

อิทธิพลของสารเคมีในตัวแทนน้ำมันแก๊สโซฮอล์
ต่อวัสดุประกอบแต่งในลอน 6 เสริมแรงด้วยเส้นใยแก้ว



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INFLUENCES OF CHEMICALS IN SURROGATE GASOHOL
ON GLASS FIBER REINFORCED NYLON 6 COMPOSITES



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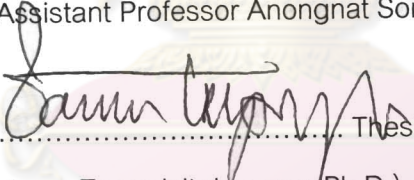
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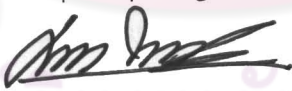
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สิริพร แคนศรี : อิทธิพลของสารเคมีในตัวแทนน้ำมันแก๊สโซฮอลล์ต่อวัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้ว (INFLUENCES OF CHEMICALS IN SURROGATE GASOHOL ON GLASS FIBER REINFORCED NYLON 6 COMPOSITES)

อ.ที่ปรึกษาวิทยานิพนธ์หลัก: อ.ดร.วรัญ แต่ไพสิฐพงษ์, 175 หน้า.

งานวิจัยนี้มุ่งศึกษาอิทธิพลของสารเคมีในตัวแทนน้ำมันแก๊สโซฮอลล์ต่อสมบัติเชิงกายภาพ สมบัติเชิงความร้อน และสมบัติเชิงกลของวัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้ว ชิ้นงานทดสอบของวัสดุไนลอน 6 และไนลอน 6 เสริมแรงด้วยเส้นใยแก้วในปริมาณ 15% และ 30% โดยนำหนักถูกขึ้นรูปด้วยเครื่องอัดขึ้นรูปและเครื่องฉีดขึ้นรูป ชิ้นงานทดสอบถูกแช่ในไอโซออกเทน โทลูอิน แอ็กเกอร์สซีฟเอทานอล และเอทานอล ที่อุณหภูมิห้องเป็นเวลา 16 สัปดาห์ โดยที่สารเคมีถูก เปลี่ยนทุก 6 สัปดาห์ การเปลี่ยนแปลงด้านน้ำหนักและขนาด อุณหภูมิที่ทำให้วัสดุโค้งตัวภายใต้แรง ดัดโค้ง อุณหภูมิแปรสภาพแก้ว สมบัติด้านรับแรงดึง ด้านการบิดงอ ด้านการกดอัด และด้านการ กระแทกของชิ้นงานทดสอบถูกวัด ผลการทดลองแสดงให้เห็นว่า เส้นใยแก้วเสริมแรงสามารถ ปรับปรุงความเสถียรด้านมวลและขนาดของชิ้นงานได้ด้วยการจำกัดการเคลื่อนไหวของเส้นสายโซ่ ของพอลิเมอร์ เส้นใยแก้วเสริมแรงช่วยปรับปรุงความแข็งแรงการรับแรงดึง โมดูลัสการรับแรงดึง ความแข็งแรงการรับแรงดัดโค้ง โมดูลัสการรับแรงดัดโค้ง ความแข็งแรงการรับแรงกด และความ แข็งแรงการรับแรงกระแทกแบบไอซอดของวัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้วได้ เพราะการเชื่อมพันธะอย่างดีตรงพื้นผิวระหว่างไนลอน 6 และเส้นใยแก้วเสริมแรง ซึ่งทำให้ความเค้น สามารถถูกถ่ายโอนไปยังเส้นใยแก้วเสริมแรงได้ เอทานอลและแอ็กเกอร์สซีฟเอทานอลมีอิทธิพลอย่าง มีนัยสำคัญต่อสมบัติเชิงกายภาพ เชิงความร้อน และเชิงกลของวัสดุไนลอน 6 และวัสดุประกอบแต่ง ไนลอน 6 เสริมแรงด้วยเส้นใยแก้วมากกว่าไอโซออกเทนและโทลูอิน เพราะเอทานอลและแอ็กเกอร์ส ซีฟเอทานอลสามารถถูกดูดซับเข้าไปในไนลอน 6 ได้ง่ายกว่า สมบัติเชิงความร้อนและเชิงกลของ ชิ้นงานทดสอบยกเว้นค่าความทนแรงกระแทกแบบไอซอดมีค่าลดลงตามปริมาณสารเคมีที่ถูกดูดซับ เข้าไปในชิ้นงาน แต่วัสดุประกอบแต่งไนลอน 6 เสริมแรงด้วยเส้นใยแก้วได้รับผลกระทบน้อยกว่า เพราะเส้นใยแก้วช่วยลดการเคลื่อนไหวของสายโซ่พอลิเมอร์ โดยรวมผลกระทบของแก๊สโซฮอลล์ ต่อสมบัติของไนลอน 6 มาจากองค์ประกอบที่เป็นแอลกอฮอล์ ดังนั้นวัสดุประกอบแต่ง ไนลอน 6 เสริมแรงด้วยเส้นใยแก้วควรถูกใช้กับแก๊สโซฮอลล์ที่มีเอทานอลเป็นส่วนผสมในปริมาณต่ำ

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SIRIPORN KAENSRI: INFLUENCES OF CHEMICALS IN SURROGATE GASOHOL ON GLASS FIBER REINFORCED NYLON 6 COMPOSITES.

ADVISOR: VARUN TAEPASITPHONGSE, Ph.D., 175 pp.

In this study, the influence of chemicals in surrogate gasohol on physical, thermal and mechanical properties of glass fiber reinforced nylon 6 (PA6) composites were investigated. Test specimens of neat PA6 and PA6 compound with 15%wt and 30%wt glass fiber were prepared by compression and injection molding machines. These specimens were immersed in isooctane, toluene, aggressive ethanol, and ethanol at room temperature for 16 weeks. The chemicals were changed every 6 weeks. Mass and dimensional stability, heat distortion temperature (HDT), glass transition temperature (T_g), tensile, flexural, compressive and Izod impact properties were investigated. The results showed that the glass fiber provided dimensional stability by restricting the movement of polymer chains. The glass fiber could improve the tensile strength, tensile modulus, flexural strength, flexural modulus, compressive strength and Izod impact strength of PA6/GF composites due to good interfacial bonding between PA6 and GF and stress could transfer to glass fiber. Ethanol and aggressive ethanol significantly affected the physical, thermal, and mechanical properties of neat PA6 and PA6/GF composites more than isooctane and toluene because they could be absorbed into PA6 matrix easier. The thermal and mechanical properties except Izod impact strength of specimens decreased with increased amount of chemicals absorbed. But the effects were reduced in the PA6/GF composites because the fiber glass could reduce the movement of polymer chains. Overall, the effects of gasohol on properties of PA6 were mainly from alcohol component than gasoline component. Therefore, PA6 and PA6/GF composites should be used with gasohol with low ethanol volume content.

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ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

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CHAPTER I

INTRODUCTION

1.1 General Introduction

According to the previous studies, there is about 700 million cars in the world at present and will be about 1500 million cars in 2020; hence, fossil-based fuel oil usage will become greater in proportion to the increased number of cars. It was estimated that the fossil-based fuel oil will run out within the next 50 years [1]. Therefore, it is important to search for alternative energy sources, such as solar power, wind power, tidal power and biofuel, to replace fuel oil. Moreover, the car manufacturers must develop new technologies to work in conjunction with other kinds of fuel. Among these alternative energy sources, the most interesting one is biofuel because it can be looked upon as energy security since it is renewable and environmental friendly [2]. Currently, the use of biofuels has expanded worldwide. The major producers and consumers of biofuels are Asia, Europe and America [3]. Biofuels in Thailand consist of bioethanol and biodiesel. Bioethanol is an alcohol made by the fermentation of molasses, a by-product of sugar manufacture, so that it has unlimited availability. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emission. This mixture is called gasohol. Gasohol comprises of 10 vol% ethanol and 90 vol% unleaded gasoline, which is referred as E10, is used in United States, Australia and Thailand. Brazil uses 100 vol% ethanol as fuel in about 20% of gasoline-powered vehicles and a 22 to 26 vol% ethanol-gasoline blend in all other vehicles [4]. The previous study in 2005 showed that carbonmonoxide (CO) and hydrocarbon emission in the four-stroke motorcycle engine exhaust is lower with operation of E10 gasohol as compared to the use of unleaded gasoline [5].

Metal corrosion caused by conventional motor fuels such as gasoline is not a serious problem because hydrocarbon fuels are inherently non-corrosive. However, the fuels containing alcohols such as gasohol or straight alcohol fuels have become a major problem because they corrode the automobile parts made from metal [6]. Therefore, the automobile part and fuel system must be designed specifically to use with gasohol.

Many engineering plastics are alternative materials for replacing metals, ceramics, and glasses in gasohol fuel system. This is mainly due to their intrinsic properties including corrosive resistance, easy molding, flexibility, light weight, recyclability and potentially lower cost. There are many useful plastics nowadays such as high-density polyethylene (HDPE) [7], polyvinyl chloride (PVC) [8] and polyamide 6 (PA6) [9]. Polyamide 6, also called nylon 6, is an engineering thermoplastic and is one of the most popular polymer with excellent chemical resistance, high mechanical strength, excellent mechanical performance at high temperature and good adhesion to reinforcements. Furthermore, the addition of glass fiber (GF) reinforcement is proven to improve the stiffness, strength, and the high temperature performance of this nylon [10-12].

The main purpose of this work was to study the influences of chemical substances in surrogate gasohol on the physical, mechanical, and thermal properties of glass fiber reinforced nylon 6 composites. The specimens were prepared by injection molding and compression molding of PA6/GF blends at various glass fiber contents and then immersed in chemicals (isooctane, toluene, aggressive ethanol and ethanol) for 16 weeks. The specimens were taken out from chemicals for characterization regularly until the end of experiment. The physical, thermal and mechanical properties of specimens were collected and analyzed.

1.2 Objective

To evaluate the influences of chemical substances in surrogate gasohol on physical, mechanical and thermal properties of PA6 and PA6/GF composites.

1.3 Scope of Work

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

2. Three of chemical substances in surrogate gasohol, namely, isooctane, toluene and aggressive ethanol according to SAE J1681 were used. Pure ethanol was also studied for comparison.

Note: *Aggressive ethanol*

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

3. Physical, mechanical and thermal properties of specimens before immersion and after immersion in test chemicals were determined regularly until the end of experiment (16 weeks).

Table 1.1 List of properties evaluated

	Property	Standard
Physical properties	Mass change	ASTM D570
	Diameter change	ASTM D570
	Thickness change	ASTM D570
	Volume change	ASTM D570
Mechanical properties	Tensile strength	ASTM D638
	Tensile modulus	ASTM D638
	Flexural strength	ASTM D790
	Flexural modulus	ASTM D790
	Compressive strength	ASTM D695
	Impact strength	ASTM D256
Thermal properties	Glass transition temperature	ASTM D7028
	Heat distortion temperature	ASTM D648

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CHAPTER II

THEORgY

2.1 Gasohol

Gasohol is one of the most interesting alternative fuels because it is cheaper than gasoline and environmentally friendly due to its perfect combustion. Gasohol is a blend of gasoline and pure alcohol at different ratio. Ethanol fuel mixtures have “E” numbers which describe the percentage by volume of ethanol in the mixture, for example, E85 has 85 vol% ethanol and 15 vol% gasoline. The proportion of ethanol used in gasohol is generally 10 vol%.

Gasohol (E10) has the same characteristics as octane 95 unleaded gasoline (benzene 95), except that the oxygenated compound, normally, MTBE (Methyl Tertiary Butyl Ether) that is required by regulation to be added to octane 95 unleaded gasoline at a 5.511 vol%, is replaced by 99.5% pure alcohol at the 10-11 vol%. In gasohol, ethanol serves as an additive to enhance oxygenate value and octane number of gasoline [13]. Therefore, gasohol has higher octane or antiknock properties than gasoline and burns more slowly, coolly, and completely. Oxygen in ethanol causes the combustion of gasohol to produce lower levels of hydrocarbons, carbon monoxide and carbon dioxide than general octane 95 gasoline, and helps to reduce black smoke, aromatic hydrocarbons, benzene, and dust emission from exhaust pipes [14].

E10 is used globally, 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, the United States, Canada and Sweden also use Gasohol 85, which has only 15 vol% 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 an octane rating as high as 105, which can boost the performances of the vehicle engine [13].

2.1.1 Alcohol in Gasohol

Alcohol is an alternative transportation fuel since it has properties that would allow its use in existing engines with minor hardware modifications. Alcohol has an octane number higher than that of gasoline. A fuel with a higher octane number can endure higher compression ratio before engine starts knocking. Engine compression ratio is the relative volume of a cylinder from the bottom most position of the piston's stroke to the top most position of the piston's stroke. The higher an engine's compression ratio, the greater the amount of heat generated in the cylinder during the compression stroke, thus a fuel with a higher octane number gives engine an ability to deliver more power efficiently and economically. Alcohols burns cleaner than regular gasoline and produce lesser carbon monoxide, hydrocarbons and oxides of nitrogen [15-17].

Methanol (CH_3OH) and ethanol ($\text{C}_2\text{H}_5\text{OH}$) are simple compounds that possess less flammability and give higher engine efficiency than gasoline. However, ethanol is considerably cleaner, less toxic, less corrosive and gives greater engine efficiency than methanol. Ethanol is a grain alcohol and can be produced from fermentation of sugar cane, cassava and other grains, to convert starch into sugar and then alcohol, respectively. The purification of alcohol by distillation is used to attain a pure alcohol of 95 vol%. Ethanol for blending with fuel to fill in the car engine is a pure alcohol of 99.5 vol% which is capable of using as fuel [2,3].

The primary disadvantage of mixing methyl or ethyl alcohol with gasoline is that under certain conditions these alcohols may phase separate from the gasoline. Hence, an engine adjusted to burn gasoline efficiently will produce less power from alcohol/gasoline mixture. Phase separation is caused by the different in polar nature of the alcohol molecules and their tendency to absorb water, also a polar substance. Methyl alcohol is the most likely to separate, while butyl alcohol is the least likely. The

tendency for phase separation increases as the temperature decreases, the quantity of water absorbed increases, and the quality of the gasoline decreases [10].

2.1.2 Gasoline

Gasoline is a petroleum-derived liquid mixture that is primarily used as fuel in internal combustion engines. It consists mostly of aliphatic hydrocarbons obtained by the fractional distillation of petroleum. Small quantities of various additives are common for specific purposes such as tuning engine performance or reducing harmful exhaust emissions. Some mixtures also contain significant quantities of ethanol as partial alternative fuel.

Octane rating

An important characteristic of gasoline is its octane rating, which is a measure of how resistant gasoline is to the abnormal combustion phenomenon known as pre-detonation (also known as knocking, pinging, spark knock, and other names). Octane rating is measured relative to a mixture of 2,2,4-trimethylpentane (an isomer of octane) and n-heptane. Octane rating of gasoline can be improved by incorporating isooctane or aromatic hydrocarbons such as toluene and benzene.

2,2,4-trimethylpentane (Isooctane)

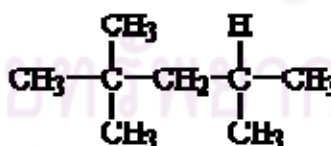


Figure 2.1 Structure of isooctane (2,2,4-trimethylpentane)

Isooctane or 2,2,4-trimethylpentane is octane isomer which defines as the 100 point on the octane rating scale compared with that of n-heptane. It is a highly branched compound that burns smoothly, with little knocking. This isooctane is particularly useful in the formulation of gasoline containing ethanol in direct blending, for example in those

produced in the United States, owing to its extremely low volatility that counterbalances the very high volatility of ethanol [11].

Toluene

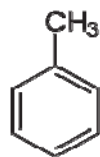


Figure 2.2 Structure of toluene (methylbenzene) [18]

Toluene (methylbenzene) is a clear water-insoluble liquid with the typical smell of paint thinners. It is an aromatic hydrocarbon (C_7H_8) that occurs naturally at low levels in crude oil and is usually produced in the process of making gasoline via a catalytic reformer, and in an ethylene cracker or making coke from coal. Final separation (either via distillation or solvent extraction) takes place in a Benzene Toluene Xylene (BTX) plant [18,19].

Toluene can be used as an octane booster in gasoline fuels in internal combustion engines. Toluene at 100% can be used as a fuel for both two-stroke and four-stroke engines; however, due to the density of the fuel and other factors, the fuel does not vaporize easily unless preheated to 70 degree Celsius. Toluene also poses similar problems as alcohol fuels, as it flows through standard rubber fuel lines and has no lubricating properties as standard gasoline which can break down fuel pumps and causes upper cylinder bore wear [18].

2.2 Polyamide 6 or Nylon 6 (PA6)

Polyamide is the chemical name for nylon. Nylon is made of repeating units with amide linkages. Nylon is classified into the largest family of engineering plastics with a very wide range of applications. It is derived from the reaction of diamine and dicarboxylic acid. Because of a variety of chemical structures of diamine and dicarboxylic acid, there are a very large number of nylon materials available to produce nylon fibers. There are several commercial nylon products, such as nylon 6, nylon 11,

nylon 12, nylon 6,6, nylon 6,10 and so on. The numbers usually appended to the "nylon" or "PA" part refer to the number of CH units between the reactive ends of the monomer [12]. Nylon 6,6 refers to the fact that both the diamine (hexamethylene diamine) and the diacid (adipic acid) have 6 carbon backbones [9,12], as shown in Figure 2.3. The two most important kinds of nylon are nylon 6 and nylon 6,6 and account for more than 90% of nylon use. Characteristic nylons are very resistant to wear and abrasion, have good mechanical properties even at elevated temperatures, have low permeability to gases and have good chemical resistance, but will absorb moisture, particularly nylon 6 and nylon 6,6. Because nylons offer good mechanical and thermal properties, they are also a very important engineering thermoplastic. For example, 35% of total nylon produced is used in the automobile industry [20-23].

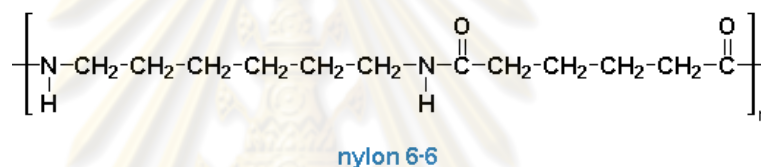


Figure 2.3 Repeating unit of nylon 6,6 [20]

Nylon 6 (PA6) and nylon 6,6 (PA6,6) were invented in the late 1930s. Nylon 6,6 was discovered first. It was invented in the United States by Wallace Carothers who was working for DuPont. Not long after that nylon 6 was invented in Germany by Paul Schlack who was working for I.G. Farben. Nylon 6, unlike most other nylons which were made from dicarboxylic acid and diamine, is made from one kind of monomer, such as a cyclic amide, by ring-opening polymerization. This makes it a special case in the composition 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 [24,25].

Nylon 6, with structure shown in Figure 2.4, is well-known as providing the best price/performance ratio of engineering plastics. This explains why nylon 6 is extensively used in automotive to optimize system cost [26]. Nylon 6 is easier to process by injection molding than nylon 6,6. It has lower mold shrinkage than nylon 6,6 with good fatigue resistance. Useful improvement in stiffness can be obtained by inclusion of glass

fiber [12,27]. Nylon 6 is as stiff as nylon 6,6 with temperatures up to 180 °C and also exhibits a better long-term heat aging than nylon 6,6. Additionally, nylon 6 is cheaper than nylon 6,6 in terms of basic cost and provides a better surface appearance and a better weld strength which leads to a better burst pressure resistance. From these reasons, nylon 6 is a better candidate than nylon 6,6 [28].

