08	0.05	0.07	0.07	0.08	0.09	0.06
%Stdev		0.15	0.10	0.13	0.14	0.16	0.18	0.13
$C(E100)_A$	1	50.03	50.06	50.05	50.06	50.00	50.05	50.03
	2	50.01	49.99	50.06	50.08	49.98	50.03	50.00
	3	50.11	50.06	50.04	50.10	50.00	50.01	50.03
	4	50.08	50.05	50.08	50.03	50.02	50.00	50.06
	5	49.95	49.95	49.98	49.91	49.97	49.90	49.95
Average		50.03	50.02	50.04	50.04	50.00	50.00	50.01
Stdev		0.06	0.05	0.04	0.07	0.02	0.06	0.04
%Stdev		0.12	0.10	0.08	0.15	0.04	0.12	0.08

Appendix B-3 Diameter of HDPE/GF 30 wt% (mm.)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
C(E0)$_A$	1	50.26	50.56	50.50	50.56	50.46	50.47	50.46
	2	50.03	50.43	50.44	50.43	50.30	50.36	50.34
	3	50.15	50.48	50.49	50.49	50.34	50.38	50.37
	4	50.13	50.50	50.52	50.55	50.43	50.45	50.45
	5	50.17	50.56	50.58	50.56	50.42	50.47	50.51
Average		50.15	50.51	50.51	50.51	50.39	50.42	50.43
Stdev		0.08	0.06	0.05	0.05	0.07	0.05	0.07
%Stdev		0.16	0.11	0.10	0.10	0.13	0.10	0.14
C(E20)$_A$	1	50.19	50.52	50.50	50.53	50.44	50.42	50.31
	2	50.12	50.51	50.45	50.55	50.47	50.44	50.25
	3	50.14	50.51	50.47	50.55	50.44	50.44	50.25
	4	50.00	50.51	50.49	50.48	50.39	50.38	50.14
	5	50.31	50.59	50.59	50.61	50.57	50.56	50.29
Average		50.15	50.53	50.50	50.55	50.46	50.45	50.25
Stdev		0.11	0.04	0.05	0.05	0.07	0.07	0.06
%Stdev		0.22	0.07	0.10	0.09	0.13	0.13	0.13
C(E85)$_A$	1	50.29	50.41	50.39	50.38	50.30	50.37	50.36
	2	50.13	50.24	50.29	50.35	50.28	50.21	50.27
	3	50.17	50.16	50.30	50.31	50.30	50.29	50.20
	4	50.25	50.41	50.40	50.41	50.38	50.37	50.35
	5	50.23	50.37	50.40	50.38	50.33	50.31	50.30
Average		50.22	50.32	50.36	50.37	50.32	50.31	50.29
Stdev		0.06	0.11	0.06	0.04	0.04	0.07	0.07
%Stdev		0.13	0.22	0.11	0.08	0.08	0.13	0.13

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
C(E100)$_A$	1	50.20	50.18	50.19	50.16	50.17	50.13	50.15
	2	50.12	50.12	50.08	50.22	50.07	50.08	50.06
	3	50.22	50.26	50.23	50.23	50.21	50.16	50.18
	4	50.15	50.06	50.13	50.09	50.08	50.02	50.06
	5	50.28	50.33	50.26	50.29	50.19	50.28	50.26
Average		50.20	50.19	50.18	50.20	50.14	50.13	50.14
Stdev		0.06	0.11	0.07	0.08	0.07	0.10	0.09
%Stdev		0.12	0.21	0.15	0.15	0.13	0.19	0.17

Appendix B-4 %Increase of Diameter on HDPE/GF composite

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	49.41	0.00	49.48	0.00	49.44	0.00	49.42	0.00
2	50.07	1.33	49.81	0.66	49.85	0.83	49.56	0.29
4	50.11	1.41	50.12	1.29	49.75	0.63	49.51	0.19
7	50.12	1.44	50.13	1.28	49.76	0.65	49.51	0.18
10	49.90	0.99	49.90	0.84	49.70	0.53	49.46	0.09
13	50.03	1.24	50.05	1.14	49.66	0.46	49.45	0.06
16	50.01	1.21	50.06	1.16	49.63	0.38	49.46	0.08

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	49.98	0.00	50.01	0.00	50.02	0.00	50.04	0.00
2	50.43	0.90	50.49	0.96	50.16	0.28	50.02	-0.03
4	50.44	0.93	50.47	0.93	50.20	0.36	50.04	0.01
7	50.47	0.99	50.51	1.00	50.27	0.50	50.04	0.01
10	50.27	0.58	50.36	0.70	50.16	0.29	50.00	-0.08
13	50.36	0.77	50.42	0.83	50.15	0.27	50.00	-0.08
16	50.39	0.82	50.43	0.85	50.14	0.24	50.01	-0.04

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	50.15	0.00	50.15	0.00	50.22	0.00	50.20	0.00
2	50.51	0.72	50.53	0.75	50.32	0.21	50.19	-0.01
4	50.51	0.74	50.50	0.69	50.36	0.28	50.18	-0.03
7	50.52	0.74	50.55	0.78	50.37	0.30	50.20	0.01
10	50.39	0.49	50.46	0.62	50.32	0.20	50.14	-0.10
13	50.42	0.55	50.45	0.59	50.31	0.19	50.13	-0.12
16	50.43	0.55	50.25	0.19	50.29	0.15	50.14	-0.10

APPENDIX C

Thickness of HDPE/GF Composites

Appendix C-1 Thickness of HDPE/GF 0 wt% (mm.)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	3.25	3.26	3.29	3.27	3.27	3.27	3.26
	2	3.28	3.29	3.29	3.30	3.28	3.26	3.27
	3	3.27	3.26	3.27	3.29	3.30	3.25	3.25
	4	3.23	3.26	3.25	3.26	3.27	3.25	3.26
	5	3.25	3.28	3.28	3.29	3.29	3.26	3.30
Average		3.26	3.27	3.28	3.28	3.28	3.26	3.27
Stdev		0.02	0.01	0.02	0.02	0.01	0.01	0.02
%Stdev		0.60	0.41	0.55	0.52	0.44	0.24	0.60
$C(E20)_A$	1	3.29	3.23	3.27	3.29	3.29	3.28	3.29
	2	3.27	3.29	3.31	3.28	3.31	3.31	3.31
	3	3.25	3.25	3.28	3.28	3.25	3.28	3.28
	4	3.28	3.27	3.29	3.27	3.31	3.30	3.30
	5	3.20	3.26	3.28	3.29	3.27	3.28	3.28
Average		3.26	3.26	3.29	3.28	3.28	3.29	3.29
Stdev		0.04	0.02	0.02	0.01	0.03	0.01	0.01
%Stdev		1.15	0.71	0.49	0.21	0.76	0.40	0.32

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
C(E85)$_A$	1	3.28	3.32	3.32	3.35	3.33	3.33	3.31
	2	3.23	3.20	3.22	3.24	3.24	3.21	3.23
	3	3.25	3.27	3.28	3.30	3.29	3.28	3.30
	4	3.25	3.28	3.28	3.31	3.28	3.29	3.29
	5	3.25	3.25	3.27	3.25	3.27	3.22	3.27
Average		3.25	3.27	3.27	3.29	3.28	3.27	3.28
Stdev		0.02	0.04	0.04	0.04	0.03	0.05	0.03
%Stdev		0.53	1.28	1.10	1.32	0.99	1.52	1.00
C(E100)$_A$	1	3.27	3.31	3.33	3.32	3.33	3.29	3.32
	2	3.20	3.25	3.25	3.25	3.27	3.23	3.24
	3	3.27	3.28	3.27	3.26	3.27	3.27	3.29
	4	3.24	3.28	3.25	3.26	3.26	3.29	3.28
	5	3.20	3.20	3.21	3.22	3.21	3.21	3.22
Average		3.24	3.27	3.26	3.26	3.27	3.26	3.27
Stdev		0.04	0.04	0.05	0.04	0.04	0.04	0.04
%Stdev		1.09	1.27	1.39	1.11	1.24	1.11	1.30

