อิทธิพลของน้ำมันแก๊สโซฮอล์ต่อวัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้ว

นางสาวปราณิศา ชูเส้ง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมเคมี ภาควิชาวิศวกรรมเคมี
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2552

INFLUENCES OF GASOHOLS ON GLASS FIBER REINFORCED POLYAMIDE 6 COMPOSITE

Miss Pranisa Chooseng

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Chemical Engineering
Department of Chemical Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2009

Thesis Title	INFLUENCES OF GASOHOLS ON GLASS FIBER REINFORCED POLYAMIDE 6 COMPOSITE
By	Miss Pranisa Chooseng
Field of Study	Chemical Engineering
Thesis Advisor	Varun Taepaisitphongse, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

………………………………………………Dean of the Faculty of Engineering
(Associate Professor Boonsom Lerdhirunwong, Dr.Ing.)

THESIS COMMITTEE

………M. Phi………………………… Chairman
(Associate Professor Muenduen Phisalaphong, Ph.D.)

………………………………………… Thesis Advisor
(Varun Taepaisitphongse, Ph.D.)

……S. Covavisaruch…………………… Examiner
(Sirijutaratana Covavisaruch, Ph.D.)

………S. Petchuay…………………… External Examiner
(Sawitree Petchuay, Ph.D.)

ปราณิศา ชูเส้ง : อิทธิพลของน้ำมันแก๊สโซฮอล์ต่อวัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้ว. (INFLUENCES OF GASOHOLS ON GLASS FIBER REINFORCED POLYAMIDE 6 COMPOSITE) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : อ.ดร.วรัญ แต้ไพสิฐพงษ์, 152 หน้า.

งานวิจัยนี้มีจุดมุ่งหมายเพื่อศึกษาอิทธิพลของน้ำมันแก๊สโซฮอล์ต่อสมบัติเชิงกายภาพและสมบัติเชิงกลของวัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้ว เม็ดไนลอน 6 และไนลอน 6 เสริมแรงด้วยเส้นใยแก้ว 15% และ 30% โดยน้ำหนัก ถูกนำมาขึ้นรูปเป็นชิ้นงานทดสอบโดยใช้เครื่องอัดและเครื่องฉีด ชิ้นงานทดสอบถูกนำมาแช่ในน้ำมันทดสอบ 4 ชนิด คือ C(E0)$_A$ C(E20)$_A$ C(E85)$_A$ และ C(E100)$_A$ ที่อุณหภูมิห้องเป็นเวลา 16 สัปดาห์ โดยที่น้ำมันจะถูกเปลี่ยนทุก 3 สัปดาห์ โครงสร้าง ปริมาณการดูดซับน้ำ การเปลี่ยนแปลงด้านน้ำหนักและขนาด สมบัติด้านรับแรงดึง ด้านการบิดงอ ด้านการกดอัด และด้านการกระแทกของชิ้นงานทดสอบถูกวัดด้วยกล้องจุลทัศน์อิเล็กตรอนแบบส่องกราด ตาชั่ง เครื่องทดสอบเชิงกล และเครื่องทดสอบแรงกระแทก ตามลำดับ

ผลการทดลองพบว่า ไนลอน 6 สามารถยึดกับเส้นใยแก้วเสริมแรงได้ดี เส้นใยแก้วเสริมแรงสามารถปรับปรุงสมบัติเชิงกลและความเสถียรด้านมวลและขนาดของชิ้นงานทดสอบได้ดีโดยการลดบริเวณที่มีโครงสร้างแบบอสัณฐานและเพิ่มบริเวณที่มีโครงสร้างแบบผลึกในชิ้นงานทดสอบ น้ำมันทดสอบที่มีส่วนผสมของแอลกอฮอล์ ได้แก่ C(E20)$_A$ C(E85)$_A$ และ C(E100)$_A$ มีผลต่อสมบัติการทนแรงดึง แรงดัดงอ และค่ายังมอดูลัส (Young's modulus) ของชิ้นงาน ไนลอน-6 ที่ไม่เสริมแรงและเสริมแรงด้วยเส้นใยแก้วมากกว่าน้ำมันทดสอบที่ไม่มีส่วนผสมของแอลกอฮอล์ ได้แก่ C(E0)$_A$ เนื่องจากการดูดซับน้ำและแอลกอฮอล์จากน้ำมันทดสอบที่มีส่วนผสมของแอลกอฮอล์ได้แก่ C(E20)$_A$ C(E85)$_A$ และ C(E100)$_A$ โดยชิ้นงาน ไนลอน 6 ที่ไม่เสริมแรงและเสริมแรงด้วยเส้นใยแก้ว

ภาควิชา วิศวกรรมเคมี ลายมือชื่อนิสิต ปราณิศา ชูเส้ง
สาขาวิชา วิศวกรรมเคมี ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก
ปีการศึกษา 2552

, # #5070339721: MAJOR CHEMICAL ENGINEERING

KEYWORDS : POLYAMIDE 6 / GLASS FIBER / COMPOSITES / GASOHOLS

PRANISA CHOOSENG : INFLUENCES OF GASOHOLS ON GLASS FIBER REINFORCED POLYAMIDE 6 COMPOSITE. THESIS ADVISOR : VARUN TAEPAISITPHONGSE, Ph.D., 152 pp.

In this study, the influences of gasohol on physical and mechanical properties of glass fiber reinforced polyamide 6 (PA6) composites were investigated. The pellets of neat PA6 and PA6 compound with 15 wt% and 30 wt% glass fiber were used. Test specimens were prepared by compression and injection molding machines. These specimens were immersed in 4 different test fuels, namely, $C(E0)_A$, $C(E20)_A$, $C(E85)_A$, and $C(E100)_A$ at room temperature for 16 weeks. The test fuels were changed every 3 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 the PA6 matrix had an excellent adhesion to glass fiber reinforcement. The glass fiber could improve the mechanical properties of the composites and mass and dimensional stability of specimens by reducing amorphous region while increasing crystalline region. Test fuels containing alcohol, i.e. $C(E20)_A$, $CE(85)_A$ and $C(E100)_A$ affected the tensile strength, flexural strength and Young's modulus of both unreinforced and reinforced PA6 composites more than $C(E0)_A$ due to adsorption of water and alcohols from $C(E20)_A$, $CE(85)_A$ and $C(E100)_A$ by both unreinforced and reinforced PA6 composites.

Department : Chemical Engineering
Field of Study : Chemical Engineering
Academic Year : 2009

Student's Signature ปราณิศา ชูเส้ง
Advisor's Signature

ACKNOWLEDGEMENTS

I would like to express sincere gratitude to my advisor, Dr. Varun Taepaisitphongse for his invaluable guidance throughout the course of this research. In addition, I would like to thank members of my thesis committee, who have given many helpful comments and recommendations for completing my thesis.

Furthermore, thank is due to UBE NYLON CO., LTD., Thailand, for providing polyamide 6 resin (1015B) and polyamide 6 compound 15 wt% and 30 wt% glass fiber (1015GC3 and 1015GC6, respectively). Partial financial support from the Graduate School Research Grant, Chulalongkorn University, and Research Assistant Grant, Faculty of Engineering, Chulalongkorn University, Bangkok, are greatly appreciated.

Thanks to all my friends, especially Miss Woraphan Aksonwong and Miss Kangsadarn Aekcharoen, and everyone at the Polymer Engineering Laboratory for their discussion and friendly encouragement.

Finally, I would like to thank my family who always give their unconditional love, understanding, and encouragement during my study.

CONTENTS

PAGE

CHAPTER

PAGE

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

LIST OF TABLES

TABLE PAGE

TABLE PAGE

CHAPTER I

INTRODUCTION

1.1 General Introduction

Biofuels are one of the most important low-green-house gas alternatives to petroleum. Bioethanol is considered a renewable fuel and is also classified as an alternative fuel since it can be used as a substitute for gasoline. Pure 99.5% by volume of ethanol can be blended with unleaded gasoline to form gasohol at various volume ratio [10]. Worldwide consumption of E10, E20, E85 and E100 gasohol are steadily increasing. Thailand has potential for producing alcohol from plants because of the prevalence of agricultural resources. Presently, the Thai government promotes the serious use of gasohol. Currently, gasohol sold in Thailand contains 10%, 20%, and 85% by volume ethanol, so called E10, E20, and E85 respectively. However, gasohol with high concentrate of ethanol can corrode materials that exposed to them. Many engineering thermoplastics are continuously replacing metals, ceramics, glass, and wood parts in the manufactures of machine parts [1]. This mainly due to the easy formability, light weight, resistance to various chemical materials and low cost of plastics. One of the most widely engineering thermoplastics is polyamide 6 (PA6) or nylon-6 because it low coefficient of friction, excellent fatigue chemical resistance, high mechanical strength, and good adhesion to reinforcements and fillers [2]. The mechanical properties of PA6 can be further improved by reinforcing with glass fiber. The main purpose of this work is to study the compatibility between gasohol and glass fiber reinforced PA6 composite. The effect of gasohol concentrations on the physical and mechanical properties of glass fiber reinforced PA6 composite at different glass fiber loading will be evaluated.

1.2 Objectives

1. To study the compatibility between PA6 and PA6/GF composites with gasohol.
2. To study the effects of glass fiber content on mechanical properties of PA6/GF composites.
3. To evaluate the effects of ethanol concentration in gasohol on physical and mechanical properties of PA6 and PA6/GF composites.

1.3 Expected Benefits of This Study

1. Gain insight into the compatibility between PA6/GF composites and gasohol.
2. Increasing of glass fiber contents in PA6 can improve the physical and the mechanical properties of composites.
3. Alcohol concentration in gasohol effests to the physical and mechanical properties of PA6/GF composites slightly.

CHAPTER II

THEORY

2.1 Polyamide 6 (PA6)

Engineering thermoplastics encompass plastics that can be formed into part suitable for bearing loads and able to withstand abuse in thermal environments traditionally tolerated by metals, ceramics, glass, and wood. A more general definition defines engineering plastics as those high performance materials that provide a combination of high ratings for mechanical, thermal, electrical, and chemical properties [1]. Polymer can be either amorphous or partially crystalline, depending on their molecular structure and conditions of formation of the solid phase (polymerization and/or thermal history). The amorphous or semicrysalline nature of each material is the form predominantly used in applications. Crystalline and amorphous polymers are distinguished by several different properties, and the most evident of them is light transmission. In Table 2.1, the qualitative dependence of some properties of polymeric materials as a function of their morphological state is reported.

Table 2.1 Relationships between Polymer Properties and Morphology [1]

Property	Crystalline	Amorphous
Solvent resistance	High	Low
Lubricity	High	Low
Dimensional stability	High	Low
Mold shrinkage	High	Low
Resistance to dynamic fatigue	High	Low
Facility to form high strength fibers	High	None
Melting temperature	Sharp	Absent

Polyamides or nylons were the first engineering plastics and still represent by far the biggest and the most important class of these types of material. Polyamides comprise a range of materials, depending on the monomers employed. Nylon-6 and nylon-6/6 continue to be the most popular types, still accounting for more than 90% of nylon use. Nylons are tough and wear resistance, but will absorb moisture, particularly nylon-6 and nylon-6/6.The first of specialty types, for example, nylon-6/10, 6/12, 12/12, 11, 12, are less water absorbent than nylon-6 or nylon-6/6 by virtue of their long hydrophobic paraffinic chains between the hydrophilic amide groups [2]. Nylons exhibit low coefficient of friction, good dielectric properties, and excellent fatigue resistance. Their excellent processability and adhesion to reinforcements and fillers make them natural candidates for high loadings of modifiers.

Polyamide6 (PA6) or nylon-6 is well-known as providing the best price/performance ratio of engineering plastics. This explains why PA6 is extensively used in automotive to optimize system cost. For specific applications, PA6 is a better candidate than PA66 in 75% of cases. PA6 is as stiff as PA66 with temperatures up to 180°C and also exhibits a better long-term heat ageing than PA66. Additionally, PA6 is less expensive than PA66 in term of basic costs and provides a better surface appearance and a better weld strength which leads to a better burst pressure resistance. All of these highly interesting performances are available in PA6 [3].

Nylon-6 is a polymer developed by Paul Schlack. Unlike most other nylons, nyon-6 is not a condensation polymer, but instead is formed by ring-opening polymerization. This makes it a special case in the comparison between condensation and addition polymers. Its competition with nylon-6/6 and the example it set have also shaped the economics of the synthetic fiber industry [4].

2.1.1 Production of PA6

PA6 or nylon-6 begins as pure caprolactam. As caprolactam has 6 carbon atoms, it got the name nylon-6. When caprolactam is heated at about 533 K in an inert atmosphere of nitrogen for about 4-5 hours, the ring breaks and undergoes polymerization. Then the molten mass is passed through spinnerets to form fibres of nylon-6 [7].

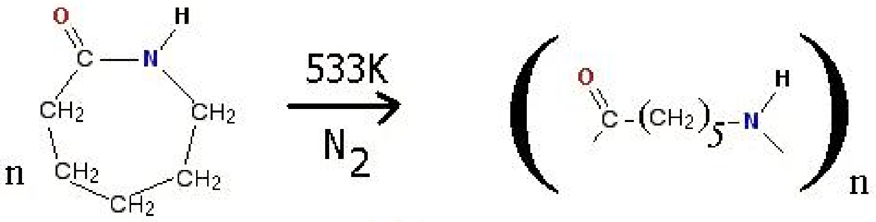


Figure 2.1 Polymerization of Caprolactam to Nylon-6 [4]

During polymerization, the peptide bond within each caprolactam molecule is broken, with the active groups on each side re-forming two new bonds as the monomer becomes part of the polymer backbone. Unlike nylon-6/6, in which the direction of the amide bond reverses at each bond, all nylon-6 amide bonds lie in the same direction (see Figure 2.2). Nylon-6 therefore resembles natural polypeptides more closely; in fact, caprolactam would become an amino acid if it were hydrolyzed. This difference has little effect on the polymer's mechanical or chemical properties, but is sufficient to create a legal distinction [4].

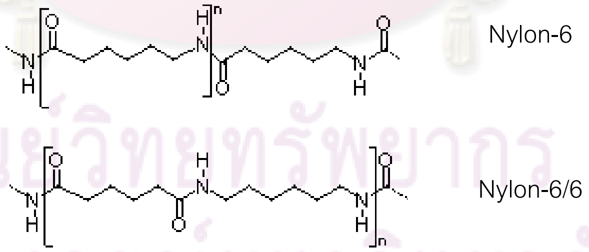


Figure 2.2 Nylon-6 (above) has a Structure Similar to Nylon-6/6 (below) [4]

2.1.2 Properties of PA6

Nylon properties are intrinsic to the chemical substance under investigation and depend on the processing operation, which confers a shape and orientation to the material. Herein, mainly intrinsic and processing properties are considered, divided into four conventional groups: bulk, physical, mechanical, and chemical. Several of such properties change remarkably depending on the morphology (amorphous or semicrystalline) or for the presence of fillers and reinforcing fibers.

a) Bulk Properties

Above their melting temperatures (T_m), thermoplastics like nylon are amorphous solids or viscous fluids in which the chains approximate random coils. Below T_m, amorphous regions alternate with regions which are lamellar crystals [9]. The amorphous regions contribute elasticity and the crystalline regions contribute strength and rigidity. The planar amide (-CO-NH-) groups are very polar, so nylon forms multiple hydrogen bonds among adjacent strands. Because the nylon backbone is so regular and symmetrical, especially if all the amide bonds are in the trans configuration, nylons often have high crystallinity and make excellent fibers. The amount of crystallinity depends on the details of formation, as well as on the kind of nylon. Apparently it can never be quenched from a melt as a completely amorphous solid. When extruded into fibers through pores in an industrial spinneret, the individual polymer chains tend to align because of viscous flow. If subjected to cold drawing afterwards, the fibers align further, increasing their crystallinity, and the material acquires additional tensile strength [5]. In practice, nylon fibers are most often drawn using heated rolls at high speeds. When dry, polyamide is a good electrical insulator. However, polyamide is hygroscopic. The absorption of water will change some of the material's properties such as its electrical resistance [4].

b) Physical Properties

Semicrytalline nylons, comprise the vast majority of commercial resins. Nylon is also available in an amorphous form that gives rise to transparency and improved toughness at the expense of high temperature properties and chemical stress-crack resistance.

- Density: Density (ρ) depends on the nature of atoms present in the chemical structure and the way molecules (chains) pack together. Conformations and crystalline phases are general more dense than amorphous phases, an average ρ_c / ρ_a ratio of 1.13±0.08 has been determined.
- Crystallinity: For common nylons such as nylon-6 and nylon-6/6, the regular spatial alignment of amide groups allows a high degree of hydrogen bonding to be developed when chain are aligned together, giving rise to a crystalline structure in that region. These nylons are semicrystalline materials that can be thought of as a combination of ordered crystalline regions and more random amorphous areas having a much lower concentration of hydrogen bonding. This semicrystalline structure gives rise to the good balance of properties .The crystalline regions contribute to the stiffness, strength, chemical resistance, creep resistance, temperature stability, and electrical properties; the amorphous areas contribute to the impact resistance and high elongation.
- Moisture Absorption: A characteristic property of nylon is the ability to absorb significant amounts of water. This related to the polar amide groups around which water molecules can become coordinated. Water absorption is generally concentrated in the amorphous regions of the polymer were it has the effect of plasticizing the material by interrupting the polymer hydrogen bonding, making it more flexible (with lower tensile strength) and increasing the impact strength. The T_g is also reduced. Nylon-6 has a higher moisture absorption than nylon-6/6 because of its lower crystallinity.

c) Mechanical Properties

The properties of nylon are effected by the type of nylon (including copolymerization), molecular weight, moisture content, temperature, and the presence of additives. Strength and modulus (stiffness) are increased by increasing density of amide groups and crystallinity in aliphatic nylons; impact strength and elongation, however, are decreased. Nylon-6 having a lower crystallinity than nylon-6/6 has a higher impact strength and slightly lower tensile strength. Increasing molecular weight gives increased impact strength without having a significant effect on tensile strength. Increasing moisture content reduces the T_g above which the modulus and tensile strength drop significantly; however, some polyamides with a high T_g, such as those containing aromatic monomers, have little change in properties with changing moisture as the T_g remains above room temperature. Increasing moisture for nylon-6 and nylons-6/6 also gives a steady increase in impact strength as a result of increasing plasticization, although at very low temperatures moisture can embrittle nylon.

Properties such as stiffness and strength can be considerably increased by adding a reinforcing agent to the polymer, particularly glass or carbon fiber. Inclusion of a filler or reinforcement forces the material to fail in a brittle rather than ductile fashion. Mechanical properties can also be modified by the inclusion of plasticizers, which have a similar effect to that of water in breaking down hydrogen bonding in the amorphous region and increasing ductility, flexibility, and impact strength.

Two more properties for which nylon shows particular advantages are abrasion resistance and coefficient of friction. These properties make the material suitable for use in, for example, unlubricated bearings and intermeshing gears; nylon has been used in such applications from an early stage in its development. Wear and friction properties can be further improved by use of appropriate additives. Table 2.2-2.7 below showed properties of nylon-6 and nylon-6/glass fiber.

Table 2.2 Mechanical Properties of Nylon-6 [7]

Mechanical Properties		Conditions		
		State 1	State 2	ASTM
Tensile Strength (MPa)	42 - 166	at break		D638
	91	at yield	dry (0.2% water content)	D638
	52	at yield	50% relative humidity	D638
Compressive Strength(MPa)	90 - 111			D695
Flexural Strength (MPa)	109		dry (0.2% water content)	D790
Flexural Strength (MPa)	41		50% relative humidity	D790
Izod Impact (J/cm)	0.3 - 1.2		dry (0.2% water content)	D256A
	1.6		50% relative humidity	D256A

Table 2.3 Physical and Processing Properties of Nylon-6 [7]

Physical and Processing Properties		Conditions	
		State	ASTM
Water Absorption (% weight increase)	8.5 - 10	Saturated	D570
	1.3 - 1.9	after 24 hrs	D570
Melt Flow (gm/10 min)	0.5 - 10		D1238
Processing Temperature (°C)	210 - 220	T_m,crystalline	
	227 - 288	Injection molding	
	227 - 274	Extrusion	
Molding Pressure (MPa)	7 - 138		
Compression Ratio	3 - 4		
Linear Mold Shrinkage (cm/cm)	0.003 - 0.015		D955

Table 2.4 Mechanical Properties of 15 wt% Glass Fiber Reinforced Nylon-6 Composite [7]

Mechanical Properties		Conditions		
		State 1	State 2	ASTM
Tensile Strength (MPa)	131	at break	Dry (0.2% water content)	D638
	71	at break	50% relative humidity	D638
Izod Impact (J/cm)	0.6			D256A

Table 2.5 Physical and Processing Properties of 15 wt% Glass Fiber Reinforced Nylon-6 Composite [7]

Physical and Processing Properties		Conditions	
		State	ASTM
Specific Gravity	1.23		D792
Water Absorption (% weight increase)	8	saturated	D570
	2.6	after 24 hrs	D570
Melting Temperature (ºC)	220	T_m, crystalline	
Processing Temperature (ºC)	272 - 291	general	
Linear Mold Shrinkage (cm/cm)	0.002 - 0.003		D955

Table 2.6 Mechanical Properties of 30 wt% Glass Fiber Reinforced Nylon-6 Composite [7]

Mechanical Properties		Conditions		
		State 1	State 2	ASTM
Tensile Strength (MPa)	166 - 191	at break	dry (0.2% water content)	D638
	131	at break	50% relative humidity	D638
Compressive Strength (MPa)	132 - 166			D695
Flexural Strength (MPa)	235 - 249		dry (0.2% water content)	D790
Flexural Strength (MPa)	145		50% relative humidity	D790
Elongation at break (%)	3 - 4		dry (0.2% water content)	D638
Izod Impact (J/cm)	1.1 - 1.8		dry (0.2% water content)	D256A
Izod Impact (J/cm)	2.0 - 2.9		50% relative humidity	D256A

Table 2.7 Physical and Processing Properties of 30 wt% Glass Fiber Reinforced Nylon-6 Composite [7]

Physical & Electrical Properties		Conditions	
		State	ASTM
Specific Gravity	1.35 - 1.42		D792
Water Absorption (% weight increase)	6.4 - 7	Saturated	D570
	0.9 - 1.2	after 24 hrs	D570
Melting Temperature (°C)	210 - 220	T_m, crystalline	
Processing Temperature (°C)	238 - 288	injection molding	

d) Chemical Properties

Effect of Chemicals and Solvents: Resistance is least to strong acids and phenols which are most effective at disrupting the hydrogen bonding and which can sometimes dissolve the nylon. Highly polar materials such as alcohols are absorbed and sometimes dissolve the nylons containing lower concentrations of amide groups.

Ethylene glycol, which is used in engine coolants, is absorbed by polyamide and dissolves nylon-6/6 (and nylon-6) above 160 °C. Certain metal salts can attack nylon causing stress cracking, eg, zinc or calcium chloride, or even dissolve the material in alcoholic solution, eg, lithium chloride.

Table 2.8 below showed the chemical resistance of nylon-6 in comparison with the other engineering thermoplastics.

Table 2.8 Chemical Resistance of Engineering Thermoplastics [1]

Material	Ketones	Acid		Alkali	Alcohol	Hydrocarbons (aromatic)	Greases and oil
		Dilute	Conc.				
PET		G	P	G	F	G	G
PBT		G	F	G	G	G	G
PC		F/G	P	G	P	G	P
PMMA	G	F	G	F	P	P	P
ABS		G	F		P		P
PA6,6	P	P	G	G	G	G	G
PA6	**P**	**P**	**G**	**G**	**G**	**G**	**G**

Note: G = Good, F = Fair, P = Poor

2.1.3 Reinforcement

The tensile strength of nylon-6 is increased by more than 2.5 times and stiffness by almost 4 times by adding 30 wt% glass fiber. Class fiber reinforced also improves dimensional stability, notched impact strength, temperature performance and long-term creep, and is normally used in the 15-60 wt% range. The fibers are normally added as 3- or 4.5-mm chopped strands (bunches of filaments), but the final product drops to a fraction of a millimeter after dispersion in the extruder. Other reinforcements include mineral fibers, carbon fiber, and para-aramid fibers (Kevlar). Carbon fibers give very high stiffness but are much more expensive than glass; aramid fibers increase abrasion resistance.

2.1.4 Processing

Nylons need to be processed dry to avoid molecular weight loss and processing problems. Extrusion applications require lower moisture contents (max 0.1-0.15% for nylon-6/6 and nylon-6) as do some other nylon types (eg, max 0.1% for nylon-11 and nylon-12; 0.05% for nylon-4/6). The materials are normally supplied dry by the manufactuer in moistureproof packaging such as foil-lined 25-kg bags or lined 1-ton boxes. Material that has absorbed some moisture can be redried using a vacuum oven at 80 ºC or a dehumidifier hopper drier.

Material should not be processed at too high temperature, eg, preferably not above 310 ºC for nylon-6/6 or 290 ºC for nylon-6, in order to avoid degradation. Residence times at the higher temperatures should be kept to a minimum.

Generally, nylon scrap or regrind can be reused satisfactorily, provided that it is dry. The level allowed depends on the amount of degradation and the specification of the final products.

2.1.5 Applications

More than 60% of nylon is used in injection-molding applications. About 55% of this use in the transportation industries, and most of this use is concerned with automobile production.

a) Automotive

The rapid increase in the number of new applications is strongly influencing the overall growth rates for the polymer type. Metal replacement is being driven by both weight savings (and therefore fuel efficiency) and lower manufacturing costs.

Interior: Again, polyamides have been used for some time for switches, handles, seat belt components, etc. Big new applications include air bag containers, pedals, and pedal boxes. Polyamides have also been used to replaced metals in seat systems.

Figure 2.3 Examples of Applications, such as Pedals, Gear Shift Console, Airbag Canister Housings [3]

Exterior: Probably the biggest exterior applications for polyamides is for wheel covers where mineral reinforced compositions are used to get the required degree of dimensional stability and flatness. Other exterior applications include sun roof surrounds, door handles, fuel filler flaps, etc. One special application is the use of a nylon product as a fuel barrier material in polyethylene fuel tanks.

Figure 2.4 Examples of Applications are Exterior Door Handles, Exterior Grill [3]

b) Electrical/Electronic

Uses include cable ties, connectors, light housings, plugs, and switches. Flame-retardant materials are also used for switchgears, housings, relays, circuit breaker components, and terminal strips. The advent of higher melting, higher heat-distortion temperature polyamides have allowed more temperature sensitive applications to convert to plastics.

Figure 2.5 Examples of Applications are Low Voltage Switchgear, Connectors, Lighting Electronics [3]

2.2 Gasohol

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) [10]. Because of this make gasohol has higher octane, or antiknock, properties than gasoline and burns more slowly, coolly, and completely [12]. The ethanol is usually obtained by fermentation, followed by distillation, using crops, such as maize, wheat, potatoes, rice, corn, tapioca or sugar cane [14]. 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 [15].

2.2.1 Background

The use of ethanol (alcohol) in motor vehicles is neither a new technology nor a new concept. There is extensive literature on the subject dating back into the 20’s and alcohol has an often been used in both war and peace.

Alternate energy sources must meet certain criteria to be competitive with conversional fuels. Some of special requirements [16] these energy supplies will have to meet are as follows:

1. Fuels must be capable of being stored over extended time periods,
2. Storage, transportation and distribution of fuels used should be economical,
3. Handling of alternate fuels should not involve additional hazards such as fire, explosion, etc., in comparison to conventional fuels,

4. Alternate fuels should not impose major engineering changes to processes and/or systems using them.

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 [13].

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 [10].

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 [4].

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 [4].

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 [4].

2.2.2 Ethanol in Automotive Fuel

Ethanol has a Btu content significantly higher than that of methanol (approximately 12,780 Btu/lb vs 9,500 Btu/lb for methanol). However, ethanol's Btu value is still significantly lower than gasoline's. A gallon of ethanol contains about 0.7 the Btu capacity of gasoline. The addition of ethanol to gasoline causes the Btu capacity to drop. In addition, there is much concern and controversy as to the mpg efficiency between ethanol-gasoline blends and gasoline.

Table 2.9 Comparison between the Properties of Isooctane and Ethanol [16]

Property	Isooctane (C_8H_{18})	Ethanol (C_2H_5OH)
Molecular Weight	114.224	46.07
C:H weight ratio	5.25	4.0
Boiling Point, °C at 1 atm	99.24	78.3
Vapor Pressure, psi at 37.8 °C	1.708	2.5
Specific Heat of Liquid, Btu/lb-F at 77 °F and 1 atm	0.5	0.6
Heat of Vaporization, Btu/lb at 25 °C and 1 atm	132	395
Heat of Combustion, Btu/lb at 25 °C		
-Higher heating value	20,556	12,780
-Liquid fuel-gaseous H2O	19,065	11,550
Octane Number	100	106

Ethanol also has a relatively high octane rating-106-107.5 RON (Research Octane Number) and 85-100 MON (Motor Octane Number). The addition of ethanol to nonleaded gasoline causes the octane rating to increase along with the antiknock capacity of the fuel [16].

2.2.3 Fuel Property Change with Ethanol Addition

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 2.10 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.

- 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 (27).

Table 2.10 Properties of Gasoline, Ethanol and Gasoline/Ethanol Blends [26]

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) (BTU/lb)	43.5 18,700	27 11,600	41.9 18,000	40 17,200
Heating Value (MJ/litre) (BTU/gal)	32 117,000	21.3 76,000	30.9 112,900	29.9 109,000
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

- Reid Vapour Pressure

Guibet (13) states that increases in the Reid Vapour Pressure (RVP) of 6 – 8 kPa can be expected with ethanol additions of only 3% to base gasoline with normal volatility. This increase in RVP is confirmed by Owen & Coley (11). 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 (28).

Figure 2.6 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%.

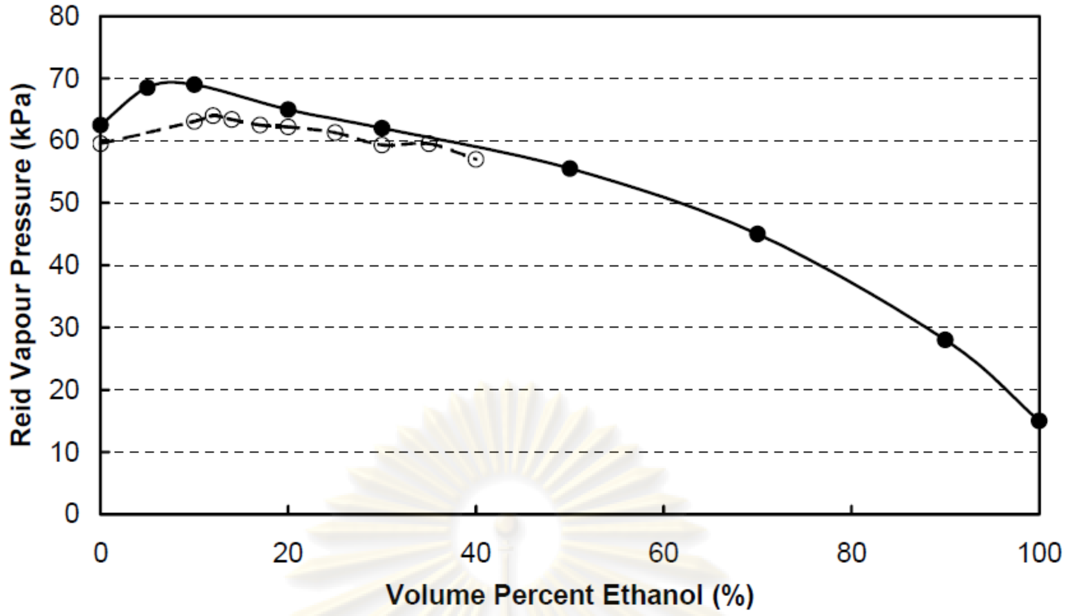


Figure 2.6 Reid Vapour Pressure with High Blend Ethanol; solid line —— Furey & Jackson, dashed line – – Guerrieri et al [26].

Table 2.11 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 2.11 Increase in RVP with ethanol addition [26]

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

2.3 Chemical Resistance

The ability of some polymers to resist strong acids, alkalis, and solvent is notable. The primary factors affecting the ability of a polymer to retain original physical properties after exposure to a reactive chemical are the exact chemical and morphological nature of the polymeric compound, type and concentration of the chemical, time and temperature of exposure, part thickness, and the mechanical stresses that are simultaneously acting on the sample. In general, chemical resistance tests, as conducted by resin suppliers and compounders, involve exposure of thin, molded plaques to a representative range of chemicals, one chemical at a time , over a limited range of temperatures, and without mechanical stress. Immediately after exposure the samples are tested for weight gain, volume swell, hardness and tensile properties, all at room temperature. Table 2.12 showed a small section of a chemical resistance rating table for one type of thermoplastic.

There are only a few special applications for which product samples have been exposed to the combined effects of chemicals and mechanical stresses for periods of years to approximate realistic expected service lives, and for which results have been published. The most notable are those for HDPE and PVC gas and water piping. Differences between relatively short-term tests and actual long-term service under combined environmental factors have to be made up at present by careful extrapolation of test results and in-depth studies of degradation mechanisms in laboratory.

Table 2.12 Effects of Chemicals on Properties of Nylon-12 [18]

Chemical	Temp. (ºC)	Time (hr)	Weight (%)	Modulus of Elasticity (GPa)	Notched Izod (kJ/m2)
Control sample	-	-	-	1.44	5.8
Sulfuric acid (1N)	23	1170	+0.9	1.13	NB
	90	331	+1.7	0.83	4.3
Sodium hydroxide (1N)	23	1293	+0.9	1.10	NB
	90	330	+1.3	0.86	NB
Benzene	23	1672	+5.9	0.91	NB
	70	330	+10.3	0.63	NB
ASTM fuel B	23	1606	+1.9	1.18	43
	70	331	+5.7	0.71	NB
Fuel B + 20% ethanol	23	1672	+14.2	0.55	NB
	70	332	+16.7	0.40	NB
Methylethyl ketone	23	1581	+2.3	0.96	NB
	68	300	+5.1	0.42	NB

Note: NB = No Breakage

The commonly used chemical resistance tests are briefly described as follows: in immersion tests with liquid chemicals, molded or machined tensile test samples (dumbbells) are completely immersed in the test liquid, which should be in a temperature controlled bath. Samples are withdrawn periodically and subjected to standard tensile stress strain tests, weight, thickness, and hardness measurements at room temperature immediately afterward. ISO 175 (ASTM D543) describes procedure in detail and gives a list of about 50 different reagents to cover the span of potentially damaging chemicals. Test data is relative, but with experience in particular product applications, results of a minor compound change to a new polymer, can be fairly reliable when combined with other data and understanding of the chemical nature of polymers. The main flaw is that the samples are under zero mechanical load during immersion. To correct this flaw, some simple tests are in use that combine mechanical stress with chemical attack over time.

In an immersion test in which the polymer does not actually breakdown because of chemical reactions with the reagent, excessive volumetric swelling will be a limiting criterion. There two stages in the process of chemical swelling by liquids. First, liquid solvent is dissolved into or absorbed on the surface of the polymer solute. Second, solvent diffuses through the free volume of the polymer. The first step occurs because solvent-solvent bonds, polymer-polymer bonds, and polymer-solvent chemical bonds for certain combinations are sufficiently similar thermodynamically that little thermal energy is needed to form solvent-polymer bonds. For convenience, imagine that the polymer is a liquid also, and that the cohesive interaction between molecules of this liquid can be measured by thermodynamic method. This interaction is measured by a property of the polymer called the *cohesive energy* density (CED), and values have been measured and published for many polymers and solvents. If the polymer CED is sufficiently similar to the solvent CED, the two materials will be compatible and the polymer will rapidly absorb the chemical solvent. Rate of diffusion of the chemical into the polymer then depends on viscosity and size of the chemical molecule, free volume of the polymer, temperature, and similar purely physical factors. As the chemical diffuses into the polymer, the polymer increases in volume or swells, and the weak interactions between macromolecules become even weaker. If the polymer is under mechanical stress, it will fail at a lower load than if it had not been chemically attacked. If a swollen polymer is not stressed, it may completely recover its original properties when the solvent is allowed time to diffuse back to the surface and evaporate. If it does recover completely, the reversibility is an indication that uptake of the chemical did not lead to chemical reactions with the polymer. Another indication of reversibility is that there is a maximum degree of swelling; that is, if weight change is plotted against time of exposure there will be an asymptote or maximum value

Water absorption is another very important property for several reasons: one is that water, the “universal solvent,” reacts chemically with the backbone chain and irreversibly degrades many polymers. A *hydrolysis reaction*, typified by water and nylon-6, is illustrated in Fig.2.7.