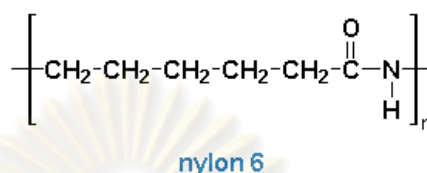


Figure 2.4 Repeating unit of nylon 6 [20]

2.2.1 Production of Nylon 6

Generally, nylons are made from a condensation polymerization using two different monomers, e.g. dicarboxylic acid and diamine. But nylon 6 is made from only one kind of monomer, such as a cyclic amide called lactum. Caprolactum is a lactum with six carbon atoms, so nylon made from caprolactum is called nylon 6 or polyamide 6 (PA6) [20]. PA6 can be produced by chain-growth polymerization of lactams which is one kind of the ring-opening polymerization. It is also a polyaddition reaction with no byproduct formed. There are two ways to carry out a ring-opening polymerization of caprolactum. The first way to make PA6 is to use a water-initiated process and the second way is to use a strong base as initiator. A strong base as initiator will not work well without poly(ethylene oxide) or N-acetylcaprolactum. By adding the strong base, high molecular weight PA6 after heating the mixture for 2-3 minutes can be obtained. Nevertheless, heating the mixture too long causes the thermally degradation resulting in lowering molecular weight of desired PA6 [25].

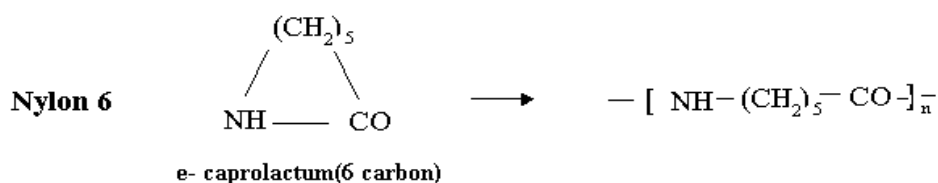


Figure 2.5 Chemical reaction for produce PA6 [20]

During polymerization, the peptide bond within each caprolactum molecule is broken reforming two new bonds as the monomer becomes part of the polymer backbone. PA6 therefore resembles natural polypeptides more closely; in fact, caprolactum would become an amino acid if it were hydrolyzed [24].

2.2.2 Properties of Nylon 6

Nylon is a semi-crystalline polymer. The amide group (-CO-NH-) provides hydrogen bonding between polyamide chains. The nitrogen-bonded hydrogens of one nylon chain will hydrogen bond very strong with the carbonyl oxygens of another nylon chain. These hydrogen bonds make crystals of nylon very strong because they hold the nylon chains together very tightly. These strong crystals make strong fibers [25], giving nylon high strength and toughness at elevated temperatures, and its other properties, such as stiffness, wear and abrasion resistance, low friction coefficient and good chemical resistance [23].

a) *Physical properties*

Semicrystalline nylon comprises the vast majority of commercial resins. Nylon is also available in an amorphous form that gives rise to transparency and improves toughness at the expense of high temperature and chemical stress-crack resistance.

- Density: Density (ρ) depends on the nature of atoms in the chemical structure and the way molecules (chains) pack together. Conformations and crystalline phases are generally denser than amorphous phases, an average ρ_c / ρ_a ratio of 1.13 ± 0.08 has been determined [9].

- Moisture absorption: A characteristic property of nylon is the ability to absorb significant amount of water. This is related to the polar amide groups which water molecules can become coordinated. Water absorption is generally concentrated in the amorphous regions of the polymer, where it has the effect of plasticizing, 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. PA6 has higher moisture absorption than PA6,6 because of its lower crystallinity.

▪ Crystallinity: For common nylons such as PA6 and PA6,6, the regular spatial alignment of amide groups allows a high degree of hydrogen bonding to be developed when the chains are able to organize themselves into a crystalline structure [29]. These nylons are semicrystalline materials which consist 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; while the amorphous regions contribute to the impact resistance and high elongation. Table 2.1 showed the physical properties of PA6 and PA6/glass fiber composites at 15% and 30 wt% glass fiber, respectively, as reported by UBE Chemicals (Thailand).

Table 2.1 Physical properties of PA6 and PA6/glass fiber composites [30-32]

Material	Physical properties		State of test	Test method
PA6	Density (g/cm ³)	1.12-1.14	-	ISO 1183
	Specific gravity	1.14	-	ASTM D 792
	Water absorption (%)	8.5-10	Saturated	ASTM D570
		1.3- 1.9	After 24 hrs	ASTM D570
	Mold shrinkage (%)	1.4	MD	UBE method
		1.6	TD	UBE method

Material	Physical properties		State of test	Test method
15 wt% glass fiber reinforced PA6	Specific gravity	1.23	-	ASTM D 792
	Water absorption (%)	8	Saturated	ASTM D570
		1.1-1.6	After 24 hrs	ASTM D570
	Mold shrinkage (%)	0.3	MD	UBE method
		0.7	TD	UBE method
	30 wt% glass fiber reinforced PA6	Density (g/cm ³)	1.36	-
Specific gravity		1.35-1.42	-	ASTM D 792
Water absorption (%)		6.4-7	Saturated	ASTM D570
		0.9-1.2	After 24 hrs	ASTM D570
Mold shrinkage (%)		0.2	MD	UBE method
		0.7	TD	UBE method

Note MD = in flow direction, TD = in perpendicular direction

b) Mechanical and thermal properties

The properties of nylon depend on the type of nylon (including copolymerization), molecular weight, moisture content, temperature, and the presence of additives. In these materials it is the amide group which is responsible for increasing inter chain attraction. Therefore, heat distortion temperature and stiffness can be improved [29]. Strength and modulus (stiffness) are increased by increasing density of amide groups and crystallinity in aliphatic nylons. Increasing molecular weight gives increased impact strength without having a significant effect on tensile strength. Increasing moisture content reduces the T_g , tensile modulus and tensile strength significantly; however, some nylons 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.

Properties such as strength and rigidity can be considerably increased by adding a reinforcing agent to the polymer matrix, particularly glass or carbon fiber. 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. Table 2.2-2.4 showed the mechanical properties of PA6 and PA6/glass fiber composites at 15% and 30 wt% glass fiber, respectively, while Table 2.5 showed the thermal properties of PA6 and PA6/glass fiber composites, as reported by UBE Chemicals (Thailand).

Table 2.2 Mechanical properties of PA6 [30-33]

Mechanical Properties		State of test	Test method
Tensile strength at yield (MPa)	71	Water content 0.2 %	ASTM D638
	49	Water content 3.5 %	ASTM D638
Tensile elongation at break (%)	>200	Water content 0.2 %	ASTM D638
Tensile modulus (MPa)	2300-2500	-	ASTM D638
Flexural strength (MPa)	103	Dry as molded	ASTM D790
Flexural modulus (MPa)	2500	Dry as molded	ASTM D790
Compressive strength (MPa)	46-90	-	ASTM D695
Impact strength (kJ/m ²)	10.98	-	ASTM D256

Table 2.3 Mechanical properties of PA6/15 wt% glass fiber composite [30-33]

Mechanical Properties		State of test	Test method
Tensile strength at yield (MPa)	125	Water content 0.2 %	ASTM D638
	71	Water content 3.5 %	ASTM D638
Tensile elongation at break (%)	2.8	Water content 0.2 %	ASTM D638
Tensile modulus (MPa)	5800	-	ASTM D638
Flexural strength (MPa)	190	-	ASTM D790
Flexural modulus (MPa)	5300	-	ASTM D790
Impact strength (kJ/m ²)	8.58	-	ASTM D256

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Table 2.4 Mechanical properties of PA6/30 wt% glass fiber composite [30-33]

Mechanical Properties		State of test	Test method
Tensile strength at yield (MPa)	166-190	Water content 0.2 %	ASTM D638
	130	50% relative humidity	ASTM D638
Tensile elongation at break (%)	2-4	Water content 0.2 %	ASTM D638
Tensile modulus (MPa)	7521	-	ASTM D638
Flexural strength (MPa)	235-248	Water content 0.2 %	ASTM D790
	145	50% relative humidity	
Flexural modulus (MPa)	8625-9660	Water content 0.2 %	ASTM D790
Compressive strength (MPa)	131	-	ASTM D695
Impact strength (kJ/m ²)	15	-	ASTM D256

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Table 2.5 Thermal properties of PA6 and PA6/glass fiber composites [30-33]

Material	Thermal properties		State of test	Test method
PA6	Melting temperature (°C)	210-225	T _m , crystalline	-
	Glass transition temperature (°C)	50-75	-	ASTM D7028
	Heat distortion temperature (°C)	65	1.82 MPa	ASTM D648
		165	0.46 MPa	ASTM D648
15 wt% glass fiber reinforced PA6	Melting temperature (°C)	210-225	T _m , crystalline	-
	Glass transition temperature (°C)	50-75	-	ASTM D7028
	Heat distortion temperature (°C)	200	1.82 MPa	ASTM D648
		220	0.46 Mpa	ASTM D 648
30 wt% glass fiber reinforced PA6	Melting temperature (°C)	215-225	T _m , crystalline	-
	Glass transition temperature (°C)	50-75	-	ASTM D7028
	Heat distortion temperature (°C)	205	1.82 MPa	ASTM D648
		220	0.46 MPa	ASTM D648

c) *Chemical resistance*

Resistance is least to strong acids and phenols which are most effective at disrupting the hydrogen bonding and 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 nylon and dissolves PA6,6 (and PA6) above 160 °C. Certain metal salts can attack nylon causing stress cracking, e.g., zinc or calcium chloride, or even dissolve the material in alcoholic solution, e.g., lithium chloride [9].

Table 2.6 Chemical resistance of engineering thermoplastics [34]

Material	Ketone	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

2.2.3 Reinforcement for Nylon 6

Nylon 6 (PA6) is possibly reinforced with inorganic or organic materials. Basically, reinforcement of PA6 is done to provide the desired mechanical, physical and chemical properties [12]. Fillers used for reinforcement of nylon are usually in the form of fibers which normally include mineral fibers, glass fibers, carbon fibers, and para-aramid fibers (Kevlar). Carbon fibers give very high stiffness but are more expensive than glass fibers. While para-aramid fibers reinforcement with nylon can be used for applications requiring high abrasion resistance. Glass fibers are widely used to improve the physical and mechanical properties of many plastics. Moreover, glass fiber reinforcement also improves dimensional stability, stiffness, strength and heat resistance since the reinforcing materials are chemically bonded to PA6. These glass fibers are glued or bonded together by the plastic materials [29,35]. High aspect ratio of glass fiber is ideal for reinforcement. The nanolayers are not easily prepared due to their preferred face-to-face stacking in agglomerated attics and the fibers were damaged in the process. In nylon based thermoplastic, 70 wt% of glass fiber is a maximum loading of reinforcement due to limitation of standard compounding techniques. For automotive structural, 45-65 wt% glass fiber reinforced nylon are proper contents that give high modulus and strength [36,37].

Glass fibers offer several advantage over other materials when used as reinforcement [38]. These advantages can be summarized as follows:

- They are produced in a variety of form to suit particular end-used
- Good mechanical performance of the injection molded structural parts after several re-molding–re-grind cycles (property losses are minimal)
 - Mould ability to close tolerances
 - Reduced melt viscosity for faster processing
 - High flow and toughness in thin sections, easy to fill complicated shapes of hollow parts
- Immune to microbiological attack
- Good resistance to most chemicals and weathering

- High dimensional stability
- High heat resistance

2.2.4 Application

Nylon is often formed into fiber and used for monofilament and yarn [22]. It can be made strong enough to stand up under the punishment tire cords must endure, fine enough for sheer, high fashion hosiery, and light enough for parachute cloth and backpacker's tents [23]. Nylon is considered as comfortable fiber in contact with the skin. From this property, nylon is made for clothing. Moreover, it is made into everyday product such as ropes, tents, toothbrush bristles, etc.

About 55% of nylon produced in the world is used in the transportation industries, and most of this use is concerned with automobile production. Automotive applications for nylons range from door handles, wheel covers to under-the-hood parts and electrical connectors. Nylon has been used to make the belts that reinforce tires. Most passenger car tires have steel belts, but tires for aircrafts, trucks and off-road vehicles are often made of nylon. It is also used for self-lubricating gears, bearings, air bag container, peddles and it has also been used to replace metal in seal system. Plasticized and glass reinforced nylons have replaced metal for fuel and vent lines and connectors. These grades of nylon offer much better corrosion resistance, better flexibility and higher impact resistance than the metal they replace [26].

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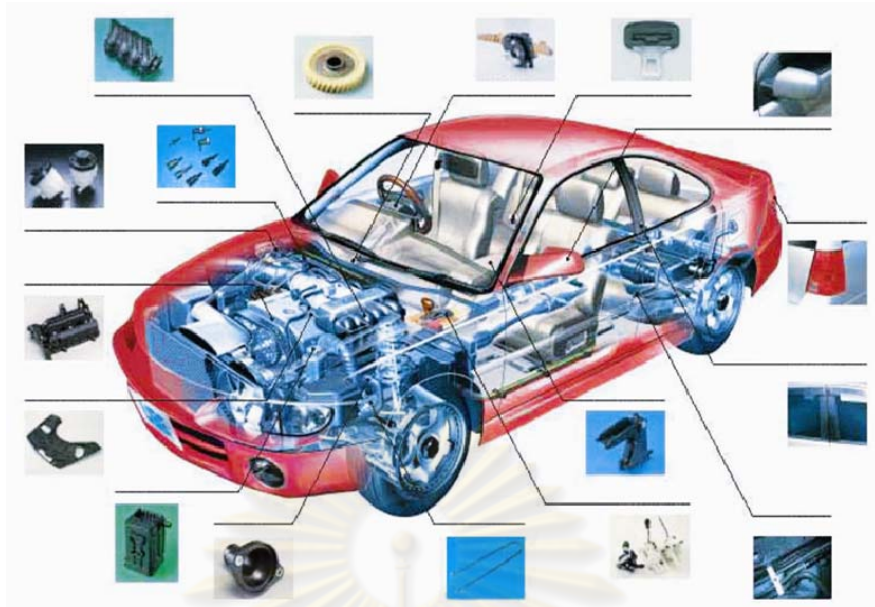


Figure 2.6 Nylon application for automobile [39]

The toughness, bending and tensile strength of nylon increase with increasing content of glass fiber while the shrinkage decreases. The 15 wt% glass fiber reinforced nylon is applied in automotive, electrical, engineering and consumer-good. High modulus/strength fiber-glass reinforced (with 45–65 wt% glass reinforced (GF)) nylon are emerging in automotive structural body panels, levers, internal and external mirror housings, seat frames, steering wheels, and various heavily stressed door handles [36]. One special application is the use of a nylon product as a fuel barrier material in polyethylene fuel tanks [9].

2.2.5 Processing

All nylons absorb moisture. The extent of moisture absorption depends on temperature, crystallinity, and humidity. Nylons need to be processed in dry condition to avoid molecular weight loss, bubble formation and significant polymer degradation during processing. Therefore, before processing of nylon resins, the polymer pellets must be dried to obtain moisture levels below 0.1-0.15 wt% for PA6,6 and PA6, 0.1 wt% for PA11 and PA12, and 0.05 wt% for nylon 4,6. The materials are normally supplied dry by the manufacture in moisture proof packaging such as foil-lined 25-kg bags or lined 1-

ton boxes. Material that has absorbed some moisture can be dried again using a vacuum oven at 80 °C or a dehumidifier hopper drier [9,23].

Material should not be processed at too high temperature, e.g., preferably not above 310 °C for nylon 6,6 and 290 °C for nylon 6, in order to avoid degradation. Residence times at the higher temperatures should be kept to minimum.

Table 2.7 Processing properties of nylon [30-32]

Material	Processing properties		State
PA6	Processing Temperature (° C)	250-255	Injection
		227-274	Extrusion
	Molding Pressure (MPa)	30-60	Injection
	Cooling Time (sec)	10-15	Injection
15 wt% glass fiber reinforced PA6	Processing Temperature (° C)	227-291	General
	Cooling Time (sec)	6-10	Injection
30 wt% glass fiber reinforced PA6	Processing Temperature (° C)	238-288	Injection
	Cooling Time (sec)	2-5	Injection

2.2.6 Degradation

The -COOH and -NH₂ end-groups in nylons are sensitive to UV light, heat, oxygen, acids and alkali. When exposed to elevated temperatures, unmodified nylons undergo molecular weight degradation resulting in loss of mechanical properties. The

degradation is highly time/temperature dependent. By adding heat stabilizer, nylon can be used at elevated temperature for long-term performance. Exposure to UV light results in degradation of nylon over an extended period of time; it appears that adding carbon black can reduce the radiation degradation [23].

2.3 Physical and Mechanical Properties Testing

2.3.1 Physical Properties

All nylons absorb moisture at different degree. The absorption process causes change in properties and dimensions [12]. Water will cause the polymer to swell and serves as a plasticizer, consequently lowering its performance, such as in electrical and mechanical behaviors. The standard tests ISO 62 and ASTM D570 are used to measure the water absorption of polymers. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environment. Mass change, diameter change, thickness change and volume change are determined under specified conditions.

Specimen size

Disk with 50.40 mm in diameter and 3.00 mm in thick is shown in Figure 2.7.

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

$$\text{Percent water absorption} = \left[\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \right] \times 100$$

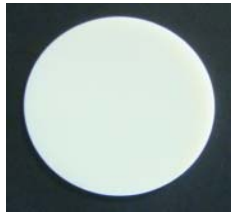


Figure 2.7 Specimen (disk) for Water Absorption, Mass Change, Diameter Change, Thickness change and Volume change [7,9]

2.3.2 Tensile Test

This test method covers the determination of the properties of plastics in standard dumbbell shaped test specimens. Tensile properties show the ability of a material to withstand a longitudinal stress[40]. The tensile strength at yield of a material is the maximum amount of tensile stress that can be applied before the material permanently deforms. It is the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress. This is a remarkable point for the engineering properties of the material since it may lose the loading capacity or it undergoes large deformations. The ultimate tensile strength (UTS) of a material is the limit stress where the material cracks grow [40].

Tensile test is the most common mechanical test performed on material science and mechanical engineering at a fixed temperature. From the data obtained, the tensile strength, yield point, elastic limit, modulus of elasticity, and other properties of the material can be collected [41]. Figure 2.8 illustrates the example of stress-strain curve.

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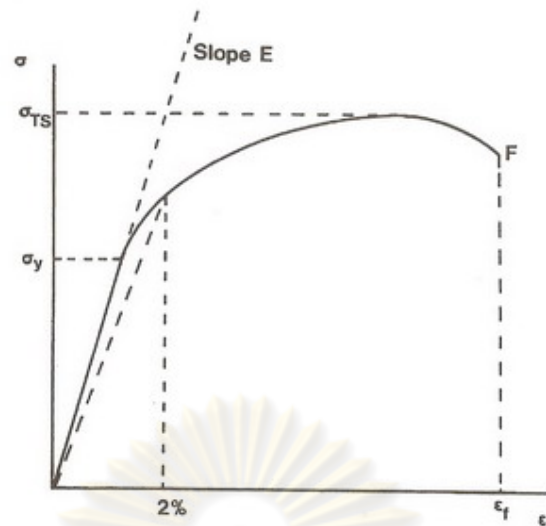


Figure 2.8 Schematic stress (σ) and strain (ϵ) curve [42].

Strain (ϵ), which can also be expressed in terms of engineering strain, is determined from the change in length of the sample compared with the original length shown as follows.

$$\epsilon \text{ (engineering strain)} = \frac{\text{change in length}}{\text{original in length}} = \frac{\Delta L}{L}$$

Stress (σ) is the force at a given time divided by the original cross sectional area of the sample:

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

where F is load applied [N]

A is cross sectional area [m^2]

The tensile strength of a sample is defined as the engineering stress at the onset of necking, or at break if no necking occurs. The Young's modulus is the slope of the initial line (linear portion) that gives the relationship of stress to strain and is a measure of the material's stiffness. In this linear region, the line obeys the relationship defined as "Hooke's Law" where the ratio of stress to strain is constant.