Appendix C-2 Thickness of HDPE/GF 15 wt% (mm.)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	3.29	3.25	3.27	3.30	3.32	3.28	3.30
	2	3.26	3.27	3.26	3.29	3.29	3.28	3.28
	3	3.31	3.29	3.29	3.30	3.30	3.29	3.31
	4	3.25	3.26	3.22	3.27	3.26	3.24	3.27
	5	3.30	3.30	3.30	3.32	3.32	3.30	3.34
Average		3.28	3.27	3.27	3.30	3.30	3.28	3.30
Stdev		0.03	0.02	0.03	0.02	0.02	0.02	0.03
%Stdev		0.78	0.60	1.00	0.56	0.75	0.68	0.78
$C(E20)_A$	1	3.26	3.28	3.29	3.28	3.29	3.29	3.29
	2	3.27	3.30	3.29	3.33	3.31	3.31	3.32
	3	3.28	3.29	3.30	3.30	3.29	3.30	3.30
	4	3.28	3.30	3.32	3.35	3.33	3.30	3.32
	5	3.26	3.27	3.27	3.29	3.27	3.30	3.28
Average		3.27	3.29	3.29	3.31	3.30	3.30	3.30
Stdev		0.01	0.01	0.02	0.03	0.02	0.01	0.02
%Stdev		0.36	0.41	0.57	0.84	0.71	0.26	0.49
$C(E85)_A$	1	3.30	3.32	3.30	3.31	3.32	3.31	3.31
	2	3.28	3.29	3.29	3.28	3.31	3.28	3.29
	3	3.24	3.29	3.33	3.31	3.29	3.28	3.29
	4	3.31	3.33	3.35	3.35	3.32	3.32	3.32
	5	3.28	3.30	3.29	3.29	3.29	3.30	3.28
Average		3.28	3.31	3.31	3.31	3.31	3.30	3.30
Stdev		0.03	0.02	0.03	0.03	0.02	0.02	0.02
%Stdev		0.77	0.55	0.85	0.79	0.54	0.58	0.50

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E100)_A$	1	3.30	3.27	3.27	3.28	3.31	3.28	3.30
	2	3.31	3.36	3.30	3.32	3.31	3.30	3.31
	3	3.28	3.27	3.30	3.29	3.28	3.29	3.29
	4	3.24	3.25	3.24	3.26	3.25	3.24	3.26
	5	3.29	3.29	3.26	3.31	3.30	3.29	3.31
Average		3.28	3.29	3.27	3.29	3.29	3.28	3.29
Stdev		0.03	0.04	0.03	0.03	0.03	0.02	0.02
%Stdev		0.86	1.32	0.79	0.77	0.76	0.75	0.62

Appendix C-3 Thickness of HDPE/GF 30 wt% (mm.)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	3.25	3.23	3.22	3.27	3.26	3.23	3.26
	2	3.30	3.31	3.27	3.31	3.32	3.28	3.31
	3	3.26	3.26	3.23	3.27	3.26	3.24	3.26
	4	3.19	3.20	3.21	3.25	3.23	3.19	3.23
	5	3.22	3.26	3.23	3.26	3.25	3.22	3.28
Average		3.25	3.25	3.23	3.27	3.26	3.23	3.27
Stdev		0.04	0.04	0.02	0.03	0.03	0.03	0.03
%Stdev		1.36	1.21	0.67	0.78	1.03	1.05	0.86

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E20)_A$	1	3.22	3.25	3.25	3.27	3.23	3.23	3.27
	2	3.18	3.22	3.23	3.24	3.21	3.21	3.23
	3	3.23	3.25	3.25	3.26	3.27	3.24	3.26
	4	3.17	3.23	3.24	3.24	3.23	3.21	3.23
	5	3.24	3.25	3.26	3.24	3.27	3.27	3.29
Average		3.21	3.24	3.25	3.25	3.24	3.23	3.26
Stdev		0.03	0.01	0.01	0.01	0.03	0.02	0.03
%Stdev		0.96	0.41	0.37	0.41	0.82	0.76	0.82
$C(E85)_A$	1	3.23	3.21	3.24	3.23	3.24	3.21	3.22
	2	3.22	3.22	3.26	3.26	3.25	3.24	3.25
	3	3.21	3.23	3.21	3.23	3.22	3.21	3.21
	4	3.21	3.21	3.23	3.24	3.23	3.23	3.24
	5	3.21	3.21	3.21	3.22	3.22	3.20	3.22
Average		3.22	3.22	3.23	3.24	3.23	3.22	3.23
Stdev		0.01	0.01	0.02	0.02	0.01	0.02	0.02
%Stdev		0.26	0.27	0.59	0.50	0.45	0.53	0.48
$C(E100)_A$	1	3.26	3.23	3.25	3.26	3.30	3.25	3.25
	2	3.22	3.22	3.22	3.23	3.20	3.24	3.23
	3	3.23	3.20	3.23	3.23	3.21	3.24	3.24
	4	3.20	3.23	3.21	3.22	3.21	3.22	3.23
	5	3.24	3.22	3.24	3.22	3.23	3.21	3.22
Average		3.23	3.22	3.23	3.23	3.23	3.23	3.23
Stdev		0.02	0.01	0.01	0.01	0.04	0.02	0.01
%Stdev		0.63	0.41	0.45	0.44	1.24	0.47	0.33

Appendix C-4 %Increase of Thickness of HDPE/GF Composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	3.26	0.00	3.26	0.00	3.25	0.00	3.24	0.00
2	3.27	0.47	3.26	0.02	3.27	0.43	3.27	0.95
4	3.28	0.66	3.29	0.86	3.27	0.66	3.26	0.78
7	3.28	0.82	3.28	0.69	3.29	1.19	3.26	0.80
10	3.28	0.84	3.28	0.78	3.28	0.94	3.27	0.99
13	3.26	0.12	3.29	0.90	3.27	0.45	3.26	0.64
16	3.27	0.37	3.29	1.02	3.28	0.84	3.27	1.01

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	3.28	0.00	3.27	0.00	3.28	0.00	3.28	0.00
2	3.27	-0.22	3.29	0.57	3.31	0.77	3.29	0.14
4	3.27	-0.37	3.29	0.76	3.31	0.87	3.27	-0.28
7	3.30	0.49	3.31	1.20	3.31	0.77	3.29	0.24
10	3.30	0.49	3.30	0.83	3.31	0.71	3.29	0.16
13	3.28	-0.08	3.30	0.88	3.30	0.53	3.28	-0.14
16	3.30	0.59	3.30	0.98	3.30	0.53	3.29	0.29

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	3.25	0.00	3.21	0.00	3.22	0.00	3.23	0.00
2	3.25	0.18	3.24	1.06	3.22	0.08	3.22	-0.39
4	3.23	-0.45	3.25	1.18	3.23	0.39	3.23	-0.02
7	3.27	0.82	3.25	1.33	3.24	0.66	3.23	0.00
10	3.26	0.54	3.24	0.98	3.23	0.50	3.23	-0.04
13	3.23	-0.41	3.23	0.69	3.22	0.06	3.23	0.00
16	3.27	0.66	3.26	1.50	3.23	0.39	3.23	0.11

Appendix D

Volume of HDPE/GF Composites

Appendix D-1 Volume of HDPE/GF 0 wt% (cm^3)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
C(E0)$_A$	1	6.27	6.46	6.52	6.46	6.42	6.45	6.43
	2	6.28	6.46	6.49	6.52	6.43	6.40	6.43
	3	6.30	6.46	6.48	6.52	6.48	6.42	6.41
	4	6.16	6.38	6.38	6.42	6.36	6.37	6.36
	5	6.21	6.45	6.46	6.48	6.42	6.40	6.47
Average		6.24	6.44	6.46	6.48	6.42	6.41	6.42
Stdev		0.06	0.04	0.05	0.04	0.04	0.03	0.04
%Stdev		0.94	0.54	0.82	0.63	0.65	0.50	0.60
C(E20)$_A$	1	6.36	6.21	6.46	6.50	6.44	6.47	6.48
	2	6.30	6.50	6.54	6.46	6.47	6.51	6.52
	3	6.25	6.42	6.46	6.47	6.35	6.44	6.46
	4	6.31	6.34	6.50	6.47	6.48	6.49	6.50
	5	6.13	6.30	6.47	6.49	6.38	6.45	6.46
Average		6.27	6.35	6.49	6.48	6.42	6.47	6.48
Stdev		0.09	0.11	0.04	0.02	0.06	0.03	0.02
%Stdev		1.39	1.74	0.55	0.25	0.90	0.47	0.39