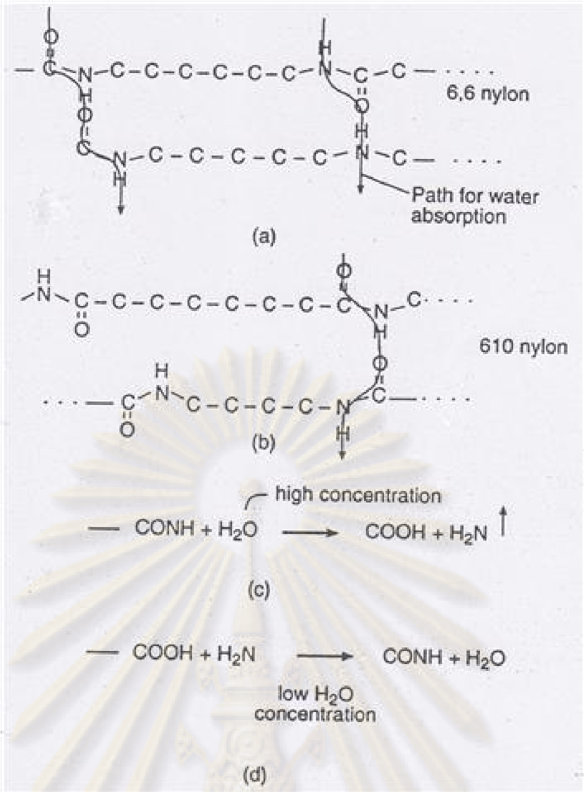


Figure 2.7 Mechanism of water absorption in nylon-6/6 (a) and nylon-6/10 (b). The greater density of pathways in (a) is reflected in an 8.5% absorption compared to only 3.5% in (b). Reaction (c) causes hydrolysis of nylons to lower MW when in the presence of high H_2O concentration (high humidity). In (d), low humidity can lead to the reverse reaction, increasing MW. Raising processing temperature favors reaction (c) for nylons and other hygroscopic plastics [18]

Hydrolysis can cause substantial decrease in tensile strength and stiffness, and increased creep strain. The chemical mechanism of the hydrolysis of nylons is that H atoms in H_2O compete with H atoms in the amine groups (N-H-O) of the nylon, associate with the electronegative O atoms, and cause chain scission. Alcohols, and partly halogenated hydrocarbons, such as chloroform, act similarly on some nylons. Fortunately, at ordinary ambient temperatures, hydrolysis reactions are rapidly only in the amorphous regions of semicrystalline plastics, such as nylons. However, at elevated temperatures, especially in the melt phase, hydrolysis reactions occur much more rapidly; thus, it is imperative to dry nylons and other hygroscopic plastics very thoroughly before melt processing, such as extrusion or injection molding. Hydrolysis reactions are possible with other condensation plastics, such as polyesters and polyurethanes, in addition to nylons, which have similar weak points. To aid in safely processing such plastics, *processing stabilizers* are added which, in conjunction with predrying to remove the bulk of the absorbed moisture, prevent degradation by reacting with the remaining water in the polymer during melt processing. In other plastics, improved hydrolytic stability can sometimes be provided by changes in types of end groups or composition of the backbone in the polymer. These chemical modifications must not decrease other physical properties while they improve the processing stability.

A second effect of water is physical destruction of adhesive bonds between polymers and fillers or reinforcing fibers. This causes strength loss in fiber-reinforced composites, and chalking or pigment diffusion to the surface (bloom) in other cases. A third effect of water is photochemical, involving generation of hydroxyl radicals or other reactive species, which can then promote other free radical reactions. Finally, excessive water absorption can lead to distortion of a molded part as a result of lowering the glass transition temperature by plastification.

In addition to effects on mechanical properties and thermal processing, absorbed moisture can affect dimensional stability of parts and reduce electrical insulating properties. There are also potential hazards when moisture absorption is combined with other chemical attack factors or with weathering. As an example of the effects of long-term humid aging on nylon-12 with 30% fiberglass content, samples tested for 10 months in dry heat at 93 ºC increased slightly in tensile strength and elongation, but decreased by 66% in both factors when exposed with no load at 93 ºC and 100% relative humidity. Samples of nylon-6/6 with 33% glass fiber showed 40% to 50% reductions in tensile and flexural strengths after 4 years of exposure to a jungle test site. Nylon-11 showed only 20% to 25% losses in the same exposure.

A quick and simple test to determine if a polymer may be sensitive to degradation by hydrolysis is the *24-hour water absorption test* (ASTM D 570) in distilled water at 23 ºC (Table 2). ASTM D 570 and ISO 62 also describe tests for longer durations (up to equilibrium uptake) and in boiling water. Percentage water absorption by weight is the reported value in all cases.

In reality, the 24-hr immersion test can be deceiving because it does not represent the equilibrium water uptake, which can take many weeks to attain for many important plastics. For example, for nylon-11, a 1-mm thick sample takes 5 weeks to reach a final water absorption of 1.9%, and a 2-mm thick sample requires 20 weeks. Nylon-11 reinforced with 30% glass fibers takes 10 weeks to reach equilibrium at 1.4%. Equilibrium moisture content of a polymer depends not only on thickness and filler content, but also on temperature, relative humidity, and plasticizer content. Glass fibers often decrease moisture vapor diffusion because the silane used to treat the glass fiber surface for adhesion to the resin matrix is hydrophobic; this tends to prevent water diffusion along the fibers. On the other hand, moisture absorption and diffusion in thermosetting plastics without fillers is very low, but will increase if hydroscopic fillers (diluents), such as wood flour are added.

The effect of morphology on chemical resistance is important. Reduced free volume in semicrystalline polymers reduces their permeability and improves chemical resistance, as does cross-linking.

2.4 Polymer Solubility

Liquid environments can have positive and negative effects on the properties of polymeric materials. Some chemical or solvents can have detrimental effects on a polymer component. Figure 2.8 shows results of creep rupture tests done on PVC tubes as a function of the hoop stress. It can be seen that the lifespan of the tubes in contact with iso-octane and isopropanol has been significantly reduced as compared to the tube in contact with water [29,30].

The measured data for the pipes exposed to iso-octane clearly show a slope reduction with a visible endurance limit, making it possible to do long-life predictions. On the other hand, the sample exposed to isopropanol do not exhibit such a slope reduction, suggesting that isopropanol is a harmful environment with acts as a solving agent and leads to gradual degradation on the PVC surface.

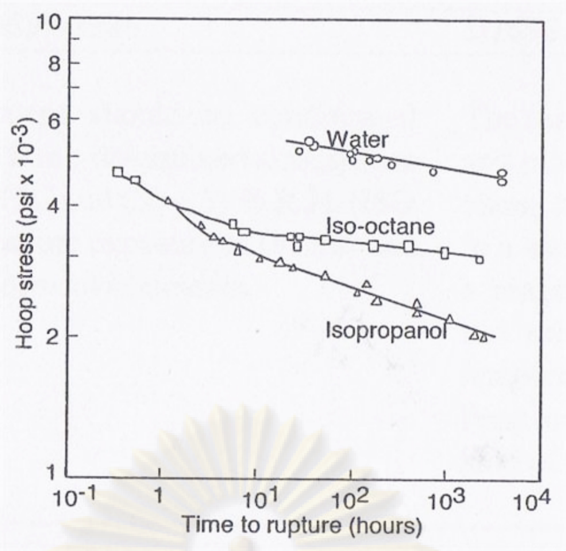


Figure 2.8 Effect of different environments on the stress rupture life of PVC pipe at 23ºC [29]

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 [29].

2.4.1 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.

2.4.2 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 ºC, is soluble in many liquids at temperature above 100 ºC, while even polytetrafluoroethylene, T_m = 325 ºC, is soluble in some of the few liquids that exist above 300 ºC. More polar crystalline polymers, such as nylon-66, T_m = 265 ºC, can dissolve at room temperature in solvent that interact strongly with them (for example, to form hydrogen bonds).

2.4.3 Solubility Parameters

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

$$\Delta G = \Delta H - T\Delta S \qquad [29]$$

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.

2.5 Composite Materials

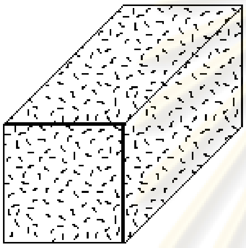
Materials consisting of more than a single phase can justifiably be described as composite materials [19]. In practice, most composites consist of a bulk material (the matrix), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This work aims to study the polymer matrix composites.

Polymer Matrix Composites (PMC) is a 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 [20]. 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 [21].

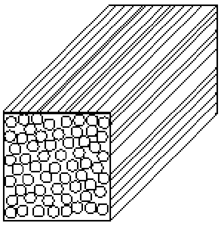
2.5.1 Common Categories of Composite Materials

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 [7]:

1. Fibers as the reinforcement (Fibrous Composites):

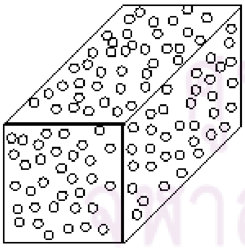


a. Random fiber (short fiber) reinforced composites

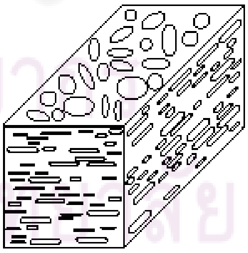


b. Continuous fiber (long fiber) reinforced composites

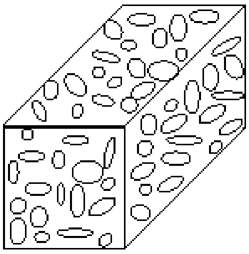
2. Particles as the reinforcement (Particulate composites)



3. Flat flakes as the reinforcement (Flake composites)



4. Fillers as the reinforcement (Filler composites):



In this work, the polymer composites, which comprise of polyamide 6 (PA6) as polymer matrix and glass fibers as reinforcement are studied.

2.5.2 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 [23, 24, 2].

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 [19, 24, 6].

2.6 Physical and Mechanical Property Testing

2.6.1 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 [31].

Figure 2.9 Scanning Electron Microscope (SEM) [32]

2.6.2 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 [30]. 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"[30]. By its basic definition the uniaxial stress is given by:

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

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

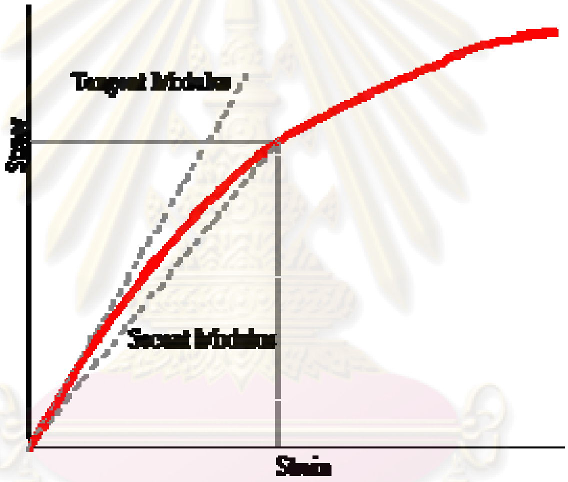


Figure 2.10 Illustration of Tensile Modulus [34]

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 Fig.2.11):

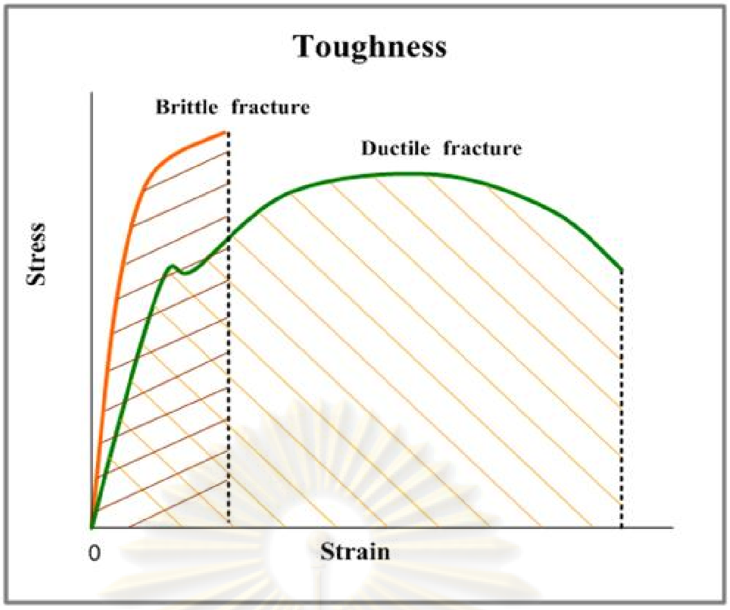


Figure 2.11 Toughness of the Ductile and Brittle of Materials [35]

- Test procedure:

A minimum of five test specimens shall be prepared by machining operation or die cutting the materials in sheet, plate, slab or similar form. Specimens can also be prepared by injection or compression molding the material to be tested. Test speed is specification in the specification for the material being tested. If no speed is specified, then use the lowest speed (5, 50, or 500 mm/min) which give rupture within 0.5 to 5.0 minutes. Modulus testing may be conducted at the same speed as the other tensile properties provided that recorder response and resolution are adequate. Extensometers are required for determining strain at yield and tensile modulus [36].

- Specimen size:

The dog-bone shape specimens are prepared for tensile testing following ASTM D638 (or ISO 527). The appearance and the dimension of sample are shown in Figure 2.12 and 2.13, respectively. At least five measurements are taken using Instron universal testing machine as presented in Figure 2.14. An average value and a standard deviation are statistically calculated.

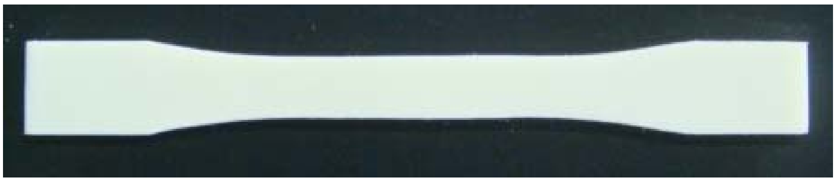
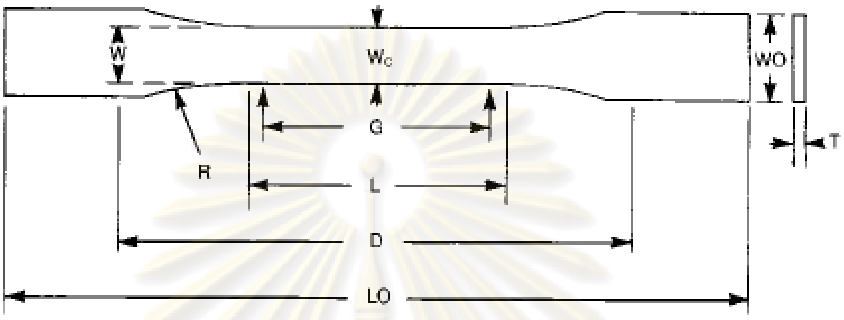


Figure 2.12 Dog-bone Shape Specimen for tensile strength evaluation



W: Width of narrow parallel portion	10 ± 0.5 mm.
L: Length of narrow parallel portion	60 ± 0.5 mm.
WO: Width at ends	20 ± 0.5 mm.
LO: Length overall, minimum	160 mm.
G: Distance between reference line	50 ± 0.5 mm.
D: Initial distance between grips	115 ± 5 mm.
R: Radius of fillet	60 mm.

Figure 2.13 Dimension of Dog-bone shape Specimen (ASTM D638 or ISO 527)

Figure 2.14 Universal Testing Machines (Instron Model 5567)

2.6.3 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 2.15. 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 [37].

- Three-Point Bend Test

In the three-point bend test, maximum flexural stress at break σ_f is calculated from fracture load F:[36]

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

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

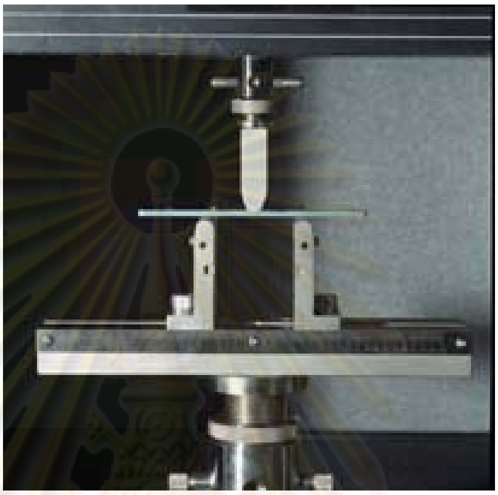


Figure 2.15 Universal Testing Machines (Instron Model T609-109) for Flexural Test [34]

- **Test Procedure:**

Most commonly the specimen lies on a support span and the load is applied to the center by the loading nose producing three points bending at a specified rate. A support span-to-dept ratio shall be of 16:1. The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain of 5.0% is reached, whichever occurs first. Procedure employs a strain rate of 0.01 mm/mm/min [39].

- **Specimen size:**

A variety of specimen shapes can be used for this test, but the most commonly used specimen size is 12.7 x 64 x 3.2 mm^3 (W×L×D) for ASTM (Figure 2.16).

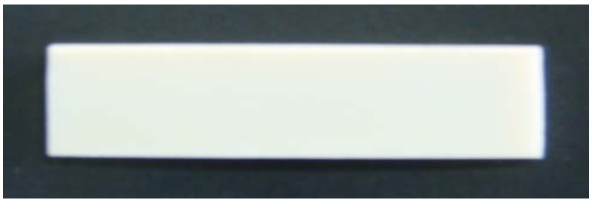
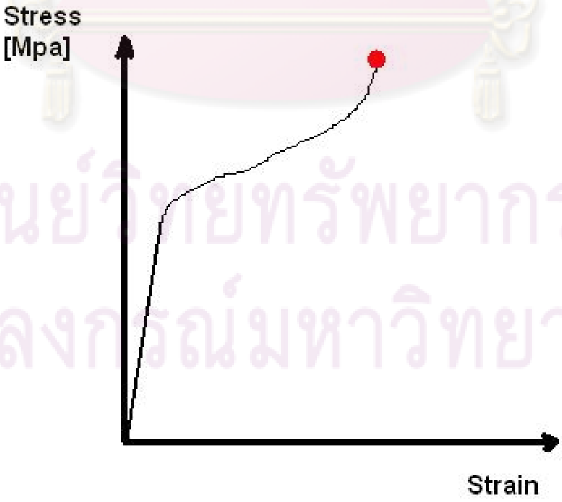


Figure 2.16 Bar shape specimen of PVC $_{stock}$ / glass fiber composite

2.6.4 Compressive 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 [30]. A large number of relatively complex loading direction and specimen configurations were developed to measure the compression strength of composite materials [36]. The compressive strength of the material would correspond to the stress at the red point shown on the curve.



Even in a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region [38] :

$$\sigma = E\varepsilon$$

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]

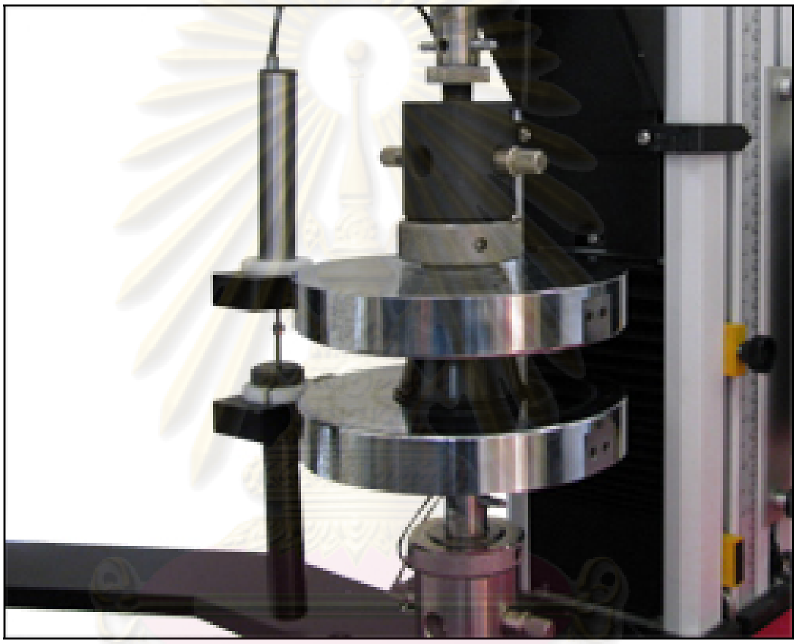


Figure 2.17 Universal Testing Machines (Instron Model T609-109) for Compressive Test

- Test Procedure:

The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture is used to determine modulus [39].

- **Specimen size:**

Specimens are blocks shape for ASTM, the typical blocks are 12.7 x 25.4 x 12.7 mm^3 (W×L×D). For ISO, the preferred specimens are 50 x 10 x 4 mm^3 (W×L×D) for modulus, 10 x 10 x 4 mm^3 (W×L×D) for strength as shown in Figure 2.18.

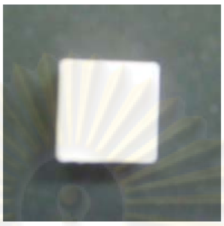


Figure 2.18 Specimen (blocks) for Compressive Properties evaluation

2.6.5 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 [36]. 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 [37].

- **Test procedure:**

The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs. ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy in J (or ft-lb) by the thickness of the specimen. At least five, preferably 10 specimens shall be prepared from sheets, composites, or molded specimens [39].

- **Specimen size:**

The bar shape specimens are prepared for Izod impact strength testing following ASTM D256 (or ISO 180) as shown in Figure 2.19 . The standard specimen for ASTM is 12.7 x 64 x 3.2 mm^3 (W×L×D) as shown in Figure 2.20. The depth under the notch of the specimen is 10.16 mm. The impact tester (Yasuda) is shown in Figure 2.21.

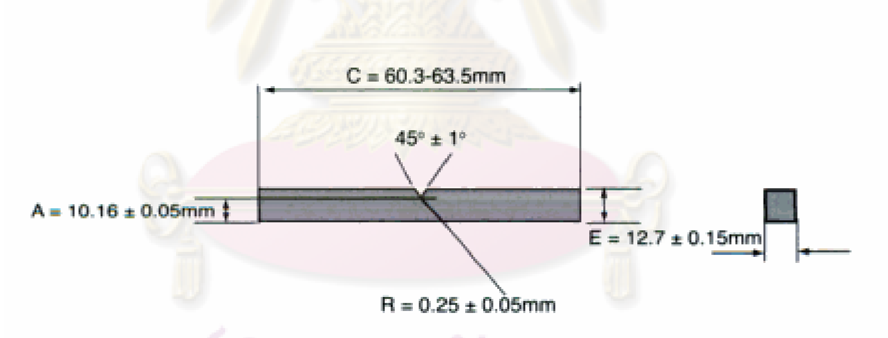


Figure 2.19 Dimension of impact test specimen ASTM D256 [39]

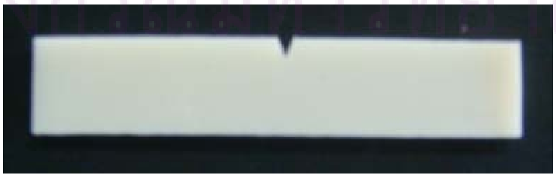


Figure 2.20 Bar shape Specimen for Izod Impact strength evaluation

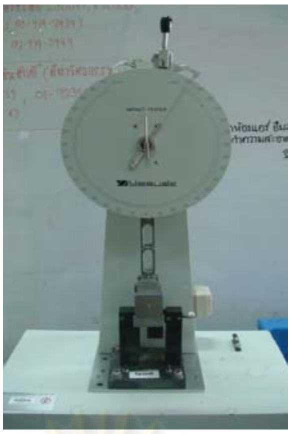


Figure 2.21 Impact Tester (Yasuda)

CHAPTER III

LITERATURE REVIEWS

A. Gullu et al. [11] in 2006 investigated the effect of 15 and 30 wt% glass fiber reinforcement on the mechanical properties of nylon 6 (PA6). Glass fibers (E glass), 13 μm in diameter and 6 mm in length, were used as reinforced in PA6. For this purpose, a die was designed and manufactured to produce tension and notched impact specimens using various injection parameters (injection speed, screw speed, heater temperatures I/II/III, injection pressure and gate types). The optical microscopy examination after the fire-ashes tests revealed that fiber length in the composites decreased with increasing fiber content. Due to the influence of injection parameters on fiber fracture and fiber orientation and consequently on the mechanical properties of the composites, injection parameters were changed. From the results, the most important parameters having influence on tensile strength and impact energy were found to be fiber length and fiber weight fraction. Glass fiber reinforcement increased the tensile strength value. According to this, the tensile strength for the unreinforced PA6 was found to be 64.7 MPa, while it increased to 112.38 and 136.61 MPa or 74% and 111% increments in the tensile strength with the addition of 15 and 30 wt% reinforcement materials, respectively, as shown in Figure 3.1.

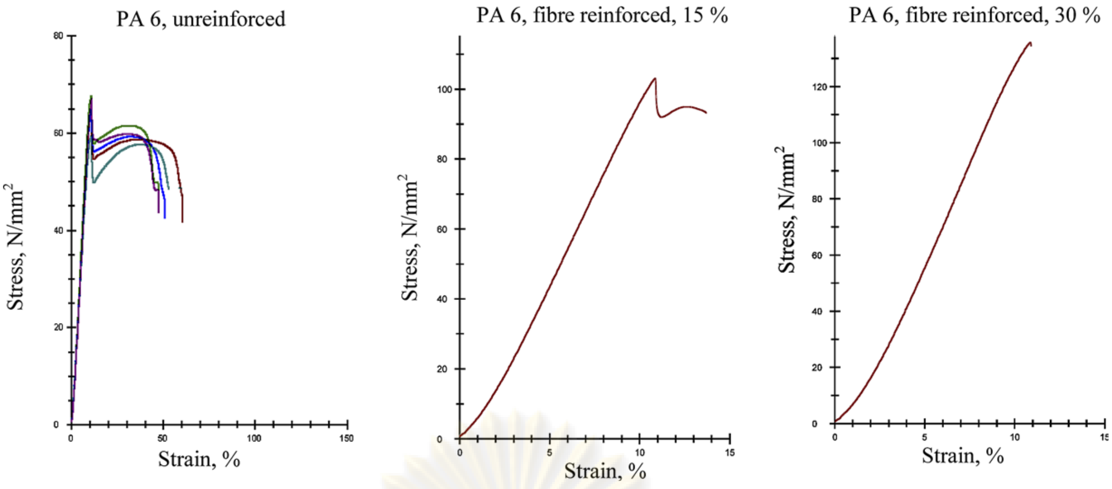


Figure 3.1 Stress–Strain Diagrams for Unreinforced and Fiber Reinforced Nylon-6 Materials [11]

It was observed that fiber reinforcement had different mechanisms on the impact energy. The 15 wt% fiber reinforcement decreased the impact energy of PA6 by 21%, while the 30 wt% fiber reinforcement increased the impact energy 9%. Depending on the fiber length in the composite, increasing fiber length improved the tensile strength and increasing fiber fracture improved the impact energy value. With increasing injection speed, fiber fractures increased and the fibers were oriented perpendicularly to the flow direction. Tensile strength decreased and impact energy increased with increasing injection speed and injection unit screw speed. Among injection parameters, increasing injection back pressure, feeding unit temperature and gate cross section increased tensile strength and decreased impact energy.

B. Jones et al. [22] in 2008 compared the effects of E20 versus E10 and gasoline on plastic materials found in automotive and small engine fuel system components. The eight materials included in this study were Acrylonitrile Butadiene Styrene (ABS), Polyamide 6 or Nylon-6 (PA6), Polyamide 66 or Nylon-66 (PA66), Polybutylene Terephthalate (PBT), Polyethylene Terephthalate (PET), Polyurethane (PUR), Polyvinyl Chloride (PVC) and Polyetherimide (PEI). Plastic samples were prepared using SAE and ASTM standards and exposed to blends of ASTM Fuel C; 90 vol% Fuel C and 10 vol% aggressive ethanol called E10; and 80 vol% Fuel C with 20 vol% aggressive ethanol called E20 at an elevated temperature of 55 ºC for 3,024 hours. The fuel was changed in weekly intervals for the 18-week study. The test samples were placed in 2-L glass jars with Teflon® lids. Stainless safety wire was used to suspend the samples in the test fluid and glass beads were used to keep the samples separated during the soaking period. The appropriate test solution was added to each of the jars and the test specimens were hung from the inner liner of the cap by stainless wire. The soaking apparatus was shown in Figure 3.2 below.

Figure 3.2 Test Container [22]

Examples of the various materials included in the study were displayed in Figure 3.3. The study focused on comparison of the changes in the physical properties of the materials after being immersed in each test fluid. Many of the materials demonstrated more discoloration when exposed to higher concentrations of ethanol-based fuels.

Figure 3.3 Samples Included in Study [22]

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 test fuels to varying degrees. The ABS specimens failed after less than one week of immersion in all three test 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. Finally, no automotive or small engine fuel system applications of ABS could be located, quite possibly due to its incompatibility with fuel. PVC (flexible version) demonstrated significant changes in mass and volume in all three fuels but to a higher degree in ethanol fuels. The PBT data also showed significant changes in impact resistance in all three fuels but to a greater extent in the ethanol blends. PUR (55D-90A durometer hardness) was deemed incompatible with both E10 and E20 due to cracking and changes in mass, volume, tensile strength, and elongation. In each case with PVC, PUR, and PBT both E10 and E20 caused large enough changes to raise a concern. Because of this, these materials would be a poor choice for use with either E10 or E20. Finally, no fuel system components made of either PUR or PVC could be located. Different degrees of discoloration were observed in many of the other test samples, slight yellowing of plastics occurred on a few samples with E20 causing more yellowing. Samples were marked with an engraver for identification purposes. All can still be easily read with the exception of the PUR sample immersed in E20. Discoloration does not mean a failure in an automotive fuel system component.

T. Jiang et al. [25] in 2005 prepared nylon6/clay nanocomposite by mixing organized montmorillonite with PA6. Solvent permeation resistance of nanocomposite was measured to estimate the resistance to solvent permeation. The permeation barrier properties of PA6 and PA6/OMMT resins were determined based on their hot-pressed sheets, because it was well known that pure PA6 and PA6/OMMT resins are difficult to process by blow molding due to their poor melt strengths. The dried pellets were hot-pressed into about 0.5 mm think sheets and cut into circular sheets with a diameter of 4.5 cm. The circular sheets were sealed as lids on the top of test flasks filled with 30 ml of the solvents (toluene and ethanol). The permeation barrier properties were determined by measuring the weight loss of the solvent after placing the flasks at 50 ºC for 14 days. The permeation barrier of hot pressed sheets of PA6 and PA6/OMMT nanocomposites resins were showed in Figures 3.4 and 3.5. The toluene and ethanol permeation resistance of nanocomposites sheets were better than those of the pure PA6 sheet, and the barrier improvements of the nylon6/OMMT nanocomposites sheets reached the maximum value as the amounts of OMMT obtained in the PA6/OMMT nanocomposite approaches 0.1 phr, which was about 3 and 4 times slower than that of pure PA6 to toluene and ethanol, respectively.

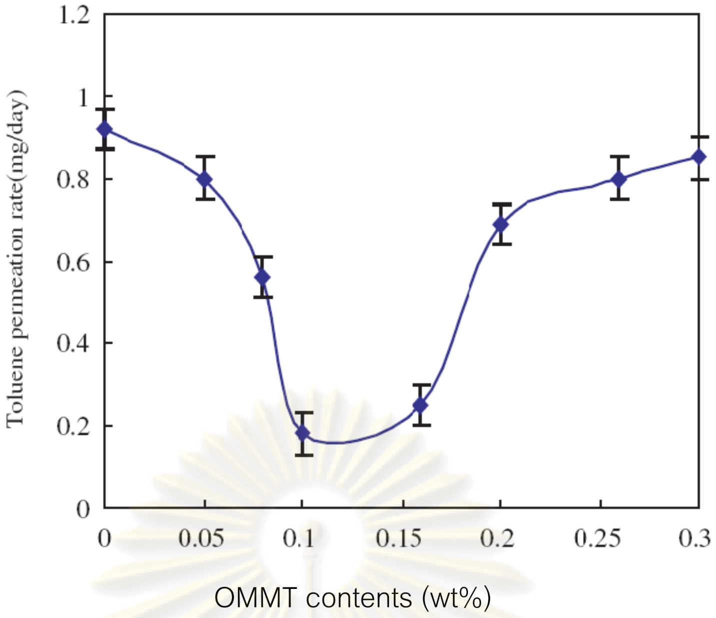


Figure 3.4 Toluene Permeation Rates of PA6/OMMT Nanocomposites as a Function of OMMT [25]

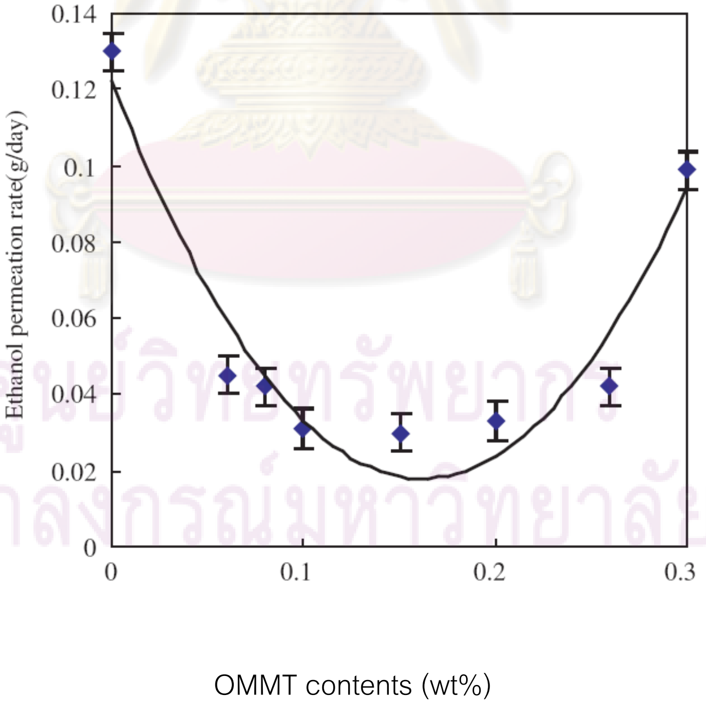


Figure 3.5 Ethanol Permeation Rates of PA6/OMMT Nanocomposites as a Function of OMMT [25]

However, the permeation rate of the solvent in PA6/OMMT nanocomposites tended to increase with the increasing contents of OMMT.

CHAPTER IV

EXPERIMENTS

4.1 Materials, Chemicals and Equipments

4.1.1 Materials

PA6 resin (1015B) and PA6 compound with 15 wt% glass fiber (1015GC3) and 30 wt% glass fiber (1015GC6) was provided by UBE Nylon Thailand Limited.

4.1.2 Chemicals

All test fuels used in this study met SAE J1681's criteria. The four test fuels used included: $C(E0)_A$, $C(E20)_A$, $C(E85)_A$, and $C(E100)_A$. The chemical required for fuels preparation was obtained from Merck Chemical that were:

- Ethanol (AR Grade, Merck Chemical)
- Isooctane (AR Grade, Merck Chemical)
- Tolulene (AR Grade, Merck Chemical)
- Sodium Chloride (AR Grade, Merck Chemical)
- Sulfuric Acid (AR Grade, Merck Chemical)
- Glacial Acetic Acid (AR Grade, Merck Chemical)

4.1.3 Equipments

- Universal testing machine
- Compression molding
- Impact tester -
- Injection molding
- Vacuum oven

- Digital vernier calipers
- Notching machine
- Mettler balance
- Scanning Electron Microsope (SEM)

4.2 Test Specimens Preparation

Both PA6 resin and PA6 compound were dried in a vacuum oven at 80 °C for 24h. The materials testing required fives different shaped test specimens. The shaped test specimens included are listed below and given in Fig 4.1.

- Disk : For physical properties testing
- Dumbbell : For tensile testing
- Bar : For flexural testing
- Izod : For impact testing
- Block : For compressive testing

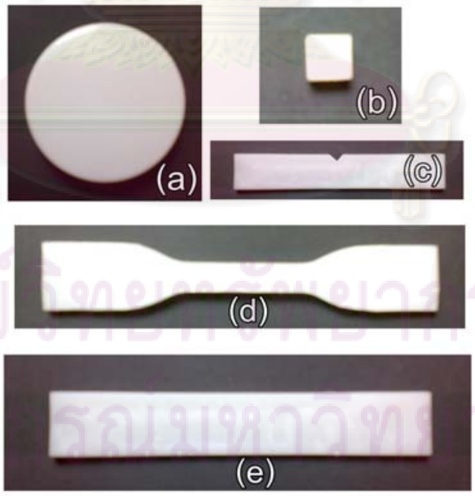


Figure 4.1 The Shape Test Specimens: Disk (a), Block(b), Izod (c) Dumbbell (d) and Bar (e)

4.2.1 Injection Molding

Dry PA6 and PA6/GF composites pellets were injection molded into standard tensile bar (ASTM D638) by Injection Molding Machine (Manumold) for measuring the tensile strength, young's modulus and flexural strength. The specimens were molded at 250, 260 and 270 ºC for unreinforced PA6, glass fiber reinforced PA6 15 wt% and 30 wt% respectively. The injction pressure was 130 bar. After molding, the specimens were placed in the vacuum desiccators before testing.