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

where E is Young's modulus

Frequently in polymers, there is no linear portion to the curve and tangent modulus (slope of a tangent to the stress-strain curve) or a secant modulus in which the slope of a line drawn from the origin to a specified (often 2%) strain value on the stress-strain curve is used to define a modulus. The yield stress is in principle the lowest stress which leads to permanent deformation after removal of the load. This is usually indicated by rapid change of slope in the curve but it can be difficult to determine. Hence, a stress at particular strain, often the stress at 2% offset strain, is then used to define a yield stress [42,43].

Test procedure

A minimum of five test specimens are 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 first step is placing of the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. Next is tightening the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test [44]. The grips move apart at a constant rate. As the beam moves the force on the sample is recorded by the load cell and strain is measured using an extensometer. The practice of using the constant separation speed of the grips to determine sample strain is prone to errors since the testing machine itself will deflect under the applied load and slippage of the sample within the grips is not uncommon. Grips slippage can be abated or prevented by the use of roughened faces on the grips [9].

Specimen size

Recommended sample dimensions are set out in ISO 527-1 which is equivalent to ASTM D638. The ASTM recommended shape for a specimen test is illustrated in

Figure 2.9. The exact dimension depends on the thickness of the specimen and a few representative examples are shown in Table 2.8. At least five measurements are taken using universal testing machine. An average value and a standard deviation are statistically calculated.

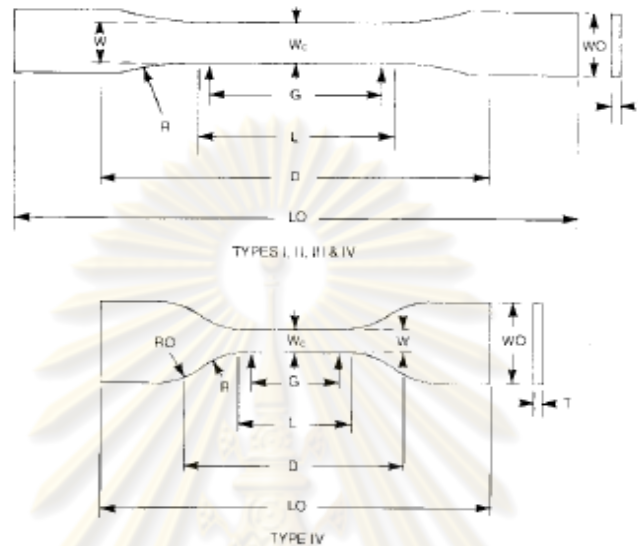


Figure 2.9 Standard tensile sample [44]

Table 2.8 Recommended tensile sample specimen dimensions for samples of the thicknesses indicated. All dimensions in mm [44]

Dimensions	Thickness of sample					Tolerances
	7 or under		7 to 14	4 or under		
	Type I	Type II	Type III	Type IV	Type V	
W	13	6	19	6	3.18	± 0.5
L	57	57	57	33	9.53	± 0.5
WO	19	19	29	19	9.53	± 6.4
LO	165	183	246	115	63.5	No max
G	50	50	50	-	7.62	± 0.25

Dimensions	7 or under		7 to 14	4 or under		Tolerances
	Type I	Type II	Type III	Type IV	Type V	
D	115	135	115	65	25.4	± 5
R	76	76	76	14	2.7	± 1
RO	-	-	-	25	-	± 1

2.3.3 Compression Test

The compression test is mainly used for determining the mechanical properties of unreinforced and reinforced rigid plastic. A compression test shows the behavior of materials under compressive loads. The specimen is compressed and deformation at various loads is measured [43]. Deformation for this test is the decrease in length produced in the gage length of the test specimen by a compressive load [45]. Compression test of ductile materials shows that the shape of stress-strain diagram depending considerably on the relative dimension of the specimen [29]. The compressive strength of the material is the maximum compressive stress exerted on the test specimens during a compression test. It may or may not be the compressive stress of the specimen at the moment of rupture [45].

Even in a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region [46]

$$\sigma = E \varepsilon$$

where E refers to the Young's Modulus for compression. By its basic definition the stress is given by:

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

where F is load applied [N]

A is area [m^2]

Test procedure

The specimen is placed between compressive plates adjusted to parallel to the surface and constant rate of crosshead speed is controlled. In the testing of materials in compression it is assumed that the compressive force is uniformly distributed over the cross section. For stress the greatest care shall be taken in machining the ends, so that smooth flat parallel surfaces are obtained. This is due to the friction on the contact surfaces between the specimen and compression head of the testing machine that prevents the lateral expansion accompanying testing. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture is used to determine strain and, hence, modulus [29,43].

Specimen size

The standard specimen size in compressive testing conforms to ASTM D 695. The specimen is in the form of a right cylinder or prism whose length is twice its width or diameter. Preferred specimen size is $12.7 \times 25.4 \times 12.7 \text{ mm}^3$ ($W \times L \times D$). Where elastic modulus and offset yield-stress data are desired, preferred specimen size is $12.7 \times 50.8 \times 12.7 \text{ mm}^3$ ($W \times L \times D$). For reinforced plastic, including high strength, the specimen size is 3.2 mm and over in thickness shall consist of a prism having cross section of 12.7 mm by the thickness and a length such that the slenderness ratio is in the range from 11:1 to 16:1 [45].

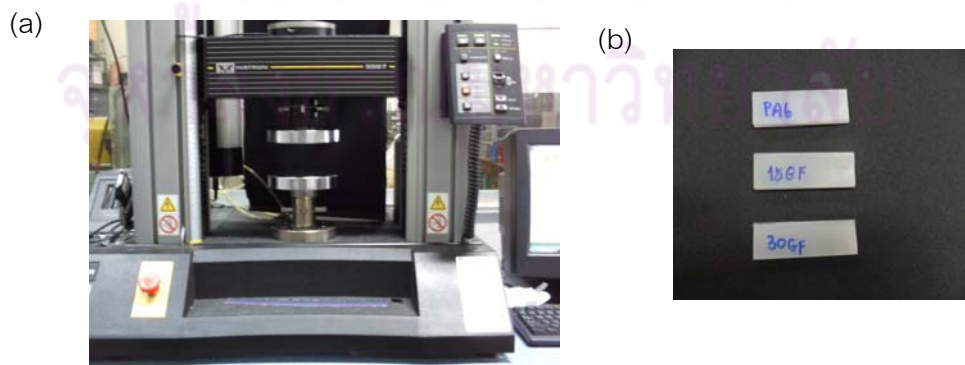


Figure 2.10 Universal testing machines for compression test (a); Specimen (rectangular) for compressive properties evaluation (b)

2.3.4 Flexural Test

The bending or flexural test, with various modifications, has been used as a standard test for various materials in specific applications. The mechanical properties that usually obtained from the flexural test are the flexural strength and flexural modulus. Flexural strength is the maximum flexural stress sustained by the test specimen during a bending test. Some materials, which are not broken at strains of up to 5%, should give a load deflection curve that shows a point at which the stress does not increase with an increase in strain. The above-mentioned point is called yield point. The flexural modulus is the slope of the initial line (linear portion) giving the relationship of stress to strain [29,47].

The classical cantilever, three point and four point bending tests, are particularly suitable for measurements of the modulus of brittle materials such as glassy polymer (see Figure 2.11). The modulus as a function of loading time by a force, F , is given by the following expression.

$$E(t) = FL^3/48al$$

This equation refers to three point bending, with a the deflection, I the moment of inertia and L the distance as illustrated in Figure 2.11 b.

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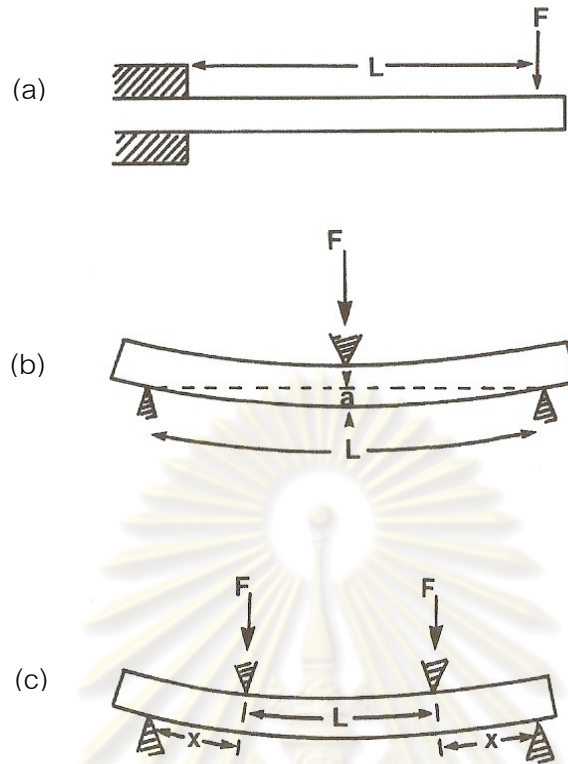


Figure 2.11 Flexural system, cantilever (a); three point bending (b); four point bending (c) [42]

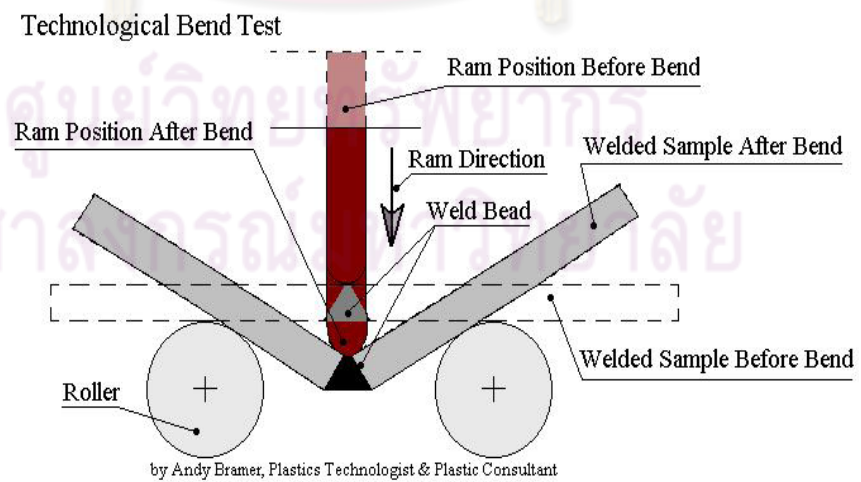


Figure 2.12 Technological three point bending test [48]

In general flexural measurement has an inherently lower accuracy than tensile test since the stress and strain vary across the thickness of the sample and cannot be unambiguously defined as in a tensile test. The simple flexural formula applies only to the case of small strain and this may be taken to mean a maximum strain in the beam of 5%. For a brittle material the fracture stress can be evaluated in a bending test by increasing the applied force in a three point bending test and noting the deflection at which fracture commences [42]. The maximum stress is given by

$$\sigma = \frac{3fL}{2wd^2}$$

where f is the ultimate center load

L is the span length

w is width of specimen

d is depth of specimen

Test procedure

Load is applied at a specified rate to the center of a rectangular cross section bar located on two supports. A support span-to-dept ratio is 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. For high strength reinforced composite, the span-to-dept ration is chosen when the failure occurs in the outer fibers of the specimens with span-to-dept ratio larger than 16:1 (32:1 or 40:1 are recommended) [43,47].

Specimen size

The specimen size for flexural testing conforms to ASTM D 790 (Flexural Properties of Unreinforced and Reinforced Plastic). The specimen may be cut from sheet, plate, or molded shape, to the desired finished dimensions. A variety of

specimen shapes can be used for this test, but the most commonly used specimen size is $12.7 \times 64 \times 3.2 \text{ mm}^3$ (W×L×D) complying with ASTM D790.

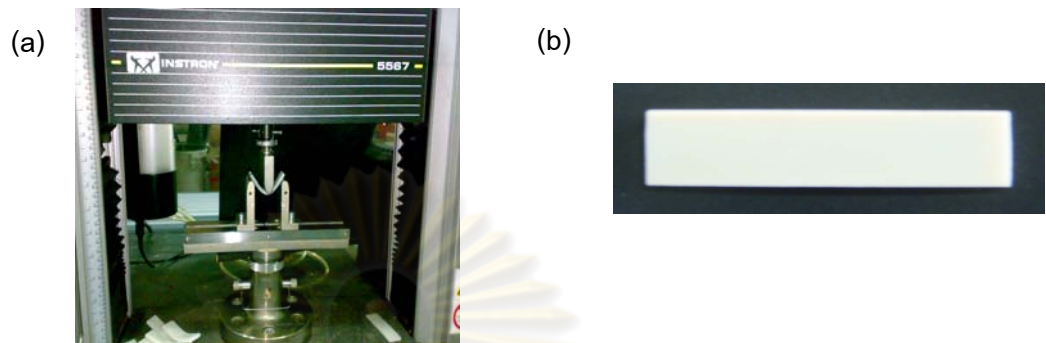


Figure 2.13 Universal testing machines for flexural test (a); Specimen bar for flexural test (b) [49]

2.3.5 Impact Test

The notched impact test is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. In the notched impact test, a notch is cut into the specified specimen dimension. 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 [41,50].

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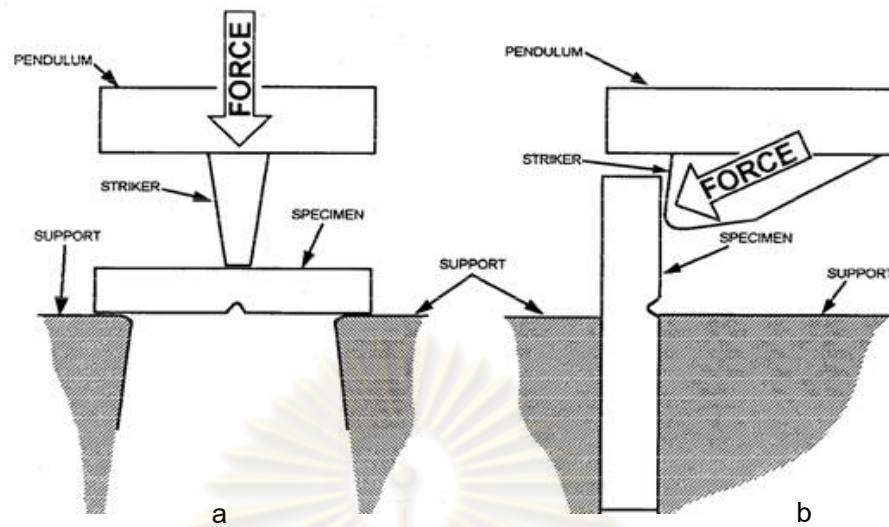


Figure 2.14 The kinds of specimens for impact testing Charpy (a); Izod (b) [41]

The two kinds of specimens used for impact testing are known as Charpy and Izod. Both test pieces are broken in an impact testing machine. The only difference is in the manner that they are anchored. The Charpy piece is supported horizontally between two anvils and the pendulum strikes opposite the notch, as shown in Figure 2.14(a). The Izod piece is supported as a vertical cantilever beam and is struck on the free end projecting over the holding vise Figure 2.14(b). Izod specimen is 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 with an impact velocity of 3.5 m/s in Izod configuration [41,50,51].

Izod 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, shown in Figure 2.16(a), and this force can be seen on an impact-measuring gauge. If breakage does not occur, a heavier hammer is used until failure occurs. From ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy by the thickness of the

specimen. At least five, preferably 10 specimens, are prepared from sheets, composites, or molded specimens [43].

Specimen size

The bar shaped specimens are prepared for Izod impact strength testing following ASTM D256 (or ISO 180) as shown in Figure 2.16 (b). The specimens may be cut from sheets, plates, or molded shapes, and then molded to the desired finished dimensions. For sheet materials, the specimens are cut from the sheet in both the lengthwise and crosswise direction unless otherwise specified. The standard specimen for ASTM is $12.7 \pm 0.20 \times 63.5 \pm 2.0 \times 3.2 \text{ mm}^3$ (W×L×D). The angle of the notch is $45 \pm 1^\circ$ with a radius of curvature at the apex of $0.25 \pm 0.05 \text{ mm}$. The dept of the plastic material remaining in the specimen under the notch is $10.16 \pm 0.05 \text{ mm}$. Impact tester is shown in Figure 2.16 (a).

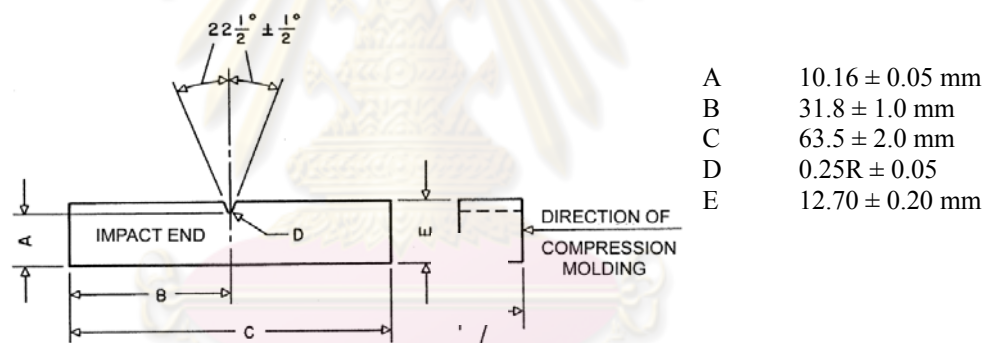


Figure 2.15 Dimension of impact test specimen ASTM D256 [52]

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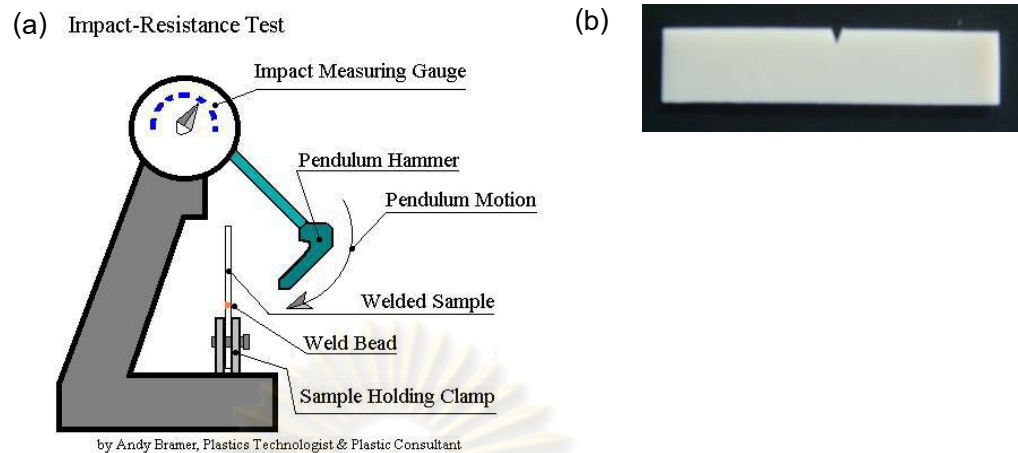


Figure 2.16 Izod impact testing (a); Bar shape specimen for Izod Impact Test (b) [9]

2.4 Thermal Properties Testing

2.4.1 Dynamic Mechanical Analysis (DMA)

DMA is a technique that does not require a lot of specialized training to use for material characterization. It supplies information about major transitions as well as secondary and tertiary transitions not readily identifiable by other methods. The DMA determines changes in sample properties resulting from changes in five experimental variables: temperature, time, frequency, force, and strain. The deformation can be applied sinusoidally under a fixed rate. It also allows characterization of bulk properties directly affecting material performance.