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E85)_A$	1	6.30	6.56	6.50	6.56	6.49	6.48	6.44
	2	6.22	6.17	6.24	6.31	6.28	6.23	6.24
	3	6.23	6.26	6.31	6.38	6.36	6.32	6.34
	4	6.24	6.48	6.41	6.43	6.38	6.39	6.37
	5	6.24	6.41	6.36	6.33	6.35	6.22	6.33
Average		6.24	6.38	6.36	6.40	6.37	6.33	6.35
Stdev		0.03	0.16	0.10	0.10	0.07	0.11	0.07
%Stdev		0.51	2.55	1.54	1.56	1.16	1.70	1.18
$C(E100)_A$	1	6.29	6.41	6.43	6.41	6.39	6.32	6.39
	2	6.15	6.31	6.28	6.28	6.31	6.23	6.24
	3	6.25	6.34	6.29	6.27	6.28	6.27	6.30
	4	6.23	6.31	6.25	6.27	6.27	6.31	6.31
	5	6.13	6.15	6.17	6.19	6.18	6.16	6.17
Average		6.21	6.31	6.28	6.28	6.28	6.26	6.28
Stdev		0.07	0.10	0.10	0.08	0.08	0.06	0.08
%Stdev		1.13	1.52	1.54	1.25	1.24	1.03	1.31

Appendix D-2 Volume of HDPE/GF 15 wt% (cm^3)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	6.47	6.51	6.47	6.61	6.60	6.54	6.60
	2	6.38	6.52	6.41	6.56	6.51	6.51	6.52
	3	6.50	6.58	6.53	6.61	6.57	6.57	6.61
	4	6.39	6.52	6.35	6.56	6.47	6.47	6.54
	5	6.46	6.58	6.51	6.66	6.57	6.57	6.64
Average		6.44	6.54	6.55	6.60	6.55	6.53	6.58
Stdev		0.05	0.03	0.07	0.04	0.05	0.04	0.05
%Stdev		0.81	0.51	1.15	0.65	0.79	0.67	0.77

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E20)_A$	1	6.38	6.54	6.55	6.59	6.54	6.55	6.55
	2	6.43	6.62	6.59	6.69	6.59	6.62	6.64
	3	6.45	6.60	6.62	6.63	6.58	6.60	6.61
	4	6.46	6.62	6.68	6.71	6.65	6.60	6.64
	5	6.40	6.55	6.53	6.57	6.51	6.59	6.56
Average		6.43	6.59	6.59	6.64	6.57	6.59	6.60
Stdev		0.03	0.04	0.06	0.06	0.05	0.03	0.04
%Stdev		0.54	0.60	0.87	0.93	0.82	0.40	0.66
$C(E85)_A$	1	6.48	6.57	6.53	6.58	6.57	6.53	6.54
	2	6.46	6.52	6.53	6.51	6.56	6.49	6.50
	3	6.37	6.52	6.60	6.56	6.51	6.49	6.52
	4	6.52	6.59	6.64	6.66	6.58	6.60	6.57
	5	6.42	6.49	6.48	6.51	6.46	6.49	6.46
Average		6.45	6.54	6.55	6.57	6.53	6.52	6.52
Stdev		0.06	0.04	0.06	0.06	0.05	0.05	0.04
%Stdev		0.88	0.63	0.97	0.95	0.74	0.70	0.65
$C(E100)_A$	1	6.49	6.44	6.43	6.46	6.50	6.45	6.49
	2	6.51	6.60	6.49	6.55	6.49	6.48	6.50
	3	6.48	6.44	6.50	6.49	6.44	6.47	6.46
	4	6.38	6.39	6.39	6.41	6.39	6.36	6.42
	5	6.44	6.46	6.41	6.47	6.48	6.44	6.48
Average		6.46	6.46	6.44	6.48	6.46	6.44	6.47
Stdev		0.05	0.08	0.05	0.05	0.04	0.05	0.03
%Stdev		0.79	1.22	0.78	0.81	0.69	0.76	0.50

Appendix D-3 Volume of HDPE/GF 30 wt% (cm^3)

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E0)_A$	1	6.46	6.48	6.40	6.58	6.53	6.46	6.53
	2	6.50	6.61	6.45	6.62	6.59	6.54	6.58
	3	6.45	6.52	6.40	6.55	6.49	6.45	6.49
	4	6.29	6.42	6.36	6.52	6.45	6.38	6.46
	5	6.37	6.55	6.41	6.54	6.49	6.44	6.57
Average		6.41	6.52	6.50	6.56	6.51	6.46	6.53
Stdev		0.08	0.07	0.03	0.04	0.05	0.06	0.05
%Stdev		1.28	1.09	0.50	0.59	0.84	0.91	0.80
$C(E20)_A$	1	6.37	6.52	6.51	6.55	6.45	6.45	6.51
	2	6.27	6.46	6.46	6.51	6.42	6.42	6.40
	3	6.39	6.51	6.50	6.55	6.53	6.48	6.48
	4	6.23	6.48	6.50	6.49	6.44	6.40	6.38
	5	6.44	6.54	6.56	6.53	6.56	6.56	6.53
Average		6.34	6.50	6.50	6.53	6.48	6.46	6.46
Stdev		0.08	0.03	0.04	0.03	0.06	0.06	0.07
%Stdev		1.34	0.49	0.57	0.44	0.96	1.00	1.02
$C(E85)_A$	1	6.41	6.42	6.46	6.45	6.45	6.40	6.42
	2	6.36	6.39	6.47	6.50	6.46	6.43	6.45
	3	6.35	6.39	6.38	6.42	6.40	6.38	6.36
	4	6.37	6.42	6.44	6.47	6.44	6.43	6.46
	5	6.36	6.41	6.41	6.42	6.40	6.36	6.39
Average		6.37	6.40	6.43	6.45	6.43	6.40	6.42
Stdev		0.02	0.01	0.04	0.03	0.03	0.03	0.04
%Stdev		0.38	0.21	0.56	0.52	0.40	0.46	0.62

Test Fuel	No.	Time (weeks)						
		0	2	4	7	10	13	16
$C(E100)_A$	1	6.45	6.39	6.43	6.44	6.53	6.41	6.42
	2	6.36	6.35	6.35	6.39	6.31	6.38	6.37
	3	6.40	6.34	6.41	6.40	6.35	6.41	6.41
	4	6.33	6.35	6.34	6.35	6.33	6.32	6.35
	5	6.44	6.41	6.43	6.41	6.39	6.38	6.40
Average		6.40	6.37	6.39	6.40	6.38	6.38	6.39
Stdev		0.05	0.03	0.04	0.03	0.09	0.03	0.03
%Stdev		0.79	0.44	0.68	0.47	1.34	0.54	0.45

Appendix D-4 %Increase of Volume on HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.24	0.00	6.27	0.00	6.24	0.00	6.21	0.00
2	6.44	3.17	6.35	1.35	6.38	2.12	6.31	1.54
4	6.46	3.51	6.49	3.47	6.36	1.93	6.28	1.17
7	6.48	3.62	6.48	3.22	6.40	2.47	6.28	1.15
10	6.42	2.84	6.42	2.47	6.37	2.03	6.28	1.17
13	6.41	2.63	6.47	3.21	6.33	1.37	6.26	0.76
16	6.42	2.81	6.48	3.38	6.35	1.62	6.28	1.18

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.44	0.00	6.43	0.00	6.45	0.00	6.46	0.00
2	6.54	1.58	6.59	2.51	6.54	1.34	6.46	0.09
4	6.55	1.65	6.59	2.63	6.55	1.61	6.44	-0.25
7	6.60	2.48	6.64	3.18	6.57	1.76	6.48	0.26
10	6.55	1.65	6.57	2.25	6.53	1.29	6.46	0.00
13	6.53	1.46	6.59	2.55	6.52	1.06	6.44	-0.29
16	6.58	2.24	6.60	2.70	6.52	1.02	6.47	0.20

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	6.41	0.00	6.34	0.00	6.37	0.00	6.40	0.00
2	6.52	1.63	6.50	2.58	6.40	0.50	6.37	-0.42
4	6.50	1.43	6.50	2.59	6.43	0.97	6.39	-0.09
7	6.56	2.32	6.53	2.85	6.45	1.26	6.40	0.02
10	6.51	1.51	6.48	2.22	6.43	0.91	6.38	-0.25
13	6.46	0.69	6.46	1.88	6.40	0.44	6.38	-0.25
16	6.53	1.78	6.46	1.88	6.42	0.70	6.39	-0.10

Appendix E

Water Absorption of HDPE/GF Composites

Appendix E-1 Water Absorption of HDPE/GF 0 wt% (g)