Figure 4.2 Injection Molding Machine (Manumold)

4.2.2. Compression Molding

Dry PA6 and PA6/GF composites pellets were placed at 220ºC into mold by Compression Molding Machine (as shown in Fig. 4.3). The compression process was started using parameters given in Table 4.1

Table 4.1 The Process parameters Setting of Compression Molding Machine

Procoess Parameters	Setting
Mold Temperature (ºC)	225
Preheating Time (min.)	2
Heating Time (min.)	4
Cooling Time (min.)	6
Molding Pressure (bar)	0-90

.

Disk, Izod and Block shape were prepared by Compression Molding Machine. These test specimens comforming to ASTM D570, ASTM D256 and ASTM D695 respectively.

Figure 4.3 Compression Molding Machine

4.3 Test Fuels Preparation

The test fuels used in this study were based on the test fuels standard specified in SAE J1681, Gasoline alcohol and diesel fuel surrogates for materials testing. Fuel C represents a worst-case-scenario gasoline due to its composition of 50 vol% iso-octane and 50 vol% toluene [9]. The four test fuels used in this study included

1. $C(E0)_A$ = Fuel C 100 vol% + Aggressive ethanol 0 vol%
2. $C(E20)_A$ = Fuel C 80 vol% + Aggressive ethanol 20 vol%
3. $C(E85)_A$ = Fuel C 15 vol% + Aggressive ethanol 85 vol%
4. $C(E100)_A$ = Fuel C 0 vol% + Aggressive ethanol 100 vol%

Formulation of aggressive ethanol components to make 1.0 L are:

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

4.4 Test Procedure

The test specimens were placed in glass jars. Each test materials were separated jar and soaked in each test fuels until the end of experiment (for 16 weeks) at room temperature and fuels are changed every three weeks. The soaking apparatus was shown in Fig. 4.4 below.

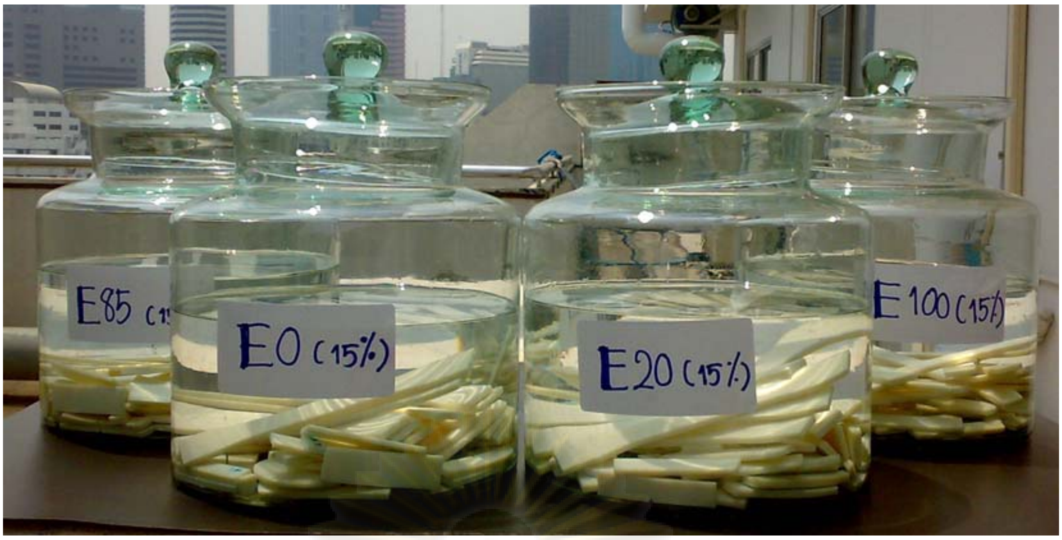


Figure 4.4 Test Containers

The specimens were taken out from the jars and left to dry in air for 24h before testing. Weights and dimensions were measured after changing test fuels while mechanical properties were measured at 0^{th}, 4^{th}, 10^{th} and 16^{th} week using Instron Machine and Impact Tester.

4.5 Physical Properties Measurement

Five pieces of disk specimen are dried in an vacuum oven for 24 h at 80ºC and then placed in a desiccator to cool. Immediately upon cooling, the specimens are tested.

4.5.1 Water Absorption

The material is then emerged in DI water at room temperature. Specimens are removed, patted dry with a lint free cloth, and weighed at 0^{th}, 4^{th}, 10^{th} and 16^{th} week using Mettler Balance.

4.5.2 Mass and Volume Change

The material is then emerged in each test fuels at room temperature. Specimens are removed, patted dry with a lint free cloth, weighed and dimension measured after changing test fuels using Mettler Balance and Digital Vernier Calipers.

4.5.3 Morphology

The morphology of the composites Unreinforced and reinforced PA6 were observed under the Scanning Electron Microscope (SEM) 200x and 2,000x.

4.6 Mechanical Properties Measurement

4.6.1 Tensile Property Measurement

The dumbbell specimens were measured by Universal Testing Machine (INSTRON Instrument) according to ASTM D638. The crosshead of speed 50 and 5 mm/min were usd for nureinforced and reinforced PA6. Data for at least 5 specimens were statistically averaged to obtain the young's modulus and the tensile strength of PA6/GF composites.

4.6.2 Flexural Property Measurement

The bar specimens were measured by Universal Testing Machine (INSTRON Instrument) according to ASTM D790. The rate of speed 5 and 1.2 mm/min were usd for nureinforced and reinforced PA6. Data for at least 5 specimens were statistically averaged to obtain the flexural strength of PA6/GF composites.

4.6.3 Compressive Property Measurement

The block specimens were measured by Universal Testing Machine (INSTRON Instrument) according to ASTM D695. The compression rate of speed 5 and 1.2 mm/min were usd for nureinforced and reinforced PA6. Data for at least 5 specimens were statistically averaged to obtain the compressive strength of PA6/GF composites.

4.6.4 Impact Property Measurement

The izod specimens were measured by Impact Tester according to ASTM D256. Data for at least 10 specimens were statistically averaged to obtain the Impact strength of PA6/GF composites.

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 The Influences of Gasohols on Physical Properties of PA6/GF Composites

5.1.1 Scanning Electron Microscope (SEM) of PA6/GF Composites

The characteristic of the composites was observed under the Scanning Electron Microscope (SEM). The SEM micrographs of the through-thickness cross sections of specimens Fig. 5.1-5.3, clarify the extent to which morphology is dictated by glass fiber loading conditions.

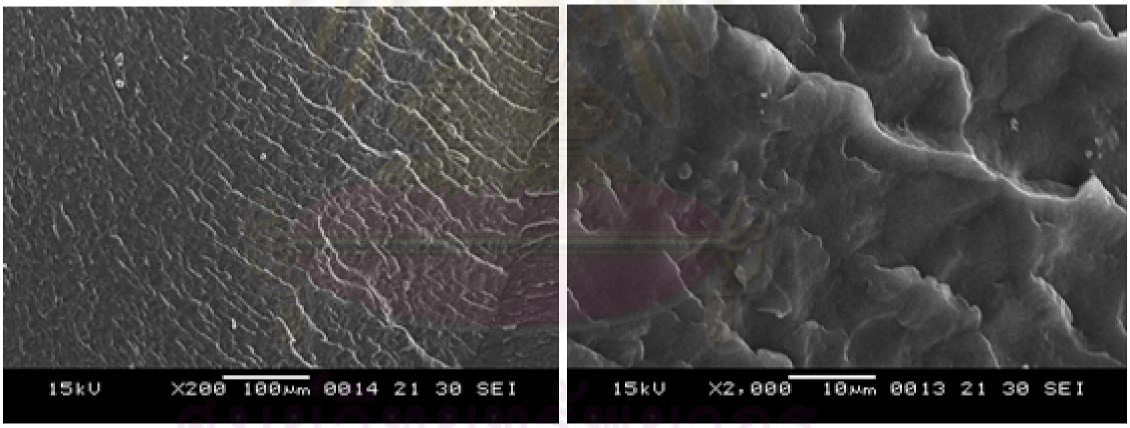


Figure 5.1 Scanning Micrographs of PA6.

Fig. 5.1 showed SEM micrograph of pure PA6. Figure 5.2 compared the fracture surface morphologies of the specimens 15 wt% (Left) and 30 wt% (Right) glass fiber reinforced PA6. The micrographs revealed the glass fiber seem to be uniformly and sparsely distributed all over the surface, but as the glass fiber content increases from 15 wt% to 30 wt% the reinforced phase seems to coalesce. When injected into fibers through pores in an machine, the composites chains tend to align because of viscous flow.

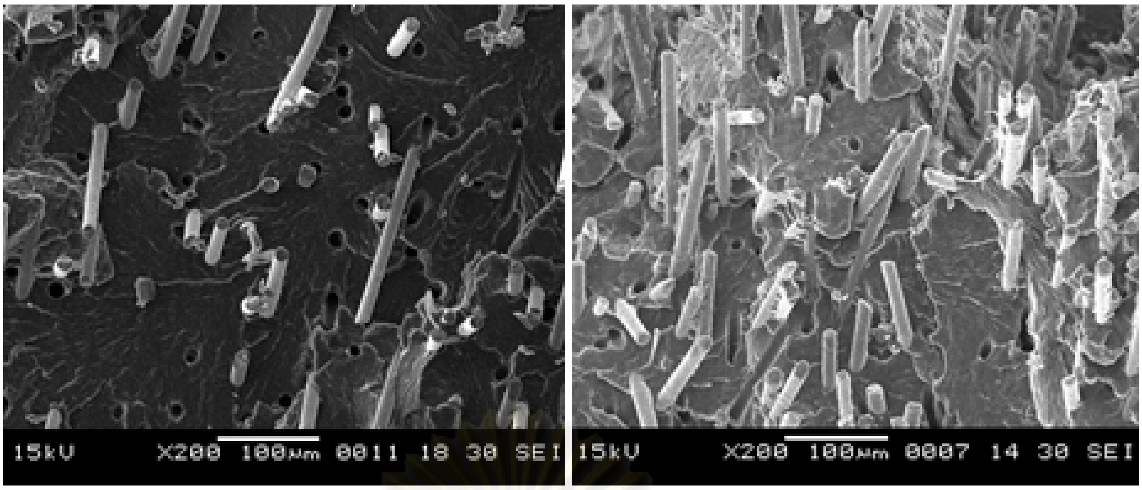


Figure 5.2 Scanning Micrographs (x200) of PA6/GF Composites, PA6 matrix containing 30 wt.% GF and 30 wt.% GF (Left and Right), respectively

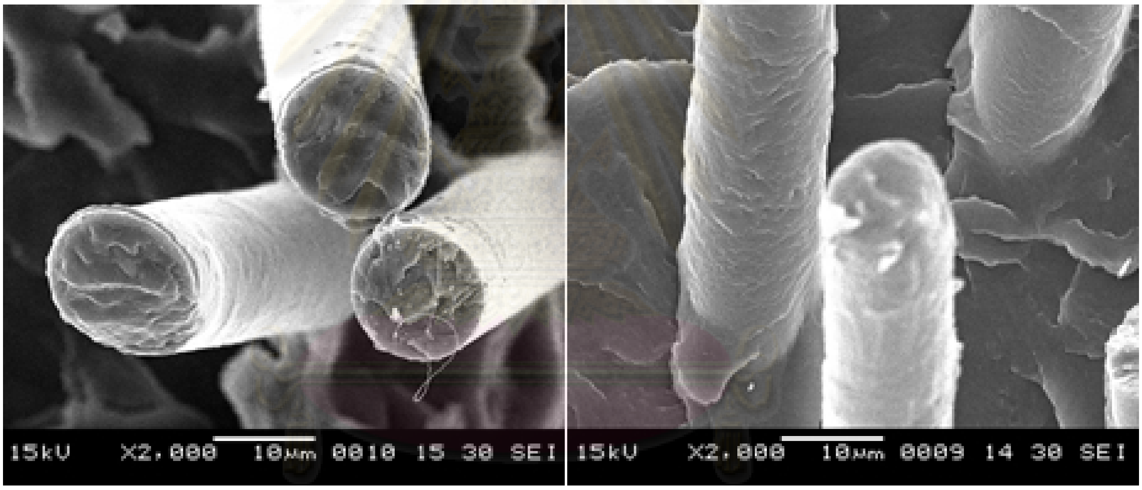


Figure 5.3 Scanning Micrographs (x2,000) of PA6/GF Composites, PA6 matrix containing 30 wt.% GF and 30 wt.% GF (Left and Right), respectively

Fig. 5.3 showed the SEM micrographs of PA6/GF composites (2,000x). The images indicated the good interfacial adhesion between the glass fiber and PA6 matrix. This indicated the use of PA6 matrix was excellent adhesion to glass fiber reinforcement. It because of PA6 was tough. This result is in agreement with that has been reported by G. Ozkoc, 2005 [41]. This morphology investigation via SEM clearly demonstrates that using glass fiber as reinforcement excellent dispersion and adhesion to PA6 matrix.

5.1.2 Water Absorption of PA6/GF Composites

Water absorption is another very important property for several reasons: one is that water, the “universal solvent,” reacts chemically with the backbone chain and irreversibly degrades many polymers especially PA6 [18].

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. 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 absorption is expressed as increase in weight percent.

Percent Water Absorption = [(Wet weight – Dry weight)/ Dry weight] x 100 [40]

Table 5.1 Percent Water Absorption of Test Materials

ASTM D570		PA6/GF Composites		
		0%GF	15%GF	30%GF
Dry Weight (g)		6.6038	7.3013	8.3474
Wet Weight (g)	After 24 hrs	6.6997	7.4015	8.4318
	Saturated	7.1657	7.8230	8.8612
% Water Absorption	After 24 hrs	1.4510	1.3715	1.0118
	Saturated	8.5076	7.1450	6.1557

Table 5.2 Percent Water Absorption of PA6/GF [7]

ASTM D570		PA6/GF Composites		
		0%GF	15%GF	30%GF
% Water Absorption	After 24 hrs	1.3-1.9	2.6	0.9-1.2
	Saturated	8.5-10	8.0	6.4-7

The water absorption of this experiments showed in Table 5.1. This results were in ranged on referent data (Table 5.2). From the results, a characteristic of PA6 was the ability to absorbed significant amounts of water. This related to the polar amide groups around which water molecules can become coordinated. Water absorption has the effect of plasticizing the material by interrupting the polymer hydrogen bonding, making it more flexible (with lower tensile strength) and increasing the impact strength [7].

Figure 5.4 shown percent water absorption of PA6/GF composites. It shown that the water absorption of the composites were increased with increasing immersion time. Water absorption has increased rapidly during the first four weeks and saturated about week 7th. The unreinforced PA6 promoted more water absorption than the glass fiber reinforced PA6. This result indicated that the use glass fiber reinforced PA6 decreased absorption of water due to the absorption of waters into specimens were mainly by PA6 matrix as shown in Fig. 5.5 when the weight increase results were adjusted to weight of PA6 matrix in composites only. This related to the polar amide groups (-CO-NH-) that exhibit very polar and hydrophilic characteristics could become coordinated with water molecules.

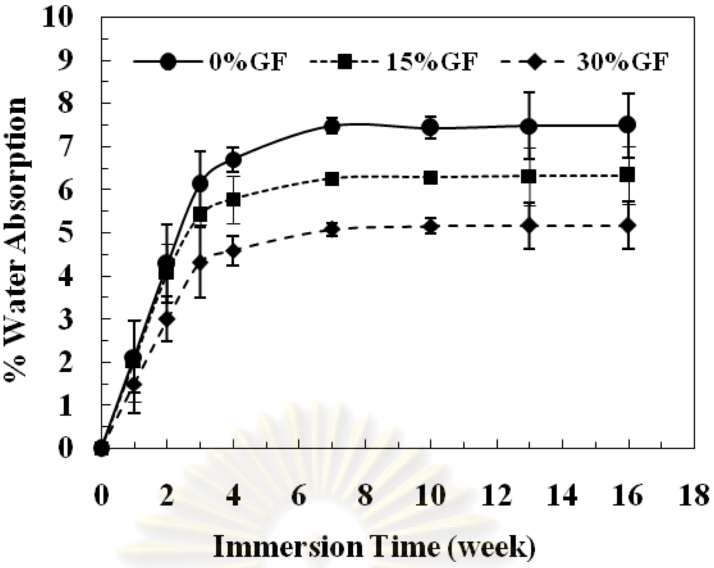


Figure 5.4 Percent water absorption of PA6 and PA6/GF composites

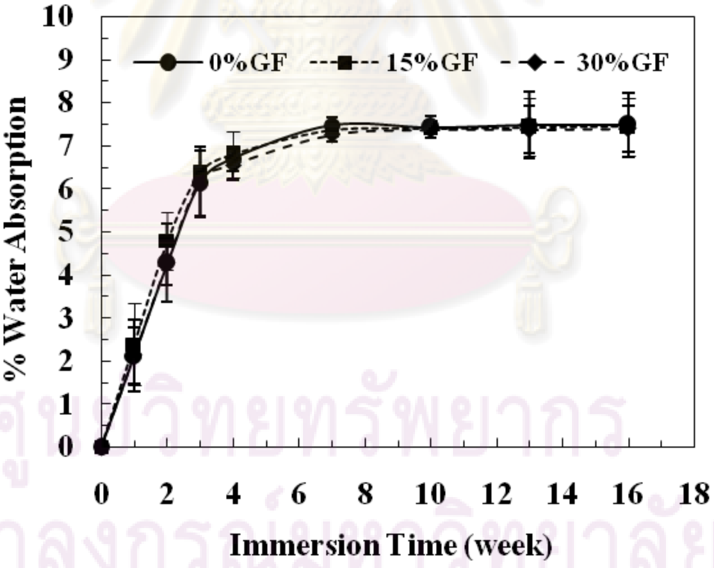


Figure 5.5 Percent water absorption of PA6 and PA6/GF composites (based on mass of PA6 matrix only)

5.1.3 Mass Change of PA6/GF Composites

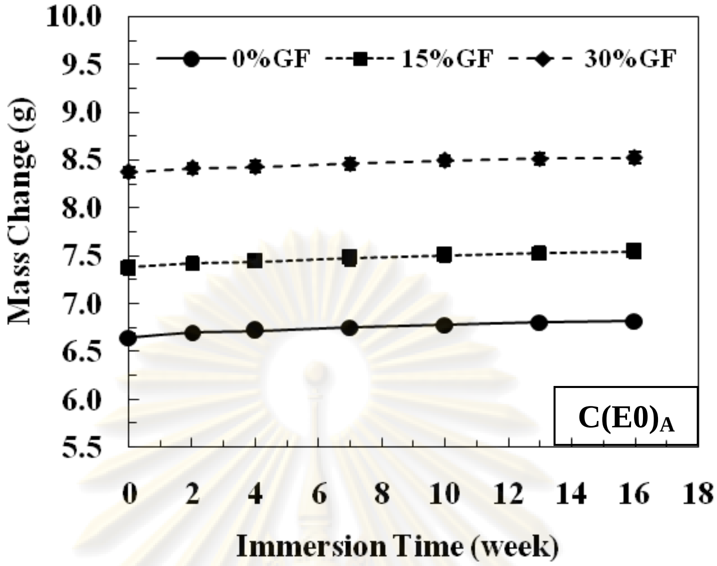


Figure 5.6 Mass change of PA6/GF composites immersed in C(E0)$_A$

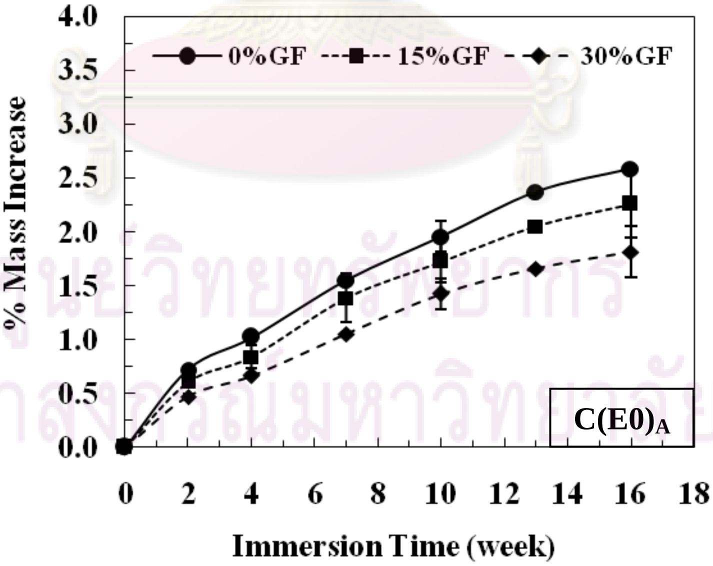


Figure 5.7 Percent mass increase of PA6/GF composites immersed in C(E0)$_A$

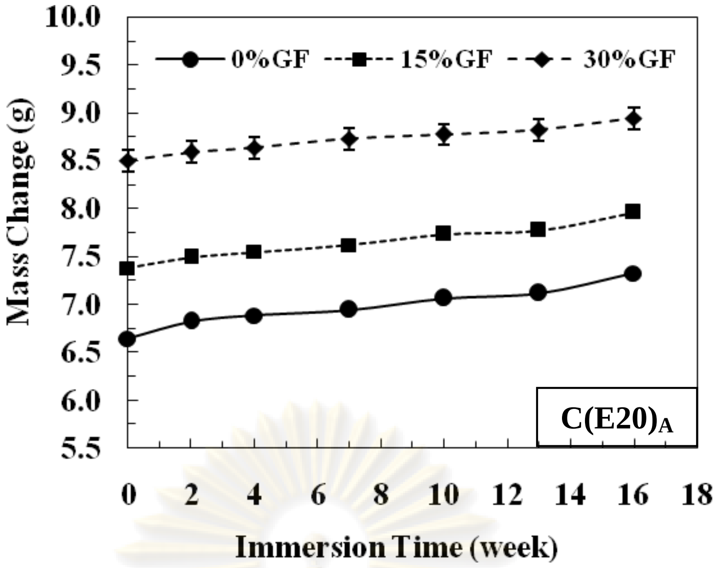


Figure 5.8 Mass change of PA6/GF composites immersed in C(E20)$_A$

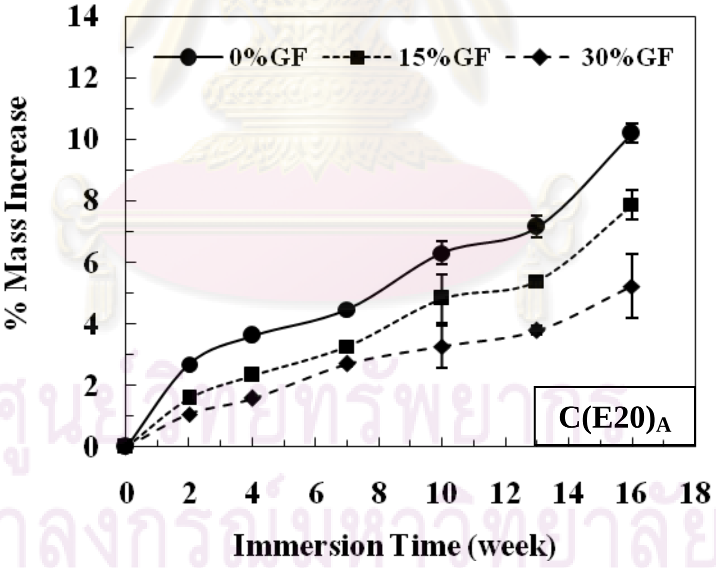


Figure 5.9 Percent mass increase of PA6/GF composites immersed in C(E20)$_A$

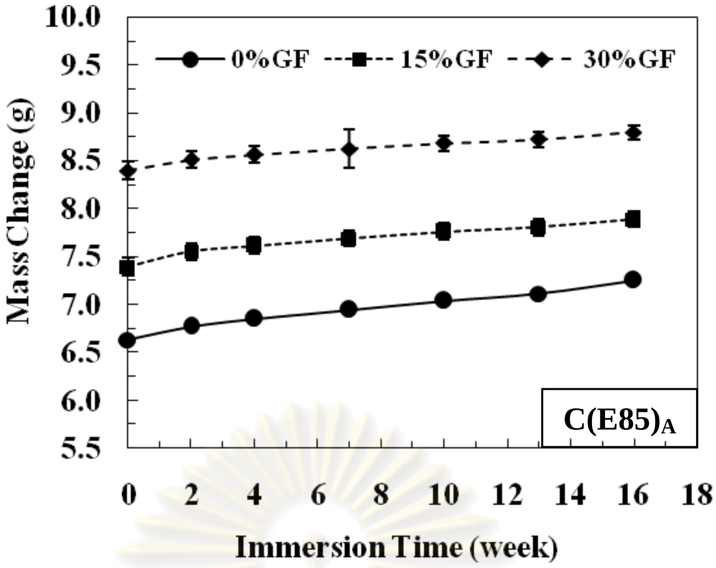


Figure 5.10 Mass change of PA6/GF composites immersed in $C(E85)_A$

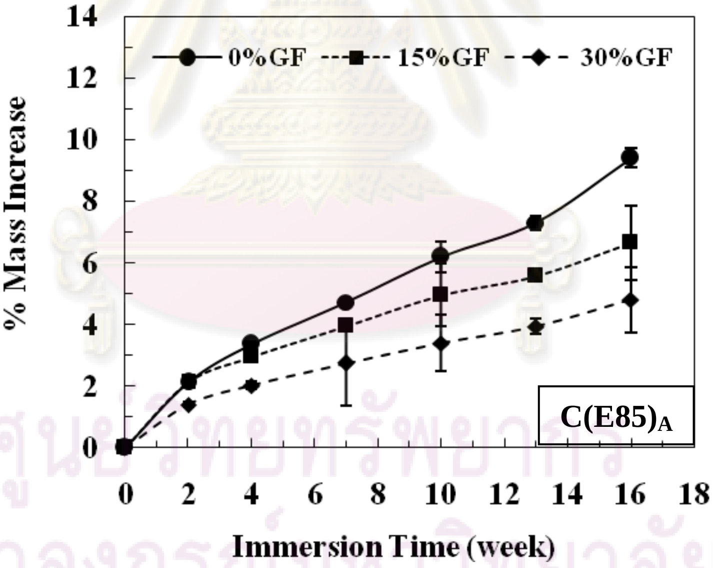


Figure 5.11 Percent mass increase of PA6/GF composites immersed in $C(E85)_A$

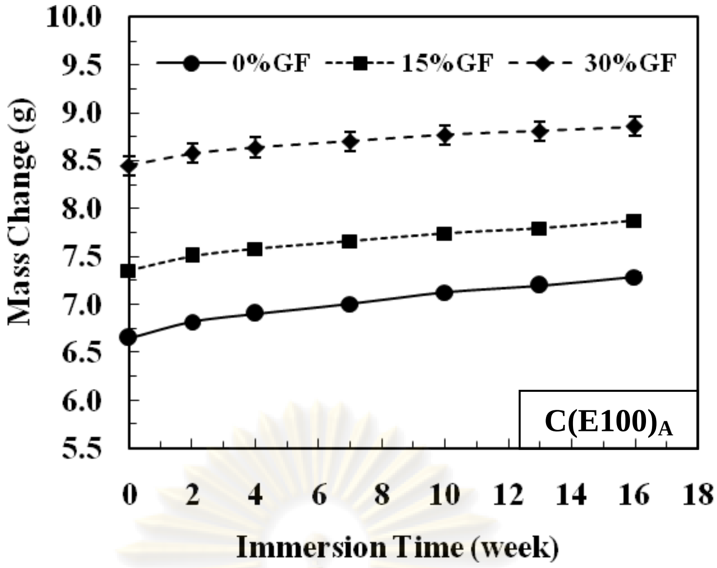


Figure 5.12 Mass change of PA6/GF composites immersed in C(E100)$_A$

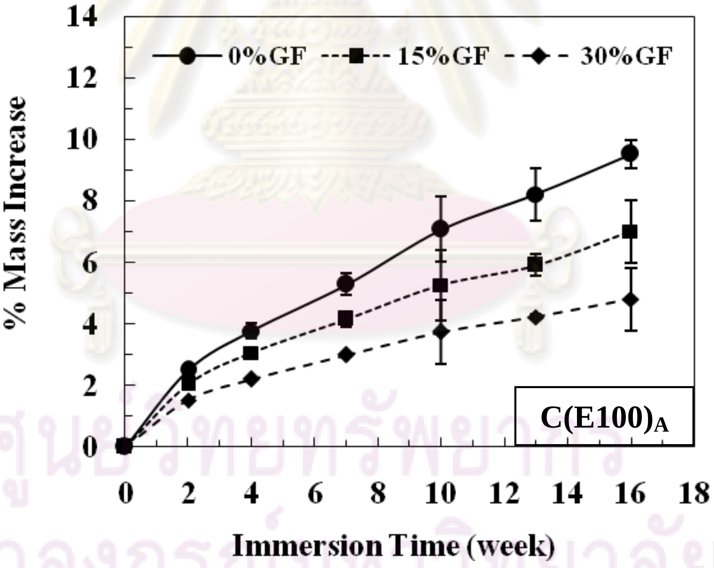


Figure 5.13 Percent mass increase of PA6/GF composites immersed in C(E100)$_A$

Fig. 5.6-5.13 showed that the weight change of specimens immersed in test fuels were increased with increasing of immersion time. The cause of this was the absorption of the fuels into the polymer matrix. This was often a slow process due to the vastly different dimensions of solvent and polymer molecules so the immersion time of this experiment not enough for saturation of mass increase. Considering the influences of glass fiber contents, the high fiber content showed the good results for the materials. The increase amount of glass fiber content in the composites could decreased the absorption that were mainly by PA6 matrix.

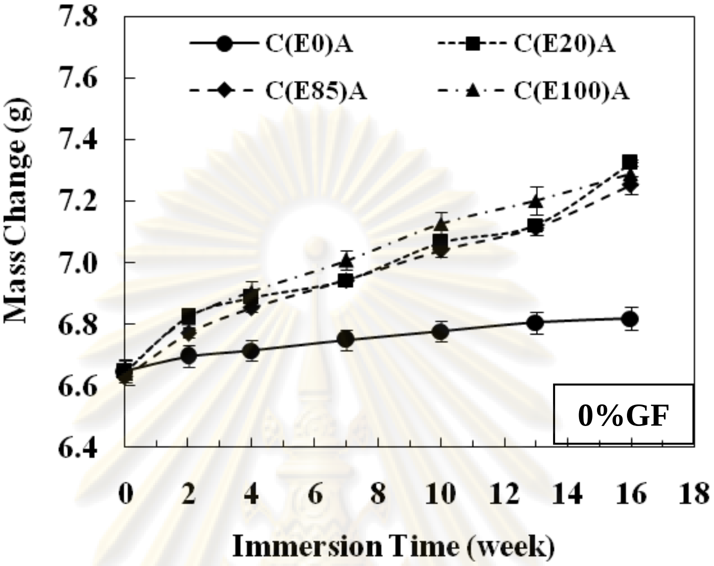


Figure 5.14 Mass change of PA6 immersed in test fuels

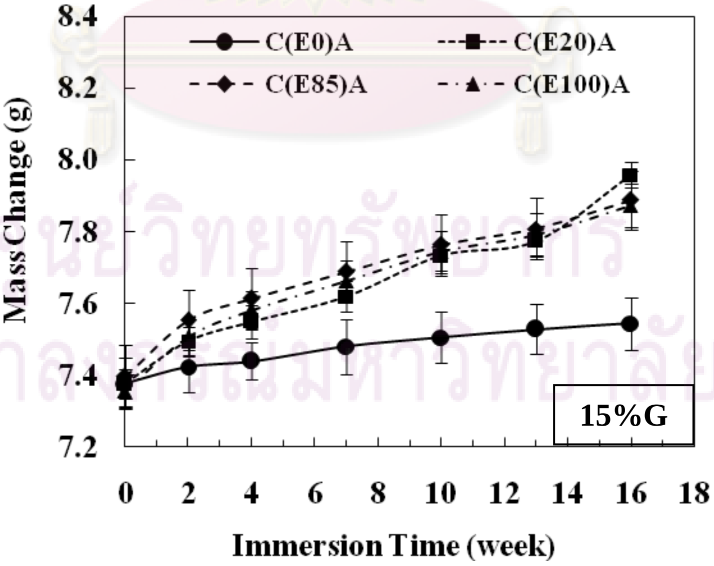


Figure 5.15 Mass change of PA6/GF (15 wt%) immersed in test fuels

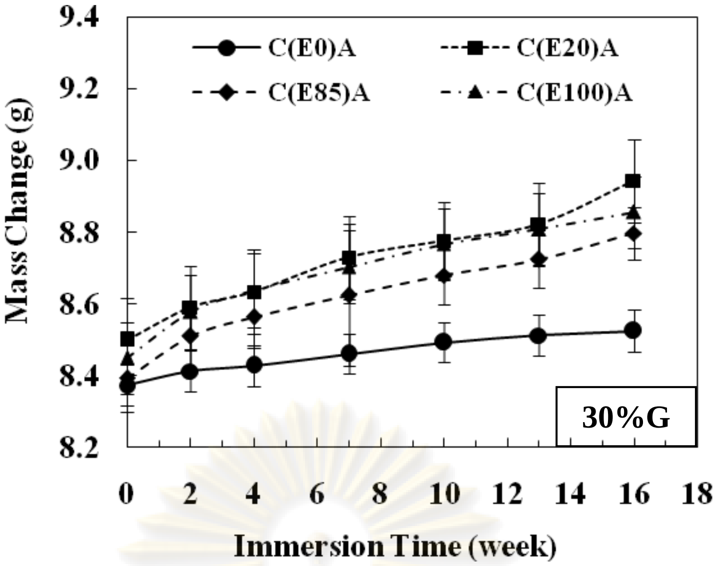


Figure 5.16 Percent mass increase of PA6/GF (30 wt%) immersed in test fuels

Fig. 5.14-5.16 showed the mass change of the unreinforced PA6 and the glass fiber reinforced PA6 15 wt% and 30 wt% immersed in each test fuels. The effects of the test fuels with the differ amount of aggressive ethanol content were investigated. From the figure, the surrogate gasohols that were $C(E20)_A$, $C(E85)_A$ and $C(E100)_A$ had the similar value and affected more than the surrogate gasoline, $C(E0)_A$ due to it more absorbed. Ethanol which was the main composition, about 99 vol%, in the aggressive ethanol had a high polar chemical. It could become coordinated with the hydrophilic amide groups (-CO-NH-). However, the mass of the test samples immersed in the surrogate gasoline was slightly increased with increasing immersion time. This was the results from the hydrophobic paraffinic chains of PA6 could be absorbed non polar toluene and isooctane that were compositions in the surrogate gasoline.

Considering volume change as shown in Fig. 5.13-5.23, the test fuels could be affected dimensional stability. It was cause swelling of test samples. This result revealed consistent the mass change. The swelling could not be seen due to it very little changed.

Besides polar characteristic, solubility parameter was important concept for predicting the simplest polymer/fluid interactions. The solubility parameter for PA6 is

27.8 MPa$^{1/2}$ and the solubility parameter for ethanol is 26.0 MPa$^{1/2}$ [42]. Both solubility parameters small differ so it was good interactions. For this experiment, PA6 did not dissolve, but slightly swell in the presence of solvent. Here was one good reason for approving the gasohols had more effects on physical properties of PA6 than the gasolines.

Bruce Jones and et.al. compared the effects of E20 versus E10 and gasoline on plastic materials. The mass and the volume change of PA6 immersed in E10 and E20 yielded approximately a 10% increase when compared to Fuel C, surrogate gasoline [41]. For This study, the mass and the volume change of PA6 immersed in $C(E20)_A$ yielded approximately 7% increase when compared to surrogate gasoline. This showed the lower percent increase due to the shorter immersion time than previous test.