In DMA, a complex modulus (E^*), an elastic modulus (E'), and an imaginary (loss) modulus (E'') are recorded from the material response to the sine wave. These different moduli allow better characterization of the material, i.e., the ability of the material to return or store energy (E'), its ability to lose energy (E''), and the ratio of these effects ($\tan \delta$), which is called damping factor ($\tan \delta$). The storage modulus, E' (elastic response) and loss modulus, E'' (viscous response) of polymers are measured as a function of temperature or time as the polymer is deformed under an oscillatory

load (stress) at a controlled temperature in a specified atmosphere. The storage modulus is related to stiffness, and the loss modulus is related to damping and energy dissipation. Some details of polymer structure can be inferred from the result.

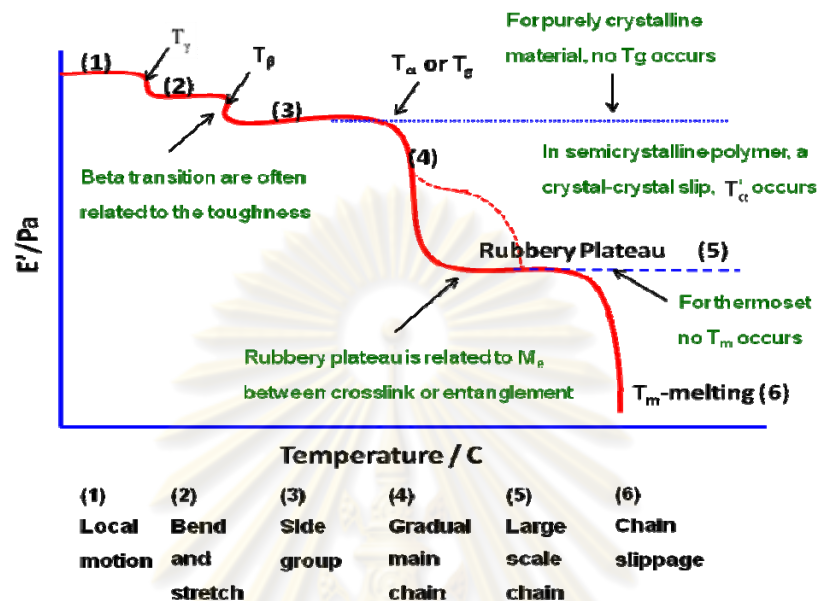


Figure 2.17 An idealized DMA scan showing the type of transitions [53]

The drop in E' and peak in $\tan \delta$ is the glass transition temperature (T_g). These transitions are labeled by counting back from melting temperature, so the T_g here is also the alpha transition (T_α). As the T_g or T_α can be assigned to gradual chain movement, so the beta transition (T_β) can be assigned to branch chain or pendant group movements and can often be related to the toughness of a polymer. The difference in the area of the T_β peak in the $\tan \delta$ and the size relative to the T_g of T_β reveal to impact via localized chain movements of materials. In the range between T_g and T_β the material possesses the stiffness to resist deformation and the flexibility to not shatter under strain. The T_g represents a major transition for many polymers, as physical properties change drastically as the material goes from a hard glassy to rubbery state. It defines one end of the temperature range over which the polymer can be used, often called the operating range of the polymer.

Additionally, the T_g is often measured by Differential Scanning Calorimetry (DSC), but the DMA technique is more sensitive and yields more easily interpreted data.

DMA can also be used to investigate the frequency (and therefore time) dependent nature of the transition. This is usual as the degree of dependence is specific to the transition type. The T_g has a strong dependence on frequency but melting temperature is frequency independent. DMA can also resolve sub- T_g transitions, like beta (β) and gamma (γ) transitions, in many materials while the DSC technique is not sensitive enough to pick up.

Test procedure

A flat rectangular specimen is placed in the DMA equipment and oscillated at a nominal frequency of 1 Hz. The two kinds of method used for glass transition temperature testing are known as three point bending mode and tension mode. The specimen is heated at rate of 5 ± 1 °C/min. The temperature at which a significant drop in storage modulus (E') begins is assigned as the glass transition temperature (DMA T_g). The peak temperature of the tangent delta curve is identified along with DMA T_g for comparison purposes [54].

Specimen size

The flat rectangular specimens are prepared for glass transition temperature testing following ASTM D 7028 as shown in Figure 2.18(b). The specimens may be cut from sheets, plates, or molded shapes, and then molded to the desired finished dimensions. The standard specimen size for ASTM D 7028 is not fixed by this method; various dynamic mechanical analyzers require different sizes. Depending on the analyzer, typical specimen size can range from $56\pm 4 \times 12\pm 1 \times 2.0\pm 0.5$ mm³ (L×W×T) to $22\pm 1 \times 3\pm 1 \times 1.0\pm 0.5$ mm³ [54].

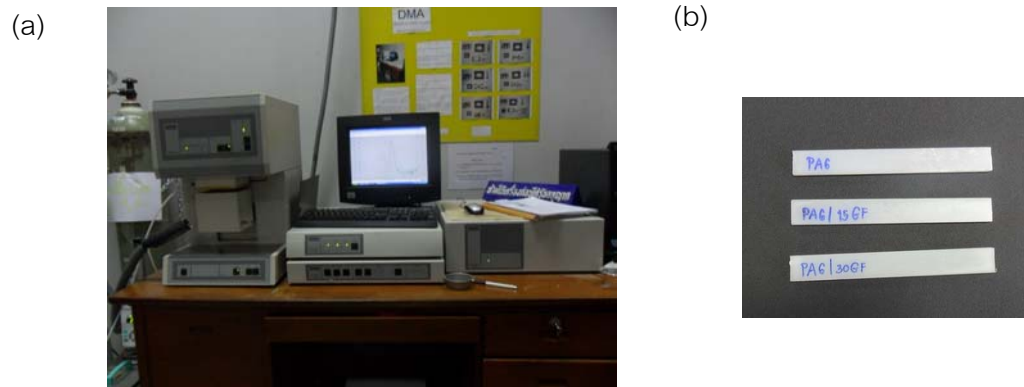


Figure 2.18 Dynamic mechanical analysis (a); Rectangular shape specimen for DMA test (b)

2.4.2 Heat Distortion Temperature (HDT)

Heat distortion temperature is defined as the temperature at which a standard test bar deflects a specified distance under load. It is used to determine short term heat resistance. It distinguishes between materials that are able to sustain light loads at high temperature and those that lose their rigidity over a narrow temperature range.

Test procedure

A bar with rectangular cross section is tested in the edgewise position as a simple beam with the load applied at its center to give maximum fiber stresses of 0.455 MPa (66 psi) or 1.82 MPa (264 psi). The support span is either 100 mm or 101.6 mm. Load is applied to the center of specimen and then immersed into a silicone oil bath provided with a means of raising the temperature at $2 \pm 0.2^\circ\text{C}/\text{min}$. The temperature of the medium is measured when the test bar has deflected of 0.25 mm (0.010 in.). This temperature is recorded as the heat distortion temperature under flexural load of the test specimen.

Specimen size

The specimens for heat distortion temperature testing conform to ASTM D 648. This test method applies to molded and sheet materials available in thickness of 3 mm or greater. The specimens may be cut from sheets, plates, or molded shapes. At least two test specimens are used to test each sample. The specimen is 127 mm in length, 13

mm in depth by any width from 3 mm to 13 mm. Tolerances on dimensions should be in the order of ± 0.13 mm over the length of the specimen [55].

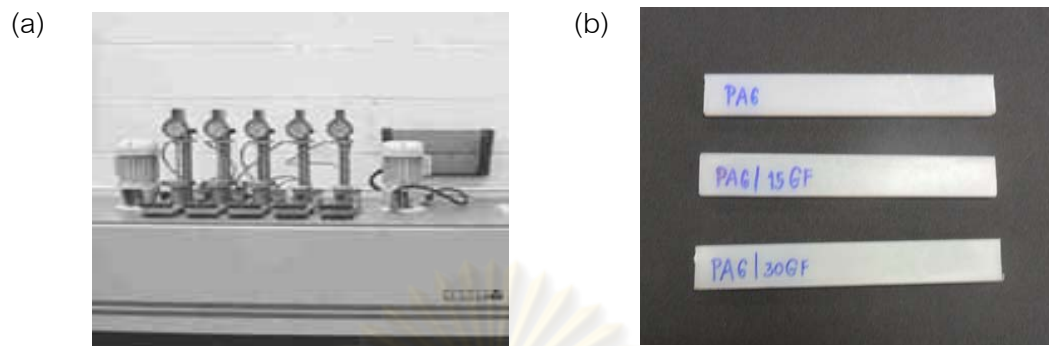


Figure 2.19 HDT/vicat (a); Rectangular shape specimen for HDT test (b)

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CHAPTER III

LITERATURE REVIEWS

B. Jones, et al [8] compared the effects of E20 versus E10 and gasoline on plastic materials found in automotive and small engine fuel system components. They studied the materials commonly used in flex-fuel vehicle fuel systems, that are acrylonitrile butadiene styrene (ABS), nylon 6 (PA6), nylon 6,6 (PA6,6), polybutylene terephthalate (PBT), polyethylene terephthalate (PET), polyetherimide 1010 moldable (PEI), polyurethane (PUR) and polyvinyl chloride flexible version (PVC). Plastic samples were prepared according to SAE and ASTM standard and exposed to surrogate Fuel C (gasoline), gasohol E10 and E20 at an elevated temperature of 55 °C for 3024 hours (Note: surrogate Fuel C is : blending between isooctane and toluene). Each fuel was changed in weekly intervals for the 18-week study. Physical and mechanical properties were measured before immersion and compared to the values recorded after the soak process.



Figure 3.1 Samples used in study of B. Jone, et al [8]

The results showed that four of the materials, PA6, PA66, PET and PEI were compatible with the three fuels. The change of properties of these four materials, such as mass, volume, tensile strength, tensile elongation and impact resistance were small for samples immersed in any of the three fuels. While the other four materials, ABS, PUR, PVC and PBT were affected by all three fuels to varying degrees. Those ABS specimens were turned to a jelly-like mass in the bottom of the jars after less than one week. PVC demonstrated significant changes in mass and volume in all three fuels but to a higher degree in ethanol fuels. The PBT data also showed impact resistance increased in all three fuels but to a greater extent in the ethanol blends. The PUR was cracked and showed changes in mass, volume, tensile strength, and elongation. The mechanical properties of plastics were shown in Figure 3.2 and Figure 3.3.

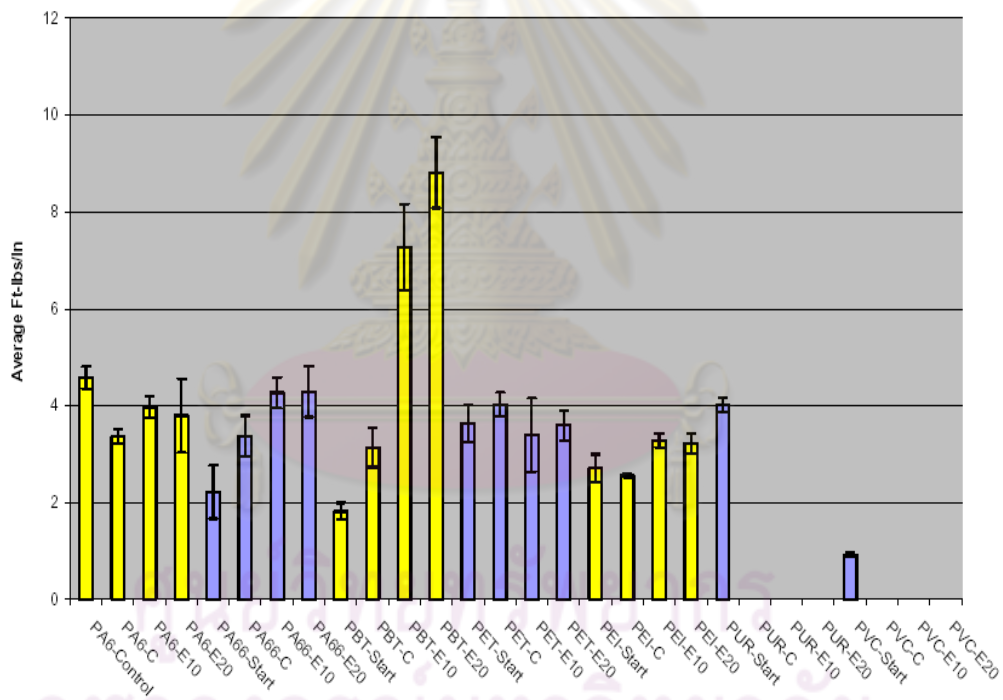


Figure 3.2 Izod impact strength of plastic samples in three test fuels [8]

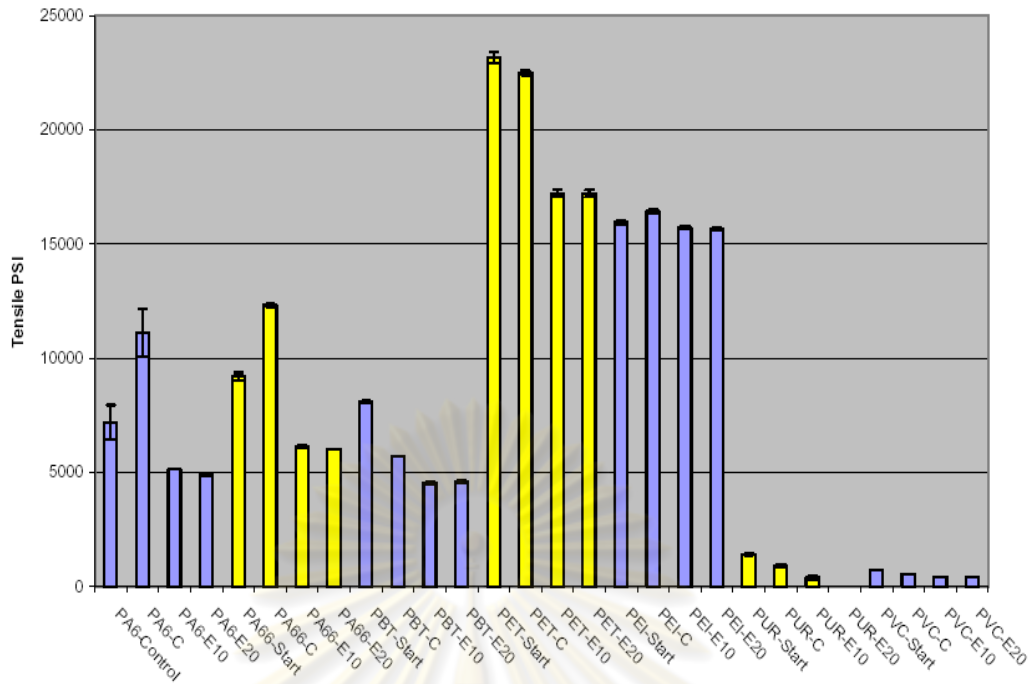


Figure 3.3 Tensile strength of plastic samples in three test fuels [8]

A. Gullu, et al [11] in 2004 investigated the influence of fiber reinforcement and injection parameters on mechanical properties of polypropylene (PP) and polyamide 6 (PA6) plastics. The plastics were reinforced with (15 and 30 wt%) silane coated glass fibers. Each test specimen was prepared by injection molding machines, where the injection parameters were controlled precisely by a computer. The results indicated that 15 wt% and 30 wt% fiber reinforcement for PP can improved the tensile strength of PP by 128% and 199%, respectively. Similarly, the same amounts of reinforcements improved the tensile strength of PA6 by 74% and 111%, respectively. But it dose not always increase impact energy when fiber content increases because fiber fractures also increase as, shown in Table 3.1

Table 3.1 The influence of the fiber content on the mechanical properties of the composite material [11]

Material	Izod impact strength (kJ/m ²)	Tensile strength (MPa)	Strain at break (%)
PA6, unreinforced	10.98	64.70	51.53
PA6, 15 wt% fiber reinforced	8.575	112.38	8.83
PA6, 30 wt% fiber reinforced	11.98	136.61	8.18
PP, unreinforced	11.24	26.26	700
PP, 15 wt% fiber reinforced	10.7	60.04	8.15
PP, 30 wt% fiber reinforced	12.8	78.61	11.05

Table 3.2 showed tensile strength decreased and impact energy increased with increasing injection screw speed. Furthermore, the result showed that by increasing injection speed, fiber fractures increased and fibers were oriented perpendicularly to the flow direction.

Table 3.2 The influence of screw speed on the mechanical properties of the composites material [11]

Material	Screw speed (rev/min)	Izod impact strength (kJ/m ²)	Tensile strength (MPa)	Strain at break (%)
<i>15 wt% fiber reinforced</i>				
PA6	100	8.57	112.38	8.83
PA6	150	10.65	107.65	8.50
PP	100	10.70	60.04	8.15
PP	150	11.10	52.28	8.39
<i>30 wt% fiber reinforced</i>				
PA6	100	11.98	136.61	8.18
PA6	150	13.10	129.26	9.01
PP	100	12.82	78.61	11.05
PP	150	14.70	70.50	11.20

P. Chooseng [9] in 2009 investigated the effects of glass fiber content and the effects of ethanol concentration in gasohol on physical and mechanical properties of neat PA6 and PA6 compound with 15 wt% and 30 wt% glass fiber. For this purpose, each polyamide 6 composite specimen was prepared by compression and injection molding machines.



Figure 3.4 Test containers [9]

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. Where $C(E0)_A$ is pure surrogate Fuel C. The soaking apparatus was shown in Figure 3.4. The results indicated that the PA6 matrix had an excellent adhesion to glass fiber reinforcement. The glass fiber could improve the mechanical properties of the composites and dimensional stability of specimens by reducing amorphous region while increasing crystalline region. Figure 3.5 showed that Young's modulus of unsoaked test materials increased with increasing fiber content.

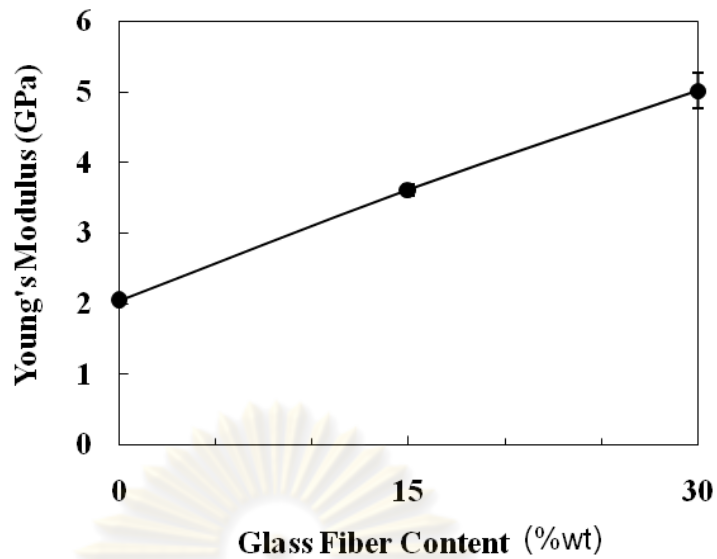


Figure 3.5 Young's modulus of unsoaked PA6/GF composites [9]

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. Figure 3.6 showed that, after long enough immersion time, the Young's modulus of three test materials soaked in test fuels containing alcohol decreased to the same value and decreased more than specimens soaked in surrogate gasoline.