Time (days)	Sample					Average
	1	2	3	4	5	
0	5.436	5.331	5.358	5.434	5.450	5.402
1	5.438	5.333	5.358	5.434	5.450	5.403
2	5.438	5.333	5.358	5.434	5.450	5.403
3	5.439	5.334	5.358	5.434	5.450	5.403
4	5.438	5.334	5.358	5.434	5.450	5.403
5	5.438	5.334	5.358	5.434	5.450	5.403
6	5.438	5.334	5.358	5.434	5.450	5.403
7	5.438	5.334	5.358	5.434	5.450	5.403
8	5.439	5.334	5.358	5.434	5.450	5.403
9	5.439	5.333	5.359	5.435	5.451	5.403
10	5.439	5.334	5.359	5.435	5.451	5.403
11	5.439	5.334	5.359	5.435	5.451	5.403
12	5.439	5.334	5.359	5.435	5.451	5.403
13	5.439	5.334	5.359	5.435	5.451	5.403
14	5.439	5.334	5.359	5.435	5.451	5.403
16	5.439	5.334	5.359	5.435	5.451	5.404
18	5.439	5.334	5.359	5.435	5.451	5.404
20	5.439	5.334	5.359	5.435	5.451	5.404
22	5.439	5.334	5.359	5.435	5.451	5.404
24	5.439	5.334	5.359	5.435	5.451	5.404
26	5.439	5.334	5.359	5.435	5.451	5.404
28	5.439	5.334	5.359	5.435	5.451	5.404

Appendix E-2 Water Absorption of HDPE/GF (15 wt%)

Time (days)	Sample					Average
	1	2	3	4	5	
0	5.937	6.015	5.983	5.954	6.001	5.978
1	5.939	6.017	5.983	5.955	6.003	5.979
2	5.939	6.017	5.984	5.956	6.003	5.980
3	5.939	6.018	5.984	5.956	6.003	5.980
4	5.940	6.018	5.984	5.956	6.003	5.980
5	5.940	6.018	5.984	5.956	6.003	5.980
6	5.940	6.018	5.984	5.956	6.003	5.980
7	5.940	6.018	5.985	5.956	6.003	5.980
8	5.940	6.018	5.985	5.957	6.003	5.981
9	5.940	6.019	5.985	5.957	6.004	5.981
10	5.941	6.019	5.985	5.957	6.004	5.981
11	5.941	6.019	5.985	5.957	6.004	5.981
12	5.941	6.019	5.985	5.958	6.004	5.982
13	5.941	6.019	5.985	5.958	6.005	5.982
14	5.942	6.019	5.985	5.958	6.005	5.982
16	5.942	6.020	5.986	5.958	6.005	5.982
18	5.943	6.020	5.986	5.958	6.005	5.982
20	5.943	6.020	5.986	5.959	6.005	5.982
22	5.943	6.021	5.986	5.959	6.005	5.983
24	5.943	6.021	5.986	5.959	6.005	5.983
26	5.943	6.021	5.986	5.959	6.005	5.983
28	5.944	6.021	5.987	5.959	6.006	5.983

Appendix E-3 Water Absorption of HDPE/GF (30 wt%)

Time (days)	Sample					Average
	1	2	3	4	5	
0	6.590	6.575	6.583	6.605	6.683	6.607
1	6.595	6.579	6.588	6.612	6.685	6.612
2	6.597	6.581	6.590	6.613	6.687	6.614
3	6.598	6.582	6.592	6.616	6.688	6.615
4	6.598	6.582	6.593	6.615	6.689	6.615
5	6.600	6.584	6.594	6.616	6.689	6.616
6	6.601	6.585	6.596	6.617	6.692	6.618
7	6.602	6.586	6.597	6.618	6.692	6.619
8	6.601	6.586	6.595	6.618	6.691	6.618
9	6.604	6.588	6.597	6.618	6.693	6.620
10	6.604	6.588	6.598	6.619	6.693	6.620
11	6.604	6.589	6.599	6.619	6.695	6.621
12	6.605	6.589	6.599	6.620	6.695	6.622
13	6.607	6.590	6.600	6.620	6.695	6.622
14	6.606	6.590	6.600	6.620	6.696	6.622
16	6.607	6.592	6.602	6.622	6.696	6.624
18	6.608	6.593	6.603	6.622	6.697	6.624
20	6.608	6.593	6.604	6.622	6.697	6.625
22	6.610	6.594	6.604	6.623	6.698	6.626
24	6.610	6.594	6.605	6.623	6.699	6.626
26	6.610	6.594	6.604	6.623	6.699	6.626
28	6.611	6.596	6.606	6.624	6.700	6.627

Appendix E-4 Water Absorption of HDPE/GF composites

Time (days)	HDPE/GF (0 wt%)		HDPE/GF (15 wt%)		HDPE/GF (30 wt%)	
	Average	%Increase	Average	%Increase	Average	%Increase
0	5.402	0.000	5.978	0.000	6.607	0.000
1	5.403	0.018	5.979	0.019	6.612	0.068
2	5.403	0.020	5.980	0.024	6.614	0.098
3	5.403	0.021	5.980	0.030	6.615	0.121
4	5.403	0.020	5.980	0.032	6.615	0.125
5	5.403	0.021	5.980	0.036	6.616	0.141
6	5.403	0.022	5.980	0.037	6.618	0.166
7	5.403	0.024	5.980	0.039	6.619	0.178
8	5.403	0.026	5.981	0.040	6.618	0.169
9	5.403	0.026	5.981	0.044	6.620	0.194
10	5.403	0.028	5.981	0.049	6.620	0.202
11	5.403	0.030	5.981	0.056	6.621	0.212
12	5.403	0.031	5.982	0.057	6.622	0.221
13	5.403	0.030	5.982	0.057	6.622	0.232
14	5.403	0.031	5.982	0.060	6.622	0.233
16	5.404	0.033	5.982	0.066	6.624	0.254
18	5.404	0.033	5.982	0.067	6.624	0.262
20	5.404	0.034	5.982	0.072	6.625	0.269
22	5.404	0.035	5.983	0.075	6.626	0.282
24	5.404	0.035	5.983	0.076	6.626	0.286
26	5.404	0.035	5.983	0.076	6.626	0.286
28	5.404	0.037	5.983	0.083	6.627	0.302

Appendix E-5 Water Absorption of HDPE/GF composites (Base on Polymer Matrix)

Time (days)	HDPE/GF (0 wt%)		HDPE/GF (15 wt%)		HDPE/GF (30 wt%)	
	Average	%Increase	Average	%Increase	Average	%Increase
0	5.402	0.000	5.978	0.000	6.607	0.000
1	5.403	0.018	5.979	0.023	6.612	0.097
2	5.403	0.020	5.980	0.028	6.614	0.140
3	5.403	0.021	5.980	0.035	6.615	0.173
4	5.403	0.020	5.980	0.037	6.615	0.179
5	5.403	0.021	5.980	0.042	6.616	0.202
6	5.403	0.022	5.980	0.043	6.618	0.237
7	5.403	0.024	5.980	0.046	6.619	0.254
8	5.403	0.026	5.981	0.047	6.618	0.241
9	5.403	0.026	5.981	0.052	6.620	0.277
10	5.403	0.028	5.981	0.058	6.620	0.289
11	5.403	0.030	5.981	0.066	6.621	0.303
12	5.403	0.031	5.982	0.067	6.622	0.315
13	5.403	0.030	5.982	0.067	6.622	0.331
14	5.403	0.031	5.982	0.071	6.622	0.333
16	5.404	0.033	5.982	0.078	6.624	0.363
18	5.404	0.033	5.982	0.078	6.624	0.374
20	5.404	0.034	5.982	0.085	6.625	0.384
22	5.404	0.035	5.983	0.088	6.626	0.403
24	5.404	0.035	5.983	0.089	6.626	0.409
26	5.404	0.035	5.983	0.089	6.626	0.409
28	5.404	0.037	5.983	0.097	6.627	0.431

APPENDIX F

Tensile Strength of HDPE/GF Composites

Appendix F-1 Tensile Strength of HDPE/GF 0 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	26.66	21.90	21.35	17.77
	2	26.07	21.91	21.51	17.91
	3	26.24	22.08	20.36	17.85
	4	26.32	22.02	21.52	17.73
	5	26.10	22.01	21.19	18.06
Average		26.28	21.98	21.19	17.86
Stdev		0.24	0.07	0.48	0.13
%Stdev		0.91	0.34	2.27	0.73
$C(E20)_A$	1	26.66	21.83	20.78	17.80
	2	26.07	21.88	20.09	17.90
	3	26.24	21.39	20.54	18.33
	4	26.32	21.35	20.50	17.93
	5	26.10	21.53	20.61	17.78
Average		26.28	21.60	20.50	17.95
Stdev		0.24	0.24	0.26	0.23
%Stdev		0.91	1.13	1.25	1.25