5.1.4 Volume Change of PA6/GF Composites

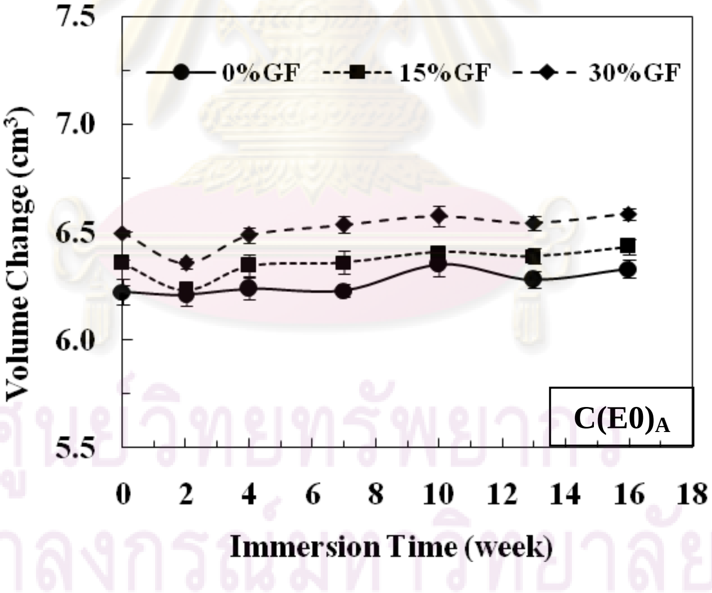


Figure 5.17 Volume change of PA6/GF composites immersed in $C(E0)_A$

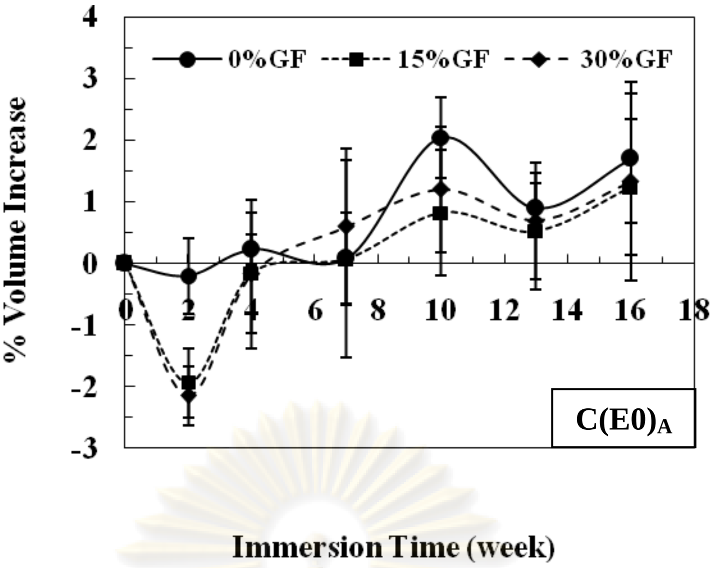


Figure 5.18 Percent volume increase of PA6/GF composites immersed in C(E0)$_A$

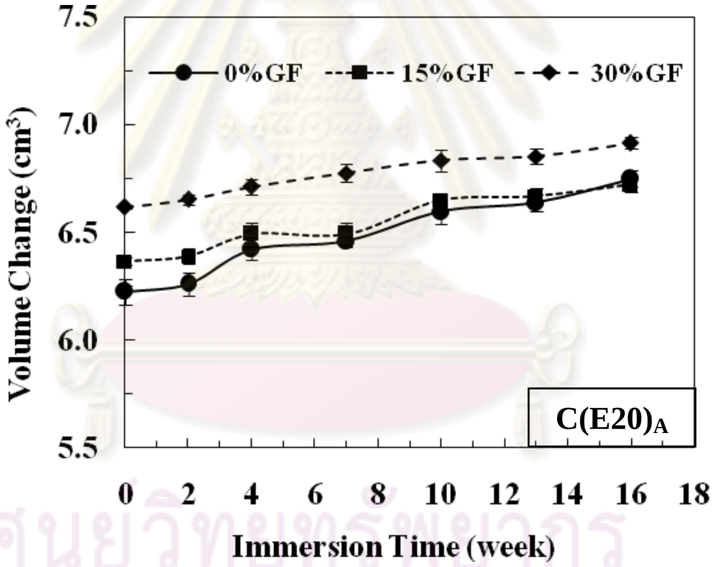


Figure 5.19 Volume change of PA6/GF composites immersed in C(E20)$_A$

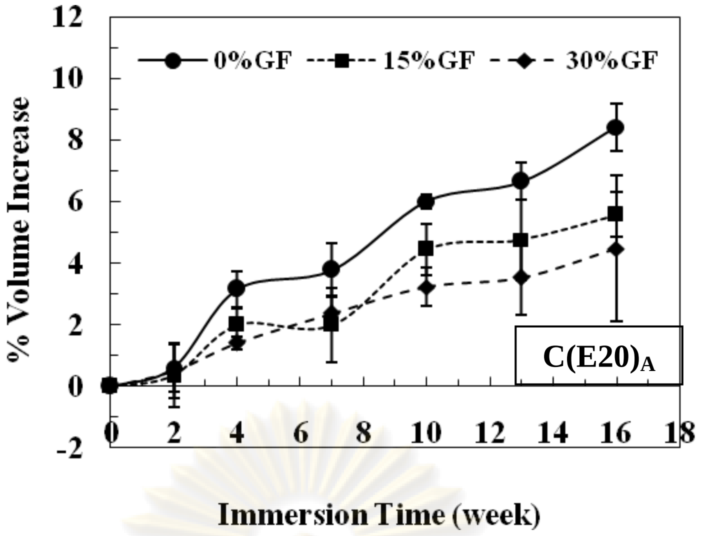


Figure 5.20 Percent volume increase of PA6/GF composites immersed in C(E20)$_A$

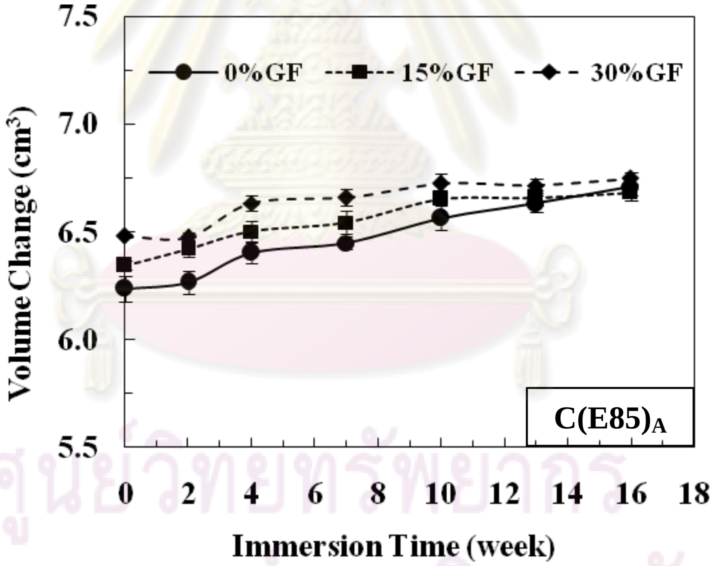


Figure 5.21 Volume change of PA6/GF composites immersed in C(E85)$_A$

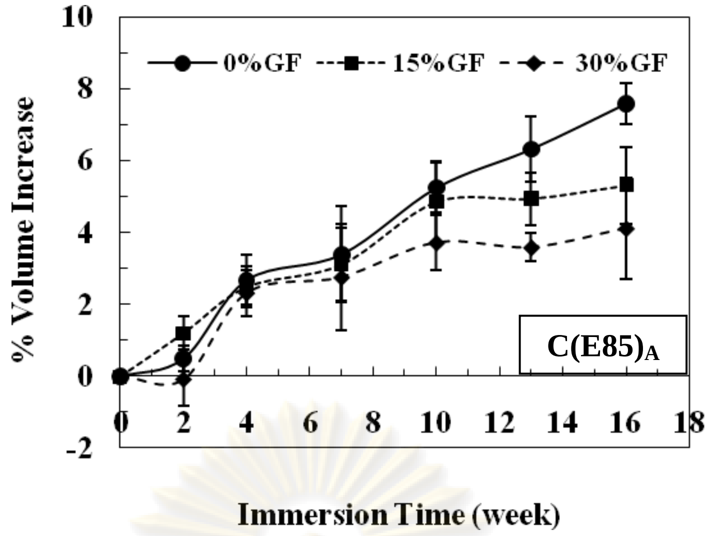


Figure 5.22 Percent volume increase of PA6/GF composites immersed in C(E85)$_A$

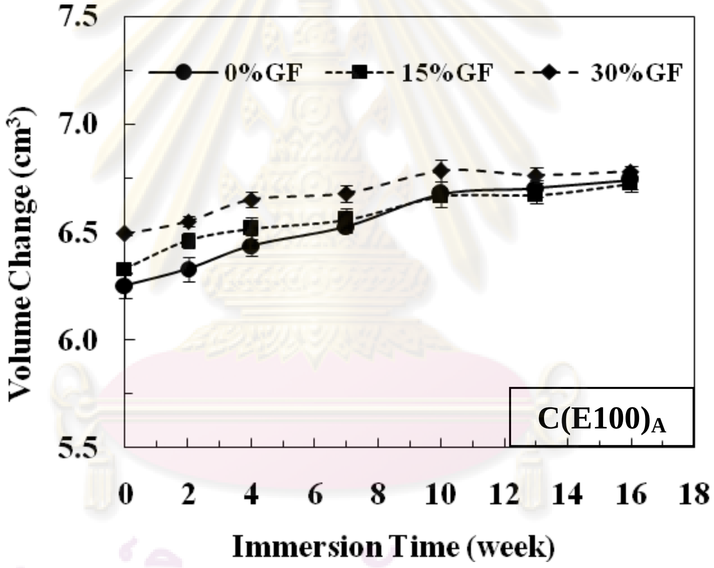


Figure 5.23 Volume change of PA6/GF composites immersed in C(E100)$_A$

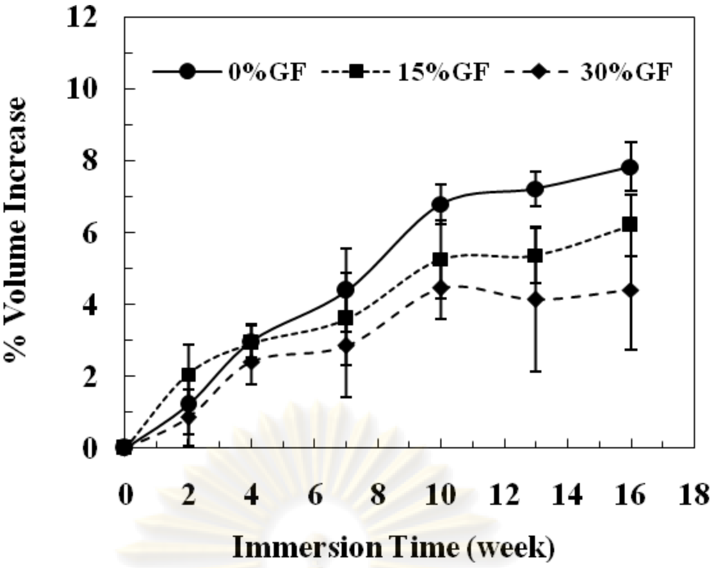


Figure 5.24 Percent volume increase of PA6/GF composites immersed in $C(E100)_A$

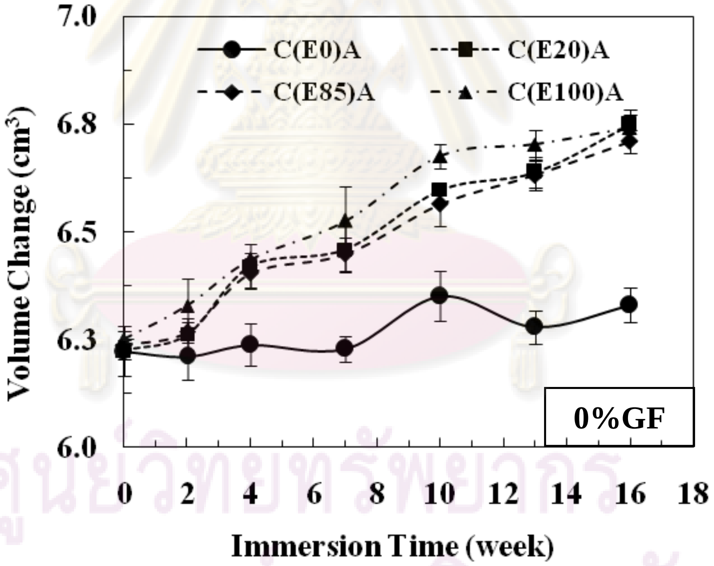


Figure 5.25 Volume change of PA6 immersed in test fuels

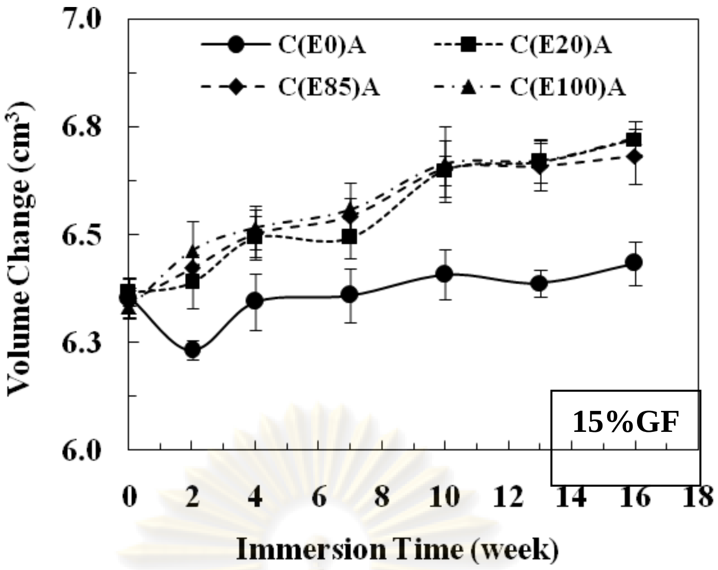


Figure 5.26 Volume change of PA6/GF (15 wt%) immersed in test fuels

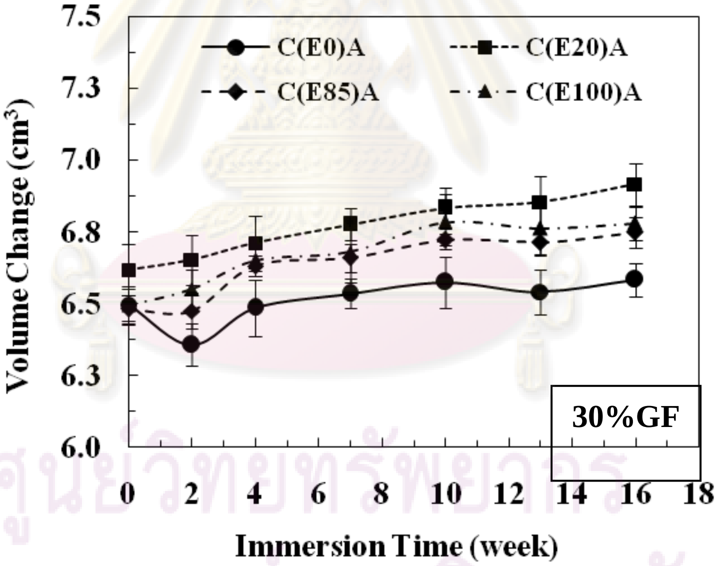


Figure 5.27 Volume change of PA6/GF (30 wt%) immersed in test fuels

5.2 The Influences of Gasohols on Mechanical Properties of PA6/GF Composites

The mechanical testing included tensile, impact, flexural and compressive tests. From tensile test two properties were investigated: tensile strength and tensile modulus; the impact test gave only breaking energy. The aim of testing these materials was to see whether there was an improvement of mechanical properties when the glass fiber were used and which test fuels gave the best properties.

The mechanical properties data collected along the study was compared to baseline. The samples were took to measured these properties on week 4th, 10th and 16th and compared to the value recorded before immersion that were used as based line. The average and the standard deviation of were compared to determine test variance. Ten pieces of measuring were used to collect for the impact strength while five pieces were used for tensile strength, young's modulus, flexural strength and compressive strength.

5.2.1 The influences of glass fiber content on the mechanical properties

Three test materials (unreinforced PA6 and glass fiber reinforced PA6 15 wt% and 30 wt%) that immersed in four test fuels were compared to investigate the effect of glass fiber content. Refer to Fig. 5.28, 5.40, 5.52, 5.64 and 5.72 for a plot show the tensile strength, young's modulus, flexural strength, impact strength and compressive strength, respectively before immersion. These figure comparing the influences of glass fiber content on mechanical properties. It showed that glass fiber reinforced PA6 exhibited improvement in mechanical properties. It was observed that tensile strength of test materials increased depending on fiber reinforcement and fiber content. As is seen from Fig. 5.28, the tensile strength for the un reinforced PA6 was found to be 78.6 MPa, while it increased to 118.7 and 170.0 MPa with the addition of 15 and 30 wt% glass fiber reinforcement, respectively. Thus, when PA6 was reinforced with 15 and 30 wt% glass fiber, 51% and 117% increment in the tensile strength were observed, respectively. This result was consistency with the study of the effect of glass fiber on mechanical properties of PA6, it was showed 74% and 111% increment in tensile strength [11]. Fig. 5.40 showed 76% and 145% increment in young's modulus with the addition of 15 and 30 wt% glass fiber reinforcement, respectively. The flexural strength of three test materials showed in Fig. 5.52 was compared. It was showed the increment of this property 60% and 122% with the use glass fiber reinforced PA6 15 and 30 wt%, respectively. Compressive strength of the reinforced with 15 and 30 wt% glass fiber showed 43% and 73% increased in this property change when compared to the unreinforced PA6. These were observed that improvement in tensile strength, young's modulus, flexural strength and compressive strength showed a linear relationship with the fiber weight fraction. Impact test was showed in Fig. 5.64 comparing the impact strength of each material. This showed the impact strength increased with increasing the glass fiber content. The change in the 15 wt% glass fiber content increased 8%, while 30 wt% glass fiber content increased 50% when compared with the unreinforced PA6. This change did not show a linear relationship. Previously study showed that impact strength of 15 wt% glass fiber reinforced PA6, 21% decrease was observed. Contrary, 9% increase in PA6 when it was reinforced with 30 wt% glass fiber [11].

After immersed in each test fuels the characteristic of the test samples were affected. The tensile strength, young's modulus and flexural strength decreased with increasing immersion time, while the impact strength increased. These were rapidly changed in the first 4 weeks. Fig. 5.29-2.36 showed the tensile strength and percent change of tensile strength of the test materials at the various times along immersed in each test fuels. This showed good results for the high fiber content composites. The plot of young's modulus and flexural strength were showed in Fig. 5.41-5.48 and Fig. 5.53-5.60, respectively. These properties showed the similar results with the tensile strength. The impact test result showed the impact strength increased with increasing immersion time as showed in Fig. 5.65-5.68. This property showed no significant difference between 15 wt% and 30 wt% glass fiber reinforced PA6. However, the reinforced samples had the lower impact strength than the unreinforced PA6 significantly. From this test showed that high fiber content in PA6 provided lower percent change in mechanical properties than the unreinforced PA6. In the other words, the glass fiber reinforcement could be reduced the decreasing of these properties. The mechanical properties had a positive correlation to the physical properties results.

This was clear that there was adhesion between fiber and matrix. Thus when the tensile load becomes large enough to fracture the PA6 phase, there was load transfer from the PA6 matrix to the glass fiber to help. This was clear that the mechanical change was the results of the physical properties change. And this change could be reduced by increased fiber content in the composites.

The most important parameters affecting the mechanical properties of composite material are fiber content and fiber length [43]. For this study, solvent absorption as an important parameter affecting on the mechanical properties (especially the material that had nitrogen in structure such as PA6).

The study of the influences of glass fiber content indicated that use glass fiber as reinforcement in PA6 could have improved mechanical properties although it immersed in test fuels. Due to the glass fiber composites had the lower PA6 matrix that was a absorption area than the unreinforced PA6. In addition, fiber direction and distribution in the PA6 matrix are known to influence the mechanical properties.

5.2.2 The influences of ethanol content on the mechanical properties

Fig. 5.37-5.39, 5.49-5.51, 5.61-5.63, 5.69-5.71 and 5.77-5.79 showed the tensile strength, young's modulus, flexural strength, impact strength and compressive strength, respectively. For these figure shown the test specimens comparing the influences of ethanol content in each test fuels. The mechanical properties of all samples were affected by immersion in all test fuels. From the test results the tensile strength, young's modulus and flexural strength of the samples immersed in all test fuels decreased while the impact strength increased with increasing immersion time. The mechanical properties dramatically changed in the first 4 weeks. Then, it slightly changed until finish test.

The comparing of the influences of each fuels found that $C(E0)_A$ had a smaller effect than the ethanol fuels ($C(E20)_A$, $C(E85)_A$ and $C(E100)_A$) while the ethanol fuels showed no significant difference effects. There is little information on the non-linear effects of increased blends on materials. This means that as the ethanol as the concentration of ethanol increase from 0 to 100% there is no model that accurately predicts the effects on materials. In fact, pure ethanol and pure gasoline often have a smaller impact on materials than gasoline-ethanol blends [22].

Ethanol that is a main component in aggressive ethanol that more absorbed in PA6. Due to the solubility parameter showed a few different between ethanol and PA6. This result indicated fuels absorption was a cause of mechanical properties change. Absorption was generally concentrated in the polymer matrix and at the same amount from the ethanol fuels. It has the effect of plasticizing the material by interrupting the polymer hydrogen bonding, making it more flexible (with lower tensile strength, young's modulus and flexural strength but higher impact strength) [4].

. The aggressive ethanol consists of de-ionize water, ethanol, sodium chloride, sulfuric acid and acetic acid. Ethanol and water could be caused of hydrolysis reaction (shown in Fig. 2.7). This reaction can cause substantial decrease in tensile strength and stiffness. The chemical mechanism of the hydrolysis of nylons is that H atoms in H_2O compete with H atoms in the amine groups (N-H-O) of the PA6, associate with the electronegative O atoms, and cause chain scission. Alcohols, and partly halogenated hydrocarbons act similarly on some PA6. At ordinary ambient temperatures, hydrolysis reactions are rapidly only in the amorphous regions of semicrystalline plastics that was PA6.

$$\text{R-CONH-R}^1 + \text{H}_2\text{O} \rightarrow \text{R-COOH} + \text{H}_2\text{N-R}^1 \qquad \text{hydrolysis reaction}$$

The acid and amine groups are produce of the chain scission from this reaction. In general, the amine groups content indicate the scission of PA6 chain. The results from Fourier Transform Infrared Spectroscopy or FT-IR could be confirmed occurs of this reaction. Fig. 5.80-5.83 showed FT-IR result of the specimens comparing before and after immersed in each test fuels. The result showed few amount of amine groups ($-NH_2$) before immersion while after immersion it significantly increased especially in the ethanol fuels. The amounts of amine groups indicated increasing of chain scission of PA6. So increasing of amine groups made the mechanical properties loss.

It was clear that the surrogate gasohols that various ethanol blended had bigger effect than surrogate gasoline. This could be due to the components in aggressive ethanol which had high polar such as de-ionized water, ethanol (alcohol), sodium chloride (metal salt) and sulfuric acid (strong acid). These highly polar solvents were easily absorbed into PA6. The strong acid was most effective at interrupting the hydrogen bonding of PA6; the metal salts could be attacked PA6 causing stress cracking.

The absorption was very important property of PA6 for several reasons: one was that the water reacted chemically with the chain and degraded PA6. In addition, it was caused of hydrolysis reaction that could be caused substantial decreased in tensile strength, flexural strength, stiffness and increased creep strain (low young’s modulus). Besides chemical reaction, water was physical destruction of adhesive bonds between PA6 matrix and glass fiber. It caused strength loss in glass fiber reinforced composites.

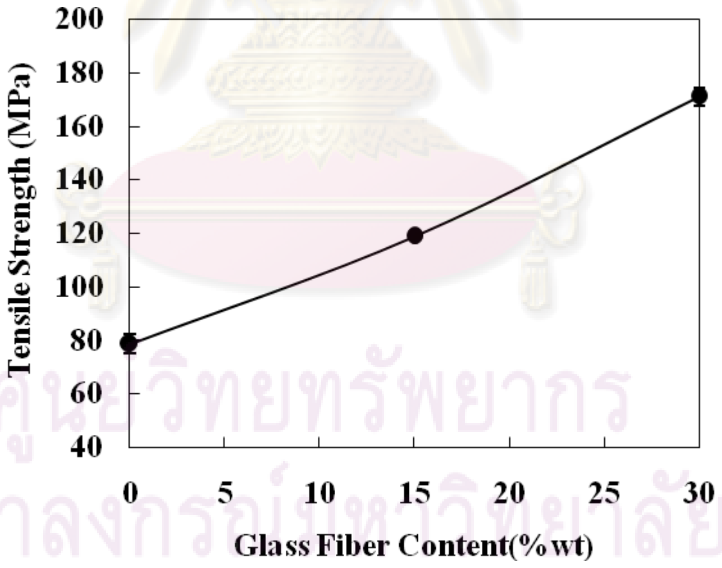


Figure 5.28 Tensile strength of unreinforced PA6 and PA6/GF composites before immersion in test fuels

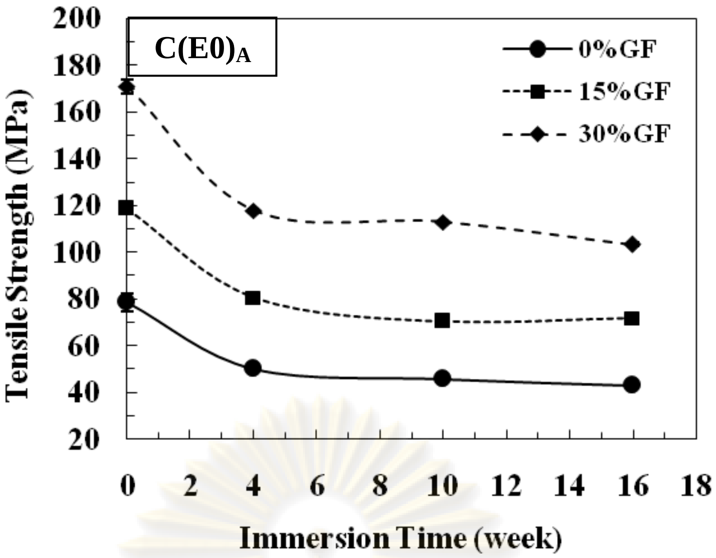


Figure 5.29 Tensile strength of PA6/GF composites immersed in C(E0)$_A$

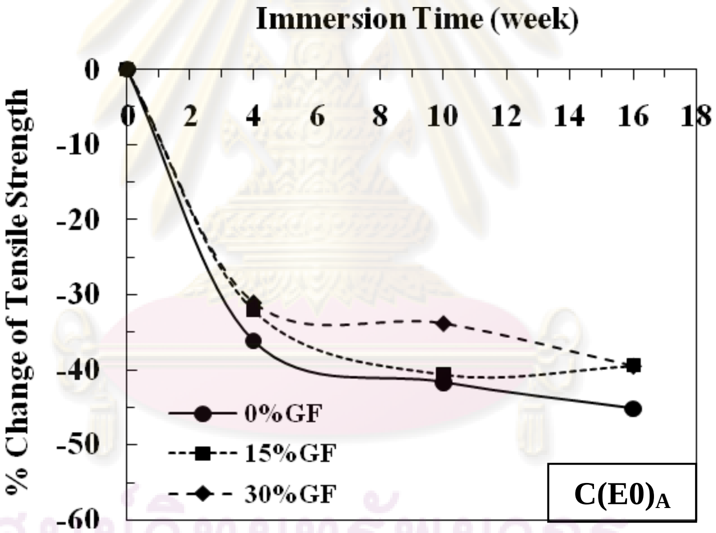


Figure 5.30 Percent change of tensile strength of PA6/GF composites immersed in C(E0)$_A$

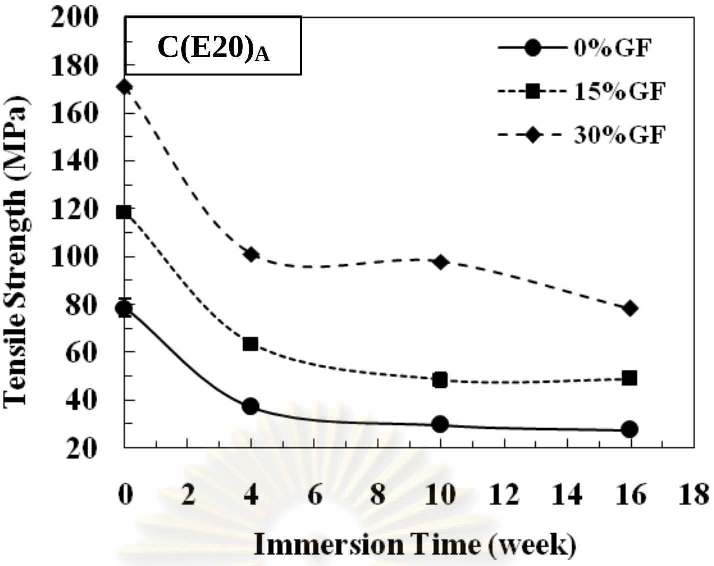


Figure 5.31 Tensile strength of PA6/GF composites immersed in C(E20)$_A$

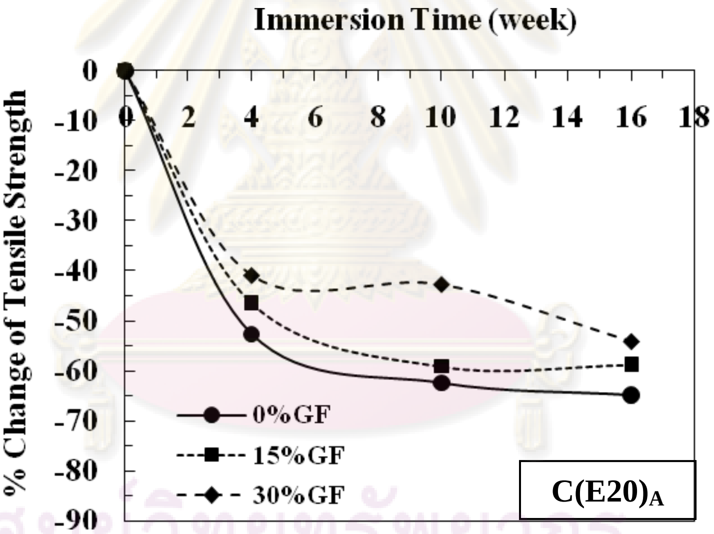


Figure 5.32 Percent change of tensile strength of PA6/GF composites immersed in C(E20)$_A$

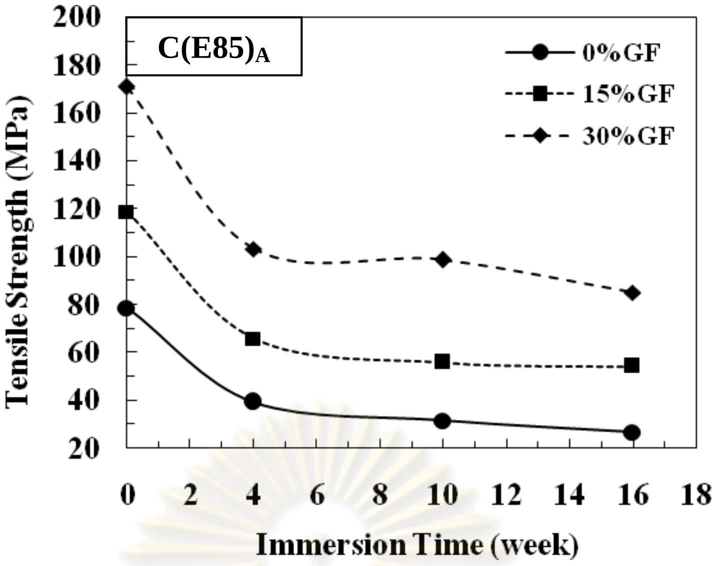


Figure 5.33 Tensile strength of PA6/GF composites immersed in C(E85)$_A$

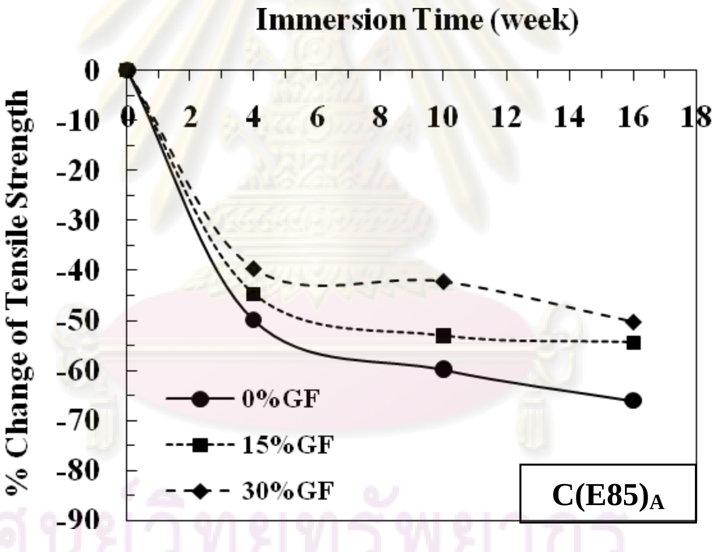


Figure 5.34 Percent change of tensile strength of PA6/GF composites immersed in C(E85)$_A$

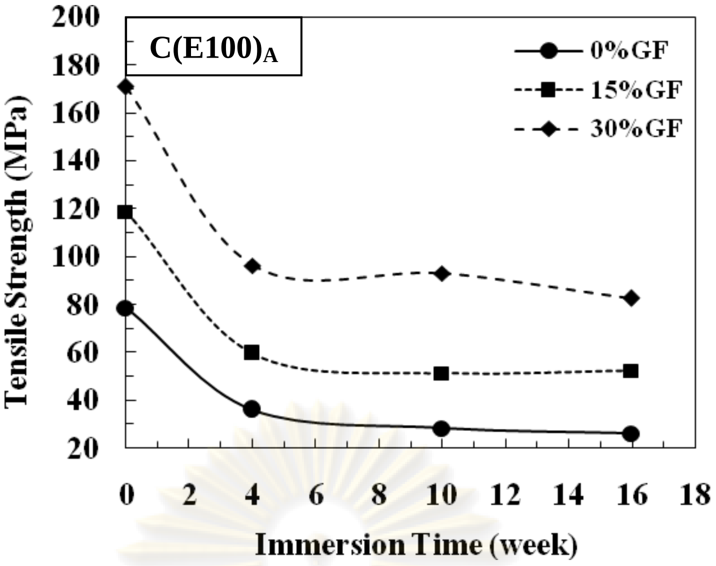


Figure 5.35 Tensile strength of PA6/GF composites immersed in C(E100)$_A$

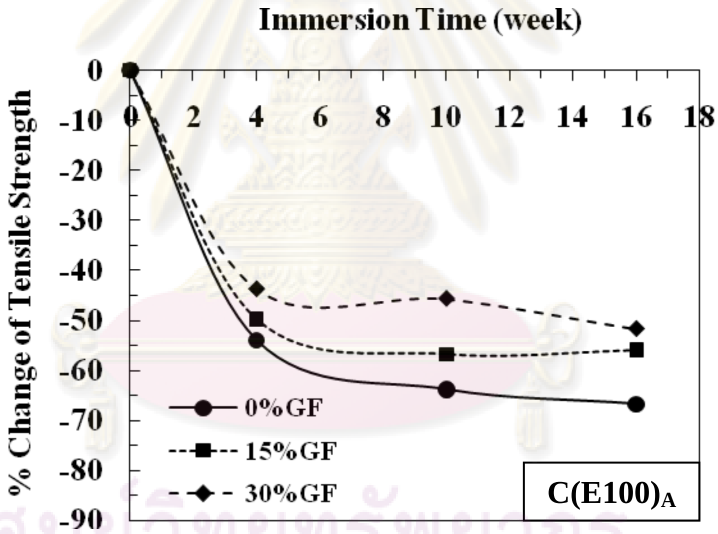


Figure 5.36 Percent change of tensile strength of PA6/GF composites immersed in C(E100)$_A$