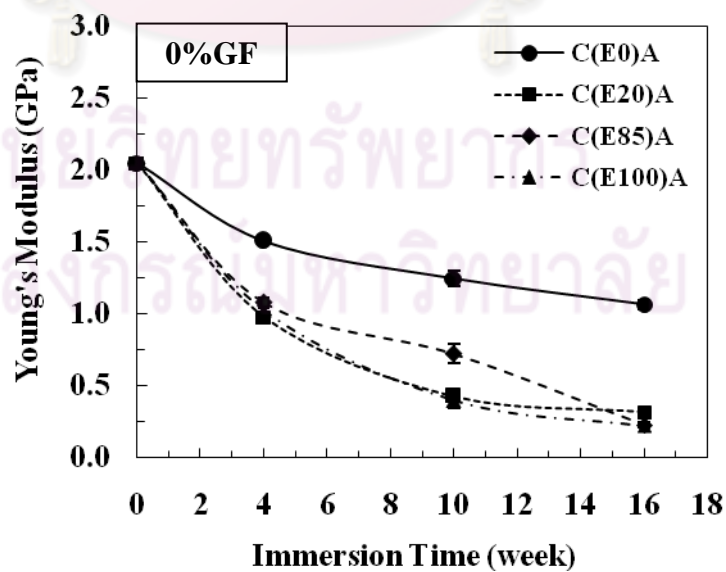


Figure 3.6 Young's modulus of PA6 immersed in test fuels [9]

D.P.N. Vlasveld, et al. [56] in 2007 studied the flexural and compressive strengths of PA6 nanocomposite reinforced with woven glass fiber at various temperature and after moisture conditioning. The strength of neat PA6 fiber composites was studied over a wide temperature range and after moisture conditioning to indicate the influence of the temperature and absorbed moisture on the strength of the composite.

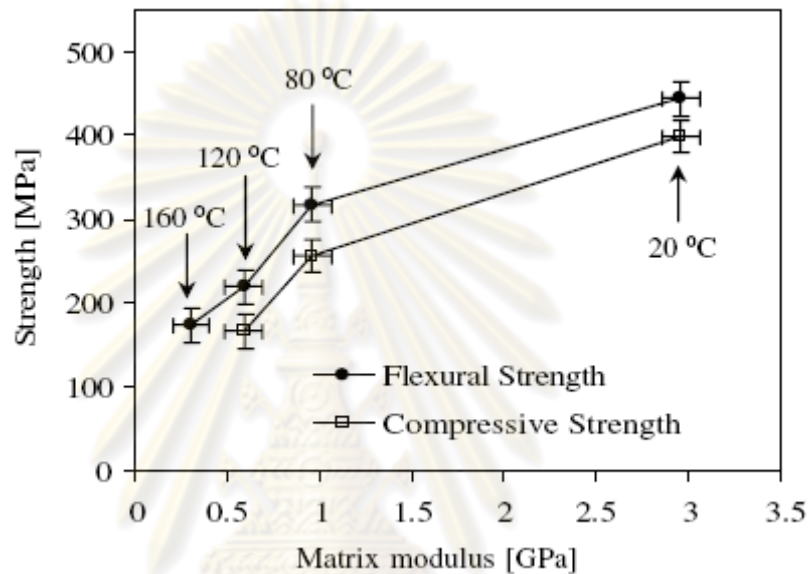


Figure 3.7 Flexural and compressive strengths of dry PA6 glass fiber composite as function of the matrix modulus (neat PA6) [56]

The result showed that flexural and compressive strength decreased with increasing temperature and the fast decrease of flexural and compressive strength around the T_g of the matrix polymer, around 65 °C for PA6, shows a correlation with the composite modulus. Influence of fiber content in polymer matrix showed the flexural strength with nanocomposite at 120 °C is similar to the flexural strength with a PA6 at 80 °C and at 160 °C the flexural strength is even higher than at 120 °C with the unfilled PA6 while the compressive strength with a nanocomposite at 120 °C is similar to the strength with a PA6 at 90 °C (per interpolation). Therefore, with this nanocomposite it is possible to increase the useful temperature range for PA6 with 30-50 °C.

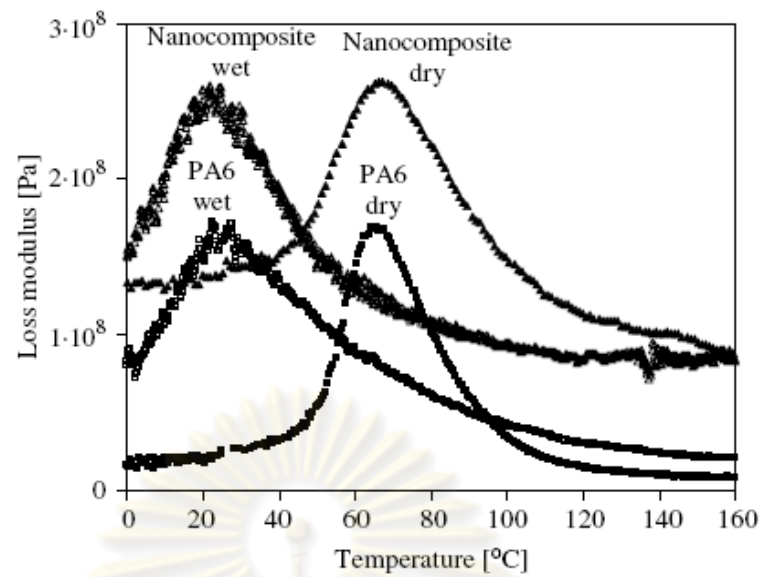


Figure 3.8 Loss modulus of PA6 and nanocomposite as a function of temperature in dry and moisture-conditioned samples [56]

The glass transition temperature, T_g , determined by DMA, corresponds to the peaks in the loss modulus curves. The T_g was the same in unfilled PA6 and the nanocomposite, but it decreased from around 65 °C in dry condition to around 20 °C as a result of moisture conditioning.

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CHAPTER IV

EXPERIMENT

4.1 Materials, Chemicals and Equipments

Materials

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

Chemicals

The three chemical substances in surrogate gasohol are isooctane, toluene and aggressive ethanol. Aggressive ethanol used in this study met SAE J1681 criteria. Aggressive ethanol comprised of ethanol 816.0 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g and glacial acetic acid 0.061 g (for 1 litre of aggressive ethanol). The chemicals required for experiment were obtained from S.R. Laboratory as follows:

- Ethanol (AR Grade, J.T. Baker SOLUSOR)
- Isooctane (AR Grade, BRIGHT CHEM SDN BHD)
- Toluene (AR Grade, J.T. Baker SOLUSOR)
- Sodium chloride (AR Grade, Merck Chemical)
- Sulfuric acid (AR Grade, Merck Chemical)
- Glacial acetic acid (AR Grade, Merck Chemical)

Equipments

- Vacuum oven (Lab-instrument 3606-1CE)
- Injection molding (Manumold 45E)

- Compression molding (Lab Tech Engineering)
- Universal testing machine (Instron 5567)
- Grinder machine (Buehler Metaserv)
- Notching machine
- Trimming Machine (George Machine CY 135A)
- Digital micrometer
- Balance (Mettler Toledo AG 204)
- Digital vernier calipers
- Dynamic Mechanical Analysis (NETZSCH DMA 242 C)
- HDT/vicat
- Impact Tester (Yasuda)

4.2 Test Specimens Preparation

Both PA6 resin and PA6 compound were dried in a vacuum oven at 80 °C for 24 hour to remove the moisture [11]. The property testing required five different shaped test specimens including

- Disk
- Bar
- Rectangular
- Dumbbell
- Izod

4.2.1 Compression Molding

Disk specimens were prepared by compression molding machine (see Figure 4.1). These test specimens conform to ASTM D570 for physical properties testing.



Figure 4.1 Compression molding machine

Table 4.1 Process parameters setting of compression molding machine for PA6

Process Parameters	Setting
Mold temperature (°C)	225
Preheating time (min.)	2
Heating time (min.)	4
Cooling time (min.)	6
Molding pressure (bar)	90

Table 4.2 Process parameters setting of compression molding machine for PA6 compound with 15 wt% glass fiber

Process Parameters	Setting
Mold temperature (°C)	230
Preheating time (min.)	3
Heating time (min.)	4.5
Cooling time (min.)	6
Molding pressure (bar)	20-90

Table 4.3 Process parameters setting of compression molding machine for PA6 compound with 30 wt% glass fiber

Process Parameters	Setting
Mold Temperature (°C)	235
Preheating Time (min.)	4
Heating Time (min.)	3.5
Cooling Time (min.)	6
Molding Pressure (bar)	20-90

4.2.2 Injection Molding

Dumbbell, bar and rectangular shapes were prepared by injection molding machine (Manumold). These test specimens conform to ASTM D638 and ASTM D790 for tensile testing and flexural testing, respectively. The izod and rectangular shapes specimens were cut from the bar shapes that were prepared by injection molding using trimming machine (Band saw) and rubbed by grinder machine. These test specimens conform to ASTM D695, ASTM D7028 and ASTM D648 for compressive testing, dynamic mechanical analysis (DMA) and heat distortion temperature testing, respectively. While izod shapes were notched by notching machine. These test specimens conform to ASTM D256 for impact testing.



Figure 4.2 Injection molding machine

Table 4.2 Process parameters setting of injection molding machine for PA6

Material	Process Parameters		Setting
PA6	Temperature (°C)	Nozzle	290
		Zone 1	285
		Zone 2	285
	Pressure (bar)	Injection forward I	60
		Injection forward II	36
		Injection forward III	36
		Holding	20
		Metering	60
	Stroke (mm)	Injection forward I	25
		Injection forward II	18
		Injection forward III	15
		Holding	15
		Metering	50
	Time (sec)	Holding	3
		Cooling	10

Table 4.3 Process parameters setting of injection molding machine for PA6 compound with 15 wt% glass fiber

Material	Process Parameters		Setting
PA6 compound with 15 wt% glass fiber	Temperature (°C)	Nozzle	295-300
		Zone 1	290-295
		Zone 2	290-295
	Pressure (bar)	Injection forward I	65-70
		Injection forward II	40-45
		Injection forward III	40
		Holding	30
		Metering	60
	Stroke (mm)	Injection forward I	25
		Injection forward II	18
		Injection forward III	15
		Holding	15
		Metering	50
	Time (sec)	Holding	2-4
		Cooling	7

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Table 4.4 Process parameters setting of injection molding machine for PA6 compound with 30 wt% glass fiber

Material	Process Parameters		Setting
PA6 compound with 30 wt% glass fiber	Temperature (°C)	Nozzle	320-325
		Zone 1	315-320
		Zone 2	315-320
	Pressure (bar)	Injection forward I	70
		Injection forward II	45
		Injection forward III	40
		Holding	30
		Metering	60
	Stroke (mm)	Injection forward I	25
		Injection forward II	18
		Injection forward III	15
		Holding	15
		Metering	50
	Time (sec)	Holding	2
		Cooling	5

4.3 Preparation of Chemicals in Surrogate Gasohol

The chemical substances in surrogate gasohol including ethanol, isooctane and toluene were obtained from S.R laboratory and aggressive ethanol is a worst-case-scenario fuel that would still be acceptable under ASTM D4806, *Standard specification for denatured fuel ethanol for blending with gasoline for using as automotive spark-ignition engine fuel*. Formulations of aggressive ethanol components to make 1.0 L are:

- Synthetic ethanol 816.00 g
- De-ionized water 8.103 g
- Sodium chloride 0.004 g
- Sulfuric acid 0.021 g
- Glacial acetic acid 0.061 g

4.4 Test Procedures



Figure 4.3 Test container

To study the effect of chemical substances in surrogate gasohol on the physical, mechanical and thermal properties of samples, the specimens were immersed in each chemical substance (see Figure 4.3), i.e., ethanol, isooctane, toluene and aggressive ethanol, in separated jars at room temperature. The chemical substances were changed every six weeks. Before physical, mechanical and thermal testing, the specimens would be taken out from the chemical substances and dried in air for 2 h before testing. Physical and mechanical properties were measured in 0th, 1st, 2nd, 3th, 5th, 7th, 10th, 13th and 16th week and thermal properties were measured in 0th, 2nd, 5th, 10th and 16th week.

4.5 Physical Properties Measurement

The disk shaped specimens were used for physical property testing. Five specimens of PA6 and PA6 compounds were tested to determine the average value.

4.5.1 Water Absorption

The specimens were immersed in DI water at room temperature. For water absorption testing the specimens would be taken out from the DI water, wiped dry with a lint free cloth and dried in air for 2 h before testing. Balance would be used for weighing of specimens. Five specimens of PA6 and PA6 compounds were tested to determine the average value.

4.5.2 Mass and Volume Change Testing

The specimens were immersed in chemical substance at room temperature. For mass and volume change testing the specimens would be taken out from the chemical substances, wiped dry with a lint free cloth and dried in air for 2 h before testing. Balance, Digital vernier calipers and Digital Micrometer, would be used for measuring mass change, diameter change and thickness change, respectively. Five specimens of PA6 and PA6 compounds were tested to determine the average value.

4.6 Mechanical Properties Measurement

4.6.1 Tensile Property Measurement

Universal testing machine (Instron model 5567) would be used for tensile property testing. The dumbbell shaped specimens were tested in tension mode at constant crosshead speed of 50 mm/min with a 30 kN load cell at 25 °C according to ASTM D638. Five specimens were tested to determine the average value. From the data, the tensile modulus and the tensile strength of PA6 and PA6/GF composites were obtained.

4.6.2 Flexural Property Measurement

The bar shaped specimens were measured to conduct the flexural strength and flexural modulus. The three point bending tests were done according to ASTM D790. A support span-to-dept ratio was 16:1 and constant crosshead speed of 1.2 mm/min was performed in a universal testing machine (Instron model 5567) with a 30 kN load cell at 25 °C. The loading point for the test was located at the center. Five specimens of PA6 and PA6 compounds were tested to determine the average value.

4.6.3 Compressive Property Measurement

The compression test of specimens before and after an immersion in chemicals of surrogate gasohol was performed according to the ASTM D695 test standard on a universal testing machine (Instron model 5567) with a 30 kN load cell at 25 °C controlling constant crosshead speed of 1.2 mm/min. Five specimens of PA6 and PA6 compounds were tested to determine the average value.

4.6.4 Impact Property Measurement

The standard test method that describes the Izod impact test is ASTM D256. Izod impact strength of specimens before and after an immersion in chemicals of surrogate gasohol was determined by Impact Tester using acutely notched specimens (notch depth is 2 mm). Five specimens of PA6 and PA6 compounds were tested to determine the average value.

4.7 Thermal Properties Measurement

4.7.1 Glass Transition Temperature

The rectangular shaped specimens were used to measure the glass transition temperature (T_g). The dynamic mechanical properties of specimens before and after an immersion in chemicals of surrogate gasohol were determined by using Dynamic Mechanical Analysis (DMA) in a three-point bending mode with a 110 mN static force and a 110 mN dynamic force. Each specimen was first cooled under liquid nitrogen to -50 °C and then heated at 5 °C/min to 200 °C at a frequency of 1 Hz under nitrogen. The storage modulus (E'), loss modulus (E'') and mechanical loss factor $\tan \delta$ were recorded as a function of temperature. The glass transition temperature of the specimen was obtained from the maximum peak of the loss tangent plot.

4.7.2 Heat Distortion Temperature

The heat distortion temperature of the specimens was measured according to ASTM D648 by HDT/vicat. The specimens were tested in a flatwise position. For the HDT measurements, the specimens were immersed into a silicone oil bath and heated from

room temperature to 200 °C at a heating rate of 2 °C/min. A load of 1820 kPa was applied to the specimen at the center. Once the specimen was deflected by 0.25 mm, the temperature was noted as heat distortion temperature (HDT) of the specimen. Three specimens of PA6 and PA6 compounds were tested to determine the average value.



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CHAPTER V

RESULTS AND DISCUSSION

5.1 Influences of Chemicals in Surrogate Gasohol on Physical Properties of PA6/GF Composites

In this study, the physical tests included mass change and volume change. The physical properties of the specimens were measured on 0th, 1st, 2nd, 3th, 5th, 7th, 10th, 13th and 16th week. Five specimens of PA6 and PA6 compounds were tested to determine the average value.

5.1.1 Water Absorption

The absorption process lead to change in properties and dimension that must be taken into account in part design and application. Then, water absorption is used to determine the amount of water absorbed under specified conditions. Water absorption is expressed as percent increase in weight [9].

$$\text{Percent water absorption} = \left[\frac{\text{Wet weight of material} - \text{Dry weight of material}}{\text{Dry weight of material}} \right] \times 100$$

PA6 is a semicrystalline polymer; one common properties of PA6 is water absorption from the environment, both form the air and form liquid water [57]. Due to the polar amide group (-CO-NH-), nitrogen and/or oxygen in polymer chain acts as potential proton acceptors to form hydrogen complexes. Then water molecules close to polar groups should be able to form hydrogen bonded complexes with nitrogen and oxygen [58]. The experimental results were shown in Figure 5.1. The results showed the water absorption of the specimens increased with immersion time and leveled off at around 4th-6th weeks. The water absorption was rapidly changed during the first three weeks for PA6. For PA6 reinforced with 15% and 30% glass fiber, the water absorption was rapidly changed during the first five weeks. The neat PA6 showed more water absorption than the PA6 compound (based on total weight of specimens).

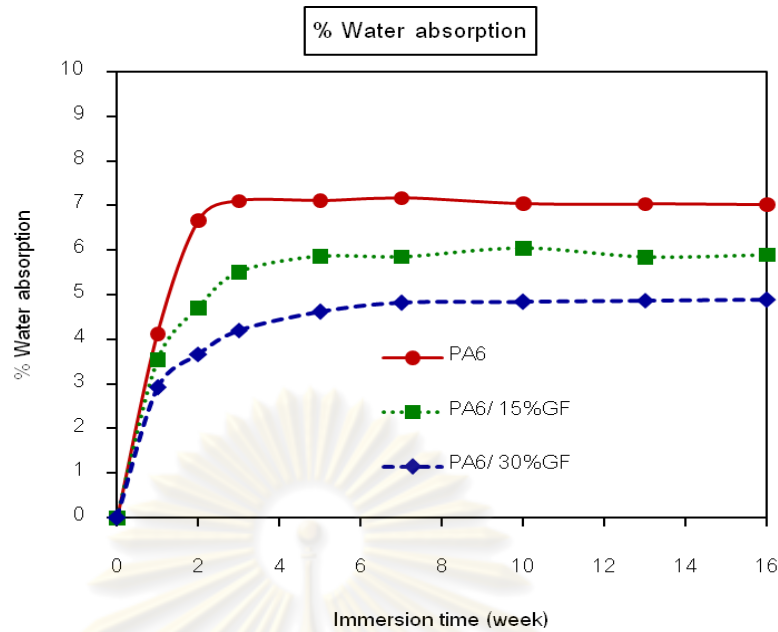


Figure 5.1 Percent water absorption of PA6 and PA6/GF composites

However, when the percent water absorption was calculated based on the amount of PA6 matrix only (so the weight of glass fiber phase was not included), the results were illustrated in Figure 5.2. The results clearly showed that the water was absorbed by the PA6 phase only. The percent water absorption reached the same value (at around 7%) after long enough immersion time. This is in general agreement with data shown in Table 2.1. The difference of percent water absorption of PA6/GF compounds in comparison with neat PA6 during the early weeks of immersion was due to the increase in the tortuous path for molecules diffusing through PA6 caused by impenetrable glass fibers. The increased tortuous path reduced the transport speed of water through the PA6 [57,59]. The reduced transport rate then reduced the rate of moisture uptake in PA6.

The volume changes of the specimens were also determined from the change in diameter and thickness of the specimens. Figure 5.3 showed that the percent change of specimens volume changed quite rapidly during the first 3-4 weeks of immersion and leveled off afterwards. This was consistent with the change in percent water absorption shown in Figure 5.1. It could be noted from Figure 5.3 that the percent change of volume

was lesser when the wt% of fiber in specimens increased. This showed that PA6/GF composites have better dimensional stability than neat PA6.