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E85)$_A$	1	26.66	22.44	22.67	20.30
	2	26.07	22.52	23.14	20.69
	3	26.24	22.88	22.27	20.10
	4	26.32	22.38	23.50	20.81
	5	26.10	22.99	22.73	20.47
Average		26.28	22.64	22.86	20.47
Stdev		0.24	0.27	0.47	0.29
%Stdev		0.91	1.21	2.07	1.40
C(E100)$_A$	1	26.66	24.54	24.02	22.36
	2	26.07	24.47	25.44	22.88
	3	26.24	24.28	25.78	22.33
	4	26.32	24.39	25.37	23.20
	5	26.10	24.48	24.13	23.06
Average		26.28	24.43	24.95	22.76
Stdev		0.24	0.10	0.81	0.40
%Stdev		0.91	0.41	3.26	1.75

Appendix F-2 Tensile Strength of HDPE/GF 15 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E0)$_A$	1	28.62	21.82	20.70	15.53
	2	28.89	21.70	22.01	15.77
	3	28.67	22.03	22.17	16.00
	4	28.17	21.98	22.38	15.12
	5	28.64	21.95	21.83	15.16
Average		28.60	21.90	21.82	15.52
Stdev		0.26	0.14	0.66	0.38
%Stdev		0.92	0.63	3.02	2.45

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E20)$_A$	1	28.62	21.97	22.42	16.71
	2	28.89	22.25	21.80	16.85
	3	28.67	22.11	22.72	17.14
	4	28.17	21.74	22.75	17.02
	5	28.64	21.96	22.71	17.08
Average		28.60	22.00	22.48	16.96
Stdev		0.26	0.19	0.40	0.18
%Stdev		0.92	0.85	1.79	1.04
C(E85)$_A$	1	28.62	23.21	22.04	19.01
	2	28.89	23.23	21.85	15.94
	3	28.67	23.48	21.63	15.19
	4	28.17	23.49	22.10	16.44
	5	28.64	23.34	22.54	16.34
Average		28.60	23.35	22.03	16.59
Stdev		0.26	0.13	0.34	1.44
%Stdev		0.92	0.57	1.53	8.68
C(E100)$_A$	1	28.62	25.28	25.79	17.19
	2	28.89	25.37	25.52	17.16
	3	28.67	25.07	25.78	17.71
	4	28.17	25.21	25.92	18.45
	5	28.64	25.10	25.71	18.00
Average		28.60	25.21	25.74	17.70
Stdev		0.26	0.13	0.15	0.55
%Stdev		0.92	0.50	0.56	3.10

Appendix F-3 Tensile Strength of HDPE/GF 30 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	33.10	21.15	24.42	16.16
	2	33.86	20.97	24.13	17.20
	3	33.30	21.15	24.54	17.13
	4	35.95	20.95	23.94	17.09
	5	33.95	20.97	23.76	18.56
Average		34.03	21.04	24.16	17.23
Stdev		1.13	0.11	0.33	0.86
%Stdev		3.33	0.50	1.36	4.98
$C(E20)_A$	1	33.10	21.32	23.78	19.37
	2	33.86	21.30	22.75	19.48
	3	33.30	20.79	23.48	19.39
	4	35.95	19.97	22.74	19.04
	5	33.95	20.33	23.17	20.31
Average		34.03	20.74	23.18	19.52
Stdev		1.13	0.59	0.45	0.47
%Stdev		3.33	2.85	1.96	2.42
$C(E85)_A$	1	33.10	22.52	24.10	22.56
	2	33.86	22.93	24.25	22.53
	3	33.30	23.45	24.45	22.00
	4	35.95	22.76	23.85	22.59
	5	33.95	23.03	23.84	22.54
Average		34.03	22.94	24.10	22.45
Stdev		1.13	0.35	0.26	0.25
%Stdev		3.33	1.51	1.08	1.10

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E100)_A$	1	33.10	24.63	24.42	23.90
	2	33.86	24.40	25.15	23.51
	3	33.30	24.60	24.31	23.73
	4	35.95	24.58	25.46	23.63
	5	33.95	24.32	24.99	23.51
Average		34.03	24.51	24.87	23.66
Stdev		1.13	0.14	0.49	0.17
%Stdev		3.33	0.55	1.97	0.70

Appendix F-4 %Decrease of Tensile Strength on HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	26.28	0.00	26.28	0.00	26.28	0.00	26.28	0.00
4	21.98	-16.34	21.60	-17.82	22.64	-13.83	24.43	-7.02
10	21.19	-19.37	20.50	-21.98	22.86	-13.00	24.95	-5.06
16	17.86	-32.02	17.95	-31.70	20.47	-22.09	22.76	-13.37

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	28.60	0.00	28.60	0.00	28.60	0.00	28.60	0.00
4	21.90	-23.43	22.00	-23.06	23.35	-18.35	25.21	-11.86
10	21.82	-23.71	22.48	-21.39	22.03	-22.97	25.74	-9.99
16	15.52	-45.74	16.96	-40.69	16.59	-42.00	17.70	-38.10

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	34.03	0.00	34.03	0.00	34.03	0.00	34.03	0.00
4	21.04	-38.18	20.74	-39.05	22.94	-32.60	24.51	-27.98
10	24.16	-29.01	23.18	-31.87	24.10	-29.19	24.87	-26.93
16	17.23	-49.37	19.52	-42.65	22.45	-34.04	23.66	-30.48

APPENDIX G

Young’s Modulus of HDPE/GF Composites

Appendix G-1 Young’s Modulus of HDPE/GF 0 wt% (GPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	0.70	0.36	0.33	0.32
	2	0.65	0.38	0.38	0.31
	3	0.69	0.37	0.33	0.31
	4	0.67	0.37	0.37	0.32
	5	0.66	0.37	0.36	0.35
Average		0.68	0.37	0.35	0.32
Stdev		0.02	0.01	0.02	0.02
%Stdev		3.63	2.05	6.31	5.43
$C(E20)_A$	1	0.70	0.34	0.35	0.33
	2	0.65	0.34	0.33	0.33
	3	0.69	0.37	0.34	0.32
	4	0.67	0.33	0.35	0.32
	5	0.66	0.35	0.34	0.34
Average		0.68	0.35	0.34	0.33
Stdev		0.02	0.02	0.01	0.01
%Stdev		3.63	4.58	3.09	1.84

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E85)_A$	1	0.70	0.45	0.43	0.40
	2	0.65	0.41	0.40	0.43
	3	0.69	0.48	0.43	0.41
	4	0.67	0.43	0.42	0.42
	5	0.66	0.44	0.42	0.42
Average		0.68	0.44	0.42	0.42
Stdev		0.02	0.03	0.01	0.01
%Stdev		3.63	5.86	2.77	2.60
$C(E100)_A$	1	0.70	0.59	0.64	0.62
	2	0.65	0.61	0.68	0.68
	3	0.69	0.60	0.65	0.64
	4	0.67	0.61	0.66	0.65
	5	0.66	0.61	0.65	0.62
Average		0.68	0.60	0.66	0.64
Stdev		0.02	0.01	0.01	0.02
%Stdev		3.63	1.47	2.13	3.56

Appendix G-2 Young's Modulus of HDPE/GF 15 wt% (GPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	2.02	0.37	0.36	0.31
	2	2.05	0.38	0.39	0.33
	3	2.17	0.38	0.36	0.33
	4	1.49	0.37	0.37	0.32
	5	2.02	0.37	0.32	0.31
Average		1.95	0.37	0.36	0.32
Stdev		0.26	0.01	0.03	0.01
%Stdev		13.52	1.79	7.19	3.20

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E20)_A$	1	2.02	0.36	0.31	0.32
	2	2.05	0.37	0.30	0.31
	3	2.17	0.38	0.37	0.33
	4	1.49	0.35	0.35	0.30
	5	2.02	0.36	0.33	0.32
Average		1.95	0.36	0.33	0.32
Stdev		0.26	0.01	0.03	0.01
%Stdev		13.52	2.39	8.62	3.62
$C(E85)_A$	1	2.02	0.48	0.46	0.44
	2	2.05	0.47	0.48	0.42
	3	2.17	0.51	0.48	0.47
	4	1.49	0.50	0.46	0.44
	5	2.02	0.46	0.44	0.41
Average		1.95	0.49	0.47	0.44
Stdev		0.26	0.02	0.02	0.02
%Stdev		13.52	4.45	4.04	4.67
$C(E100)_A$	1	2.02	0.89	0.75	0.65
	2	2.05	0.88	0.72	0.65
	3	2.17	0.92	0.74	0.65
	4	1.49	0.90	0.62	0.67
	5	2.02	0.91	0.72	0.64
Average		1.95	0.90	0.71	0.65
Stdev		0.26	0.01	0.05	0.01
%Stdev		13.52	1.57	7.25	1.35