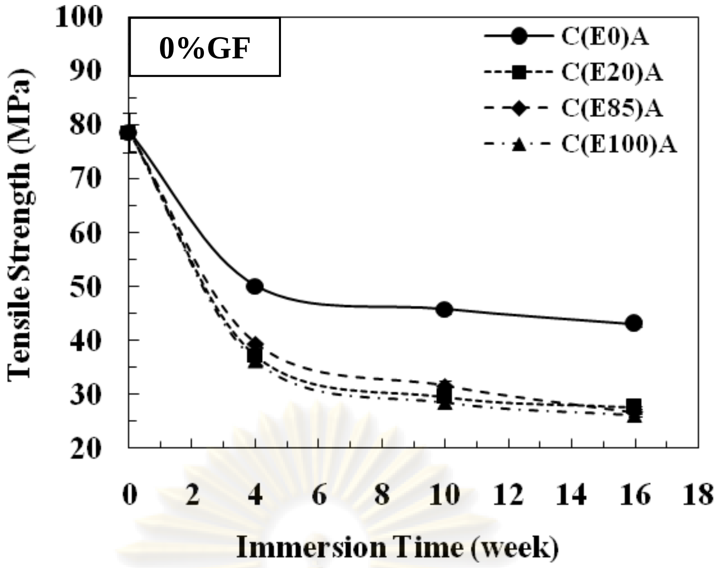


Figure 5.37 Tensile strength of PA6 immersed in test fuels

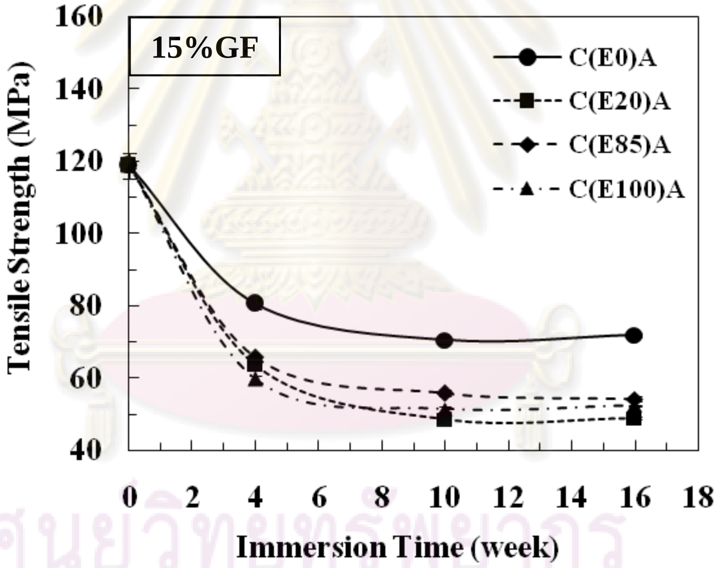


Figure 5.38 Tensile strength of PA6/GF (15 wt%) immersed in test fuels

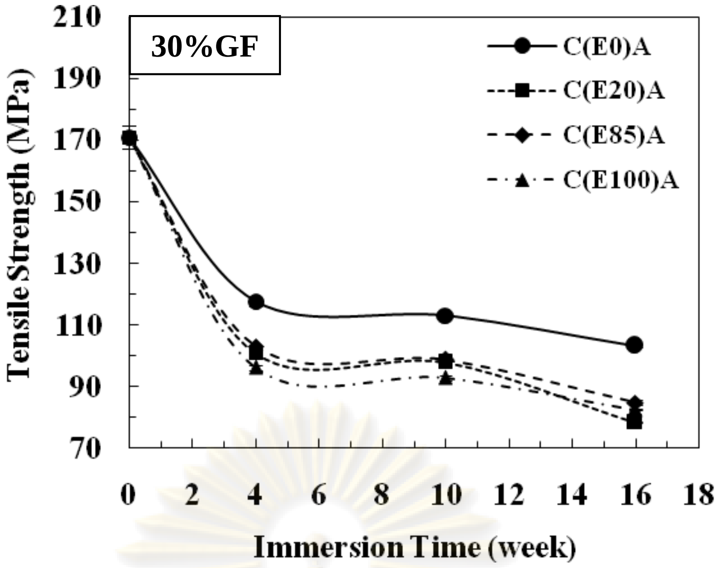


Figure 5.39 Tensile strength of PA6/GF (30 wt%) immersed in test fuels

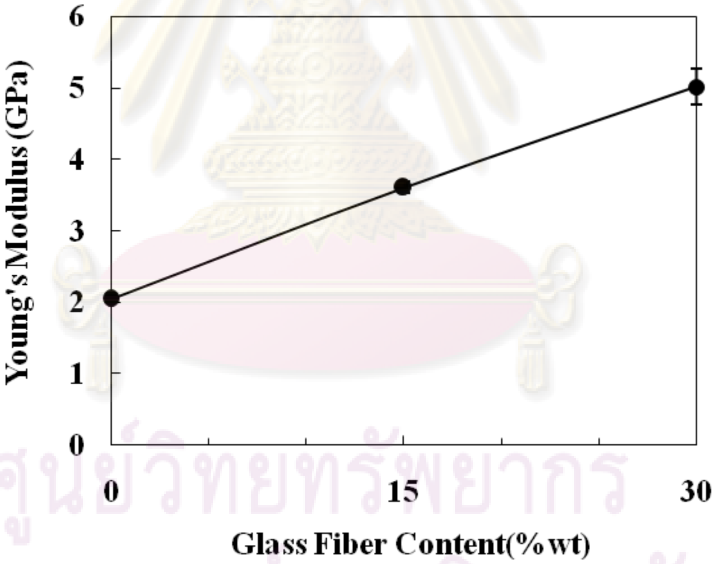


Figure 5.40 Young's modulus of unreinforced PA6 and PA6/GF composites before immersion in test fuels

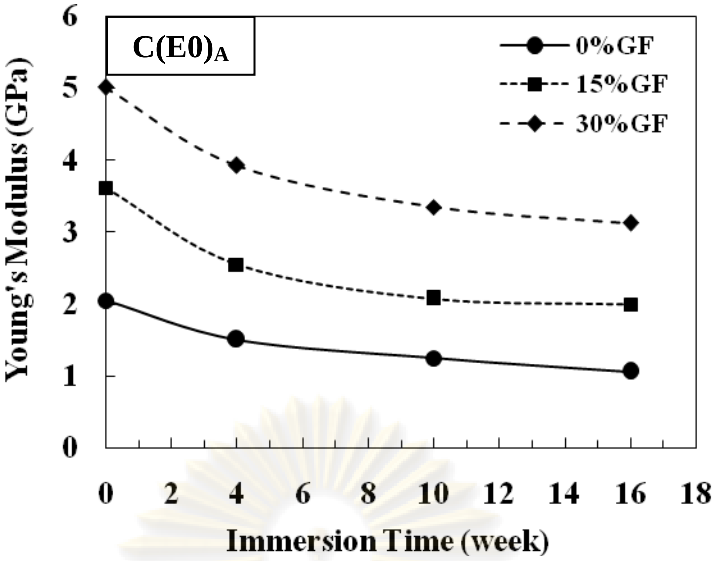


Figure 5.41 Young's modulus of PA6/GF composites immersed in C(E0)$_A$

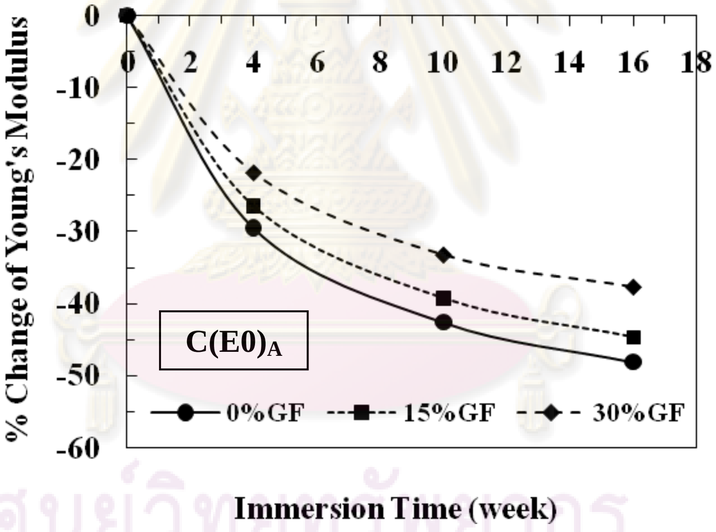


Figure 5.42 Percent change of young's modulus of PA6/GF composites immersed in C(E0)$_A$

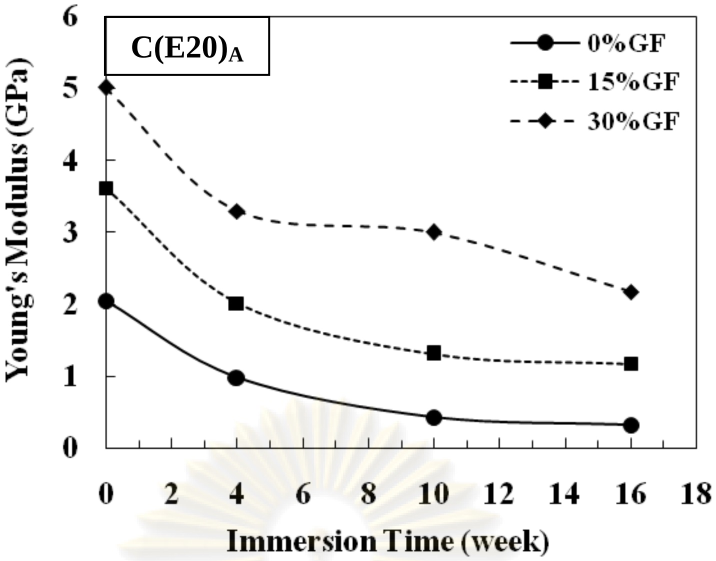


Figure 5.43 Young's modulus of PA6/GF composites immersed in C(E20)$_A$

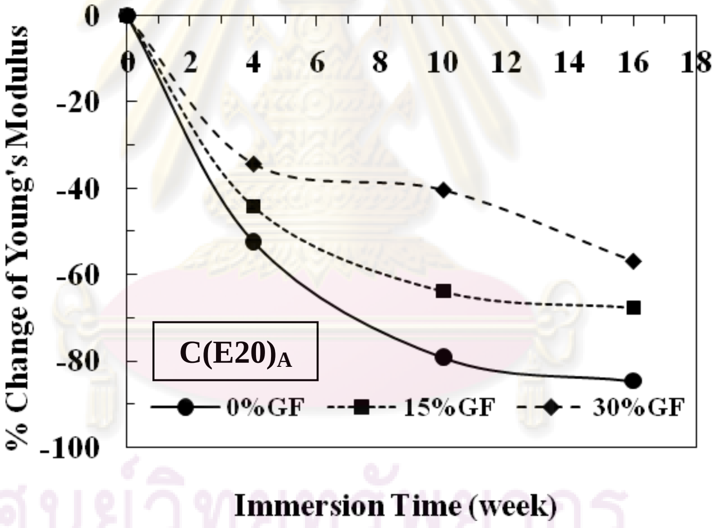


Figure 5.44 Percent change of young's modulus of PA6/GF composites immersed in C(E20)$_A$

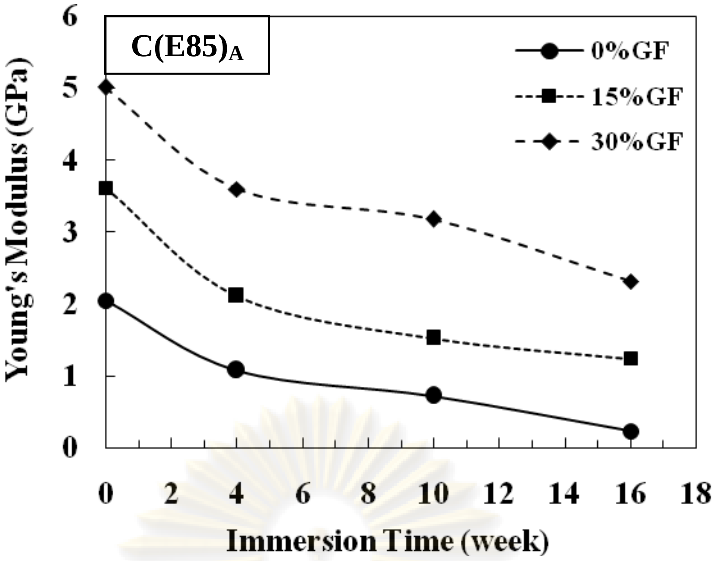


Figure 5.45 Young's modulus of PA6/GF composites immersed in C(E85)$_A$

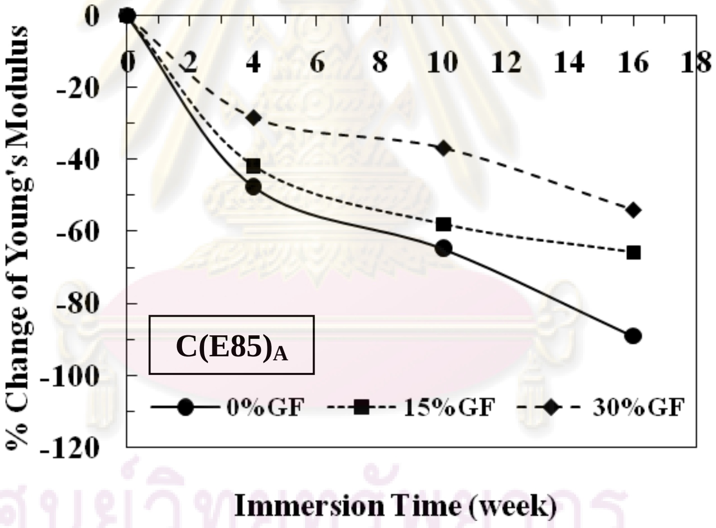


Figure 5.46 Percent change of young's modulus of PA6/GF composites immersed in C(E85)$_A$

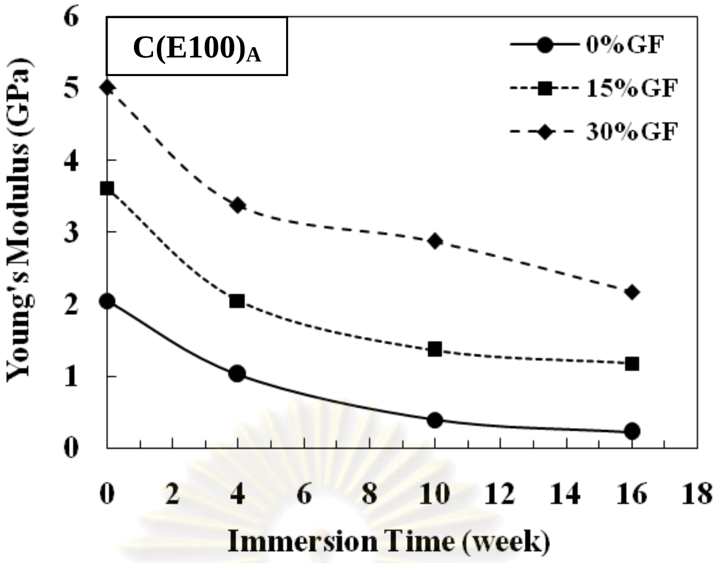


Figure 5.47 Young's modulus of PA6/GF composites immersed in C(E100)$_A$

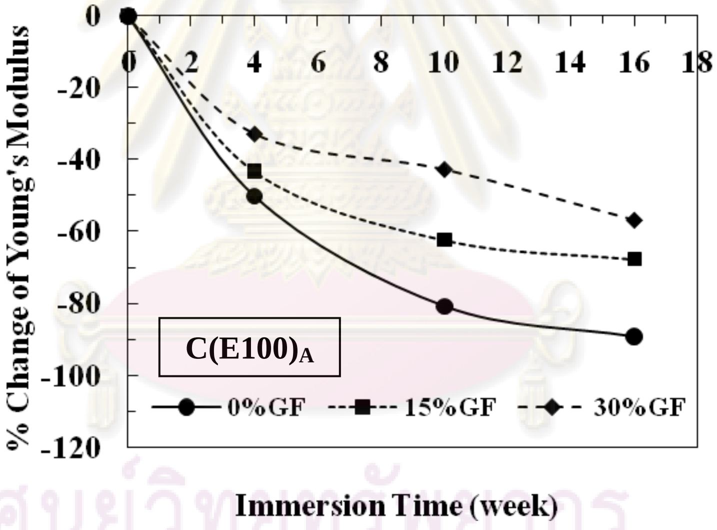


Figure 5.48 Percent change of young's modulus of PA6/GF composites immersed in C(E100)$_A$

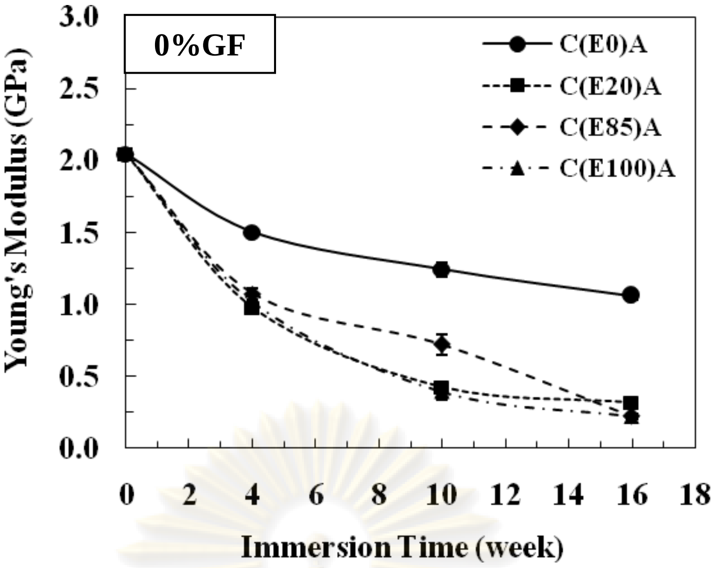


Figure 5.49 Young's modulus of PA6 immersed in test fuels

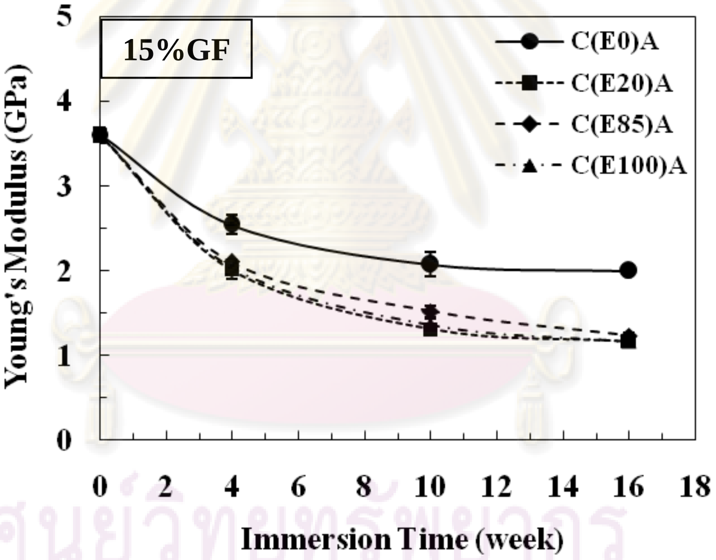


Figure 5.50 Young's modulus of PA6/GF (15 wt%) immersed in test fuels

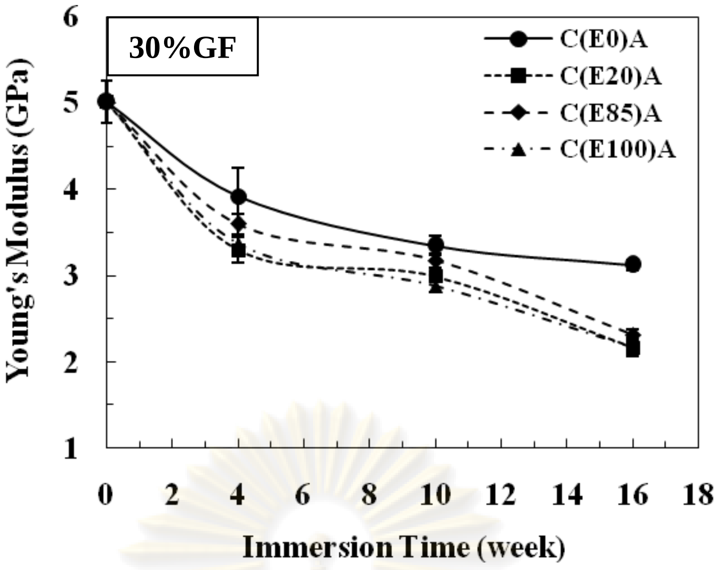


Figure 5.51 Young's modulus of PA6/GF (30 wt%) immersed in test fuels

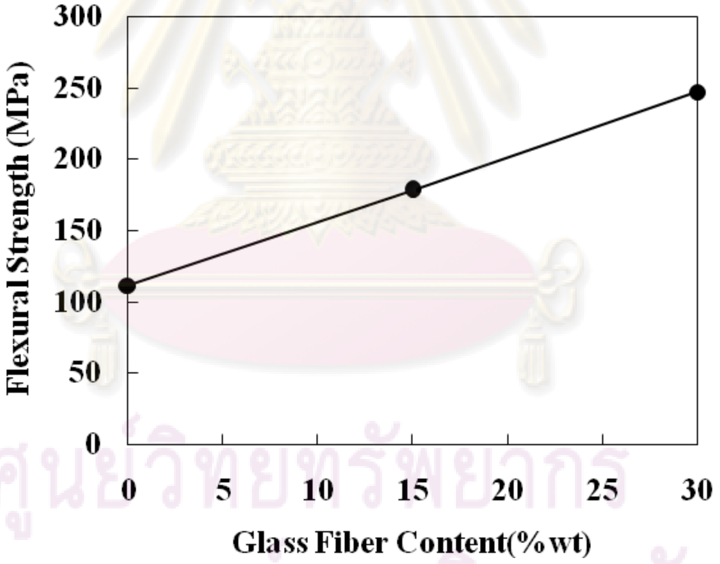


Figure 5.52 Flexural strength of unreinforced PA6 and PA6/GF composites before immersion in test fuels

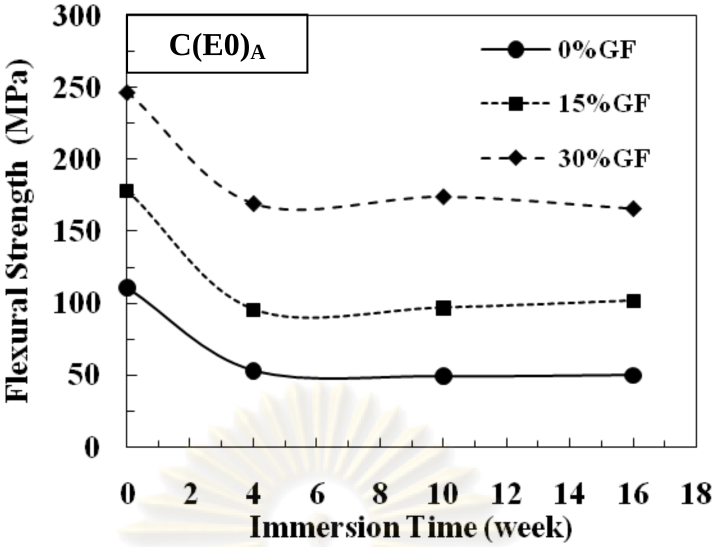


Figure 5.53 Flexural strength of PA6/GF composites immersed in C(E0)$_A$

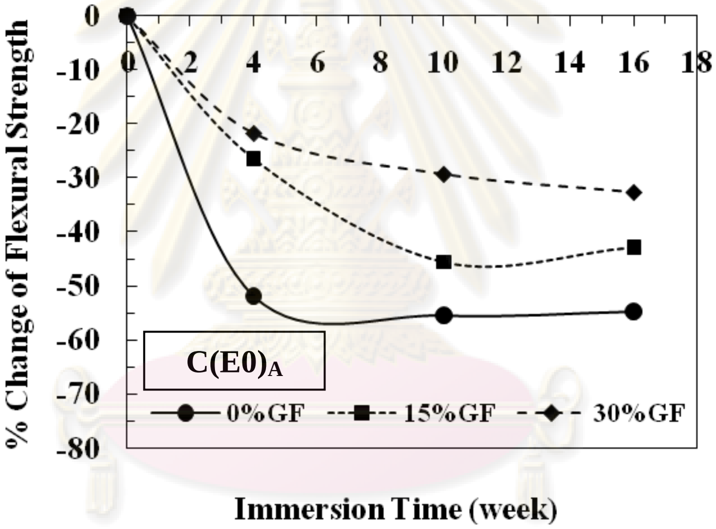


Figure 5.54 Percent change of flexural strength of PA6/GF composites immersed in C(E0)$_A$

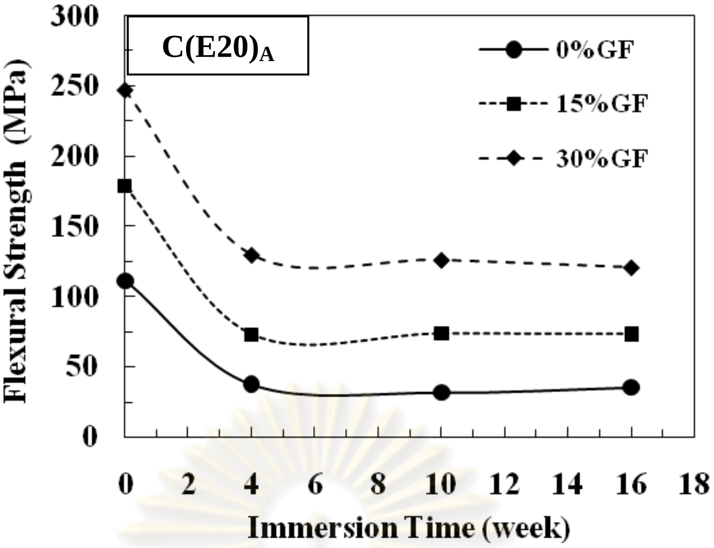


Figure 5.55 Flexural strength of PA6/GF composites immersed in C(E20)$_A$

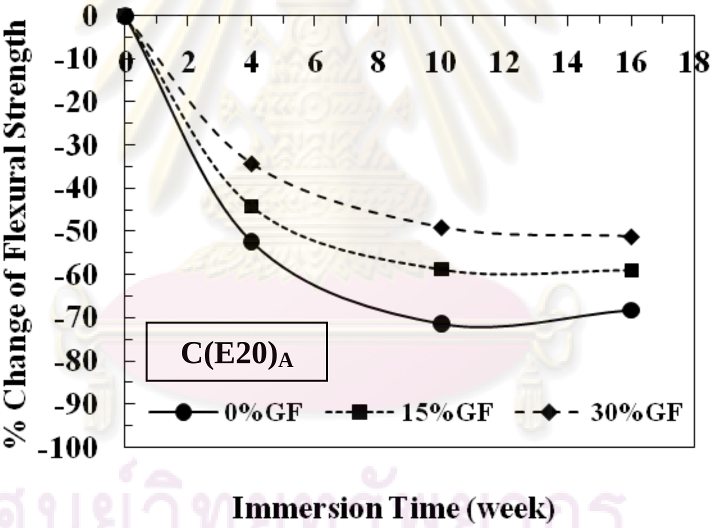


Figure 5.56 Percent change of flexural strength of PA6/GF composites immersed in C(E20)$_A$

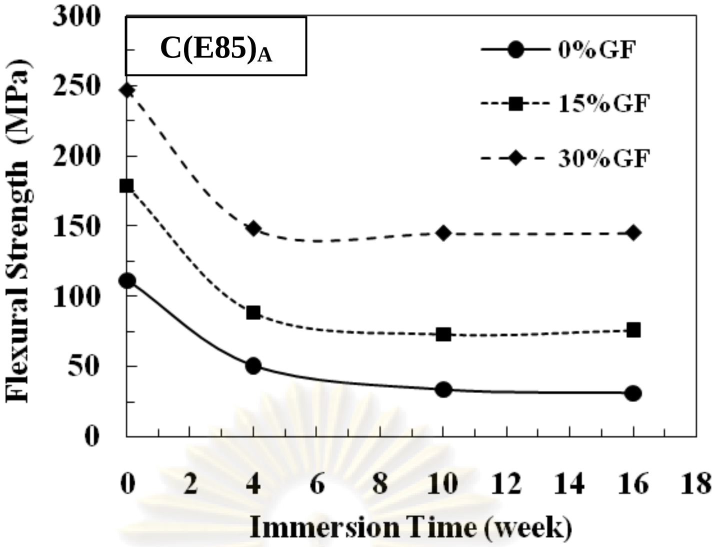


Figure 5.57 Flexural strength of PA6/GF composites immersed in C(E85)$_A$

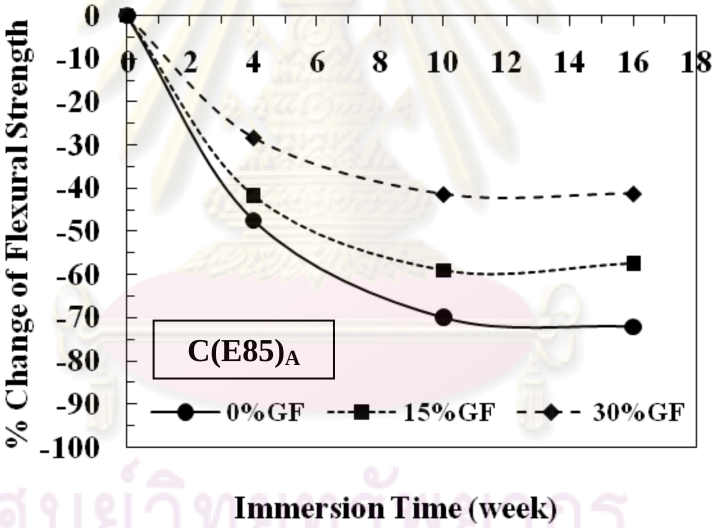


Figure 5.58 Percent change of flexural strength of PA6/GF composites immersed in C(E85)$_A$

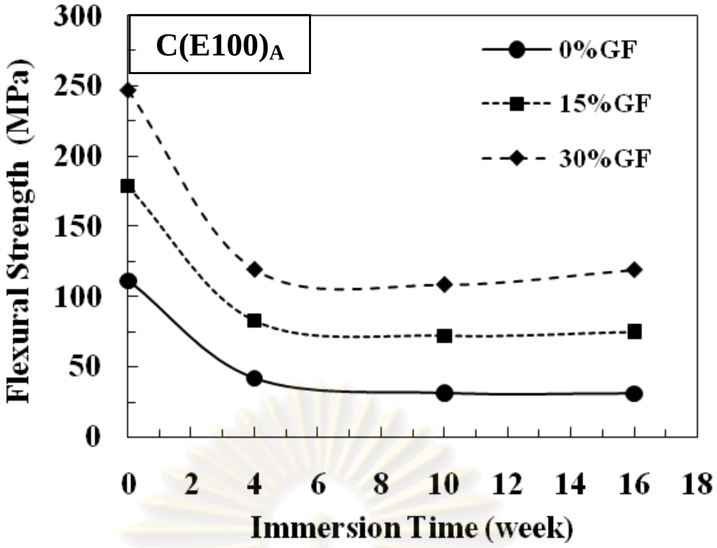


Figure 5.59 Flexural strength of PA6/GF composites immersed in C(E100)$_A$

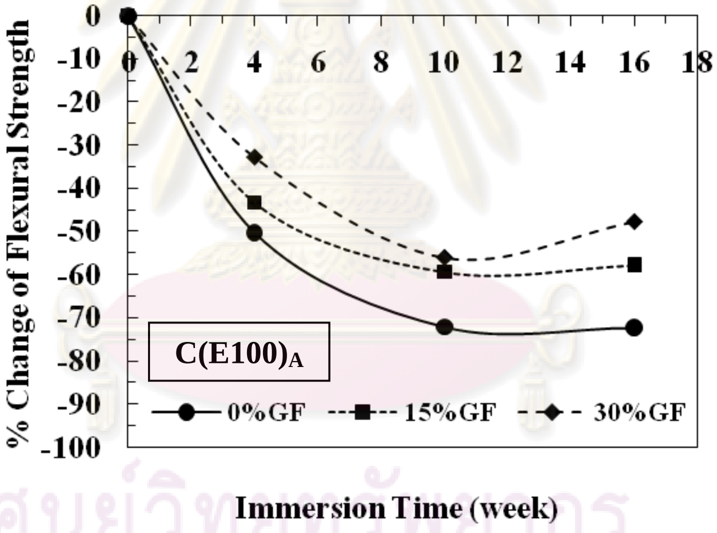


Figure 5.60 Percent change of flexural strength of PA6/GF composites immersed in C(E100)$_A$

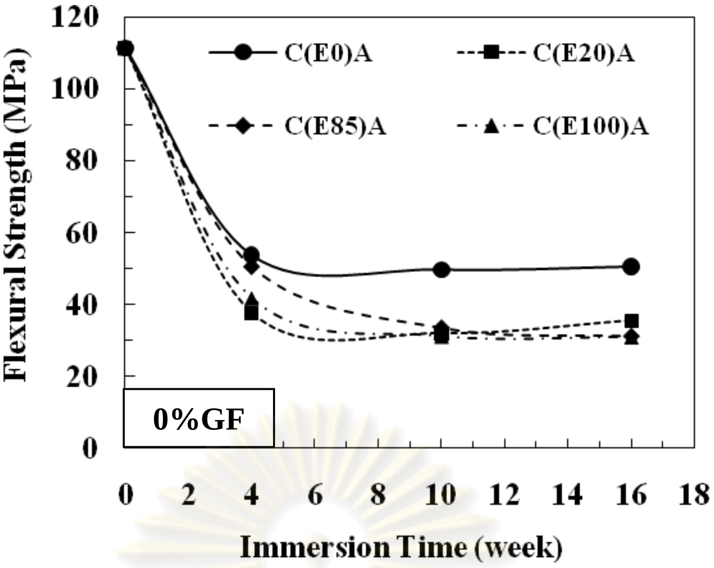


Figure 5.61 Flexural strength of PA6 immersed in test fuels

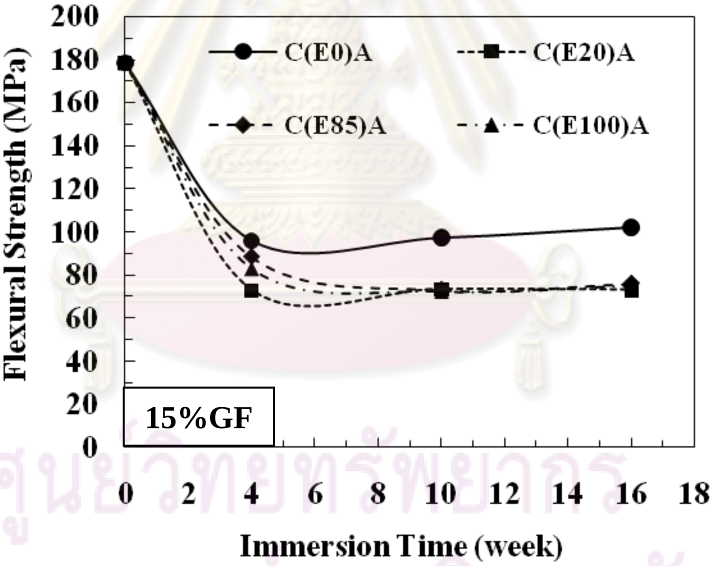


Figure 5.62 Flexural strength of PA6/GF (15 wt%) immersed in test fuels

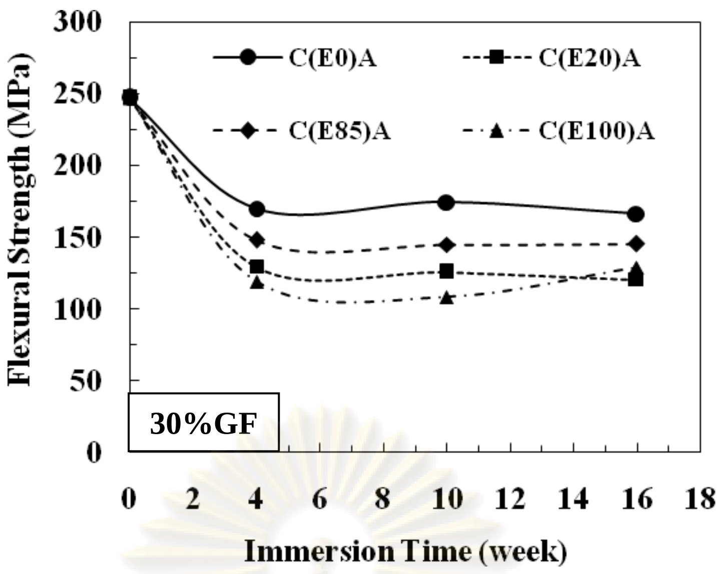


Figure 5.63 Flexural strength of PA6/GF (30 wt%) immersed in test fuels

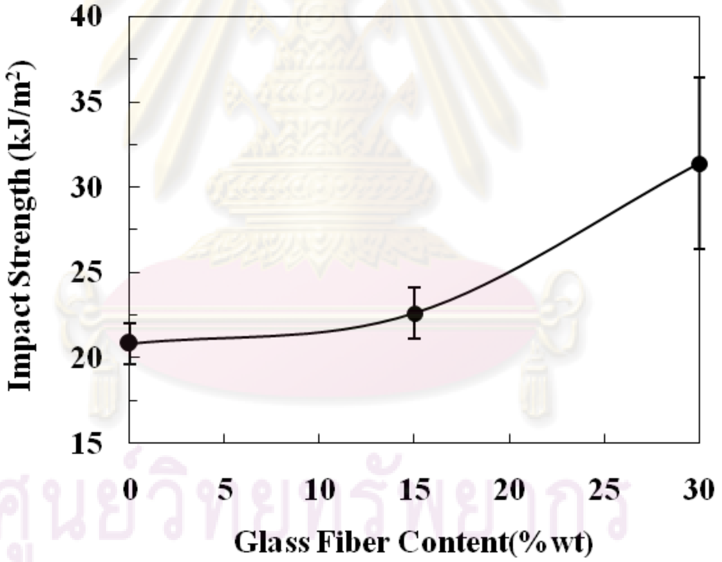


Figure 5.64 Impact strength of unreinforced PA6 and PA6/GF composites before immersion in test fuels