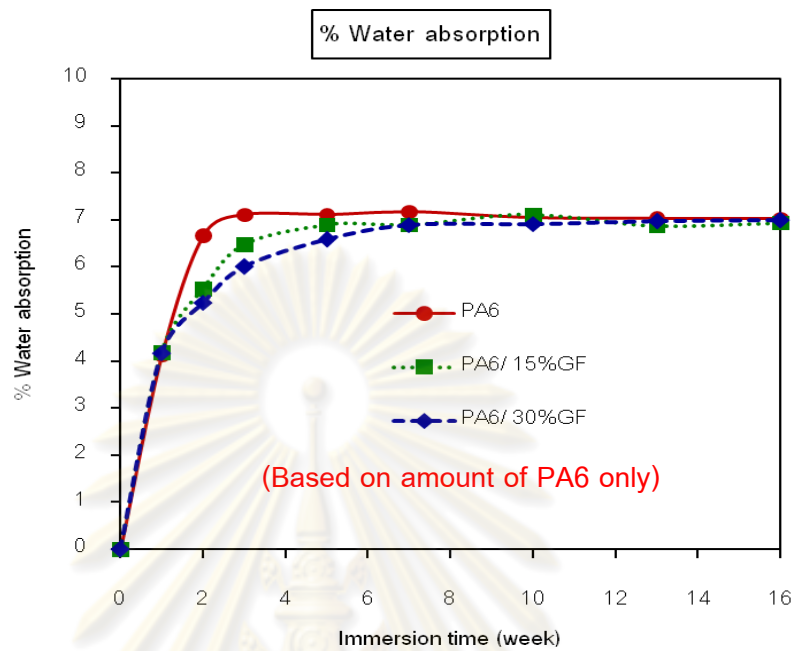


Figure 5.2 Percent water absorption of PA6 and PA6/GF composites based on the amount of PA6 matrix

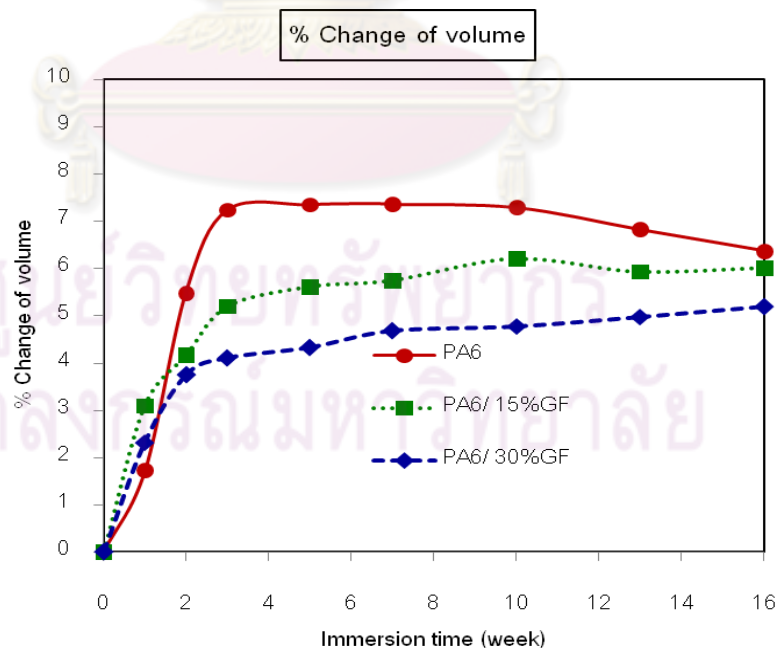


Figure 5.3 Percent volume change of PA6 and PA6/GF composites immersed in water

5.1.2 Mass Change of PA6/GF Composites

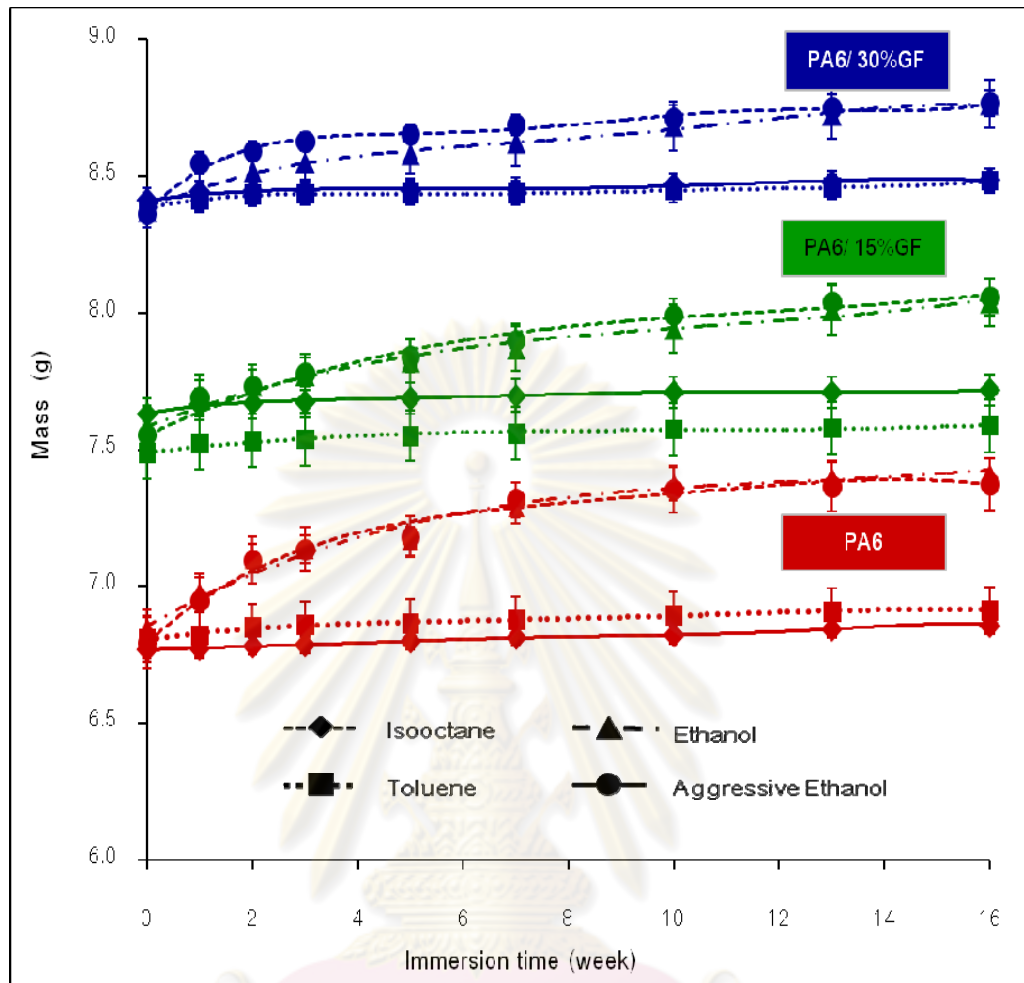


Figure 5.4 Mass of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

Figure 5.4 showed the mass of PA6 and PA6/GF composites increased with increasing immersion time in the chemicals of surrogate gasohol, especially the first 2-5 weeks, because the solvent was absorbed into the PA6 matrix. It was very clear from the results that ethanol and aggressive ethanol were absorbed into PA6 and PA6/GF composites more than isooctane and toluene. These were also illustrated in Figures 5.5-5.8 when percent change of mass plotted against immersion time. Figures 5.5 and 5.6 showed that isooctane and toluene were absorbed into PA6 and PA6/GF composites at almost 0.5-1% only. But Figs 5.7 and 5.8 showed that ethanol and aggressive ethanol were absorbed into PA6 and PA6/GF composite at almost 4-8%. This was because ethanol and PA6 have solubility parameters close to each other. Also ethanol is a polar

molecule and PA6 can absorb polar molecules better than non-polar molecules such as isooctane and toluene. Aggressive ethanol seems to be absorbed more into PA6 and PA6/GF composites than ethanol because aggressive ethanol has water as its component.

Figures 5.7-5.8 also showed that the rate of absorption of ethanol and aggressive ethanol into PA6/GF composites decreased with increasing fiber content. This was because there were less PA6 matrix in PA6/GF composites than neat PA6 specimens and glass fiber must increase the tortuous path for molecules to diffuse into PA6 matrix [57, 59].

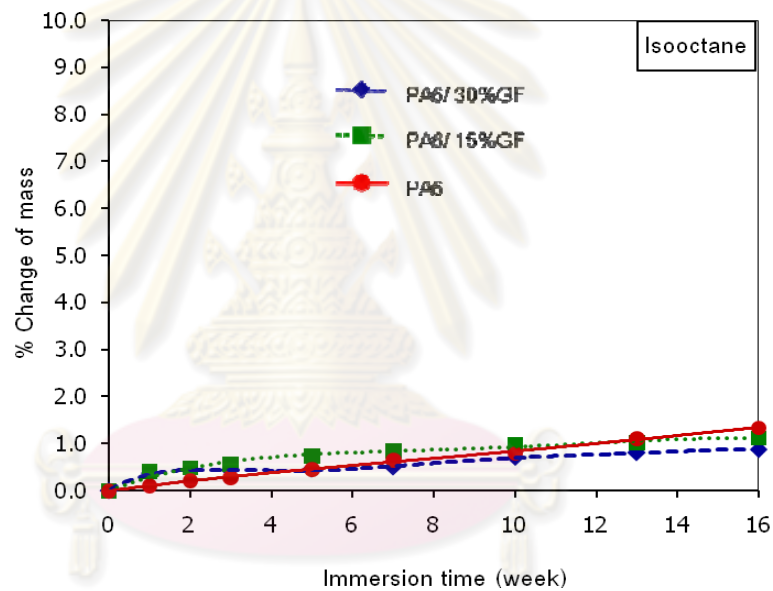


Figure 5.5 Percent mass change of PA6 and PA6/GF composites immersed in isooctane

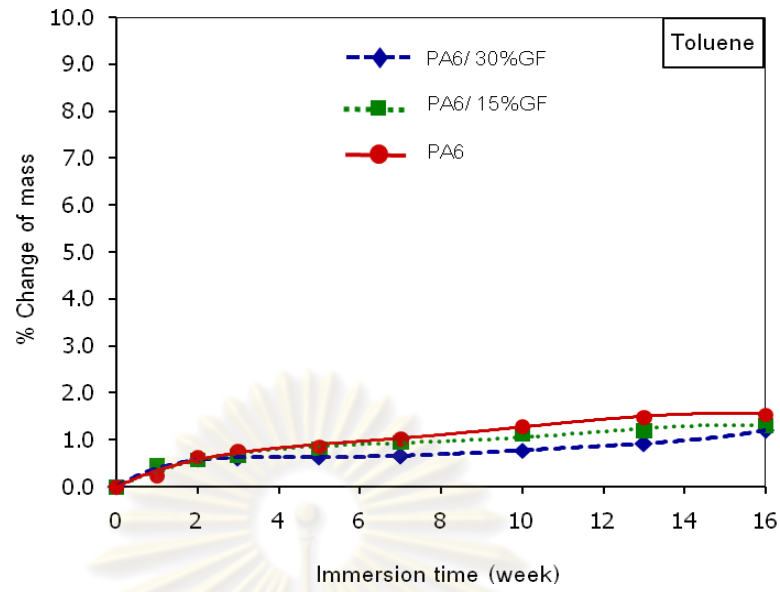


Figure 5.6 Percent mass change of PA6 and PA6/GF composites immersed in toluene

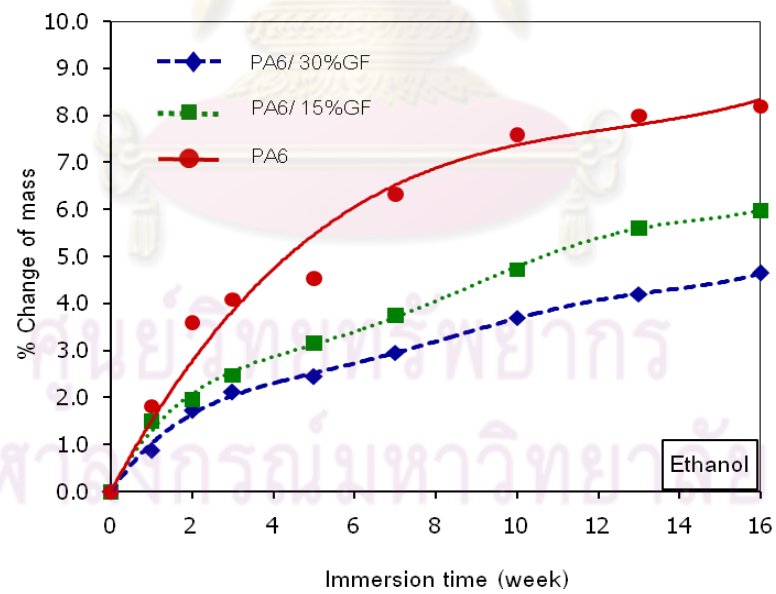


Figure 5.7 Percent mass change of PA6 and PA6/GF composites immersed in ethanol

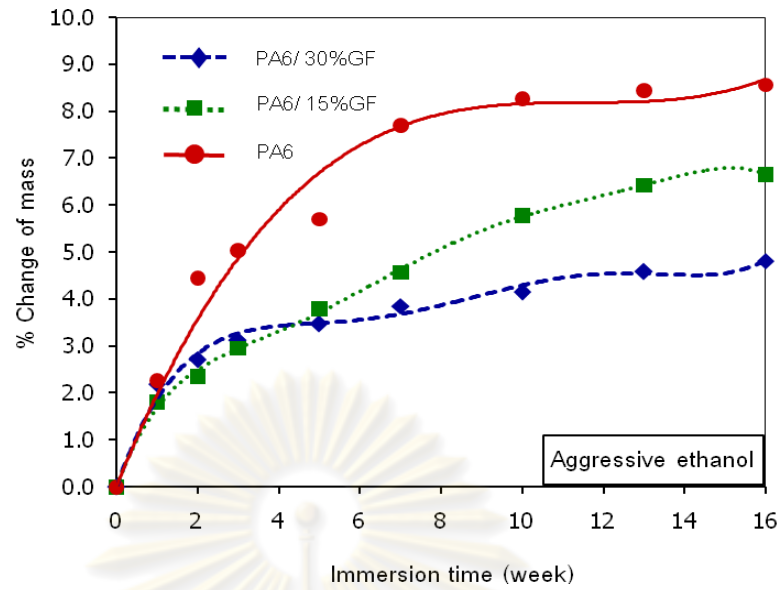


Figure 5.8 Percent mass change of PA6 and PA6/GF composites immersed in aggressive ethanol

5.1.3 Volume Change of PA6/GF Composites

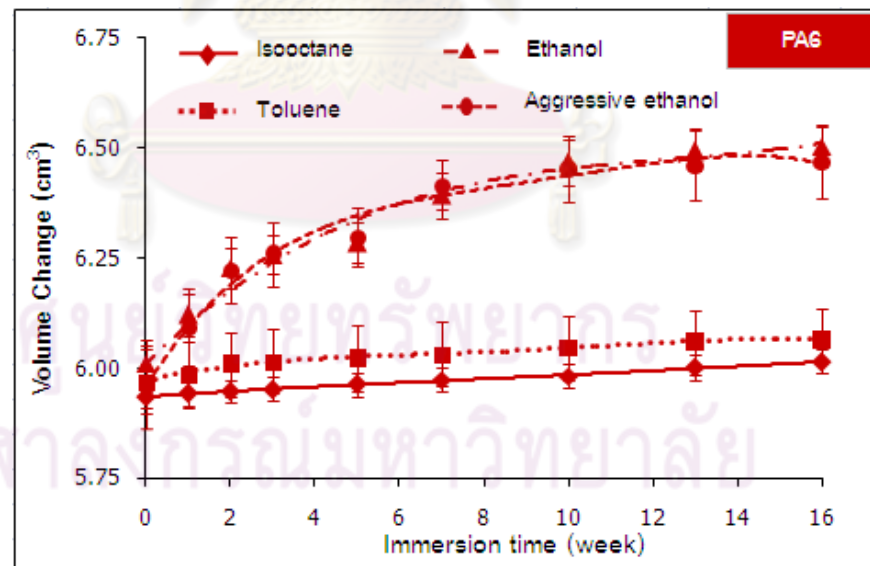


Figure 5.9 Volume of PA6 after immersed in chemicals of surrogate gasohol

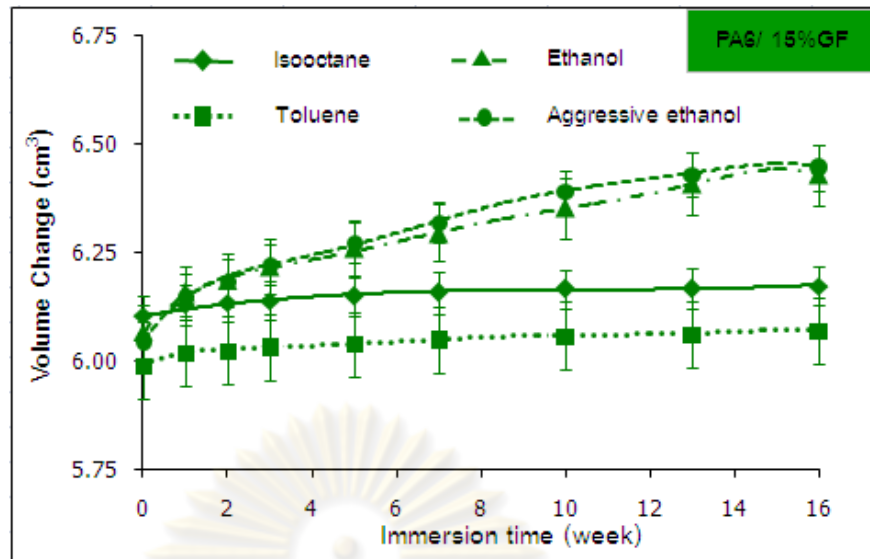


Figure 5.10 Volume of PA6/GF (15 wt%) after immersed in chemicals of surrogate gasohol

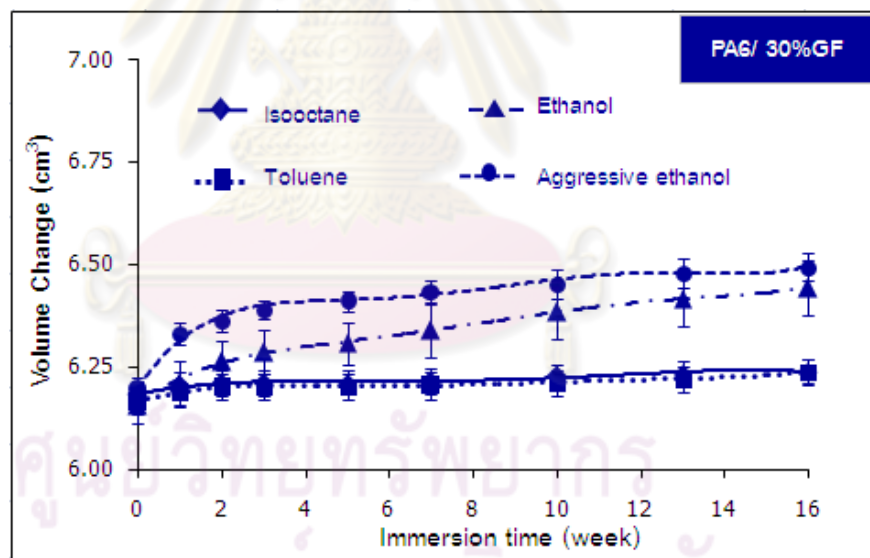


Figure 5.11 Volume of PA6/GF (30 wt%) after immersed in chemicals of surrogate gasohol

To study the effect of solvent absorption on dimensional stability of the specimens, thus the volume of specimens recorded, after immersed in each component of surrogate gasohol (by measuring the diameter and thickness of specimens). Figure 5.9-5.11 showed that the volume of PA6 and PA6/GF composites gradually increased

with increasing immersion time, especially during the first 2-5 weeks. These results were in agreement with mass change of specimens. The solvent absorbed into the PA6 matrix causes the swelling of the specimens. It was noted that the volume of neat PA6 specimens changed more than PA6/GF specimens because glass fibers in PA6/GF composites restricted the movement of PA6 chains [11].