Appendix G-3 Young's Modulus of HDPE/GF 30 wt% (GPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	4.22	0.69	0.67	0.49
	2	3.85	0.65	0.55	0.48
	3	3.82	0.74	0.77	0.49
	4	4.04	0.61	0.75	0.50
	5	3.91	0.62	0.66	0.49
Average		3.97	0.66	0.68	0.49
Stdev		0.17	0.05	0.09	0.01
%Stdev		4.19	7.98	13.01	1.72
$C(E20)_A$	1	4.22	0.69	0.68	0.48
	2	3.85	0.65	0.55	0.49
	3	3.82	0.74	0.61	0.49
	4	4.04	0.61	0.53	0.49
	5	3.91	0.62	0.56	0.49
Average		3.97	0.66	0.59	0.49
Stdev		0.17	0.05	0.06	0.01
%Stdev		4.19	7.98	10.22	1.12
$C(E85)_A$	1	4.22	0.89	0.63	0.58
	2	3.85	0.85	0.69	0.50
	3	3.82	1.06	0.74	0.45
	4	4.04	0.79	0.66	0.53
	5	3.91	0.91	0.76	0.48
Average		3.97	0.90	0.70	0.51
Stdev		0.17	0.10	0.05	0.05
%Stdev		4.19	11.46	7.83	9.56

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E100)_A$	1	4.22	1.96	1.13	0.67
	2	3.85	1.47	1.17	0.67
	3	3.82	1.58	0.95	0.67
	4	4.04	1.67	1.09	0.67
	5	3.91	1.56	1.15	0.64
Average		3.97	1.65	1.10	0.67
Stdev		0.17	0.19	0.09	0.01
%Stdev		4.19	11.55	8.01	2.13

Appendix G-4 %Decrease of Young's Modulus on HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	0.68	0.00	0.68	0.00	0.68	0.00	0.68	0.00
4	0.37	-45.48	0.35	-48.59	0.44	-34.22	0.61	-10.37
10	0.35	-47.56	0.34	-49.19	0.42	-37.78	0.66	-2.81
16	0.32	-52.01	0.33	-51.32	0.42	-38.06	0.64	-4.92

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	1.95	0.00	1.95	0.00	1.95	0.00	1.95	0.00
4	0.37	-80.88	0.36	-81.34	0.49	-75.14	0.90	-53.92
10	0.36	-81.60	0.33	-83.09	0.47	-76.11	0.71	-63.51
16	0.32	-83.43	0.32	-83.69	0.44	-77.57	0.65	-66.60

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	3.97	0.00	3.97	0.00	3.97	0.00	3.97	0.00
4	0.66	-83.34	0.66	-83.35	0.90	-77.30	1.65	-58.46
10	0.68	-82.84	0.59	-85.20	0.70	-82.45	1.10	-72.38
16	0.49	-87.69	0.49	-87.71	0.51	-87.20	0.67	-83.24

APPENDIX H

Impact Strength of HDPE/GF Composites

Appendix H-1 Impact strength of HDPE/GF 0 wt% (kJ/m^2)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E0)$_A$	1	14.53	20.15	19.47	20.09
	2	14.68	20.62	20.12	20.10
	3	14.39	21.67	21.28	19.83
	4	14.81	21.15	21.67	20.61
	5	14.03	21.47	20.00	21.11
	6	14.32	19.71	21.44	21.19
	7	14.03	21.00	17.20	20.20
	8	14.32	19.86	22.66	21.42
	9	14.32	21.58	21.44	21.07
	10	13.61	21.58	20.22	21.51
Average		14.30	20.88	20.55	20.71
Stdev		0.35	0.75	1.52	0.62
%Stdev		2.42	3.58	7.40	2.99

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E20)$_A$	1	14.53	20.27	18.04	20.40
	2	14.68	19.86	19.23	21.21
	3	14.39	21.30	19.27	20.62
	4	14.81	20.50	18.30	20.30
	5	14.03	20.34	17.95	20.03
	6	14.32	20.50	19.32	20.73
	7	14.03	20.62	19.07	21.06
	8	14.32	20.72	18.26	20.83
	9	14.32	20.32	18.64	20.67
	10	13.61	20.44	18.85	21.37
Average		14.30	20.49	18.69	20.72
Stdev		0.35	0.37	0.53	0.42
%Stdev		2.42	1.80	2.82	2.01
C(E85)$_A$	1	14.53	14.04	15.76	15.38
	2	14.68	13.77	16.16	15.35
	3	14.39	14.58	15.65	15.67
	4	14.81	13.23	14.45	15.24
	5	14.03	14.31	15.36	15.51
	6	14.32	14.45	14.96	14.95
	7	14.03	15.74	16.42	15.42
	8	14.32	13.23	16.36	14.81
	9	14.32	14.65	16.45	15.32
	10	13.61	14.38	13.77	14.59
Average		14.30	14.24	15.53	15.22
Stdev		0.35	0.74	0.91	0.33
%Stdev		2.42	5.20	5.84	2.20

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E100)_A$	1	14.53	12.68	12.77	11.91
	2	14.68	12.62	13.06	12.05
	3	14.39	11.28	13.01	12.83
	4	14.81	11.15	12.92	12.42
	5	14.03	13.55	12.76	12.29
	6	14.32	13.43	12.84	12.23
	7	14.03	12.24	13.27	13.76
	8	14.32	13.36	13.03	12.92
	9	14.32	13.77	12.85	12.98
	10	13.61	12.28	13.34	11.76
Average		14.30	12.64	12.98	12.51
Stdev		0.35	0.92	0.20	0.61
%Stdev		2.42	7.28	1.53	4.85

Appendix H-2 Impact strength of HDPE/GF 15 wt% (kJ/m^2)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E0)$_A$	1	16.42	20.58	19.81	20.68
	2	16.29	19.39	20.68	21.54
	3	16.97	18.88	22.89	20.62
	4	16.26	17.94	18.88	21.42
	5	16.04	22.22	23.23	20.60
	6	16.18	19.34	21.33	22.00
	7	16.78	18.37	20.80	22.00
	8	16.97	22.56	19.57	20.17
	9	15.94	20.32	22.45	21.31
	10	16.00	20.28	20.64	21.98
Average		16.38	19.99	21.03	21.23
Stdev		0.39	1.53	1.45	0.67
%Stdev		2.38	7.64	6.90	3.17
C(E20)$_A$	1	16.42	22.43	19.93	20.58
	2	16.29	22.02	22.22	21.75
	3	16.97	21.07	18.44	21.31
	4	16.26	21.57	20.52	21.31
	5	16.04	21.80	18.52	20.54
	6	16.18	20.21	20.65	22.44
	7	16.78	22.56	24.35	19.41
	8	16.97	21.64	20.58	21.11
	9	15.94	20.15	19.78	22.66
	10	16.00	22.56	22.33	21.47
Average		16.38	21.60	20.73	21.26
Stdev		0.39	0.89	1.82	0.94
%Stdev		2.38	4.11	8.76	4.45

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E85)_A$	1	16.42	18.49	17.49	16.60
	2	16.29	17.45	17.91	17.71
	3	16.97	16.57	18.05	16.13
	4	16.26	16.58	18.26	16.39
	5	16.04	16.50	18.41	17.96
	6	16.18	16.54	17.92	17.58
	7	16.78	17.49	17.92	17.79
	8	16.97	17.36	17.28	16.21
	9	15.94	16.82	17.36	18.68
	10	16.00	18.28	17.02	18.55
Average		16.38	17.21	17.76	17.36
Stdev		0.39	0.74	0.45	0.96
%Stdev		2.38	4.27	2.54	5.51
$C(E100)_A$	1	16.42	16.23	16.60	17.40
	2	16.29	17.32	18.60	16.42
	3	16.97	17.24	15.23	17.71
	4	16.26	15.40	17.28	16.85
	5	16.04	16.98	15.76	16.02
	6	16.18	16.52	15.76	15.45
	7	16.78	16.82	15.76	16.02
	8	16.97	16.36	15.73	17.35
	9	15.94	17.20	16.21	15.80
	10	16.00	16.44	15.08	15.88
Average		16.38	16.65	16.20	16.49
Stdev		0.39	0.59	1.06	0.78
%Stdev		2.38	3.52	6.54	4.76