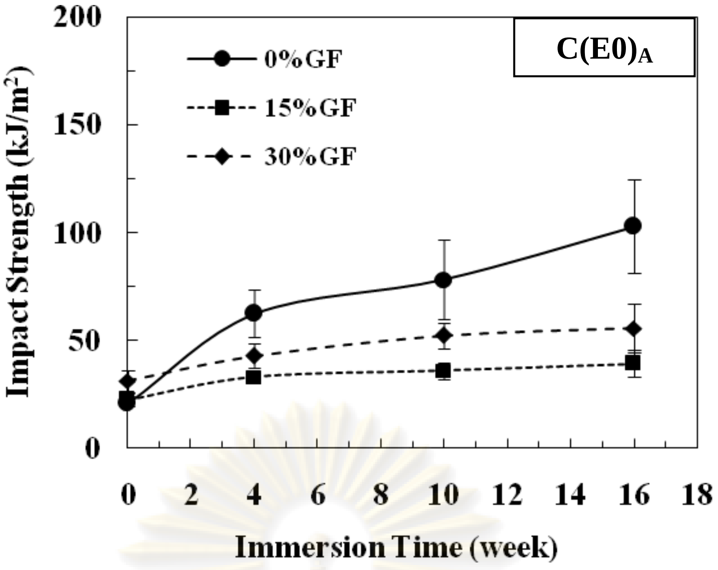


Figure 5.65 Impact Strength of PA6/GF Composites Immersed in C(E0)$_A$

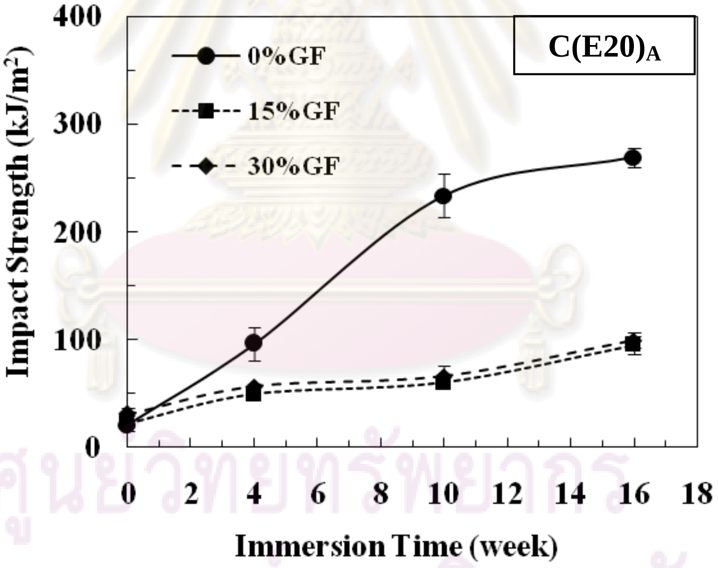


Figure 5.66 Impact Strength of PA6/GF Composites Immersed in C(E20)$_A$

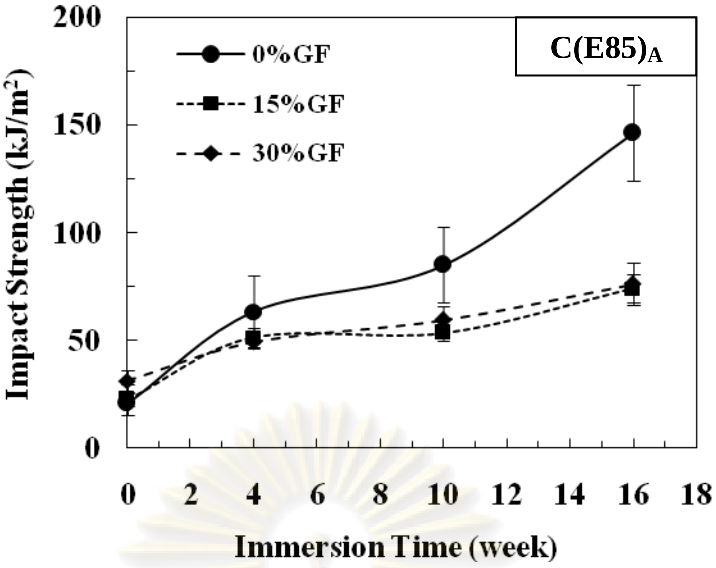


Figure 5.67 Impact Strength of PA6/GF Composites Immersed in C(E85)$_A$

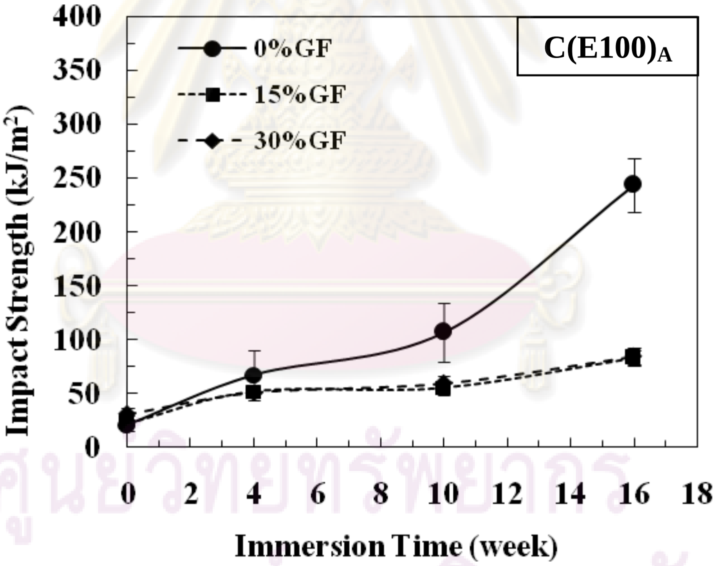


Figure 5.68 Impact Strength of PA6/GF Composites Immersed in C(E100)$_A$

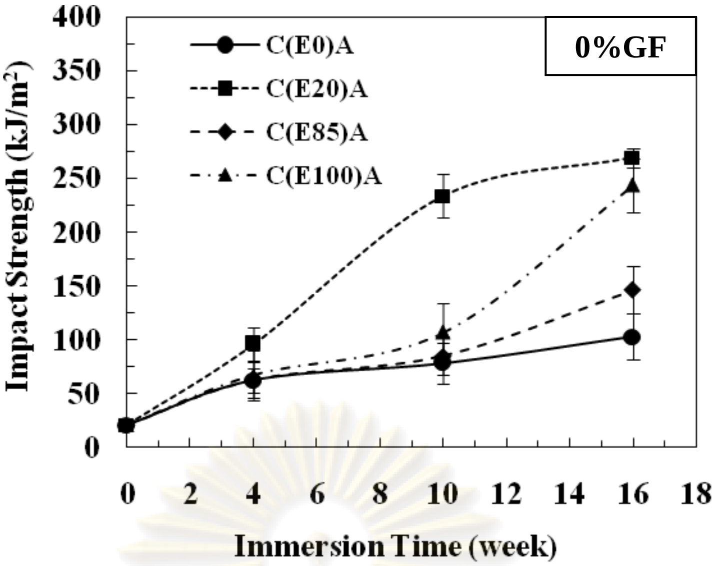


Figure 5.69 Impact Strength of PA6 immersed in test fuels

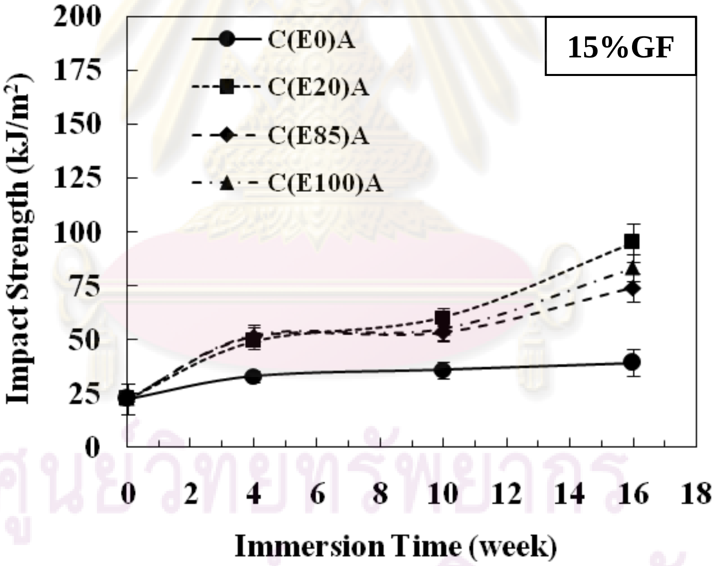


Figure 5.70 Impact Strength of PA6/GF (15 wt%) immersed in test fuels

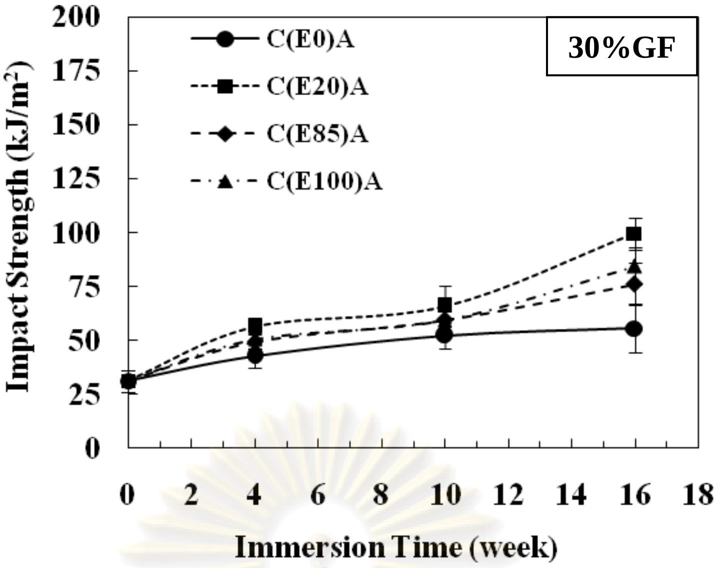


Figure 5.71 Impact Strength of PA6/GF (30 wt%) immersed in test fuels

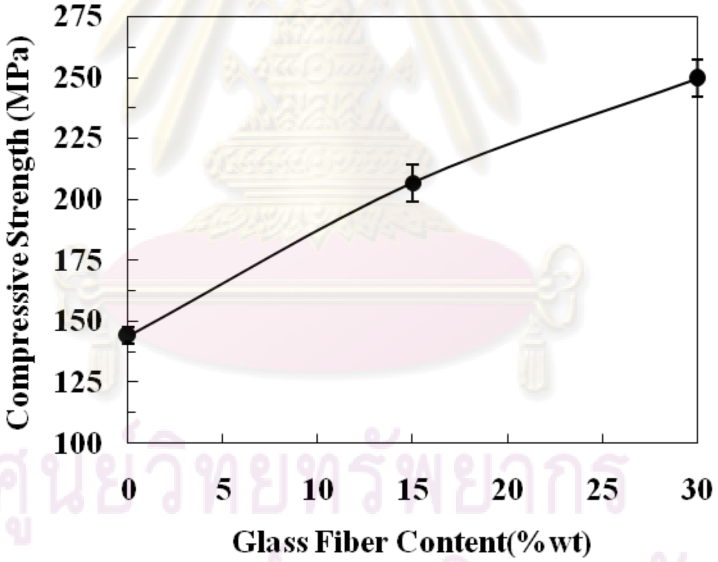


Figure 5.72 Compressive strength of unreinforced PA6 and PA6/GF composites before immersion in test fuels

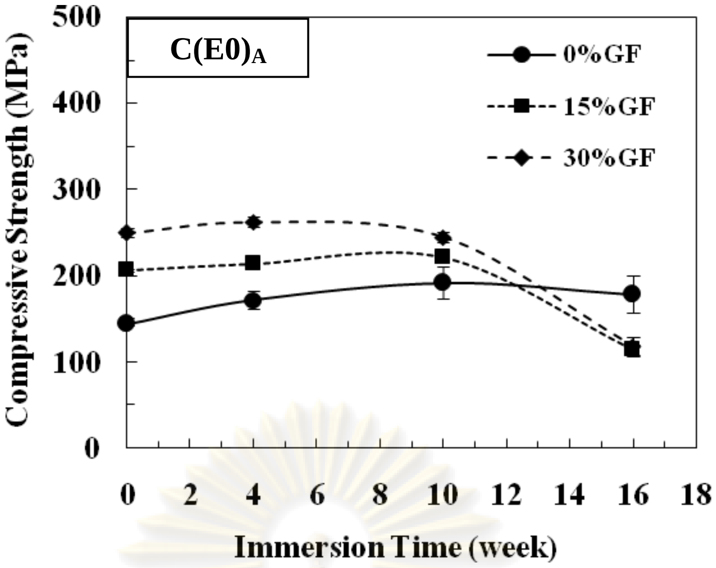


Figure 5.73 Compressive strength of PA6/GF composites immersed in $C(E0)_A$

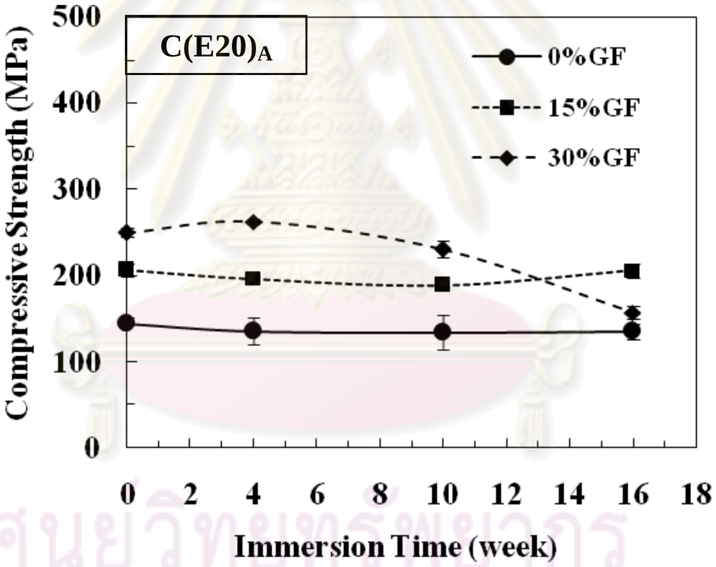


Figure 5.74 Compressive strength of PA6/GF composites immersed in $C(E20)_A$

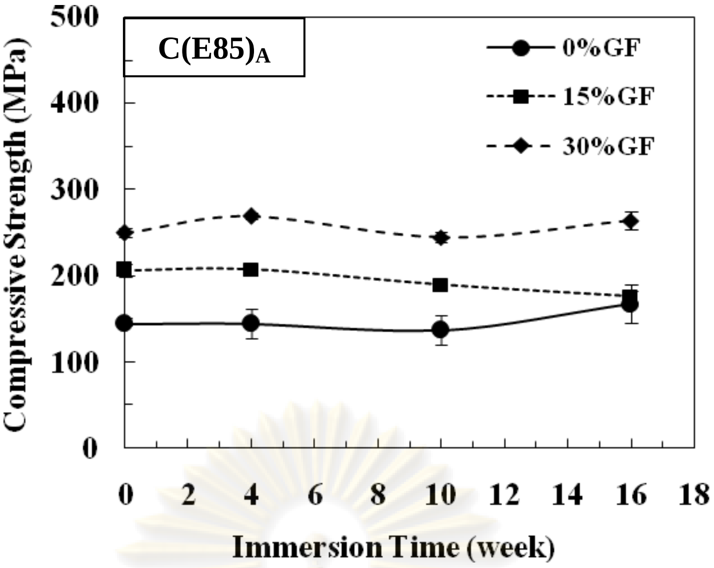


Figure 5.75 Compressive strength of PA6/GF composites immersed in $C(E85)_A$

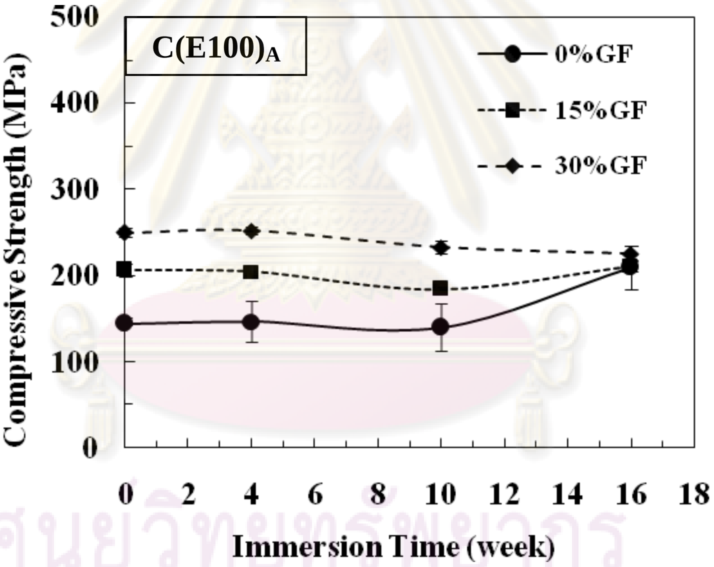


Figure 5.76 Compressive strength of PA6/GF composites immersed in $C(E100)_A$

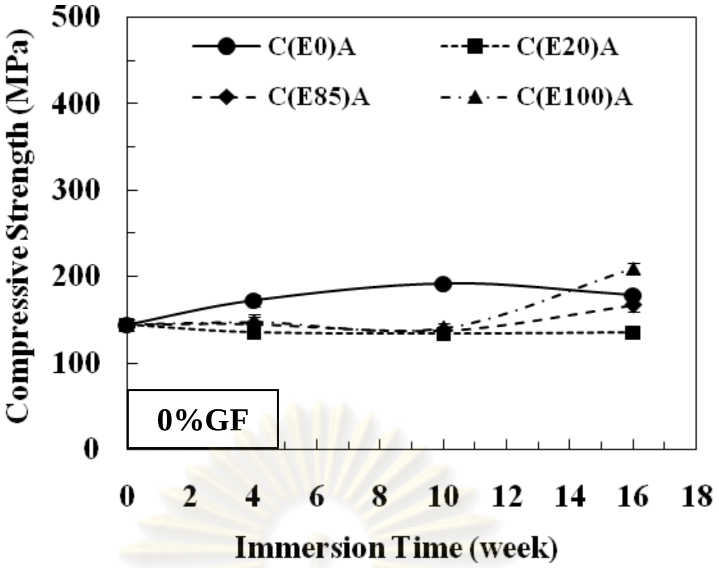


Figure 5.77 Compressive strength of PA6 immersed in each test fuels

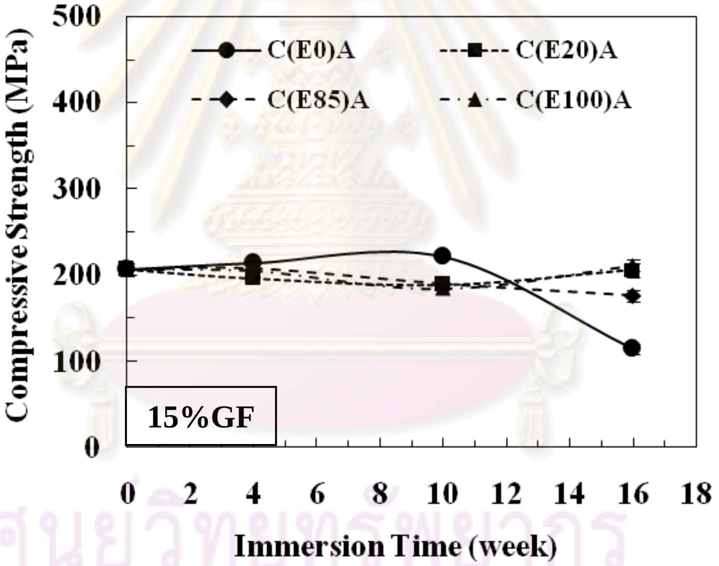


Figure 5.78 Compressive strength of PA6/GF (15 wt%) immersed in each test fuels

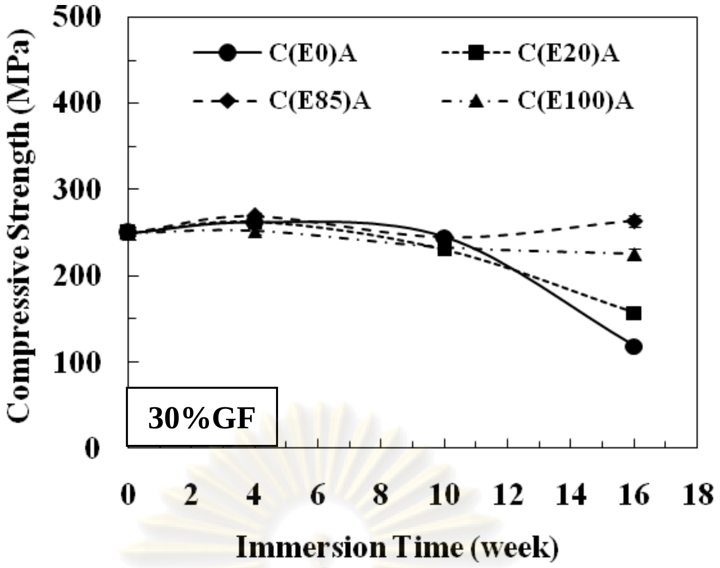


Figure 5.79 Compressive strength of PA6/GF (30 wt%) immersed in each test fuels

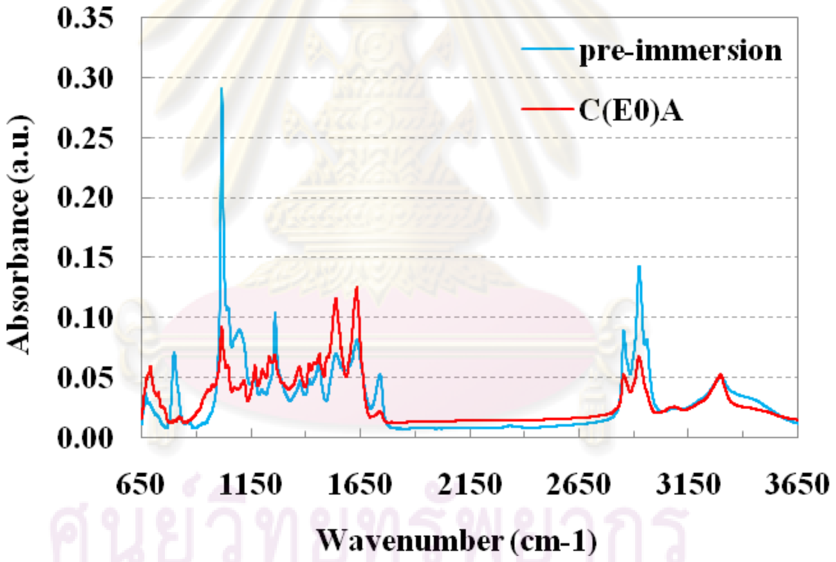


Figure 5.80 FTIR spectra of PA6, before immersion and after immersion in $C(E0)_A$

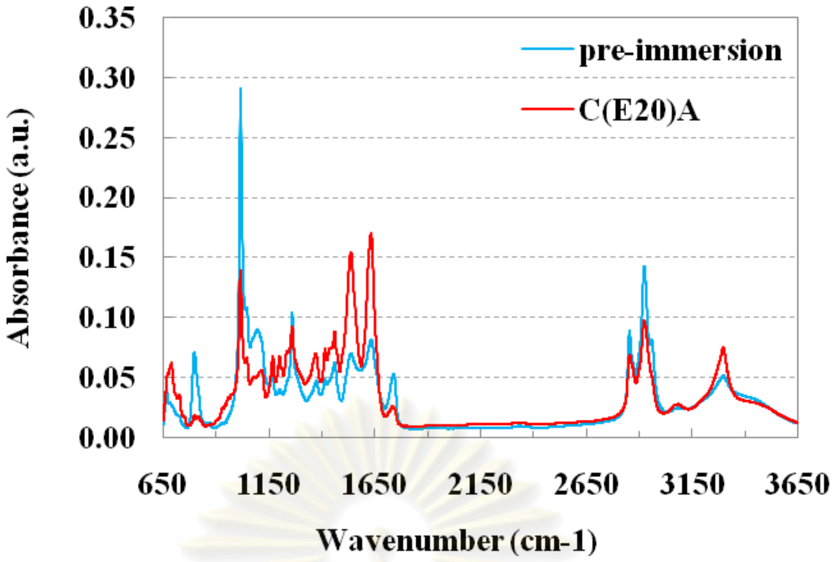


Figure 5.81 FTIR spectra of PA6, before immersion and after immersion in C(E20)$_A$

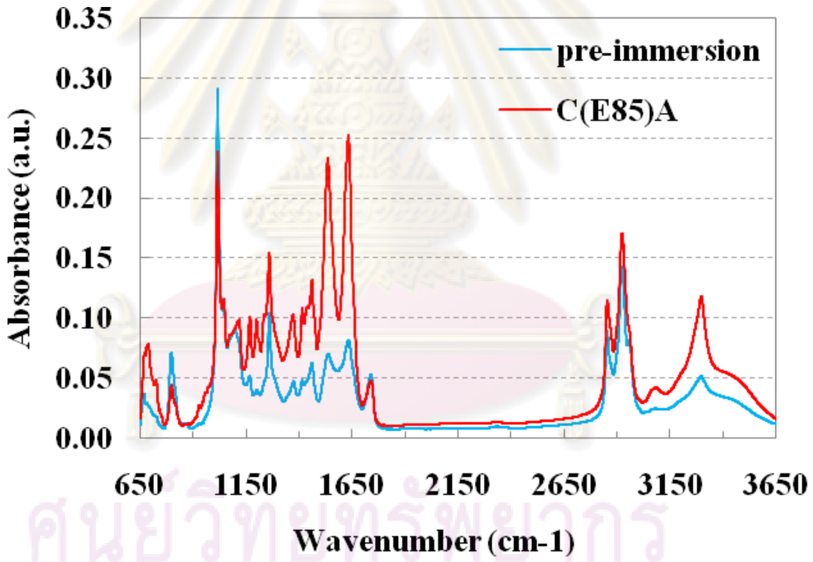


Figure 5.82 FTIR spectra of PA6, before immersion and after immersion in C(E85)$_A$

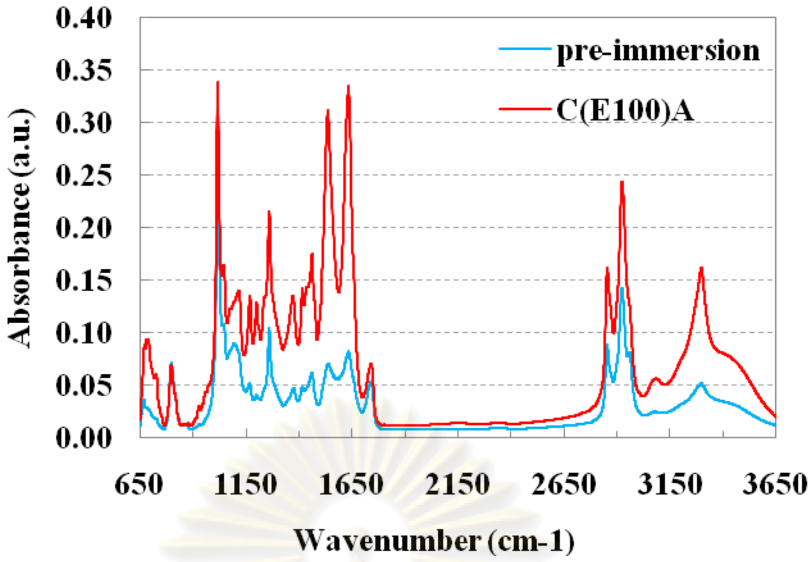


Figure 5.83 FTIR spectra of PA6, before immersion and after immersion in C(E100)$_A$

CHAPTER VI

CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

The findings obtained in this work can be summarized as the followings:

1. The PA6 matrix had an excellent adhesion to glass fiber reinforcement. Glass fiber could improve the mechanical properties, i.e. tensile, flexural, compressive and impact strengths of the composites.
2. Glass fiber could also improve the dimensional stability of the specimens by reducing the amorphous region while increasing crystalline region of the specimens.
3. PA6 has the ability to absorb significant amount of water. Water was generally concentrated in the amorphous region of PA6, making it more flexible and thus increasing the impact strength of PA6.
4. Test fuels affected both unreinforced and reinforced PA6 composites. Increasing of immersion time decreased tensile, flexural and compressive strength while increased impact strength. But the test fuels affected the mechanical properties of PA6/GF composites less than that of PA6 specimens.
5. Surrogate gasohols, namely, $C(E20)_A$, $CE(85)_A$ and $C(E100)_A$ affected the tensile strength, flexural strength and Young's modulus of both unreinforced and reinforced PA6 composites more than $C(E0)_A$ due to adsorption of water and alcohols from $C(E20)_A$, $CE(85)_A$ and $C(E100)_A$ by both unreinforced and reinforced PA6 composites.

6.2 Recommendations

To investigate further the effects of gasohols on glass fiber reinforced PA6 composites, the following recommendations are suggested.

1. Besides surrogate gasoline and gasohols used in this experiment, the effect of each component of the surrogate fuels on physical and mechanical properties of unreinforced and reinforced composites should be studied. The absorption and solubility of these components by composites should also be determined.
2. The experimental data should be compared with the other plastics to find the suitable materials for automotive fuel system running on gasohols.

REFERENCES

[1] Mark, H. F. Encyclopedia of Polymer Science and Technology. 3th ed., 2007.

[2] Roger, F. J., Michell, R., and Donald V.R. Guide to Start Fiber Reinforced Plastics, 1998.

[3] Polyamide 6 and Polyamide 66[Online]. 1995. Available from: http://www.Omnexus.com/tc/polyamides-center/index.aspx?id=pa6.html[2009, April 3]

[4] Nylon.[Online]. 2009. Available from: http://en.wikipedia.org/wiki/Nylon.html[2009, April 7]

[5] Polyamide Features and Uses.[Online]. 2009. Available from: http://www.ides.com/generics/Nylon.html[2009, June 15]

[6] Charles, A. H. Handbook of Plastics and Elastomer. Editor-in-chief: McGraw-Hill, 1975.

[7] Properties of Glass Fiber Reinforced Nylon 6 Composites. Thomas Publishing Company. [Online]. 2009. Available from: http://www.efunda.com.html[2009, June 14]

[8] William, C. Filler for Plastics. Co-Ordinating Editor. The City University London: Iliffe for the Plastics Institute, 1971.

[9] SAE Standard J1681, Gasoline, Alcohol and Diesel Fuel Surrogates for Material Testing, 1998.

[10] Petroleum Authority of Thailand (PTT) [Online]. Available from: http://www.pttplc.com/en/Default.aspx[2008, July 12]

[11] Gullu, A., Ozdemir, A. and Ozdemir, E. Experimental Investigation of The Effect of Glass Fibres on The Mechanical Properties of Polypropylene (PP) and Polyamide 6 (PA6) Plastics. Materials and Design 27 (2006): 316-323.

[12] Gasohol. The Columbia Encyclopedia, 6th ed., [online]. 2007. Available from: http://en cyclopedia.com[2009, March 24]

[13] Smith, J.L. and Workman, J.P. Alcohol for Motor Fuels[online]. Available from: http://www. ext.colostate.edu/pubs/farmmgt/05010.html[2008, June 12]

[14] Gasohol.[Online]. 2008. Available from: http://encyclopedia.farlex.com/gasohol.html [2008, December 9]

[15] Gasohol 95. Ministry of Energy[Online]. 2004. Available from: http://www.energy.go.th/en/- knowledgeDetail.asp?id=38.html[2008, December 9]

[16] Nicholas P.Cheremisinoff. Gasohol for Energy Production. Energy Technology Series: Ann Arbor Science Publishers, 1979.

[17] Lyons, T.P. Gasohol, a Step to Energy Independence: Alltech Technical Publichers, 1981.

[18] Belofsky, H. Plastics Product Design and Process Engineering. The University of Akron, 1995.

[19] Packham, D.E. Handbook of Adhesion. 2nd ed. New York: Wiley Inter Science, 2005.

[20] Mel, M.S. Composite Materials Volume I. New York: McGraw-Hill, 1996.

[21] McCrum, N.G., Buckley, C.P., and Bucknall, C.B. Principles of Polymer Engineering. USA: Oxford University Press, 1988.

[22] Bruce, J., Gary, M. and Paul S. The Effects of E20 on Plastic Automotive Fuel System Components. Minnesota Center for Automotive Research (2008).

[23] Mel, M.S. Composite Materials, Volume II, Processing, Fabrication and Application. New York: MaGraw-Hill, 1997.

[24] Nicholas P.Cheremisinoff, and Paul, N. C. Fiber glass Reinforced Plastics: Springer, 1978.

[25] Jiang, T., Wang, Y. and Yeh, J. Study on Solvent Permeation Resistance Properties of Nylon6/Clay Nanocomposite. European Polymer Journal 41 (2005): 459-466.

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

[27] Robert, L., Furey and Marvin, W. J., SAE Standard 779008, Exhaust and evaporative emissions from a Brazilian Chevrolet fuelled with ethanol-gasoline blends.

[28] Owen, K. and Coley, T. Automotive Fuels Reference Book. 2nd ed. Society of Automotive Engineers: Warrendale, 1995.

[29] Fred, W. B., JR. Textbook of Polymer Science. 3th ed. Professor of Analytical Chemistry Rensscla er Polytechnic Institue. New York, 1984.

[30] Alberto, N, Maria, P. N., Tim, O., Alejandro, R. A. and Juan, D. S. Plastics Testing and Characterization, 2008.

[31] Mahmound, R., Charles, D. Polymerization Compounding of HDPE/Kevlar Composite. I.Morphology and Mechanical Properties. Society of Plastics Engineers, 2006.

[32] Scanning Electron Microscope[Online]. 2009. Available from: http://en.wikipedia.-org/wiki/Scanning_electron_microscope.html[2009, May 26]

[33] Collyer, A. A., Utracki, L. A. and Kagakkai, N. Polymer rheology processing. Chemical Institute of Canada, American Chemical Society: 294-230.

[34] Instron. Instron Worldwide Headquarters[Online]. 2008. Available from: http://www.-instron.us/wa/applications.co.th.html[2008, October 4]

[35] Kopeliovich, D. Fracture Toughness[Online]. 2008. Available from: http://www.sub-stech.com \/dokuwiki/doku.php?id=fracture_toughness.html[2008, October 5]

[36] Wolfgang, G., Sabine S. Polymer Testing: Hanser Gardner, 2007.

[37] Plastics Testing. Intertex Plastics Technology[Online]. 2008. Available from: http://-www.ptli.com.html[2008, November 30]

[38] Compression Test[Online]. 2008. Available from: http://www.instron.co.th/wa/-applications/test_types/compression.aspx.html[2008, December 10]

[39] Alberto, C. Naranjo. Plastic Testing and characterization. vol.1: Hanser Gardner, 2008.

[40] ASTM Standard D570-98, Standard Test Method for Water Absorption of Plastics, 2005.

[41] Ozkoc, G., Bayram, G., and Bayramli, E. Processing and Characterization of Short Glass Fiber/ABS/Polyamide-6 Composites. Polymer Composites 26 (2005): 745-755.

[42] Van Krevelen, D. W. Properties of Polymer. 2nd ed. Amsterdam: Elsevier, 1976.

[43] Ozdemir, E., The experimental investigation of the physical properties of polypropylene (PP) and nylon 6 (PA6) that unreinforced and fiber rein Master's Thesis. Institute of Science and Technology Gazi University. 2001.