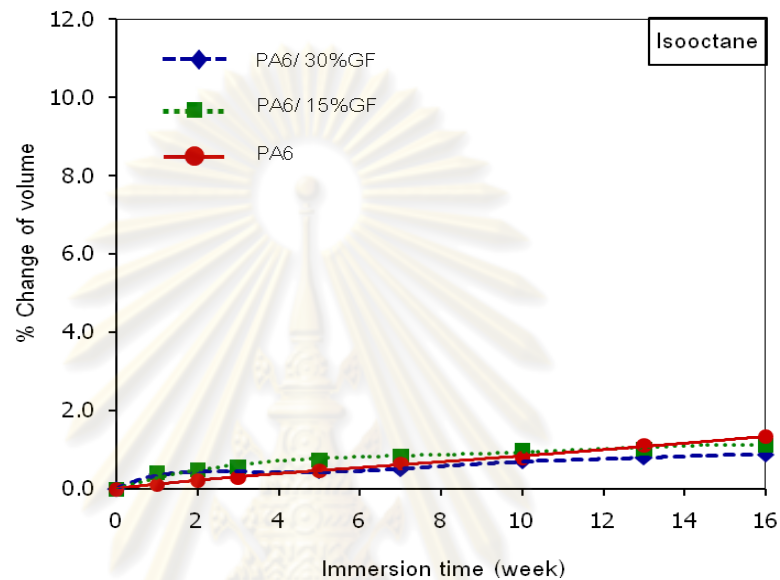


Figure 5.12 Percent volume change of PA6 and PA6/GF composites immersed in isooctane

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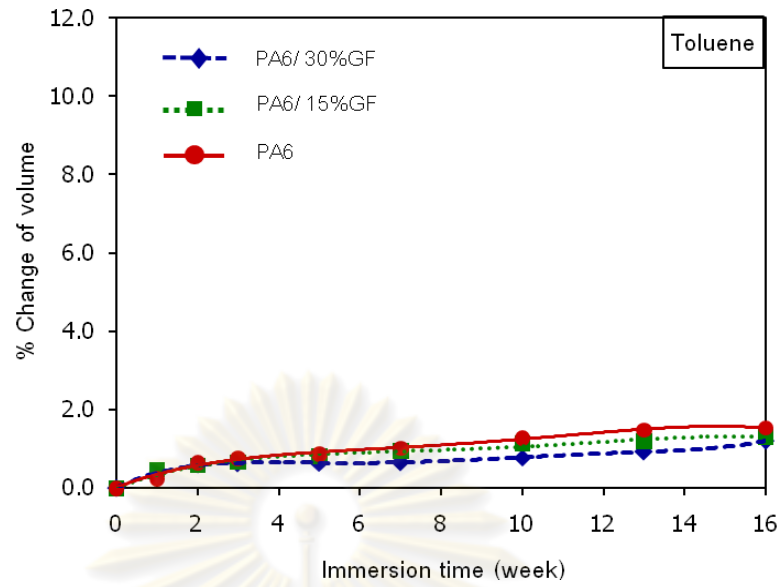


Figure 5.13 Percent volume change of PA6 and PA6/GF composites immersed in toluene

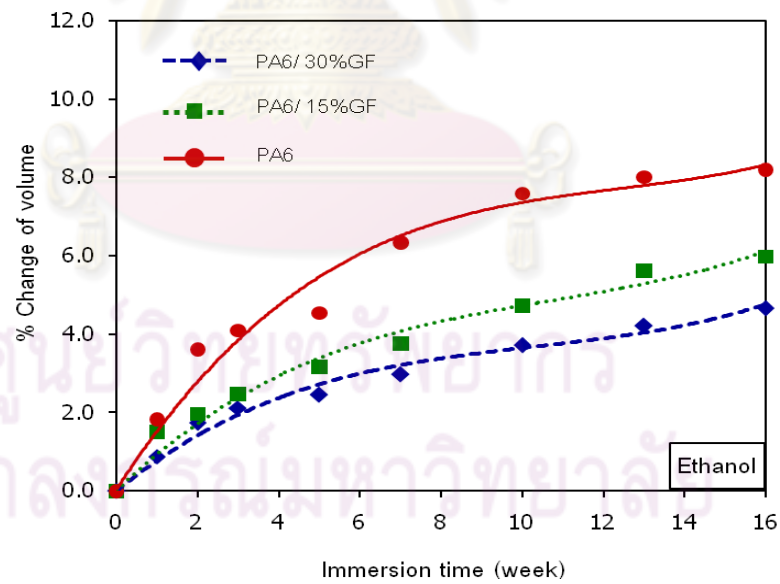


Figure 5.14 Percent volume change of PA6 and PA6/GF composites immersed in ethanol

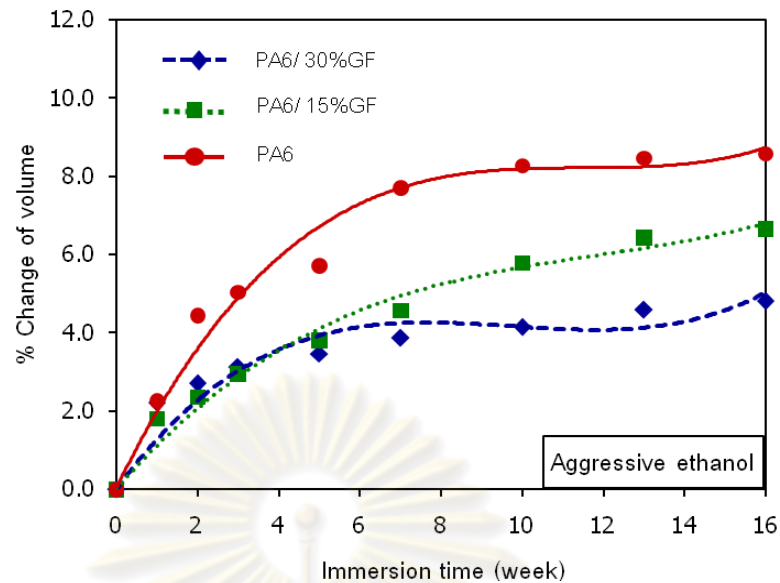


Figure 5.15 Percent volume change of PA6 and PA6/GF composites immersed in aggressive ethanol

Figure 5.12-5.15 showed the percent volume change of PA6 and PA6/GF composites increased with increasing immersion time in the chemicals of surrogate gasohol, especially the first 2-5 weeks, because the solvent was absorbed into the PA6 matrix. It was very clear from the results that ethanol and aggressive ethanol were absorbed into PA6 and PA6/GF composites more than isooctane and toluene. These were also illustrated in Figures 5.12-5.15 when percent change of volume plotted against immersion time. Figures 5.12 and 5.13 showed that isooctane and toluene were produced volume change of PA6 and PA6/GF composites at almost 1-2% only. But Figs 5.14 and 5.15 showed that ethanol and aggressive ethanol were produced volume change of PA6 and PA6/GF composite at almost 5-9%. This was because ethanol and PA6 have solubility parameters close to each other. Also ethanol is a polar molecule and PA6 can absorb polar molecules better than non-polar molecules such as isooctane and toluene. Aggressive ethanol seems to be absorbed more into PA6 and PA6/GF composites than ethanol because aggressive ethanol has water as its component. Figures 5.14-5.15 also showed that the volume change of PA6/GF composites after immersed in ethanol and aggressive ethanol decreased with increasing fiber content. This was because there were less PA6 matrix in PA6/GF composites than neat PA6

specimens and glass fiber must increase the tortuous path for molecules to diffuse into PA6 matrix.

5.2 Influences of Chemicals in Surrogate Gasohol on Thermal Properties of PA6/GF Composites

In this study, the dynamic mechanical analysis (DMA) and HDT/vicat were used to determine the glass transition temperature and the heat distortion temperature of the specimens, respectively. The thermal properties of the specimens were measured on 0th, 2nd, 5th, 10th and 16th week. Two samples of each specimen were used to determine the average value of glass transition temperature and three samples of each specimen were used to determine the average value of heat distortion temperature.

5.2.1 Influences of Glass Fiber Content on Thermal Properties

Table 5.1 Heat distortion temperature and glass transition temperature of unsoaked PA6 and PA6 compounds reinforced with 15% and 30% glass fiber

Material	Heat distortion temperature (°C)	Glass transition temperature (°C)
Neat PA6	83.83 ± 2.47	73.65 ± 1.48
PA6 compound with 15% GF	176.50 ± 0.2	73.70 ± 1.13
PA6 compound with 30% GF	182.67 ± 0.76	74.90 ± 1.70

Table 5.1 summarized the influences of glass fiber content on the thermal properties of PA6/GF composites. The result was showed that heat distortion temperature (HDT) of unsoaked PA6/GF composites improved with increase of glass fiber content. The HDT of PA6/GF composites increased from 83.83 °C (neat PA6) to 176.50 °C and 182.67 °C when incorporating 15 wt% and 30 wt% glass fiber into the composites, respectively. Therefore, HDT of PA6/GF composites increased by 111% and 118% when incorporating 15 wt% and 30 wt% glass fiber into the composites,

respectively. This was due to the fact that PA6 is a microcrystalline material containing polar group which provides strong inter-chain bonding. And the glass fiber in PA6/GF composites plays a key role as a physical hindrance to the crystallization of PA6 molecular chains and thus limit the thermal movement of polymer chain and prevent the elastic and plastic deformation which can improve the HDT of PA6 [35,60,61].

The results also suggested that 15 wt% glass fiber was more than enough to hinder the movement of PA6. In contrast to HDT result as mentioned above, it was clear that addition of glass fiber did not affect the glass transition temperature (T_g) of PA6/GF composites. The T_g of neat PA6 was 73.65 °C whereas T_g of PA6 compound with 15% and 30% glass fiber were 73.70 °C and 74.90 °C respectively. These results clearly showed that the chain movement at T_g was from PA6 chain molecules only. This result was in agreement with the study of the improvement of flexural and compressive strength of PA6 nanocomposite at elevated temperature done by Vlasveld et al [56] which showed the T_g of materials were the same for unfilled PA6 and the nanocomposites.

The effects of glass fiber on HDT of PA6/GF composites were shown in Figure 5.16. Figure 5.16, showed that HDT of the specimens decreased rapidly during the first 2-3 weeks and level off after that. When the percent change of HDT were plotted in Figure 5.17-5.20, it again could be seen that 15 wt% glass fiber was more than enough to hinder the movement of PA6 molecules.

Additionally, the T_g of material rapidly decreased from around 74 °C around to -6 °C after immersion in ethanol and aggressive ethanol for 2-3 weeks and T_g gradually decreased to around 50 °C for specimen immersed in isooctane and toluene, as illustrated in Figure 5.21. These again showed that glass fiber content had no effect on T_g . The decrease in thermal properties occurs because solvent in PA6 matrix reduces chemical bond between PA6 and glass fiber and increases free space in the structure so that easier chain movement can occur [62].

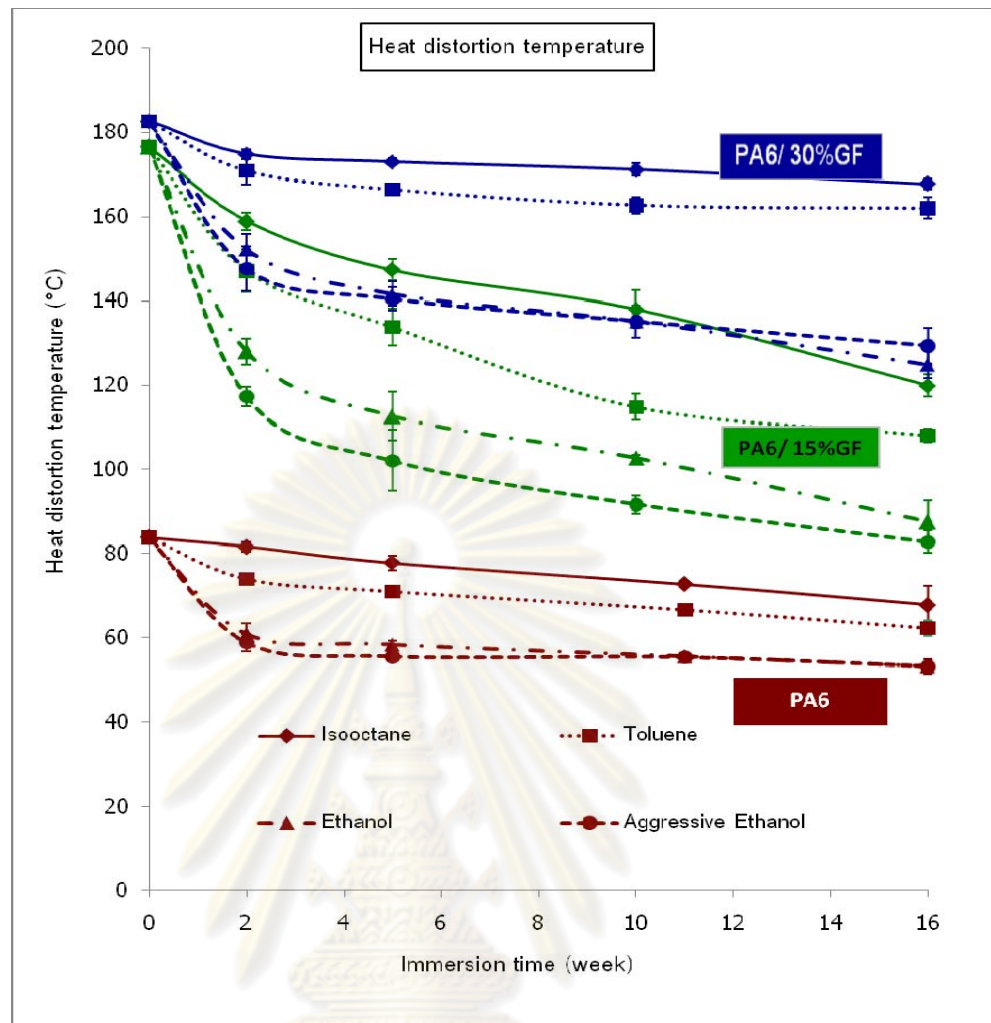


Figure 5.16 Heat distortion temperatures of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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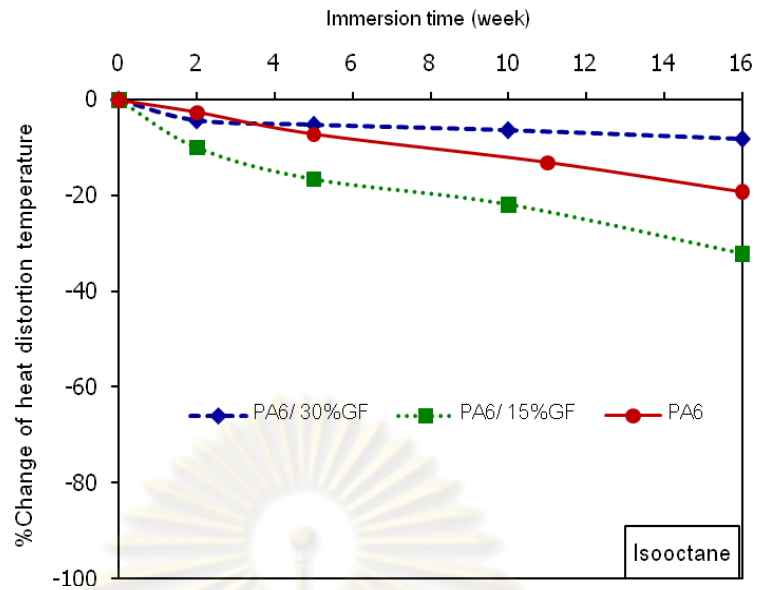


Figure 5.17 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in isooctane

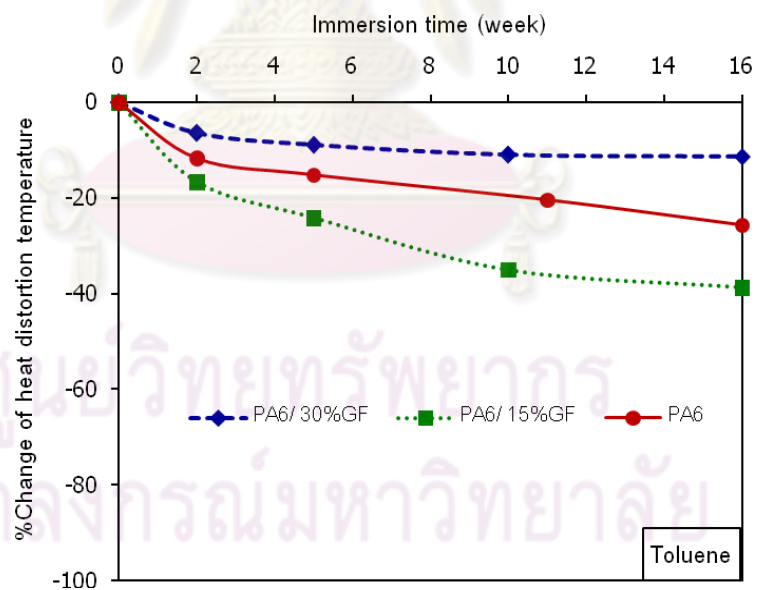


Figure 5.18 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in toluene

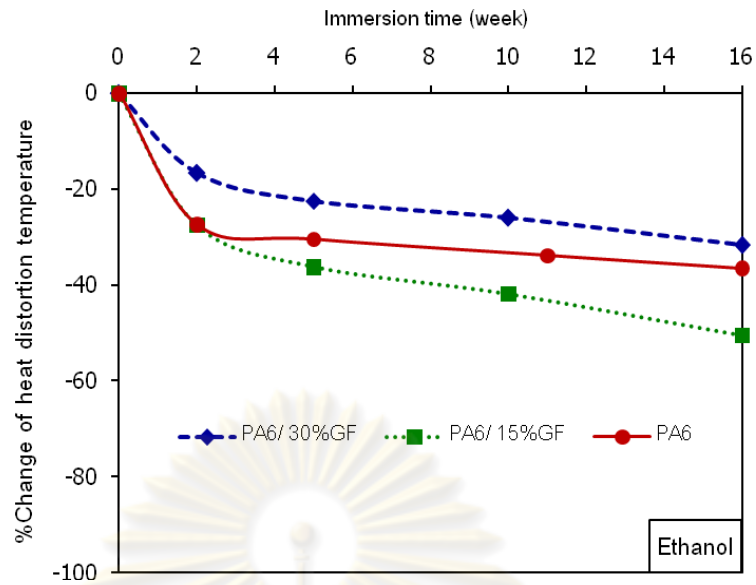


Figure 5.19 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in ethanol

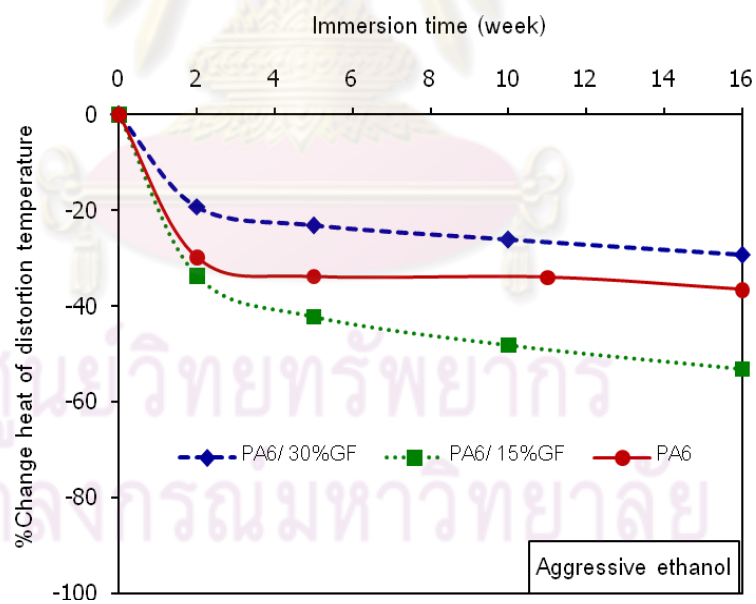


Figure 5.20 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in aggressive ethanol