Appendix H-3 Impact strength of HDPE/GF 30 wt% (kJ/m^2)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E0)$_A$	1	18.16	19.71	21.51	22.89
	2	18.28	22.67	21.67	22.33
	3	20.48	20.15	22.24	22.32
	4	18.05	19.82	21.86	24.48
	5	20.25	21.16	20.80	23.23
	6	17.39	20.86	22.55	23.11
	7	17.27	22.13	21.78	22.21
	8	16.80	22.24	21.33	23.45
	9	16.80	20.30	20.70	20.30
	10	16.88	20.67	22.45	23.64
Average		18.04	20.97	21.69	22.80
Stdev		1.35	1.05	0.63	1.12
%Stdev		7.48	5.03	2.91	4.91
C(E20)$_A$	1	18.16	20.40	23.54	21.27
	2	18.28	19.75	20.68	28.46
	3	20.48	20.56	21.06	22.22
	4	18.05	18.41	21.16	21.69
	5	20.25	21.62	23.56	21.43
	6	17.39	20.21	20.40	21.11
	7	17.27	18.67	23.22	21.11
	8	16.80	20.47	25.45	21.00
	9	16.80	20.49	24.73	21.67
	10	16.88	20.52	25.14	20.44
Average		18.04	20.11	22.89	22.04
Stdev		1.35	0.95	1.93	2.30
%Stdev		7.48	4.72	8.42	10.46

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E85)$_A$	1	18.16	17.94	20.94	19.78
	2	18.28	18.67	21.68	18.98
	3	20.48	19.48	19.35	19.83
	4	18.05	19.43	20.22	19.13
	5	20.25	19.27	20.73	19.52
	6	17.39	18.73	20.87	21.53
	7	17.27	18.67	20.34	19.07
	8	16.80	17.48	19.01	20.22
	9	16.80	18.61	18.70	20.52
	10	16.88	19.76	20.50	20.60
Average		18.04	18.80	20.23	19.92
Stdev		1.35	0.71	0.94	0.81
%Stdev		7.48	3.79	4.64	4.07
C(E100)$_A$	1	18.16	18.55	19.07	17.01
	2	18.28	17.32	18.19	17.71
	3	20.48	16.05	18.07	17.18
	4	18.05	18.32	16.80	17.71
	5	20.25	16.68	19.81	17.36
	6	17.39	17.32	20.10	18.01
	7	17.27	17.44	17.32	18.28
	8	16.80	19.55	18.47	18.41
	9	16.80	16.10	17.06	18.81
	10	16.88	17.85	17.24	20.10
Average		18.04	17.52	18.21	18.06
Stdev		1.35	1.10	1.16	0.91
%Stdev		7.48	6.27	6.34	5.06

Appendix H-4 %Increase of Impact strength on HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	14.30	0.00	14.30	0.00	14.30	0.00	14.30	0.00
4	20.88	45.96	20.49	43.23	14.24	-0.47	12.64	-11.67
10	20.55	43.68	18.69	30.68	15.54	8.61	12.99	-9.22
16	20.71	44.81	20.72	44.86	15.22	6.43	12.51	-12.51

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	16.38	0.00	16.38	0.00	16.38	0.00	16.38	0.00
4	19.99	22.00	21.60	31.85	17.21	5.03	16.65	1.64
10	21.03	28.34	20.73	26.54	17.76	8.42	16.20	-1.11
16	21.23	29.58	21.26	29.75	17.36	5.96	16.49	0.65

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_A$		C(E20)$_A$		C(E85)$_A$		C(E100)$_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	18.04	0.00	18.04	0.00	18.04	0.00	18.04	0.00
4	20.97	16.29	20.11	11.51	18.81	4.27	17.52	-2.87
10	21.69	20.26	22.89	26.94	20.23	12.19	18.21	0.99
16	22.80	26.39	22.04	22.21	19.92	10.45	18.06	0.13

APPENDIX I

Flexural Strength of HDPE/GF Composites

Appendix I-1 Flexural Strength of HDPE/GF 0 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	25.25	23.62	20.16	18.62
	2	29.50	20.01	19.16	21.93
	3	25.71	21.39	22.50	20.37
	4	25.59	21.25	20.15	14.76
	5	28.91	19.04	18.25	18.89
Average		26.99	21.06	20.04	18.92
Stdev		2.04	1.72	1.59	2.67
%Stdev		7.56	8.18	7.91	14.13
$C(E20)_A$	1	25.25	18.44	20.53	23.07
	2	29.50	20.77	16.92	19.06
	3	25.71	20.45	17.72	20.26
	4	25.59	21.47	19.70	19.74
	5	28.91	19.77	19.15	12.60
Average		26.99	20.18	18.80	18.95
Stdev		2.04	1.15	1.47	3.86
%Stdev		7.56	5.71	7.81	20.39

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E85)_A$	1	25.25	22.70	22.50	21.05
	2	29.50	22.47	21.59	21.21
	3	25.71	24.08	20.36	20.16
	4	25.59	20.80	17.32	17.45
	5	28.91	21.27	20.24	21.69
Average		26.99	22.26	20.40	20.31
Stdev		2.04	1.29	1.96	1.69
%Stdev		7.56	5.81	9.60	8.34
$C(E100)_A$	1	25.25	27.39	21.24	20.50
	2	29.50	24.99	26.33	25.15
	3	25.71	21.82	24.79	19.09
	4	25.59	23.58	19.43	21.25
	5	28.91	23.23	18.69	21.60
Average		26.99	24.20	22.09	21.52
Stdev		2.04	2.11	3.34	2.25
%Stdev		7.56	8.72	15.12	10.43

Appendix I-2 Flexural Strength of HDPE/GF 15 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	35.83	27.61	23.63	23.26
	2	36.18	27.80	22.75	19.73
	3	35.93	24.26	21.39	20.64
	4	35.64	24.10	21.90	17.77
	5	35.27	22.47	19.54	19.18
Average		35.77	25.25	21.84	20.12
Stdev		0.34	2.35	1.54	2.04
%Stdev		0.96	9.32	7.07	10.16

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E20)$_A$	1	35.83	18.31	22.96	19.04
	2	36.18	18.83	20.53	19.48
	3	35.93	18.32	21.02	18.05
	4	35.64	19.13	21.54	17.92
	5	35.27	18.69	20.39	18.92
Average		35.77	18.65	21.29	18.68
Stdev		0.34	0.35	1.04	0.67
%Stdev		0.96	1.87	4.87	3.59
C(E85)$_A$	1	35.83	25.43	25.14	21.85
	2	36.18	26.24	21.14	21.23
	3	35.93	24.70	25.02	21.24
	4	35.64	24.98	23.41	21.80
	5	35.27	22.80	21.36	20.52
Average		35.77	24.83	23.21	21.33
Stdev		0.34	1.27	1.92	0.54
%Stdev		0.96	5.13	8.27	2.54
C(E100)$_A$	1	35.83	28.33	28.92	21.88
	2	36.18	26.36	29.76	20.37
	3	35.93	24.43	28.10	20.65
	4	35.64	30.80	27.18	20.44
	5	35.27	25.93	23.76	20.55
Average		35.77	27.17	27.54	20.78
Stdev		0.34	2.46	2.32	0.63
%Stdev		0.96	9.05	8.43	3.02

Appendix I-3 Flexural Strength of HDPE/GF 30 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	43.44	19.08	27.61	19.45
	2	39.38	18.34	26.28	18.69
	3	42.06	18.75	25.50	18.71
	4	38.84	17.54	24.58	18.57
	5	33.05	17.91	23.34	19.44
Average		39.35	18.32	25.46	18.97
Stdev		4.00	0.62	1.62	0.44
%Stdev		10.17	3.40	6.38	2.30
$C(E20)_A$	1	43.44	27.93	26.63	19.75
	2	39.38	26.13	25.74	19.49
	3	42.06	25.18	24.88	19.75
	4	38.84	26.65	26.02	18.98
	5	33.05	22.71	23.79	18.98
Average		39.35	25.72	25.41	19.39
Stdev		4.00	1.95	1.11	0.39
%Stdev		10.17	7.60	4.35	2.00
$C(E85)_A$	1	43.44	32.41	26.75	20.39
	2	39.38	28.18	25.84	21.04
	3	42.06	26.69	25.59	21.19
	4	38.84	25.46	27.37	20.76
	5	33.05	26.66	26.25	21.34
Average		39.35	27.88	26.36	20.94
Stdev		4.00	2.71	0.71	0.38
%Stdev		10.17	9.71	2.71	1.81