APPENDICES

APPENDIX A

THE EXPERINTAL DATA OF PHYSICAL PROPERTIES

Appendix A1. Water absorption

Table A1-1 Water absorption of PA6 and PA6/GF composites

Week	Material	Mass (g)					Average (g)
		1	2	3	4	5	
0	PA6	6.67	6.63	6.65	6.64	6.75	6.6669 ± 0.0486
	PA6/GF (15 wt%)	7.37	7.41	7.33	7.29	7.38	7.3576 ± 0.0461
	PA6/GF (30 wt%)	8.41	8.43	8.49	8.43	8.37	8.4255 ± 0.0441
1	PA6	6.79	6.82	6.82	6.81	6.80	6.8085 ± 0.0101
	PA6/GF (15 wt%)	7.50	7.49	7.52	7.54	7.48	7.5071 ± 0.0237
	PA6/GF (30 wt%)	8.59	8.58	8.52	8.56	8.50	8.5513 ± 0.0381
2	PA6	6.95	6.96	6.96	6.96	6.93	6.9521 ± 0.0113
	PA6/GF (15 wt%)	7.66	7.65	7.66	7.65	7.65	7.6570 ± 0.0052
	PA6/GF (30 wt%)	8.66	8.69	8.68	8.68	8.68	8.6782 ± 0.0100
3	PA6	7.08	7.06	7.09	7.07	7.07	7.0744 ± 0.0133
	PA6/GF (15 wt%)	7.78	7.79	7.72	7.71	7.78	7.7548 ± 0.0398
	PA6/GF (30 wt%)	8.79	8.79	8.76	8.78	8.83	8.7887 ± 0.0242
4	PA6	7.10	7.08	7.12	7.09	7.18	7.1132 ± 0.0405
	PA6/GF (15 wt%)	7.80	7.82	7.74	7.78	7.78	7.7827 ± 0.0284
	PA6/GF (30 wt%)	8.78	8.86	8.85	8.83	8.73	8.8114 ± 0.0543
7	PA6	7.16	7.12	7.17	7.14	7.24	7.1653 ± 0.0443
	PA6/GF (15 wt%)	7.84	7.87	7.78	7.77	7.84	7.8179 ± 0.0427
	PA6/GF (30 wt%)	8.84	8.86	8.94	8.84	8.79	8.8532 ± 0.0556
10	PA6	7.14	7.12	7.17	7.14	7.24	7.1620 ± 0.0471
	PA6/GF (15 wt%)	7.84	7.87	7.78	7.76	7.85	7.8202 ± 0.0458
	PA6/GF (30 wt%)	8.84	8.87	8.95	8.85	8.79	8.8598 ± 0.0589
13	PA6	7.17	7.16	7.17	7.16	7.16	7.1647 ± 0.0080
	PA6/GF (15 wt%)	7.82	7.82	7.82	7.82	7.82	7.8220 ± 0.0010
	PA6/GF (30 wt%)	8.86	8.86	8.86	8.86	8.86	8.8601 ± 0.0070
16	PA6	7.17	7.16	7.17	7.16	7.17	7.1657 ± 0.0032
	PA6/GF (15 wt%)	7.83	7.83	7.82	7.82	7.82	7.8230 ± 0.0046
	PA6/GF (30 wt%)	8.86	8.86	8.86	8.86	8.86	8.8612 ± 0.0014

Table A1-2 Percent water absorption of PA6 and PA6/GF composites

Week	% Water Absorption		
	PA6	PA6/GF (15 wt%)	PA6/GF (30 wt%)
0	0.0000	0.0000	0.0000
1	2.1239	2.0319	1.4931
2	4.2779	4.0693	2.9992
3	6.1123	5.3985	4.3107
4	6.6943	5.7777	4.5801
7	7.4757	6.2561	5.0763
10	7.4262	6.2874	5.1546
13	7.4669	6.3109	5.1584
16	7.4810	6.3249	5.1715

Table A1-3 Percent water absorption of PA6 and PA6/GF composites (based on mass of PA6 matrix only)

Week	% Water Absorption		
	PA6	PA6/GF (15 wt%)	PA6/GF (30 wt%)
0	0.0000	0.0000	0.0000
1	2.1239	2.3905	2.1330
2	4.2779	4.7874	4.2846
3	6.1123	6.3512	6.1582
4	6.6943	6.7973	6.5431
7	7.4757	7.3601	7.2518
10	7.4262	7.3969	7.3637
13	7.4669	7.4246	7.3691
16	7.4810	7.4410	7.3878

Appendix A2. Mass Change

Table A2-1 Mass change of PA6 immersed in test fuels

Week	Test Fuels	Mass (g)					Average (g)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	6.6376	6.6793	6.6054	6.6272	6.6882	6.6475 ± 0.0352	0.5292
	$C(E20)_A$	6.6686	6.6730	6.6263	6.6470	6.6160	6.6462 ± 0.0251	0.3783
	$C(E85)_A$	6.6186	6.6337	6.6290	6.6206	6.6470	6.6298 ± 0.0114	0.1723
	$C(E100)_A$	6.6536	6.6424	6.6661	6.6121	6.7016	6.6552 ± 0.0328	0.4924
2	$C(E0)_A$	6.6859	6.7292	6.6540	6.6747	6.7344	6.6956 ± 0.0350	0.5225
	$C(E20)_A$	6.8458	6.8442	6.8106	6.8260	6.7994	6.8252 ±0.0204	0.2989
	$C(E85)_A$	6.7546	6.7741	6.7709	6.7605	6.7916	6.7703 ±0.0142	0.2103
	$C(E100)_A$	6.8124	6.8099	6.8207	6.7889	6.8750	6.8214 ± 0.0322	0.4718
4	$C(E0)_A$	6.7082	6.7468	6.6756	6.6925	6.7545	6.7155 ± 0.0342	0.5091
	$C(E20)_A$	6.9074	6.9024	6.8778	6.8858	6.8623	6.8871 ± 0.0184	0.2667
	$C(E85)_A$	6.8365	6.8553	6.8603	6.8411	6.8729	6.8532 ± 0.0147	0.2150
	$C(E100)_A$	6.8902	6.8991	6.9013	6.8805	6.9613	6.9065 ± 0.0317	0.4594
7	$C(E0)_A$	6.7416	6.7819	6.7109	6.7303	6.7884	6.7506 ± 0.0335	0.4956
	$C(E20)_A$	6.9607	6.9564	6.9374	6.9411	6.9199	6.9431 ± 0.0163	0.2346
	$C(E85)_A$	6.9227	6.9453	6.9536	6.9335	6.9604	6.9431 ± 0.0152	0.2187
	$C(E100)_A$	6.9881	7.0032	6.9928	6.9904	7.0638	7.0077 ± 0.0319	0.4554
10	$C(E0)_A$	6.7584	6.8073	6.8182	6.7356	6.7687	6.7776 ± 0.0344	0.5080
	$C(E20)_A$	7.0865	7.0602	7.0655	7.0506	7.0664	7.0658 ± 0.0131	0.1861
	$C(E85)_A$	7.0308	7.0546	7.0352	7.0699	7.0131	7.0407 ± 0.0220	0.3125
	$C(E100)_A$	7.0942	7.1245	7.1280	7.1883	7.0941	7.1258 ± 0.0385	0.5397
13	$C(E0)_A$	6.7955	6.8366	6.7627	6.7858	6.8458	6.8053 ± 0.0350	0.5149
	$C(E20)_A$	7.1420	7.1206	7.1221	7.1028	7.1192	7.1213 ± 0.0139	0.1956
	$C(E85)_A$	7.0811	7.1057	7.1305	7.1041	7.1479	7.1139 ± 0.0258	0.3632
	$C(E100)_A$	7.2734	7.2057	7.1566	7.1684	7.2035	7.2015 ± 0.0456	0.6326
16	$C(E0)_A$	6.8103	6.8500	6.7753	6.7991	6.8614	6.8192 ± 0.0358	0.5257
	$C(E20)_A$	7.3418	7.3178	7.3269	7.3212	7.3129	7.3241 ± 0.0111	0.1518
	$C(E85)_A$	7.2203	7.2389	7.2841	7.2403	7.2803	7.2528 ± 0.0280	0.3864
	$C(E100)_A$	7.2636	7.2844	7.2653	7.2736	7.3560	7.2886 ± 0.0386	0.5293

Table A2-2 Mass change of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Mass (g)					Average (g)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	7.3720	7.3556	7.4896	7.3769	7.2954	7.3779 ± 0.0704	0.9540
	$C(E20)_A$	7.3771	7.3542	7.4309	7.3996	7.3236	7.3771 ± 0.0412	0.5584
	$C(E85)_A$	7.3890	7.3291	7.4290	7.3072	7.5268	7.3962 ± 0.0875	1.1827
	$C(E100)_A$	7.3381	7.3684	7.2927	7.3730	7.4098	7.3564 ± 0.0438	0.5950
2	$C(E0)_A$	7.4189	7.4031	7.5336	7.4199	7.3377	7.4226 ± 0.0706	0.9510
	$C(E20)_A$	7.4927	7.4743	7.5473	7.5161	7.4390	7.4939 ± 0.0411	0.5479
	$C(E85)_A$	7.5420	7.4930	7.5854	7.4660	7.6794	7.5532 ± 0.0841	1.1139
	$C(E100)_A$	7.4984	7.5116	7.4302	7.5297	7.5643	7.5068 ± 0.0495	0.6591
4	$C(E0)_A$	7.4485	7.4327	7.5652	7.4526	7.4690	7.4736 ± 0.0528	0.7066
	$C(E20)_A$	7.5403	7.5495	7.6009	7.5682	7.4887	7.5495 ± 0.0475	0.6294
	$C(E85)_A$	7.6033	7.5563	7.6470	7.5249	7.7409	7.6145 ± 0.0845	1.1100
	$C(E100)_A$	7.5724	7.5854	7.5000	7.6093	7.6401	7.5814 ± 0.0523	0.6900
7	$C(E0)_A$	7.4756	7.5616	7.5933	7.4804	7.3969	7.5016 ± 0.0776	1.0347
	$C(E20)_A$	7.6159	7.6024	7.6738	7.6417	7.5611	7.6190 ± 0.0423	0.5551
	$C(E85)_A$	7.6749	7.6344	7.7215	7.5995	7.8153	7.6891 ± 0.0840	1.0920
	$C(E100)_A$	7.6574	7.6622	7.5740	7.6933	7.7256	7.6625 ± 0.0565	0.7379
10	$C(E0)_A$	7.4979	7.5049	7.4852	7.6176	7.4195	7.5050 ± 0.0715	0.9523
	$C(E20)_A$	7.7207	7.7258	7.7862	7.6746	7.7566	7.7328 ± 0.0418	0.5410
	$C(E85)_A$	7.7951	7.8895	7.6718	7.7469	7.7116	7.7630 ± 0.0840	1.0826
	$C(E100)_A$	7.6480	7.7427	7.8073	7.7778	7.7404	7.7432 ± 0.0600	0.7743
13	$C(E0)_A$	7.5240	7.5075	7.6418	7.5277	7.4459	7.5294 ± 0.0709	0.9419
	$C(E20)_A$	7.7659	7.7674	7.8260	7.7976	7.7169	7.7748 ± 0.0407	0.5236
	$C(E85)_A$	7.7914	7.7575	7.8398	7.7169	7.9364	7.8084 ± 0.0846	1.0833
	$C(E100)_A$	7.7919	7.7899	7.6912	7.8329	7.8515	7.7915 ± 0.0620	0.7958
16	$C(E0)_A$	7.6586	7.5235	7.5379	7.4588	7.5438	7.5445 ± 0.0722	0.9569
	$C(E20)_A$	7.9565	7.9001	7.9863	7.9920	7.9548	7.9579 ± 0.0365	0.4584
	$C(E85)_A$	7.8424	7.8704	7.9166	8.0139	7.7975	7.8882 ± 0.0825	1.0463
	$C(E100)_A$	7.8722	7.9303	7.9091	7.8754	7.7724	7.8719 ± 0.0606	0.7703

Table A2-3 Mass change of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Mass (g)					Average (g)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	8.3649	8.4239	8.3128	8.4392	8.3267	8.3735 ± 0.0566	0.6757
	$C(E20)_A$	8.3930	8.3630	8.5397	8.5627	8.6384	8.4994 ± 0.1171	1.3781
	$C(E85)_A$	8.2612	8.4837	8.4830	8.3643	8.3766	8.3938 ± 0.0933	1.1110
	$C(E100)_A$	8.6164	8.3624	8.4184	8.3938	8.4599	8.4502 ± 0.0995	1.1777
2	$C(E0)_A$	8.4030	8.4654	8.3513	8.4781	8.3684	8.4132 ± 0.0567	0.6745
	$C(E20)_A$	8.4842	8.4545	8.6290	8.6496	8.7330	8.5901 ± 0.1173	1.3660
	$C(E85)_A$	8.3873	8.6008	8.5968	8.4818	8.4877	8.5109 ± 0.0896	1.0529
	$C(E100)_A$	8.7506	8.4903	8.5443	8.5208	8.5858	8.5784 ± 0.1024	1.1938
4	$C(E0)_A$	8.4201	8.4813	8.3673	8.4951	8.3843	8.4296 ± 0.0570	0.6759
	$C(E20)_A$	8.5272	8.5000	8.6723	8.6909	8.7785	8.6338 ± 0.1172	1.3575
	$C(E85)_A$	8.4444	8.6532	8.6488	8.5362	8.5374	8.5640 ± 0.0879	1.0268
	$C(E100)_A$	8.8089	8.5478	8.6053	8.5829	8.6445	8.6379 ± 0.1018	1.1791
7	$C(E0)_A$	8.4516	8.5129	8.4009	8.5267	8.4154	8.4615 ± 0.0565	0.6682
	$C(E20)_A$	8.6230	8.5979	8.7687	8.7822	8.8747	8.7293 ± 0.1163	1.3317
	$C(E85)_A$	8.2323	8.7142	8.7102	8.6005	8.5989	8.5712 ± 0.1976	2.3059
	$C(E100)_A$	8.8728	8.6126	8.6700	8.6488	8.7115	8.7031 ± 0.1014	1.1647
10	$C(E0)_A$	8.5594	8.4848	8.5407	8.4338	8.4460	8.4929 ± 0.0558	0.6573
	$C(E20)_A$	8.6766	8.6532	8.8311	8.9030	8.8212	8.7770 ± 0.1074	1.2240
	$C(E85)_A$	8.7654	8.7584	8.6539	8.6488	8.5710	8.6795 ± 0.0821	0.9461
	$C(E100)_A$	8.6775	8.7139	8.7343	8.9354	8.7751	8.7672 ± 0.1004	1.1452
13	$C(E0)_A$	8.5058	8.5621	8.4497	8.5779	8.4664	8.5124 ± 0.0567	0.6659
	$C(E20)_A$	8.7159	8.6936	8.8602	8.8687	8.9730	8.8223 ± 0.1164	1.3192
	$C(E85)_A$	8.6201	8.8069	8.8024	8.7012	8.6911	8.7243 ± 0.0797	0.9137
	$C(E100)_A$	8.9731	8.7183	8.7741	8.7565	8.8195	8.8083 ± 0.0990	1.1244
16	$C(E0)_A$	8.5768	8.4612	8.5167	8.5919	8.4796	8.5252 ± 0.0578	0.6779
	$C(E20)_A$	8.9783	8.8380	8.8220	8.9796	9.0996	8.9435 ± 0.1149	1.2843
	$C(E85)_A$	8.8694	8.8740	8.7573	8.7765	8.7076	8.7970 ± 0.0727	0.8268
	$C(E100)_A$	8.8672	8.8203	8.7612	9.0205	8.8099	8.8558 ± 0.0995	1.1231

Table A2-4 Percent mass increase of PA6 and PA6/GF composites

Week	Test Fuels	Average Mass (g)			% Mass Increase (g)		
		0%GF	15%GF	30%GF	0%GF	15%GF	30%GF
0	$C(E0)_A$	6.6475	7.3779	8.3735	0.0000	0.0000	0.0000
	$C(E20)_A$	6.6462	7.3771	8.4994	0.0000	0.0000	0.0000
	$C(E85)_A$	6.6298	7.3962	8.3938	0.0000	0.0000	0.0000
	$C(E100)_A$	6.6552	7.3564	8.4502	0.0000	0.0000	0.0000
2	$C(E0)_A$	6.6956	7.4226	8.4132	0.7236	0.6064	0.4746
	$C(E20)_A$	6.8252	7.4939	8.5901	2.6933	1.5833	1.0671
	$C(E85)_A$	6.7703	7.5532	8.5109	2.1192	2.1219	1.3953
	$C(E100)_A$	6.8214	7.5068	8.5784	2.4973	2.0450	1.5169
4	$C(E0)_A$	6.7155	7.4736	8.4296	1.0229	1.2971	0.6702
	$C(E20)_A$	6.8871	7.5495	8.6338	3.6246	2.3376	1.5815
	$C(E85)_A$	6.8532	7.6145	8.5640	3.3696	2.9510	2.0282
	$C(E100)_A$	6.9065	7.5814	8.6379	3.7760	3.0591	2.2213
7	$C(E0)_A$	6.7506	7.5016	8.4615	1.5510	1.6761	1.0509
	$C(E20)_A$	6.9431	7.6190	8.7293	4.4672	3.2791	2.7054
	$C(E85)_A$	6.9431	7.6891	8.5712	4.7256	3.9601	2.1142
	$C(E100)_A$	7.0077	7.6625	8.7031	5.2966	4.1610	2.9935
10	$C(E0)_A$	6.7776	7.5050	8.4929	1.9571	1.7230	1.4264
	$C(E20)_A$	7.0658	7.7328	8.7770	6.3134	4.8217	3.2668
	$C(E85)_A$	7.0407	7.7630	8.6795	6.1978	4.9587	3.4042
	$C(E100)_A$	7.1258	7.7432	8.7672	7.0712	5.2586	3.7521
13	$C(E0)_A$	6.8053	7.5294	8.5124	2.3738	2.0532	1.6586
	$C(E20)_A$	7.1213	7.7748	8.8223	7.1484	5.3908	3.7993
	$C(E85)_A$	7.1139	7.8084	8.7243	7.3019	5.5728	3.9384
	$C(E100)_A$	7.2015	7.7915	8.8083	8.2086	5.9143	4.2380
16	$C(E0)_A$	6.8192	7.5445	8.5252	2.5829	2.2584	1.8121
	$C(E20)_A$	7.3241	7.9579	8.9435	10.1998	7.8738	5.2256
	$C(E85)_A$	7.2528	7.8882	8.7970	9.3970	6.6512	4.8036
	$C(E100)_A$	7.2886	7.8719	8.8558	9.5174	7.0072	4.8004

Table A2-5 Percent mass of PA6 and PA6/GF composites (based on mass of PA6 matrix only)

Week	Test Fuels	% Mass Increase (g) (Based on Mass of Matrix)		
		0%GF	15%GF	30%GF
0	$C(E0)_A$	0.0000	0.0000	0.0000
	$C(E20)_A$	0.0000	0.0000	0.0000
	$C(E85)_A$	0.0000	0.0000	0.0000
	$C(E100)_A$	0.0000	0.0000	0.0000
2	$C(E0)_A$	0.7236	0.7134	0.6780
	$C(E20)_A$	2.6933	1.8627	1.5245
	$C(E85)_A$	2.1192	2.4963	1.9933
	$C(E100)_A$	2.4973	2.4059	2.1670
4	$C(E0)_A$	1.0229	1.5260	0.9574
	$C(E20)_A$	3.6246	2.7501	2.2593
	$C(E85)_A$	3.3696	3.4717	2.8974
	$C(E100)_A$	3.7760	3.5989	3.1732
7	$C(E0)_A$	1.5510	1.9719	1.5013
	$C(E20)_A$	4.4672	3.8577	3.8648
	$C(E85)_A$	4.7256	4.6590	3.0203
	$C(E100)_A$	5.2966	4.8953	4.2765
10	$C(E0)_A$	1.9571	2.0270	2.0377
	$C(E20)_A$	6.3134	5.6726	4.6669
	$C(E85)_A$	6.1978	5.8338	4.8631
	$C(E100)_A$	7.0712	6.1865	5.3602
13	$C(E0)_A$	2.3738	2.4155	2.3694
	$C(E20)_A$	7.1484	6.3421	5.4276
	$C(E85)_A$	7.3019	6.5563	5.6263
	$C(E100)_A$	8.2086	6.9580	6.0543
16	$C(E0)_A$	2.5829	2.6569	2.5888
	$C(E20)_A$	10.1998	9.2633	7.4651
	$C(E85)_A$	9.3970	7.8250	6.8622
	$C(E100)_A$	9.5174	8.2438	6.8577

Appendix A3. Dimension Change

Table A3-1 Thickness of PA6 immersed in test fuels

Week	Test Fuels	Thickness (mm)					Average (mm)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	3.1700	3.1667	3.1433	3.1383	3.2000	3.1637 ± 0.0246	0.7787
	$C(E20)_A$	3.1833	3.1733	3.1700	3.1750	3.1516	3.1706 ± 0.0117	0.3696
	$C(E85)_A$	3.1650	3.1683	3.1666	3.1633	3.1883	3.1703 ± 0.0102	0.3227
	$C(E100)_A$	3.1816	3.1566	3.1733	3.1833	3.1833	3.1756 ± 0.0114	0.3593
2	$C(E0)_A$	3.1433	3.1333	3.1667	3.1400	3.1267	3.1420 ± 0.0152	0.5225
	$C(E20)_A$	3.1933	3.1400	3.1733	3.1700	3.1767	3.1707 ± 0.0194	0.2989
	$C(E85)_A$	3.1533	3.1800	3.1767	3.1600	3.1867	3.1713 ± 0.0141	0.2103
	$C(E100)_A$	3.1733	3.1533	3.2100	3.1967	3.2367	3.1940 ± 0.0323	0.4718
4	$C(E0)_A$	3.1533	3.1567	3.1333	3.1433	3.1900	3.1553 ± 0.0214	0.5091
	$C(E20)_A$	3.2233	3.2533	3.2267	3.2300	3.1833	3.2233 ± 0.0253	0.2667
	$C(E85)_A$	3.2400	3.2233	3.2100	3.2300	3.2100	3.2227 ± 0.0130	0.2150
	$C(E100)_A$	3.2400	3.2333	3.2167	3.2367	3.2300	3.2313 ± 0.0090	0.4594
7	$C(E0)_A$	3.1233	3.1500	3.1433	3.1300	3.1667	3.1427 ± 0.0171	0.4956
	$C(E20)_A$	3.2333	3.2200	3.1967	3.2633	3.2233	3.2273 ± 0.0242	0.2346
	$C(E85)_A$	3.4033	3.3867	3.3600	3.3133	3.4067	3.3740 ± 0.0386	0.2187
	$C(E100)_A$	3.3133	3.3000	3.2700	3.3367	3.3200	3.3080 ± 0.0250	0.4554
10	$C(E0)_A$	3.1800	3.1867	3.1733	3.1933	3.2400	3.1947 ± 0.0264	0.5080
	$C(E20)_A$	3.2667	3.2667	3.2667	3.2700	3.2333	3.2607 ± 0.0153	0.1861
	$C(E85)_A$	3.2600	3.2200	3.2400	3.2300	3.2833	3.2467 ± 0.0253	0.3125
	$C(E100)_A$	3.2733	3.2500	3.2733	3.2767	3.2733	3.2693 ± 0.0109	0.5397
13	$C(E0)_A$	3.1500	3.1633	3.1400	3.1400	3.1767	3.1540 ± 0.0159	0.5149
	$C(E20)_A$	3.2667	3.2433	3.2533	3.2333	3.2167	3.2427 ± 0.0191	0.1956
	$C(E85)_A$	3.2467	3.2467	3.2800	3.2767	3.3100	3.2720 ± 0.0265	0.3632
	$C(E100)_A$	3.2600	3.2300	3.2533	3.2433	3.2300	3.2433 ± 0.0135	0.6326
16	$C(E0)_A$	3.2067	3.1667	3.1600	3.1833	3.1767	3.1787 ± 0.0180	0.5257
	$C(E20)_A$	3.2433	3.2467	3.2267	3.2500	3.2600	3.2453 ± 0.0122	0.1518
	$C(E85)_A$	3.2400	3.2300	3.2367	3.2100	3.2233	3.2280 ± 0.0119	0.3864
	$C(E100)_A$	3.2633	3.2467	3.2300	3.2433	3.2233	3.2413 ± 0.0156	0.5293

Table A3-2 Thickness of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Thickness (mm)					Average (mm)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	3.1960	3.2140	3.2320	3.1680	3.2060	3.2032 ± 0.0237	0.7396
	$C(E20)_A$	3.1840	3.1800	3.2180	3.1900	3.2100	3.1964 ± 0.0167	0.5224
	$C(E85)_A$	3.2020	3.2120	3.1980	3.1740	3.1900	3.1952 ± 0.0143	0.4461
	$C(E100)_A$	3.1760	3.1860	3.1880	3.2040	3.1940	3.1896 ± 0.0103	0.3240
2	$C(E0)_A$	3.1267	3.1333	3.1700	3.1233	3.1667	3.1440 ± 0.0225	0.7167
	$C(E20)_A$	3.1700	3.1800	3.1900	3.2433	3.2033	3.1973 ± 0.0285	0.8920
	$C(E85)_A$	3.2200	3.2233	3.2300	3.1900	3.2433	3.2213 ± 0.0197	0.6104
	$C(E100)_A$	3.2467	3.2433	3.2133	3.2767	3.2200	3.2400 ± 0.0251	0.7733
4	$C(E0)_A$	3.1600	3.1833	3.2133	3.2067	3.1633	3.1853 ± 0.0243	0.7640
	$C(E20)_A$	3.2133	3.2400	3.2567	3.2167	3.2733	3.2400 ± 0.0257	0.7936
	$C(E85)_A$	3.2767	3.2667	3.2500	3.2367	3.2167	3.2493 ± 0.0239	0.7340
	$C(E100)_A$	3.2500	3.2733	3.2367	3.2667	3.2667	3.2587 ± 0.0150	0.4609
7	$C(E0)_A$	3.1967	3.1867	3.1467	3.2367	3.1833	3.1900 ± 0.0322	1.0104
	$C(E20)_A$	3.2333	3.2667	3.2200	3.2067	3.1967	3.2247 ± 0.0272	0.8449
	$C(E85)_A$	3.2133	3.1900	3.2267	3.2400	3.2333	3.2207 ± 0.0198	0.6141
	$C(E100)_A$	3.1867	3.2733	3.2467	3.2500	3.2667	3.2447 ± 0.0343	1.0567
10	$C(E0)_A$	3.1600	3.2167	3.2333	3.1833	3.2500	3.2087 ± 0.0367	1.1442
	$C(E20)_A$	3.3000	3.2600	3.2833	3.2967	3.2733	3.2827 ± 0.0166	0.5047
	$C(E85)_A$	3.2533	3.3100	3.2933	3.2633	3.3367	3.2913 ± 0.0340	1.0343
	$C(E100)_A$	3.2633	3.3333	3.2433	3.3233	3.2767	3.2880 ± 0.0388	1.1814
13	$C(E0)_A$	3.1800	3.1700	3.2200	3.1967	3.2167	3.1967 ± 0.0220	0.6877
	$C(E20)_A$	3.3400	3.3633	3.3733	3.3967	3.4667	3.3880 ± 0.0485	1.4302
	$C(E85)_A$	3.2567	3.2700	3.2600	3.2567	3.2967	3.2680 ± 0.0169	0.5181
	$C(E100)_A$	3.2533	3.2700	3.2600	3.2933	3.2933	3.2740 ± 0.0186	0.5687
16	$C(E0)_A$	3.2133	3.2267	3.2000	3.2167	3.2333	3.2180 ± 0.0128	0.3985
	$C(E20)_A$	3.2633	3.2533	3.2667	3.2733	3.2900	3.2694 ± 0.0136	0.4167
	$C(E85)_A$	3.2333	3.2967	3.3000	3.2533	3.2567	3.2680 ± 0.0291	0.8910
	$C(E100)_A$	3.2867	3.2867	3.2967	3.2700	3.2667	3.2813 ± 0.0126	0.3841

Table A3-3 Thickness of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Thickness (mm)					Average (mm)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	3.2960	3.2520	3.2600	3.2760	3.2200	3.2608 ± 0.0283	0.8691
	$C(E20)_A$	3.2480	3.3100	3.3440	3.3520	3.3720	3.3252 ± 0.0486	1.4619
	$C(E85)_A$	3.2520	3.2740	3.2520	3.2580	3.2120	3.2496 ± 0.0229	0.7036
	$C(E100)_A$	3.3060	3.2260	3.2420	3.2540	3.2600	3.2576 ± 0.0300	0.9213
2	$C(E0)_A$	3.2433	3.1567	3.1767	3.2067	3.1533	3.1873 ± 0.0378	1.1864
	$C(E20)_A$	3.2433	3.3600	3.3433	3.3400	3.3800	3.3333 ± 0.0528	1.5827
	$C(E85)_A$	3.2233	3.2467	3.2833	3.2367	3.2000	3.2380 ± 0.0308	0.9508
	$C(E100)_A$	3.3233	3.2900	3.2567	3.2700	3.2567	3.2793 ± 0.0281	0.8577
4	$C(E0)_A$	3.3000	3.2733	3.1867	3.2533	3.2267	3.2480 ± 0.0436	1.3412
	$C(E20)_A$	3.2700	3.3300	3.3767	3.3867	3.4000	3.3527 ± 0.0532	1.5867
	$C(E85)_A$	3.2867	3.3100	3.3167	3.3333	3.2833	3.3060 ± 0.0210	0.6353
	$C(E100)_A$	3.3533	3.3200	3.3133	3.3133	3.3000	3.3200 ± 0.0200	0.6024
7	$C(E0)_A$	3.2767	3.3000	3.2733	3.2400	3.2467	3.2673 ± 0.0243	0.7441
	$C(E20)_A$	3.2367	3.2433	3.2367	3.2633	3.2900	3.2540 ± 0.0229	0.7038
	$C(E85)_A$	3.2700	3.2367	3.3067	3.2233	3.2700	3.2613 ± 0.0326	1.0004
	$C(E100)_A$	3.3533	3.2600	3.2967	3.3733	3.3267	3.3220 ± 0.0451	1.3566
10	$C(E0)_A$	3.2967	3.2400	3.2700	3.3400	3.2467	3.2787 ± 0.0409	1.2464
	$C(E20)_A$	3.3433	3.3633	3.3900	3.4233	3.4433	3.3927 ± 0.0413	1.2161
	$C(E85)_A$	3.3400	3.3267	3.3467	3.3400	3.3267	3.3360 ± 0.0089	0.2681
	$C(E100)_A$	3.4000	3.3500	3.3233	3.3300	3.4067	3.3620 ± 0.0391	1.1618
13	$C(E0)_A$	3.2600	3.2833	3.2633	3.2967	3.1933	3.2593 ± 0.0398	1.2217
	$C(E20)_A$	3.2233	3.2300	3.2367	3.2333	3.2600	3.2367 ± 0.0139	0.4308
	$C(E85)_A$	3.3100	3.3467	3.3400	3.2967	3.2867	3.3160 ± 0.0264	0.7960
	$C(E100)_A$	3.3067	3.3033	3.3967	3.3367	3.3500	3.3387 ± 0.0380	1.1375
16	$C(E0)_A$	3.2433	3.3167	3.3133	3.2533	3.2700	3.2793 ± 0.0339	1.0351
	$C(E20)_A$	3.4533	3.3967	3.3633	3.3700	3.4000	3.3967 ± 0.0355	1.0455
	$C(E85)_A$	3.3233	3.3133	3.2800	3.3300	3.3333	3.3160 ± 0.0215	0.6491
	$C(E100)_A$	3.3233	3.3767	3.3200	3.3133	3.3467	3.3360 ± 0.0260	0.7785

Table A3-4 Diameter of PA6 immersed in test fuels

Week	Test Fuels	Diameter (mm)					Average (mm)	% Error
		1	2	3	4	5		
0	C(E0)$_A$	50.09	50.06	50.10	49.94	50.08	50.0505 ± 0.0662	0.1323
	C(E20)$_A$	49.95	50.08	49.96	49.95	50.05	49.9970 ± 0.0621	0.1242
	C(E85)$_A$	50.06	50.06	50.05	50.10	49.98	50.0503 ± 0.0422	0.0843
	C(E100)$_A$	50.09	50.11	50.11	49.95	50.08	50.0672 ± 0.0664	0.1326
2	C(E0)$_A$	50.14	50.10	50.08	49.94	50.60	50.1720 ± 0.252	0.5020
	C(E20)$_A$	50.12	50.19	50.11	50.11	50.22	50.1500 ± 0.0504	0.1006
	C(E85)$_A$	50.16	50.17	50.19	50.22	50.10	50.1673 ± 0.0440	0.0877
	C(E100)$_A$	50.25	50.27	50.22	50.14	50.25	50.2273 ± 0.0537	0.1069
4	C(E0)$_A$	50.22	50.17	50.21	50.06	50.20	50.1740 ± 0.0663	0.1322
	C(E20)$_A$	50.31	50.43	50.34	50.32	50.43	50.3633 ± 0.0588	0.1167
	C(E85)$_A$	50.31	50.32	50.31	50.37	50.21	50.3027 ± 0.0573	0.1139
	C(E100)$_A$	50.27	50.34	50.41	50.39	50.42	50.3667 ± 0.0595	0.1182
7	C(E0)$_A$	50.29	50.13	50.24	50.28	50.25	50.2387 ± 0.0626	0.1245
	C(E20)$_A$	50.53	50.49	50.41	50.45	50.54	50.4840 ± 0.0545	0.1079
	C(E85)$_A$	50.51	50.52	50.41	50.47	50.56	50.4927 ± 0.0564	0.1118
	C(E100)$_A$	50.56	50.66	50.54	50.71	50.58	50.6080 ± 0.0712	0.1407
10	C(E0)$_A$	50.34	50.33	50.31	50.24	50.35	50.3133 ± 0.0439	0.0873
	C(E20)$_A$	50.72	50.76	50.74	50.68	50.90	50.7607 ± 0.0809	0.1594
	C(E85)$_A$	50.71	50.70	50.77	50.79	50.73	50.7387 ± 0.0364	0.0718
	C(E100)$_A$	50.93	51.11	50.81	51.00	51.10	50.9913 ± 0.1262	0.2475
13	C(E0)$_A$	50.39	50.37	50.39	50.25	50.36	50.3507 ± 0.0576	0.1144
	C(E20)$_A$	50.98	50.95	51.07	51.22	51.06	51.0567 ± 0.1041	0.2040
	C(E85)$_A$	51.01	51.04	51.14	51.13	51.06	51.0760 ± 0.0586	0.1148
	C(E100)$_A$	51.39	51.37	51.14	51.20	51.39	51.2987 ± 0.1196	0.2331
16	C(E0)$_A$	50.39	50.36	50.34	50.34	50.35	50.3560 ± 0.0196	0.0390
	C(E20)$_A$	51.47	51.41	51.47	51.37	51.56	51.4567 ± 0.0710	0.1380
	C(E85)$_A$	51.39	51.37	51.55	51.52	51.42	51.4480 ± 0.0802	0.1559
	C(E100)$_A$	51.40	51.53	51.38	51.44	51.56	51.4613 ± 0.0779	0.1513

Table A3-5 Diameter of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Diameter (mm)					Average (mm)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	50.32	50.35	50.23	50.39	50.03	50.2624 ± 0.1419	0.2824
	$C(E20)_A$	50.39	50.34	50.32	50.37	50.38	50.3584 ± 0.0304	0.0605
	$C(E85)_A$	50.35	50.25	50.21	50.33	50.29	50.2852 ± 0.0587	0.1167
	$C(E100)_A$	50.32	50.32	50.19	50.32	50.20	50.2728 ± 0.0684	0.1361
2	$C(E0)_A$	50.31	50.32	50.19	50.37	50.02	50.2413 ± 0.1392	0.2770
	$C(E20)_A$	50.50	50.44	50.37	50.47	50.43	50.4427 ± 0.0492	0.0975
	$C(E85)_A$	50.45	50.36	50.31	50.44	50.36	50.3820 ± 0.0581	0.1152
	$C(E100)_A$	50.47	50.49	50.28	50.42	50.30	50.3920 ± 0.0935	0.1856
4	$C(E0)_A$	50.40	50.45	50.32	50.46	50.17	50.3620 ± 0.1198	0.2379
	$C(E20)_A$	50.53	50.51	50.43	50.58	50.51	50.5142 ± 0.0609	0.1205
	$C(E85)_A$	50.57	50.46	50.42	50.47	50.48	50.4793 ± 0.0560	0.1110
	$C(E100)_A$	50.56	50.49	50.32	50.57	50.36	50.4600 ± 0.1136	0.2250
7	$C(E0)_A$	50.50	50.20	50.47	50.34	50.42	50.3847 ± 0.1211	0.2403
	$C(E20)_A$	50.64	50.61	50.59	50.66	50.68	50.6347 ± 0.0386	0.0763
	$C(E85)_A$	50.68	50.54	50.64	50.53	50.60	50.5973 ± 0.0642	0.1268
	$C(E100)_A$	50.49	50.71	50.64	50.64	50.55	50.6040 ± 0.0860	0.1700
10	$C(E0)_A$	50.43	50.53	50.38	50.58	50.22	50.4260 ± 0.1394	0.2764
	$C(E20)_A$	50.76	50.83	50.72	50.85	50.76	50.7840 ± 0.0539	0.1062
	$C(E85)_A$	50.79	50.71	50.59	50.82	50.75	50.7320 ± 0.0908	0.1790
	$C(E100)_A$	50.88	50.84	50.74	50.83	50.72	50.8007 ± 0.0687	0.1352
13	$C(E0)_A$	50.48	50.52	50.39	50.57	50.27	50.4453 ± 0.1195	0.2369
	$C(E20)_A$	50.93	51.00	50.90	50.99	50.90	50.9440 ± 0.0471	0.0925
	$C(E85)_A$	51.31	50.84	50.74	50.93	50.84	50.9340 ± 0.2211	0.4340
	$C(E100)_A$	50.84	50.85	51.03	50.93	51.02	50.9353 ± 0.0894	0.1755
16	$C(E0)_A$	50.43	50.54	50.50	50.21	50.58	50.4540 ± 0.1468	0.2910
	$C(E20)_A$	51.14	51.18	51.02	51.26	51.22	51.1633 ± 0.0905	0.1769
	$C(E85)_A$	50.99	51.12	50.91	51.02	51.07	51.0227 ± 0.0786	0.1541
	$C(E100)_A$	51.11	51.00	51.16	51.15	50.99	51.0813 ± 0.0809	0.1583

Table A3-6 Diameter of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Diameter (mm)					Average (g)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	50.39	50.38	50.29	50.38	50.41	50.3692 ± 0.0478	0.0950
	$C(E20)_A$	50.45	50.31	50.22	50.40	50.34	50.3448 ± 0.0869	0.1726
	$C(E85)_A$	50.37	50.43	50.42	50.39	50.39	50.3984 ± 0.0259	0.0514
	$C(E100)_A$	50.42	50.35	50.42	50.27	50.46	50.3833 ± 0.0746	0.1481
2	$C(E0)_A$	50.38	50.41	50.32	50.41	50.46	50.3967 ± 0.0511	0.1014
	$C(E20)_A$	50.53	50.43	50.33	50.42	50.34	50.4107 ± 0.0813	0.1613
	$C(E85)_A$	50.46	50.48	50.46	50.47	50.45	50.4653 ± 0.0110	0.0217
	$C(E100)_A$	50.54	50.38	50.45	50.32	50.47	50.4307 ± 0.0827	0.1639
4	$C(E0)_A$	50.47	50.43	50.32	50.43	50.47	50.4240 ± 0.0625	0.1240
	$C(E20)_A$	50.58	50.50	50.38	50.55	50.45	50.4907 ± 0.0809	0.1603
	$C(E85)_A$	50.53	50.55	50.52	50.52	50.58	50.5413 ± 0.0272	0.0539
	$C(E100)_A$	50.60	50.44	50.55	50.40	50.54	50.4833 ± 0.0835	0.1654
7	$C(E0)_A$	50.34	50.54	50.46	50.49	50.52	50.4687 ± 0.0765	0.1517
	$C(E20)_A$	50.44	50.57	50.59	50.71	50.54	50.5700 ± 0.0995	0.1968
	$C(E85)_A$	50.62	50.63	50.64	50.63	50.65	50.6340 ± 0.0095	0.0189
	$C(E100)_A$	50.65	50.54	50.65	50.68	50.48	50.6007 ± 0.0849	0.1678
10	$C(E0)_A$	50.55	50.50	50.42	50.57	50.61	50.5327 ± 0.0722	0.1430
	$C(E20)_A$	50.76	50.68	50.51	50.67	50.59	50.6413 ± 0.0949	0.1874
	$C(E85)_A$	50.71	50.66	50.65	50.62	50.64	50.6567 ± 0.0363	0.0716
	$C(E100)_A$	50.79	50.63	50.75	50.54	50.73	50.6887 ± 0.0996	0.1964
13	$C(E0)_A$	50.55	50.58	50.46	50.58	50.60	50.5547 ± 0.0534	0.1056
	$C(E20)_A$	50.85	50.78	50.66	50.75	50.71	50.7520 ± 0.0728	0.1435
	$C(E85)_A$	50.79	50.75	50.74	50.84	50.77	50.7773 ± 0.0383	0.0753
	$C(E100)_A$	50.66	50.87	50.84	50.72	50.84	50.7873 ± 0.0939	0.1849
16	$C(E0)_A$	50.60	50.45	50.58	50.56	50.61	50.5600 ± 0.0635	0.1255
	$C(E20)_A$	50.87	51.03	50.97	50.80	50.91	50.9160 ± 0.0866	0.1701
	$C(E85)_A$	50.84	50.91	50.86	50.92	51.00	50.9067 ± 0.0594	0.1168
	$C(E100)_A$	50.92	50.93	50.82	50.91	50.78	50.8713 ± 0.1318	0.1318

Table A3-7 Volume of PA6 and PA6/GF composites immersed in test fuels

Week	Test Fuels	Volume (cm^3)		
		0%GF	15%GF	30%GF
0	$C(E0)_A$	6.2241 ± 0.0586	6.3552 ± 0.0462	6.4971 ± 0.0561
	$C(E20)_A$	6.2244 ± 0.0189	6.3660 ± 0.0312	6.6188 ± 0.0875
	$C(E85)_A$	6.2370 ± 0.0109	6.3451 ± 0.0266	6.4823 ± 0.0486
	$C(E100)_A$	6.2517 ± 0.0198	6.3310 ± 0.0253	6.4944 ± 0.0686
2	$C(E0)_A$	6.2114 ± 0.0535	6.2324 ± 0.0219	6.3576 ± 0.0725
	$C(E20)_A$	6.2626 ± 0.0358	6.3892 ± 0.0591	6.6523 ± 0.0889
	$C(E85)_A$	6.2682 ± 0.0235	6.4217 ± 0.0315	6.4763 ± 0.0629
	$C(E100)_A$	6.3282 ± 0.0624	6.4616 ± 0.0687	6.5500 ± 0.0681
4	$C(E0)_A$	6.2383 ± 0.0493	6.3450 ± 0.0652	6.4858 ± 0.0994
	$C(E20)_A$	6.4209 ± 0.0502	6.4928 ± 0.0514	6.7122 ± 0.0956
	$C(E85)_A$	6.4042 ± 0.0361	6.5026 ± 0.0555	6.6322 ± 0.0377
	$C(E100)_A$	6.4377 ± 0.0138	6.5163 ± 0.0494	6.6511 ± 0.0529
7	$C(E0)_A$	6.2293 ± 0.0302	6.3600 ± 0.0627	6.5358 ± 0.0512
	$C(E20)_A$	6.4598 ± 0.0530	6.4929 ± 0.0492	6.7761 ± 0.0549
	$C(E85)_A$	6.4486 ± 0.0392	6.5424 ± 0.0427	6.6606 ± 0.0495
	$C(E100)_A$	6.5264 ± 0.0781	6.5588 ± 0.0616	6.6801 ± 0.1039
10	$C(E0)_A$	6.3512 ± 0.0572	6.4075 ± 0.0578	6.5752 ± 0.0879
	$C(E20)_A$	6.5981 ± 0.0122	6.6488 ± 0.0350	6.8330 ± 0.0730
	$C(E85)_A$	6.5641 ± 0.0497	6.6527 ± 0.0643	6.7230 ± 0.0214
	$C(E100)_A$	6.6760 ± 0.0289	6.6641 ± 0.0880	6.7841 ± 0.0960
13	$C(E0)_A$	6.2800 ± 0.0385	6.3885 ± 0.0313	6.5420 ± 0.0786
	$C(E20)_A$	6.6385 ± 0.0364	6.6690 ± 0.0480	6.8534 ± 0.0893
	$C(E85)_A$	6.6313 ± 0.0347	6.6583 ± 0.0553	6.7145 ± 0.0470
	$C(E100)_A$	6.7030 ± 0.0343	6.6709 ± 0.0513	6.7632 ± 0.0891
16	$C(E0)_A$	6.3301 ± 0.0396	6.4335 ± 0.0513	6.5835 ± 0.0595
	$C(E20)_A$	6.7485 ± 0.0349	6.7211 ± 0.0426	6.9155 ± 0.0733
	$C(E85)_A$	6.7102 ± 0.0271	6.6815 ± 0.0629	6.7489 ± 0.0540
	$C(E100)_A$	6.7414 ± 0.0309	6.7242 ± 0.0388	6.7801 ± 0.0577

Table A3-8 Percent volume increase of PA6 and PA6/GF composites immersed in test fuels

Week	Test Fuels	% Volume Increase		
		0%GF	15%GF	30%GF
0	$C(E0)_A$	0.0000	0.0000	0.0000
	$C(E20)_A$	0.0000	0.0000	0.0000
	$C(E85)_A$	0.0000	0.0000	0.0000
	$C(E100)_A$	0.0000	0.0000	0.0000
2	$C(E0)_A$	-0.2030	-1.9318	-2.1468
	$C(E20)_A$	0.6139	0.3646	0.5058
	$C(E85)_A$	0.5010	1.2060	-0.0922
	$C(E100)_A$	1.2228	2.0643	0.8567
4	$C(E0)_A$	0.2290	-0.1611	-0.1735
	$C(E20)_A$	3.1574	1.9913	1.4107
	$C(E85)_A$	2.6804	2.4818	2.3129
	$C(E100)_A$	2.9750	2.9287	2.4124
7	$C(E0)_A$	0.0832	0.0731	0.5967
	$C(E20)_A$	3.7815	1.9938	2.3762
	$C(E85)_A$	3.3926	3.1083	2.7508
	$C(E100)_A$	4.3946	3.5998	2.8599
10	$C(E0)_A$	2.0427	0.8219	1.2025
	$C(E20)_A$	6.0044	4.4423	3.2346
	$C(E85)_A$	5.2453	4.8467	3.7135
	$C(E100)_A$	6.7863	5.2624	4.4610
13	$C(E0)_A$	0.8933	0.5231	0.6923
	$C(E20)_A$	6.6527	4.7593	3.5438
	$C(E85)_A$	6.3214	4.9351	3.5827
	$C(E100)_A$	7.2181	5.3702	4.1394
16	$C(E0)_A$	1.7038	1.2314	1.3307
	$C(E20)_A$	8.4204	5.5785	4.4821
	$C(E85)_A$	7.5865	5.3008	4.1125
	$C(E100)_A$	7.8324	6.2122	4.3995

APPENDIX B

THE EXPERINTAL DATA OF MECHANICAL PROPERTIES

Appendix B1. Impact Test

Table B1-1 Impact strength of PA6 immersed in test fuels

Week	Test Fuels	Impact Strength (kJ/m^2)										Average (kJ/m^2)
		1	2	3	4	5	6	7	8	9	10	
0	C(E0)$_A$	19	19	20	20	21	21	22	22	22	22	20.85
	C(E20)$_A$											
	C(E85)$_A$											
	C(E100)$_A$											
4	C(E0)$_A$	74	54	56	53	49	75	68	51	69	75	62.41
	C(E20)$_A$	109	99	82	81	90	105	78	94	129	99	96.58
	C(E85)$_A$	56	42	71	88	65	64	78	83	46	43	63.44
	C(E100)$_A$	40	54	40	93	44	96	67	101	65	73	67.19
10	C(E0)$_A$	65	81	56	69	93	62	73	69	108	108	78.35
	C(E20)$_A$	182	237	288	166	290	237	200	260	247	229	233.51
	C(E85)$_A$	77	86	102	112	79	77	101	88	80	49	85.13
	C(E100)$_A$	59	157	81	67	167	172	56	194	52	65	106.94
16	C(E0)$_A$	128	115	120	96	98	129	61	85	111	88	102.95
	C(E20)$_A$	270	271	287	257	274	260	275	263	262	274	269.37
	C(E85)$_A$	224	195	166	129	220	114	78	199	62	77	146.33
	C(E100)$_A$	241	251	268	252	243	187	259	276	221	238	243.55

Table B1-2 Impact strength of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Impact Strength (kJ/m^2)										Average (kJ/m^2)
		1	2	3	4	5	6	7	8	9	10	
0	C(E0)$_A$	22	21	22	22	23	23	22	23	25	25	22.60
	C(E20)$_A$											
	C(E85)$_A$											
	C(E100)$_A$											
4	C(E0)$_A$	32	31	36	32	34	38	30	34	35	29	33.10
	C(E20)$_A$	50	51	44	56	51	44	47	49	52	49	49.30
	C(E85)$_A$	60	48	47	57	50	47	53	49	54	50	51.50
	C(E100)$_A$	48	54	59	49	50	50	48	47	58	58	52.19
10	C(E0)$_A$	40	32	39	33	36	36	37	38	41	29	36.13
	C(E20)$_A$	65	66	59	61	54	56	58	63	60	62	60.48
	C(E85)$_A$	53	53	53	59	53	49	49	58	51	57	53.53
	C(E100)$_A$	53	56	62	60	59	55	47	63	46	50	55.24
16	C(E0)$_A$	30	41	45	42	40	33	44	50	31	37	39.38
	C(E20)$_A$	94	92	102	82	108	91	89	98	87	107	95.01
	C(E85)$_A$	70	78	73	77	66	87	65	78	72	73	73.94
	C(E100)$_A$	75	87	88	96	83	79	86	83	76	81	83.34

Table B1-3 Impact strength of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Impact Strength (kJ/m^2)										Average (kJ/m^2)
		1	2	3	4	5	6	7	8	9	10	
0	$C(E0)_A$	25	30	30	39	31	32	31	29	40	26	31.38
	$C(E20)_A$											
	$C(E85)_A$											
	$C(E100)_A$											
4	$C(E0)_A$	48	46	43	35	42	38	34	52	45	46	42.99
	$C(E20)_A$	56	58	55	53	57	62	55	57	51	60	56.44
	$C(E85)_A$	47	46	53	50	44	49	52	55	49	50	49.46
	$C(E100)_A$	52	48	48	51	52	59	46	47	47	55	50.49
10	$C(E0)_A$	57	50	54	58	63	51	45	49	46	51	52.28
	$C(E20)_A$	72	62	57	60	65	71	58	90	63	62	66.01
	$C(E85)_A$	67	60	54	63	59	51	53	53	67	67	59.59
	$C(E100)_A$	55	54	73	61	50	53	61	64	57	67	59.54
16	$C(E0)_A$	60	42	59	51	64	43	45	78	61	54	55.67
	$C(E20)_A$	112	98	100	93	87	107	106	102	98	93	99.56
	$C(E85)_A$	89	64	78	66	90	64	77	74	73	87	76.23
	$C(E100)_A$	99	76	78	98	90	79	78	77	80	89	84.43

Table B1-4 Percent Impact strength increase of PA6 and PA6/GF composites

Week	Test Fuels	Impact Strength (kJ/m^2)			% Impact Strength Increase		
		0%GF	15%GF	30%GF	0%GF	15%GF	30%GF
0	$C(E0)_A$	20.85	22.60	31.38	0	0	0
	$C(E20)_A$						
	$C(E85)_A$						
	$C(E100)_A$						
4	$C(E0)_A$	62.41	33.10	42.99	199	46	37
	$C(E20)_A$	96.58	49.30	56.44	363	118	80
	$C(E85)_A$	63.44	51.50	49.46	204	128	58
	$C(E100)_A$	67.19	52.19	50.49	222	131	61
10	$C(E0)_A$	78.35	36.13	52.28	276	60	67
	$C(E20)_A$	233.51	60.48	66.01	1020	168	110
	$C(E85)_A$	85.13	53.53	59.59	308	137	90
	$C(E100)_A$	106.94	55.24	59.54	413	144	90
16	$C(E0)_A$	102.95	39.38	55.67	394	74	77
	$C(E20)_A$	269.37	95.01	99.56	1192	320	217
	$C(E85)_A$	146.33	73.94	76.23	602	227	143
	$C(E100)_A$	243.55	83.34	84.43	1068	269	169

Appendix B2. Compressive Test

Table B2-1 Compressive strength of PA6 immersed in test fuels

Week	Test Fuels	Compressive Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	C(E0)$_A$	146	142	147	143	145	144.61 ± 2.10	1.46
	C(E20)$_A$							
	C(E85)$_A$							
	C(E100)$_A$							
4	C(E0)$_A$	164	166	174	178	178	172.12 ± 6.68	3.88
	C(E20)$_A$	134	134	134	136	137	134.87 ± 1.49	1.11
	C(E85)$_A$	132	142	142	143	164	144.59 ± 11.96	8.27
	C(E100)$_A$	139	145	152	152	147	146.81 ± 6.43	4.38
10	C(E0)$_A$	188	189	191	194	197	191.81 ± 3.86	2.01
	C(E20)$_A$	128	128	134	136	142	133.73 ± 6.08	4.54
	C(E85)$_A$	132	136	138	139	141	137.24 ± 3.56	2.59
	C(E100)$_A$	116	123	125	130	131	125.06 ± 6.01	4.81
16	C(E0)$_A$	182	180	177	176	177	178.20 ± 2.51	1.41
	C(E20)$_A$	115	120	112	112	113	114.53 ± 3.27	2.86
	C(E85)$_A$	112	125	121	120	112	118.31 ± 5.71	4.83
	C(E100)$_A$	136	134	135	135	136	135.15 ± 1.11	0.82

Table B2-2 Compressive strength of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Compressive Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	212	198	210	209	210	207.84 ± 5.58	2.68
	$C(E20)_A$							
	$C(E85)_A$							
	$C(E100)_A$							
4	$C(E0)_A$	211	213	213	226	229	218.36 ± 8.35	3.82
	$C(E20)_A$	197	198	196	197	198	197.32 ± 0.75	0.38
	$C(E85)_A$	200	209	210	210	210	207.69 ± 4.15	2.00
	$C(E100)_A$	201	200	206	207	208	204.55 ± 3.68	1.80
10	$C(E0)_A$	221	225	230	235	235	229.21 ± 6.18	2.69
	$C(E20)_A$	196	181	190	197	192	190.89 ± 6.27	3.28
	$C(E85)_A$	195	189	189	190	190	190.47 ± 2.48	1.30
	$C(E100)_A$	182	183	184	184	189	184.39 ± 2.56	1.44
16	$C(E0)_A$	201	208	205	215	200	205.66 ± 5.99	2.91
	$C(E20)_A$	156	159	152	159	159	157.18 ± 3.13	1.99
	$C(E85)_A$	175	173	159	170	160	167.36 ± 7.41	4.43
	$C(E100)_A$	174	178	180	182	167	176.24 ± 5.85	3.32

Table B2-3 Compressive strength of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Compressive Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	253	243	259	244	251	249.82 ± 6.76	2.71
	$C(E20)_A$							
	$C(E85)_A$							
	$C(E100)_A$							
4	$C(E0)_A$	259	261	262	267	273	264.38 ± 5.55	2.10
	$C(E20)_A$	259	261	262	267	273	264.38 ± 5.55	2.10
	$C(E85)_A$	255	260	260	273	279	265.48 ± 10.03	3.78
	$C(E100)_A$	249	249	259	260	264	255.99 ± 6.80	2.66
10	$C(E0)_A$	237	237	240	243	249	241.13 ± 5.06	2.10
	$C(E20)_A$	223	224	234	236	236	230.42 ± 6.76	2.94
	$C(E85)_A$	243	243	246	248	254	246.49 ± 4.49	1.82
	$C(E100)_A$	223	232	237	232	239	232.72 ± 7.02	3.02
16	$C(E0)_A$	263	270	247	273	266	263.84 ± 9.96	3.78
	$C(E20)_A$	209	213	213	213	199	209.43 ± 5.93	2.83
	$C(E85)_A$	211	212	212	213	210	211.49 ± 1.15	0.55
	$C(E100)_A$	223	226	228	223	226	225.11 ± 2.21	0.98

Table B2-4 Percent compressive strength increase of PA6 and PA6/GF composites

Week	Test Fuels	Compressive Strength (MPa)			% Compressive Strength Increase		
		0%GF	15%GF	30%GF	0%GF	15%GF	30%GF
0	C(E0)$_A$	144.61	208.84	249.82	0.00	0.00	0.00
	C(E20)$_A$						
	C(E85)$_A$						
	C(E100)$_A$						
4	C(E0)$_A$	172.12	218.36	264.38	19.03	4.56	5.83
	C(E20)$_A$	134.87	197.32	264.38	-6.74	-5.52	5.83
	C(E85)$_A$	144.59	207.69	265.48	-0.01	-0.55	6.27
	C(E100)$_A$	146.81	204.55	255.99	1.52	-2.05	2.47
10	C(E0)$_A$	191.81	229.21	241.13	32.64	9.75	-3.48
	C(E20)$_A$	133.73	190.89	230.42	-7.53	-8.59	-7.76
	C(E85)$_A$	137.24	190.47	246.49	-5.09	-8.79	-1.33
	C(E100)$_A$	125.06	184.39	232.57	-13.52	-11.71	-6.90
16	C(E0)$_A$	178.20	205.66	263.84	23.23	-1.52	5.61
	C(E20)$_A$	114.53	157.18	209.43	-20.80	-24.73	-16.17
	C(E85)$_A$	118.31	167.36	211.49	-18.19	-19.86	-15.34
	C(E100)$_A$	135.15	176.24	225.11	-6.54	-15.61	-9.89

Appendix B3. Tensile Test

Table B3-1 Tensile strength of PA6 immersed in test fuels

Test Fuels	Tensile Strength (MPa)					Average (MPa)	% Error
	1	2	3	4	5		
C(E0)$_A$	71	73	78	80	80	76.23 ± 4.24	5.57
C(E20)$_A$							
C(E85)$_A$							
C(E100)$_A$							
C(E0)$_A$	51	50	50	50	50	50.13 ± 0.26	0.51
C(E20)$_A$	38	37	37	37	37	37.20 ± 0.43	1.16
C(E85)$_A$	40	40	39	39	39	39.40 ± 0.25	0.63
C(E100)$_A$	36	38	36	35	36	36.16 ± 0.94	2.61
C(E0)$_A$	47	45	46	46	45	45.81 ± 0.86	1.88
C(E20)$_A$	30	30	29	30	29	29.53 ± 0.33	1.10
C(E85)$_A$	33	32	31	31	31	31.59 ± 0.90	2.86
C(E100)$_A$	30	29	28	28	27	28.43 ± 0.83	2.93
C(E0)$_A$	43	43	44	43	42	43.07 ± 060	1.40
C(E20)$_A$	27	28	28	28	27	27.61 ± 0.21	0.76
C(E85)$_A$	27	27	27	26	28	26.70 ± 0.78	2.92
C(E100)$_A$	27	26	26	26	26	26.14 ± 0.26	1.00

Table B3-2 Tensile strength of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Tensile Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	$C(E0)_A$ $C(E20)_A$ $C(E85)_A$ $C(E100)_A$	118	118	118	120	119	118.71 ± 0.82	0.69
4	$C(E0)_A$	81	81	82	80	78	80.61 ± 1.47	1.82
	$C(E20)_A$	65	64	63	63	63	63.60 ± 0.93	1.46
	$C(E85)_A$	67	66	65	65	65	65.67 ± 0.65	0.98
	$C(E100)_A$	62	60	59	59	59	59.69 ± 1.23	2.06
10	$C(E0)_A$	71	70	70	71	71	70.52 ± 0.40	0.57
	$C(E20)_A$	53	50	47	46	46	48.57 ± 3.13	6.44
	$C(E85)_A$	57	56	56	55	54	55.73 ± 1.07	1.92
	$C(E100)_A$	54	53	53	49	48	51.43 ± 2.58	5.01
16	$C(E0)_A$	72	72	72	72	71	71.85 ± 0.49	0.68
	$C(E20)_A$	49	49	49	49	48	48.96 ± 0.50	1.03
	$C(E85)_A$	55	54	54	54	55	54.17 ± 0.54	1.00
	$C(E100)_A$	52	52	52	53	53	52.38 ± 0.56	1.08

Table B3-3 Tensile strength of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Tensile Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	C(E0)$_A$	167	168	168	170	173	169.24±2.53	1.49
	C(E20)$_A$							
	C(E85)$_A$							
	C(E100)$_A$							
4	C(E0)$_A$	118	118	117	119	117	117.77 ± 0.68	0.58
	C(E20)$_A$	102	101	101	101	100	100.95 ± 0.80	0.79
	C(E85)$_A$	104	104	103	102	102	103.14 ± 0.77	0.75
	C(E100)$_A$	97	96	96	96	95	96.19 ± 0.57	0.60
10	C(E0)$_A$	113	114	112	113	113	113.05 ± 0.47	0.42
	C(E20)$_A$	99	98	98	97	97	97.84 ± 0.80	0.82
	C(E85)$_A$	100	99	98	98	98	98.71 ± 1.02	1.04
	C(E100)$_A$	94	94	92	92	92	92.90 ± 1.09	1.17
16	C(E0)$_A$	104	104	103	104	102	103.33 ± 0.72	0.69
	C(E20)$_A$	80	80	77	79	77	78.36 ± 1.39	1.77
	C(E85)$_A$	85	86	85	84	84	84.89 ± 0.86	1.01
	C(E100)$_A$	83	82	81	83	84	82.60 ± 1.01	1.22

Table B3-4 Percent tensile strength increase of PA6 and PA6/GF composites

Week	Test Fuels	Tensile Strength (MPa)			% Tensile Strength Increase		
		0%GF	15%GF	30%GF	0%GF	15%GF	30%GF
0	C(E0)$_A$	76.23	118.71	169.24	0.00	0.00	0.00
	C(E20)$_A$						
	C(E85)$_A$						
	C(E100)$_A$						
4	C(E0)$_A$	50.13	80.61	117.77	-34.24	-32.09	-30.41
	C(E20)$_A$	37.20	63.60	100.95	-51.20	-46.42	-40.35
	C(E85)$_A$	39.40	65.67	103.14	-48.32	-44.68	-39.06
	C(E100)$_A$	36.16	59.69	96.19	-52.57	-49.72	-43.16
10	C(E0)$_A$	45.81	70.52	113.05	-39.90	-40.60	-33.20
	C(E20)$_A$	29.53	48.57	97.84	-61.26	-59.09	-42.19
	C(E85)$_A$	31.59	55.73	98.71	-58.56	-53.05	-41.67
	C(E100)$_A$	28.43	51.43	92.90	-62.71	-56.68	-45.11
16	C(E0)$_A$	43.07	71.85	103.33	-43.50	-39.48	-38.94
	C(E20)$_A$	27.61	48.96	78.36	-63.78	-58.76	-53.70
	C(E85)$_A$	26.70	54.17	84.89	-64.98	-54.37	-49.84
	C(E100)$_A$	26.14	52.38	82.60	-65.70	-55.88	-51.19

Table B3-5 Young’s modulus of PA6 immersed in test fuels

Week	Test Fuels	Young's Modulus (GPa)					Average (GPa)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	2.06	2.06	2.08	2.19	2.25	2.13 ± 0.09	4.00
	$C(E20)_A$							
	$C(E85)_A$							
	$C(E100)_A$							
4	$C(E0)_A$	1.52	1.52	1.48	1.51	1.49	1.50 ± 0.02	1.34
	$C(E20)_A$	1.01	0.97	0.98	0.97	0.95	0.98 ± 0.02	2.06
	$C(E85)_A$	1.11	1.03	1.05	1.06	1.12	1.08 ± 0.04	3.58
	$C(E100)_A$	1.02	1.07	0.99	0.98	1.04	1.02 ± 0.04	3.61
10	$C(E0)_A$	1.32	1.24	1.20	1.26	1.19	1.24 ± 0.05	4.14
	$C(E20)_A$	0.43	0.39	0.41	0.48	0.43	0.43 ± 0.03	7.74
	$C(E85)_A$	0.80	0.73	0.67	0.77	0.64	0.72 ± 0.07	9.43
	$C(E100)_A$	0.37	0.42	0.43	0.31	0.44	0.39 ± 0.05	13.13
16	$C(E0)_A$	1.09	1.07	1.08	1.05	1.02	1.06 ± 0.03	2.68
	$C(E20)_A$	0.30	0.32	0.32	0.33	0.31	0.32 ± 0.01	3.92
	$C(E85)_A$	0.24	0.21	0.24	0.20	0.24	0.23 ± 0.02	7.97
	$C(E100)_A$	0.24	0.21	0.21	0.22	0.22	0.22 ± 0.01	4.52

Table B3-6 Young's modulus of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Young's Modulus (GPa)					Average (GPa)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	3.67	3.53	3.69	3.64	3.38	3.58 ± 0.13	3.56
	$C(E20)_A$							
	$C(E85)_A$							
	$C(E100)_A$							
4	$C(E0)_A$	2.57	2.39	2.48	2.58	2.71	2.55 ± 0.12	4.65
	$C(E20)_A$	2.00	1.97	1.86	2.14	2.10	0.11 ± 0.11	5.51
	$C(E85)_A$	2.14	2.06	2.10	2.14	2.10	2.11 ± 0.03	1.60
	$C(E100)_A$	2.02	2.06	2.10	2.11	1.95	2.05 ± 0.07	3.20
10	$C(E0)_A$	2.08	2.04	2.29	1.90	2.06	2.07 ± 0.14	6.89
	$C(E20)_A$	1.39	1.32	1.33	1.20	1.29	1.31 ± 0.07	5.24
	$C(E85)_A$	1.45	1.56	1.47	1.62	1.51	1.52 ± 0.0.7	4.46
	$C(E100)_A$	1.40	1.35	1.25	1.46	1.36	1.36 ± 0.08	5.70
16	$C(E0)_A$	1.96	1.94	2.02	2.04	2.03	2.00 ± 0.05	2.27
	$C(E20)_A$	1.18	1.19	1.22	1.16	1.12	1.17 ± 0.04	3.30
	$C(E85)_A$	1.28	1.19	1.26	1.21	1.25	1.24 ± 0.03	2.76
	$C(E100)_A$	1.21	1.16	1.09	1.24	1.14	1.17 ± 0.06	5.01

Table B3-7 Young's modulus of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Young's Modulus(GPa)					Average (GPa)	% Error
		1	2	3	4	5		
0	C(E0)$_A$ C(E20)$_A$ C(E85)$_A$ C(E100)$_A$	4.97	4.90	4.69	4.59	5.45	4.92 ± 0.34	6.81
4	C(E0)$_A$	4.19	4.19	3.85	4.00	3.38	3.92 ± 0.33	8.47
	C(E20)$_A$	3.22	3.40	3.47	3.09	3.30	3.30 ± 0.33	4.63
	C(E85)$_A$	3.66	3.63	3.38	3.64	3.67	3.60 ± 0.12	3.35
	C(E100)$_A$	3.45	3.28	3.48	3.35	3.31	3.37 ± 0.09	2.58
10	C(E0)$_A$	3.33	3.44	3.46	3.19	3.34	3.35 ± 0.11	3.22
	C(E20)$_A$	3.07	2.94	2.94	3.02	3.01	3.00 ± 0.06	1.92
	C(E85)$_A$	3.26	3.27	3.14	3.05	3.15	3.17 ± 0.09	2.77
	C(E100)$_A$	2.95	2.78	2.84	2.91	2.91	2.88 ± 0.07	2.37
16	C(E0)$_A$	3.11	3.04	3.13	3.13	3.21	3.13 ± 0.06	1.91
	C(E20)$_A$	2.26	2.06	2.20	2.21	2.13	2.17 ± 0.08	3.56
	C(E85)$_A$	2.31	2.24	2.41	2.33	2.29	2.31 ± 0.06	2.74
	C(E100)$_A$	2.15	2.13	2.05	2.21	2.32	2.17 ± 0.10	4.64

Table B3-8 Percent young’s modulus increase of PA6 and PA6/GF composites

Week	Test Fuels	Young's Modulus (GPa)			% Young's Modulus Increase		
		0%GF	15%GF	30%GF	0%GF	15%GF	30%GF
0	$C(E0)_A$	2.13	3.58	4.92	0.00	0.00	0.00
	$C(E20)_A$						
	$C(E85)_A$						
	$C(E100)_A$						
4	$C(E0)_A$	1.50	2.55	3.92	-29.28	-28.93	-20.29
	$C(E20)_A$	0.98	2.01	3.30	-54.14	-43.76	-32.99
	$C(E85)_A$	1.08	2.11	3.60	-49.45	-41.23	-26.88
	$C(E100)_A$	1.02	2.05	3.37	-52.07	-42.84	-31.47
10	$C(E0)_A$	1.24	2.07	3.35	-41.58	-42.11	-31.91
	$C(E20)_A$	0.43	1.31	3.00	-79.91	-63.48	-39.12
	$C(E85)_A$	0.72	1.52	3.17	-66.05	-57.53	-35.48
	$C(E100)_A$	0.39	1.36	2.88	-81.46	-61.97	-41.50
16	$C(E0)_A$	1.06	2.00	3.13	-50.06	-44.25	-36.46
	$C(E20)_A$	0.32	1.17	2.17	-85.14	-67.26	-55.88
	$C(E85)_A$	0.23	1.24	2.31	-89.39	-65.40	-52.99
	$C(E100)_A$	0.22	1.17	2.17	-89.62	-67.34	-55.82

Appendix B4. Flexural Test

Table B4-1 Flexural strength of PA6 immersed in test fuels

Week	Test Fuels	Flexural Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	$C(E0)_A$	113	112	117	109	113	112.79 ± 2.75	2.44
	$C(E20)_A$							
	$C(E85)_A$							
	$C(E100)_A$							
4	$C(E0)_A$	45	50	55	56	61	53.62 ± 6.10	11.37
	$C(E20)_A$	38	34	37	40	40	37.64 ± 2.58	6.86
	$C(E85)_A$	50	50	51	50	51	50.48 ± 0.34	0.67
	$C(E100)_A$	39	41	42	43	43	41.76 ± 1.81	4.34
10	$C(E0)_A$	48	50	50	50	51	49.65 ± 1.06	2.14
	$C(E20)_A$	33	33	32	31	31	31.92 ± 0.88	2.75
	$C(E85)_A$	32	33	33	34	35	33.43 ± 1.00	3.00
	$C(E100)_A$	31	32	32	31	31	31.20 ± 0.34	1.08
16	$C(E0)_A$	49	49	53	51	51	50.46 ± 1.71	3.39
	$C(E20)_A$	36	35	37	36	35	35.49 ± 0.89	2.51
	$C(E85)_A$	32	30	30	31	32	31.09 ± 0.96	3.09
	$C(E100)_A$	31	31	30	31	32	30.96 ± 0.90	2.89

Table B4-2 Flexural strength of PA6/GF (15 wt%) immersed in test fuels

Week	Test Fuels	Flexural Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	C(E0)$_A$ C(E20)$_A$ C(E85)$_A$ C(E100)$_A$	180	178	181	178	182	179.87 ± 1.66	0.93
4	C(E0)$_A$	73	77	80	83	86	79.77 ± 4.98	6.24
	C(E20)$_A$	44	47	48	48	49	47.06 ± 1.94	4.12
	C(E85)$_A$	86	86	87	88	94	88.44 ± 3.16	3.57
	C(E100)$_A$	78	82	85	85	85	83.08 ± 3.13	3.77
10	C(E0)$_A$	96	96	97	97	100	97.08 ± 1.58	1.63
	C(E20)$_A$	69	72	74	76	77	73.58 ± 2.85	3.87
	C(E85)$_A$	71	71	73	74	77	73.19 ± 2.50	3.42
	C(E100)$_A$	70	71	73	74	75	72.50 ± 2.20	3.04
16	C(E0)$_A$	102	100	101	103	104	101.96 ± 1.33	1.31
	C(E20)$_A$	72	73	74	74	73	73.29 ± 1.00	1.36
	C(E85)$_A$	77	76	77	74	76	76.08 ± 1.24	1.63
	C(E100)$_A$	74	77	75	75	75	75.28 ± 1.20	1.59

Table B4-3 Flexural strength of PA6/GF (30 wt%) immersed in test fuels

Week	Test Fuels	Flexural Strength (MPa)					Average (MPa)	% Error
		1	2	3	4	5		
0	C(E0)$_A$	246	246	248	251	248	247.63 ± 1.89	0.76
	C(E20)$_A$							
	C(E85)$_A$							
	C(E100)$_A$							
4	C(E0)$_A$	165	169	171	171	172	169.66 ± 2.85	1.68
	C(E20)$_A$	126	127	130	132	133	129.56 ± 3.09	2.39
	C(E85)$_A$	142	142	146	147	150	145.16 ± 3.24	2.23
	C(E100)$_A$	112	116	120	123	125	119.29 ± 5.13	4.30
10	C(E0)$_A$	172	176	166	172	185	174.44 ± 7.05	4.04
	C(E20)$_A$	138	139	139	135	142	138.93 ± 2.48	1.79
	C(E85)$_A$	144	146	147	145	142	144.97 ± 2.01	1.39
	C(E100)$_A$	147	145	142	143	144	144.43 ± 1.95	1.35
16	C(E0)$_A$	168	165	159	171	168	166.18 ± 4.72	2.84
	C(E20)$_A$	121	123	118	121	120	120.65 ± 1.87	1.55
	C(E85)$_A$	123	128	125	124	121	124.57 ± 2.85	2.07
	C(E100)$_A$	130	129	129	129	129	129.09 ± 0.43	0.33

Table B4-4 Percent flexural strength increase of PA6 and PA6/GF composites

Week	Test Fuels	Flexural Strength (MPa)			% Flexural Strength Increase		
		0%GF	15%GF	30%GF	0%GF	15%GF	30%GF
0	C(E0)$_A$	112.79	179.87	247.63	0.00	0.00	0.00
	C(E20)$_A$						
	C(E85)$_A$						
	C(E100)$_A$						
4	C(E0)$_A$	53.62	79.77	169.66	-52.46	-55.65	-31.49
	C(E20)$_A$	37.64	47.06	129.56	-66.63	-73.84	-47.68
	C(E85)$_A$	50.48	88.44	145.16	-55.25	-50.83	-41.38
	C(E100)$_A$	41.76	83.08	119.29	-62.98	-53.81	-51.83
10	C(E0)$_A$	49.65	97.08	174.44	-55.98	-46.03	-29.56
	C(E20)$_A$	31.92	73.58	138.93	-71.70	-59.09	-43.90
	C(E85)$_A$	33.43	73.19	144.97	-70.36	-59.31	-41.46
	C(E100)$_A$	31.20	72.50	144.43	-72.34	-59.69	-41.68
16	C(E0)$_A$	50.46	101.96	166.18	-55.26	-43.32	-32.89
	C(E20)$_A$	35.49	73.29	120.65	-68.54	-59.25	-51.28
	C(E85)$_A$	31.09	76.08	124.57	-72.44	-57.71	-49.70
	C(E100)$_A$	30.96	75.28	129.09	-72.55	-58.15	-47.87

VITA

Miss Pranisa Chooseng was born in Phatthalung, Thailand, on October 4th, 1984. She received her high school diploma in 2002 from Phatthalung School, Phatthalung. She received the Bachelor of Engineering Degree with a major in Chemical Engineering from the Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangkok, in 2006. She continued her study for a Master's Degree in Chemical Engineering at the Faculty of Engineering, Chulalongkorn University, Bangkok, in 2007.