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E100)_A$	1	43.44	26.90	30.07	22.40
	2	39.38	24.81	28.40	21.87
	3	42.06	23.36	30.35	22.02
	4	38.84	22.91	29.38	22.04
	5	33.05	23.83	29.66	21.49
Average		39.35	24.36	29.57	21.96
Stdev		4.00	1.58	0.75	0.33
%Stdev		10.17	6.51	2.54	1.50

Appendix I-4 %Decrease of Flexural Strength of HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_{A}$		C(E20)$_{A}$		C(E85)$_{A}$		C(E100)$_{A}$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	26.99	0.00	26.99	0.00	26.99	0.00	26.99	0.00
4	21.06	-21.97	20.18	-25.23	22.26	-17.51	24.20	-10.33
10	20.04	-25.74	18.80	-30.33	20.40	-24.42	22.09	-18.14
16	18.92	-29.92	18.95	-29.81	20.31	-24.74	21.52	-20.28

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_{A}$		C(E20)$_{A}$		C(E85)$_{A}$		C(E100)$_{A}$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	35.77	0.00	35.77	0.00	35.77	0.00	35.77	0.00
4	25.25	-29.41	18.65	-47.85	24.83	-30.58	27.17	-24.05
10	21.84	-38.94	21.29	-40.49	23.21	-35.10	27.54	-23.00
16	20.12	-43.76	18.68	-47.77	21.33	-40.38	20.78	-41.91

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	C(E0)$_{A}$		C(E20)$_{A}$		C(E85)$_{A}$		C(E100)$_{A}$	
	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease	Avg	%Decrease
0	39.35	0.00	39.35	0.00	39.35	0.00	39.35	0.00
4	18.32	-53.44	25.72	-34.65	27.88	-29.15	24.36	-38.10
10	25.46	-35.30	25.41	-35.43	26.36	-33.02	29.57	-24.86
16	18.97	-51.79	19.39	-50.72	20.94	-46.78	21.96	-44.19

APPENDIX J

Compressive Strength of HDPE/GF Composites

Appendix J-1 Compressive Strength of HDPE/GF 0 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
C(E0)_A	1	100.03	96.60	111.74	113.04
	2	111.14	105.90	112.12	111.82
	3	103.86	105.98	112.71	111.96
	4	106.65	97.29	114.68	111.69
	5	102.76	103.68	110.22	106.33
Average		104.89	101.89	112.29	110.97
Stdev		4.22	4.61	1.62	2.65
%Stdev		4.03	4.53	1.44	2.39
C(E20)_A	1	100.03	115.42	103.80	116.49
	2	111.14	114.78	102.43	113.84
	3	103.86	112.88	103.16	116.16
	4	106.65	112.37	106.70	117.95
	5	102.76	112.92	108.43	114.82
Average		104.89	113.68	104.90	115.85
Stdev		4.22	1.34	2.55	1.59
%Stdev		4.03	1.18	2.43	1.37

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E85)_A$	1	100.03	121.27	118.65	125.86
	2	111.14	117.76	115.29	117.73
	3	103.86	120.73	118.22	136.55
	4	106.65	122.26	117.41	133.31
	5	102.76	121.56	115.50	128.60
Average		104.89	120.72	117.01	128.41
Stdev		4.22	1.74	1.54	7.26
%Stdev		4.03	1.44	1.32	5.65
$C(E100)_A$	1	100.03	125.42	113.68	126.44
	2	111.14	130.08	114.09	126.66
	3	103.86	128.10	122.83	118.38
	4	106.65	127.34	122.69	116.14
	5	102.76	128.57	122.14	122.53
Average		104.89	127.90	119.09	122.03
Stdev		4.22	1.71	4.76	4.72
%Stdev		4.03	1.34	3.99	3.87

Appendix J-2 Compressive Strength of HDPE/GF 15 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	122.85	118.88	107.35	133.50
	2	121.39	121.57	120.29	135.59
	3	128.36	116.10	116.75	132.12
	4	122.30	99.27	105.50	139.17
	5	122.91	103.02	109.74	127.84
Average		123.56	111.77	111.92	133.64
Stdev		2.75	9.98	6.33	4.19
%Stdev		2.22	8.93	5.65	3.14

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E20)_A$	1	122.85	107.04	113.06	131.68
	2	121.39	106.09	107.99	137.04
	3	128.36	129.84	123.65	134.24
	4	122.30	109.52	122.83	121.08
	5	122.91	108.22	108.52	118.91
Average		123.56	112.14	115.21	128.59
Stdev		2.75	9.98	7.59	8.11
%Stdev		2.22	8.90	6.59	6.31
$C(E85)_A$	1	122.85	129.56	125.04	121.56
	2	121.39	129.61	117.71	118.09
	3	128.36	125.64	120.61	111.26
	4	122.30	126.29	115.94	116.72
	5	122.91	127.95	114.86	117.53
Average		123.56	127.81	118.83	117.03
Stdev		2.75	1.83	4.10	3.72
%Stdev		2.22	1.43	3.45	3.18
$C(E100)_A$	1	122.85	135.95	129.74	124.35
	2	121.39	136.20	106.25	135.76
	3	128.36	134.50	112.49	124.03
	4	122.30	139.45	129.03	120.34
	5	122.91	138.18	128.86	136.96
Average		123.56	136.86	121.28	128.29
Stdev		2.75	1.96	11.09	7.55
%Stdev		2.22	1.43	9.15	5.88

Appendix J-3 Compressive Strength of HDPE/GF 30 wt% (MPa)

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E0)_A$	1	138.40	137.20	139.78	143.99
	2	135.93	135.74	143.99	146.95
	3	145.00	137.88	143.44	144.86
	4	142.72	141.57	142.11	144.87
	5	134.85	141.67	138.44	140.67
Average		139.38	138.81	141.55	144.27
Stdev		4.36	2.68	2.38	2.29
%Stdev		3.13	1.93	1.68	1.58
$C(E20)_A$	1	138.40	119.09	147.85	157.33
	2	135.93	143.91	146.09	153.87
	3	145.00	142.05	151.51	131.49
	4	142.72	141.92	147.62	156.94
	5	134.85	138.06	144.86	157.34
Average		139.38	137.00	147.59	151.40
Stdev		4.36	10.24	2.51	11.22
%Stdev		3.13	7.47	1.70	7.41
$C(E85)_A$	1	138.40	143.54	153.03	161.95
	2	135.93	140.64	151.57	157.19
	3	145.00	144.05	126.68	162.77
	4	142.72	142.86	158.21	137.55
	5	134.85	139.82	157.16	165.77
Average		139.38	142.18	149.33	157.05
Stdev		4.36	1.85	12.96	11.33
%Stdev		3.13	1.30	8.68	7.21

Test Fuel	No.	Time (weeks)			
		0	4	10	16
$C(E100)_A$	1	138.40	150.55	160.96	160.74
	2	135.93	128.68	131.79	159.54
	3	145.00	120.06	158.82	163.03
	4	142.72	120.30	132.70	159.75
	5	134.85	152.28	154.58	160.52
Average		139.38	134.37	147.77	160.72
Stdev		4.36	15.95	14.36	1.39
%Stdev		3.13	11.87	9.72	0.86

Appendix J-4 %Increase of Compressive Strength on HDPE/GF composites

HDPE/GF (0 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	104.89	0.00	104.89	0.00	104.89	0.00	104.89	0.00
4	101.89	-2.85	113.68	8.38	120.72	15.10	127.90	21.95
10	112.29	7.06	104.90	0.02	117.01	11.56	119.09	13.54
16	110.97	5.80	115.85	10.46	128.41	22.43	122.03	16.35

HDPE/GF (15 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	123.56	0.00	123.56	0.00	123.56	0.00	123.56	0.00
4	111.77	-9.54	112.14	-9.24	127.81	3.44	136.86	10.76
10	111.92	-9.42	115.21	-6.76	118.83	-3.83	121.28	-1.85
16	133.64	8.16	128.59	4.07	117.03	-5.28	128.29	3.83

HDPE/GF (30 wt%)

Time (weeks)	Test Fuel							
	$C(E0)_A$		$C(E20)_A$		$C(E85)_A$		$C(E100)_A$	
	Avg	%Increase	Avg	%Increase	Avg	%Increase	Avg	%Increase
0	139.38	0.00	139.38	0.00	139.38	0.00	139.38	0.00
4	138.81	-0.41	137.00	-1.70	142.18	2.01	134.37	-3.59
10	141.55	1.56	147.59	5.89	149.33	7.14	147.77	6.02
16	144.27	3.51	151.40	8.62	157.05	12.67	160.72	15.31

VITA

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