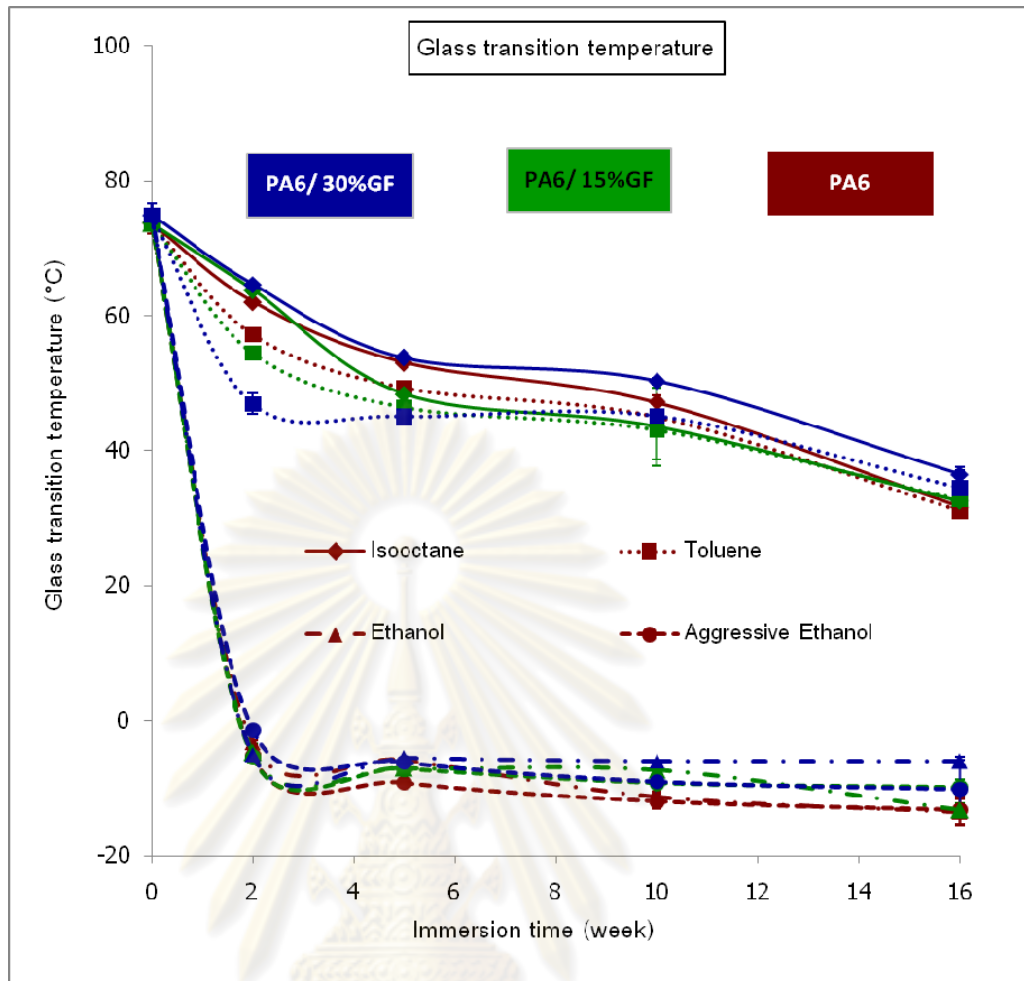


Figure 5.21 Glass transition temperatures of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

5.2.2 Influence of Chemicals of Surrogate Gasohol on Thermal Properties

Figures 5.16-5.20 showed that the HDT rapidly changed after 2-3 weeks for specimens immersed in ethanol and aggressive ethanol. The HDT of PA6 was 83.83 °C and decreased to 60.83 °C and 58.80 °C when the specimens were immersed in ethanol and aggressive ethanol for 2-3 weeks, respectively. Therefore, HDT of PA6 decreased to -27.38% and -29.81% respectively. However, HDT of the specimens was gradually decreased for specimen immersed in toluene and isooctane. These results were expected as ethanol and aggressive ethanol were absorbed into PA6/GF composites more than isooctane and toluene. The change in glass transition temperature of the specimens after immersion also showed similar trend as shown in Figure 5.21. The T_g

rapidly changed after 2-3 weeks for specimens immersed in ethanol and aggressive ethanol. The T_g of composite was about $74\text{ }^{\circ}\text{C}$ and decreased to around $-5\text{ }^{\circ}\text{C}$ and $-6\text{ }^{\circ}\text{C}$, respectively. While T_g of specimens immersed in toluene and isooctane slowly decreased due to the fact that the hydrophobic paraffinic chains of PA6 could not absorb non polar chemicals such as toluene and isooctane but not as well as those polar chemicals [9].

5.3 Influences of Chemicals in Surrogate Gasohol on Mechanical Properties of PA6/GF Composites

In this study, the mechanical tests included tensile, flexural, compressive, and izod impact test. Tensile test recorded two important properties: tensile strength and tensile modulus. Flexural test gave flexural strength and flexural modulus. On the other hand, compressive and impact tests gave only compressive strength and breaking energy, respectively.

The mechanical properties of the specimens were measured on 0th, 1st, 2nd, 3th, 5th, 7th, 10th, 13th and 16th. Five specimens of PA6 and PA6/GF compounds were tested to determine the average value.

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5.3.1 Influences of Glass Fiber Content on the Mechanical Properties

Table 5.2 Mechanical properties of unsoaked PA6 and PA6 compounds reinforced with 15% and 30% glass fiber

Material	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Compressive Strength (MPa)	Izod Impact Strength (kJ/m ²)
Neat PA6	66.26±0.61	2204±22	100.23±0.87	2578±26	43.83±1.92	8.40±1.26
PA6 compound with 15 wt% GF	123.46±1.65	3937±28	150.14±2.14	4258±127	70.08±5.45	10.97±0.45
PA6 compound with 30 wt% GF	167.11±2.16	5626±76	213.84±2.89	6905±69	125.89±8.01	19.08±0.51

Table 5.2 was compared to the influence of glass fiber in polymer matrix on the mechanical properties of unsoaked PA6/GF composites. The result showed that the mechanical properties of PA6 can be improved with increasing of glass fiber content. The tensile strength, tensile modulus, flexural strength, flexural modulus, compressive strength and impact strength, and also the percentage change of these properties of PA6/GF compounds at different glass fiber content were shown in Figures 5.22-5.53. For instance, tensile strength of PA6 was 66.26 MPa and increased to 123.46 MPa and 167.11 MPa at 15 wt% and 30 wt% reinforced glass fiber content, respectively. The increase of tensile strengths of PA6/15%GF and PA6/30%GF composites were 86% and 152% in comparison to the unreinforced PA6, respectively. Moreover, tensile modulus of PA6 increased from 2204 MPa to 3937 MPa and 5626 MPa, which were 79% and 155%, when 15 wt% and 30 wt% glass fiber were used to reinforce, respectively. The enhancement of tensile properties agreed with the results investigated by Gullu, et al

[11] which reported that 15 wt% and 30 wt% fiber reinforcement for PA6 can improve the tensile strength by 74% and 111%, respectively. Similarly, the flexural strength and flexural modulus of PA6 reinforced with 30 wt% glass fiber increased from 100.23 MPa and 2578 MPa to 213.84 MPa and 6905 MPa, respectively. The enhancement of flexural properties was generally in agreement with the study of mechanical, thermal and morphological properties of glass fiber and carbon fiber reinforced PA6 and PA6/clay nanocomposites done by Wu, et al [37] which revealed that 30 wt% glass fiber reinforcement for PA6 can improved the flexural strength and flexural modulus by 113% and 367%, respectively. Compressive strength and impact strength of three test materials were shown in Table 5.2. Compressive strength of PA6 showed increased from 43.83 MPa to 70.08 MPa and 125.89 MPa with 15 wt% and 30 wt% glass fibers reinforce , respectively. Also, the Izod impact strength of PA6 increased from 8.40 kJ/m² to 19.08 kJ/m², which were 30% and 127% increment, respectively, with 15 wt% and 30 wt% glass fiber reinforcement. The good increment of mechanical properties obtained when the glass fiber content increased was because glass fiber can be homogeneously dispersed into the PA6 phase and PA6 matrix can adhere to glass fiber reinforcement. The good interfacial bonding resist the matrix peeling off from the fiber and stress transfer over to glass fiber [63].

After all specimens were immersed in each component of surrogate gasohol, the mechanical properties of specimens were measured as a function of immersion time. Figures 5.22-5.31 showed the tensile strength and percentage change of tensile strength, tensile modulus and percentage change of tensile modulus. The results revealed that tensile strength and tensile modulus of the specimens decreased with increasing immersion time. These decrement rapidly occurred during the first 5 weeks and then leveled off. But it could be seen that reduction was lesser for specimens with higher glass fiber content. Similarly, the flexural properties and compressive strength also decreased when the immersion time increased as illustrated in Figures 5.32-5.46 These results were obtained because when solvents were absorbed into PA6, these produced more spacing in the structure and allowed polymer chains bend and twist back upon itself [35], thus reducing these properties. However, the glass fibers in

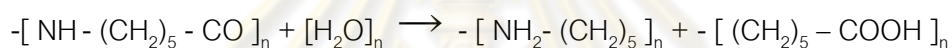
compounds counteract the solvent effect. The higher glass fiber content, the stiffer the composites become; hence, the reduction in these mechanical properties was less. Figures 5.47-5.53 revealed Izod impact strength and percent change of Izod impact strength of the specimens after immersion in each chemical at various time. The results showed that the glass fiber content significantly affected impact strength.

In conclusion, the mechanical properties of PA6 can be enhanced with the addition of glass fiber since glass fiber is highly crystalline material [37] and chemically bonded to PA6 [12,64]. Chooseng [9] investigated morphology of PA6 matrix reinforced with glass fiber via scanning electron microscopy (SEM) and found that PA6 matrix provided excellent dispersion and adhesion to glass fiber reinforcement. Dispersion of the glass fiber into discrete monolayer is further enhanced by the intrinsic incompatibility of hydrophobic layered glass fiber and hydrophilic PA6. The complete dispersion of glass fiber in PA6 optimizes the number of available reinforcing elements for carrying an applied load and deflecting cracks. The coupling between the enormous surface area of the glass fiber and PA6 matrix simplifies stress transfer to reinforcement phase [65]. The lateral support of the fiber from matrix also reduces the tendency for fiber micro bucking or kinking. Hence, glass fiber can improve tensile strength, flexural strength, elongation and toughness of PA6/GF composites [57].

5.3.2 Influences of Chemicals of Surrogate Gasohol on Mechanical Properties

The specimens immersed in each component of surrogate gasohol were tested to analyze the influences of chemicals of surrogate gasohol on the mechanical properties. Figure 5.22, 5.27, 5.32, 5.37, 5.42 and 5.47 showed the mechanical properties of the specimens before and after immersion in each chemical at various times. The results revealed that mechanical properties except Izod impact strength of specimens decreased with increasing immersion time. These were rapidly changed during the first 5 weeks for specimens immersed in ethanol and aggressive ethanol but were gradually decreased for specimens immersed in isooctane and toluene. However, Izod impact strength increased with increasing immersion time as shown in Figure 5.47-5.49.

Ethanol and aggressive ethanol significantly affected the mechanical properties more than isooctane and toluene. This was because ethanol and PA6 have a similar solubility parameter and ethanol behaves like a plasticizer to PA6 by interrupting the polymeric hydrogen bonding. Thus, PA6 has more flexibility and impact resistance [12]. Comparing the effect of ethanol and aggressive ethanol, the aggressive ethanol seems to have a bit more effect due to aggressive ethanol has water as ingredient. Because of the strong polar groups, as amide group (-CO-NH-), in PA6, polymer chains containing nitrogen and/or oxygen can act as potential proton acceptors to form hydrogen complexes. Then water molecules close to polar groups should be able to form hydrogen bonded complexes with nitrogen and oxygen. Generally, water molecules were considered as a softening agent (spacer between chains) [58]. The reaction mechanism was described as below.



From the reaction, the hydrogen in H₂O molecules formed hydrogen bonding to (-NH-) groups in polymeric chain of PA6 leading to amide groups(-NH₂). While, hydroxyl groups (OH) formed bond with -CO- to generate the acid groups (-COOH). Thus the polymer chain of PA6 was cut off with water molecules resulting in shorter chain length. From the increased space between chains, the chain movement and chain rotation occurred easier. These results were consistent with the decrease of glass transition temperature which led to the decrease of mechanical properties. The small amount of water in aggressive ethanol has a large impact to mechanical properties of PA6.

The results obtained in this work were in agreement with previous work of Chooseng [9] which studied the effects of ethanol concentration in surrogate gasohol on physical and mechanical properties of PA6 and PA6/GF composites. The results showed test fuels containing alcohol, i.e. C(E20)_A, C(E85)_A and C(E100)_A, affected the physical and mechanical properties of unreinforced and reinforced PA6 composites more than C(E0)_A [9].

Furthermore, the changes in mechanical properties of the specimens obtained here corresponded with the changes of glass transition temperature. Before immersion

in each chemical, the mechanical properties of specimens were high due to the condition of testing (about 25 °C) is below its T_g , then such bond rotation cannot occur. But after immersion in chemicals of surrogate gasohol the mechanical properties such as tensile strength, tensile modulus, flexural strength, flexural modulus and compressive strength showed decrease while impact strength showed increase due to the condition of testing (about 25 °C) is more above its T_g (i.e. about T_g+30 °C the material is the leathery state [62]). If PA6 and PA6/GF composites are above their T_g then large elastic deformations are possible due to the molecules being able to unwind by rotating about their carbon-to-carbon bonds. Moreover, the fast decrease of the matrix modulus above its T_g causes the lateral support of the fiber to decrease, which can lead to failure at a lower stress. Nevertheless, pure ethanol and pure gasoline often have a smaller effect on materials than gasoline-ethanol blend [8].



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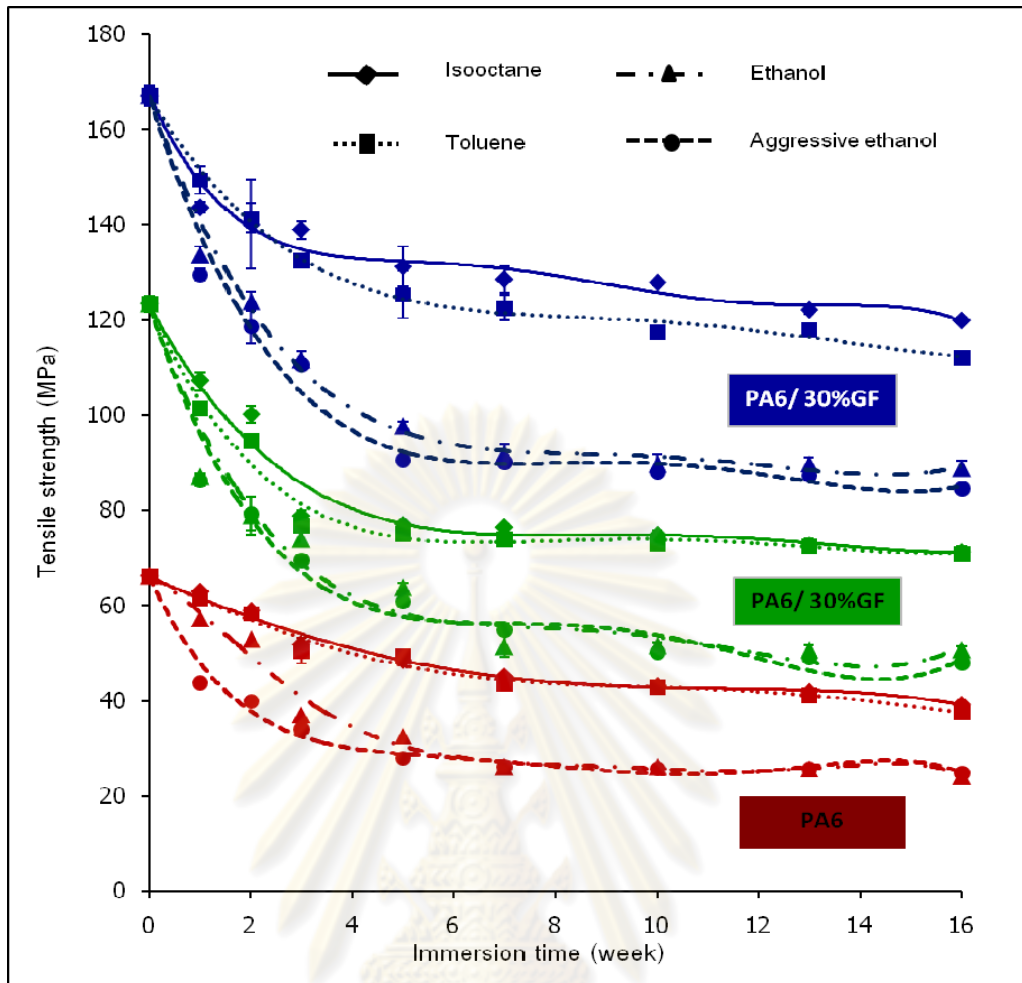


Figure 5.22 Tensile strength of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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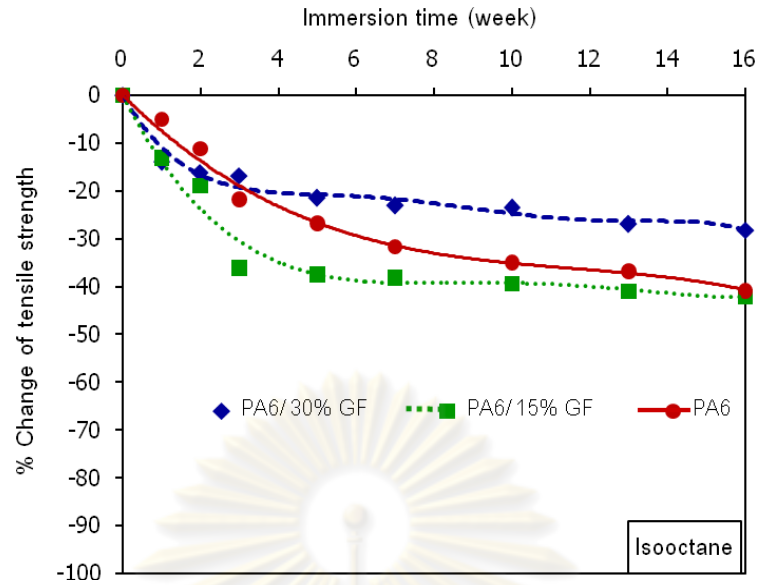


Figure 5.23 Percent change of tensile strength of PA6 and PA6/GF composites immersed in isooctane

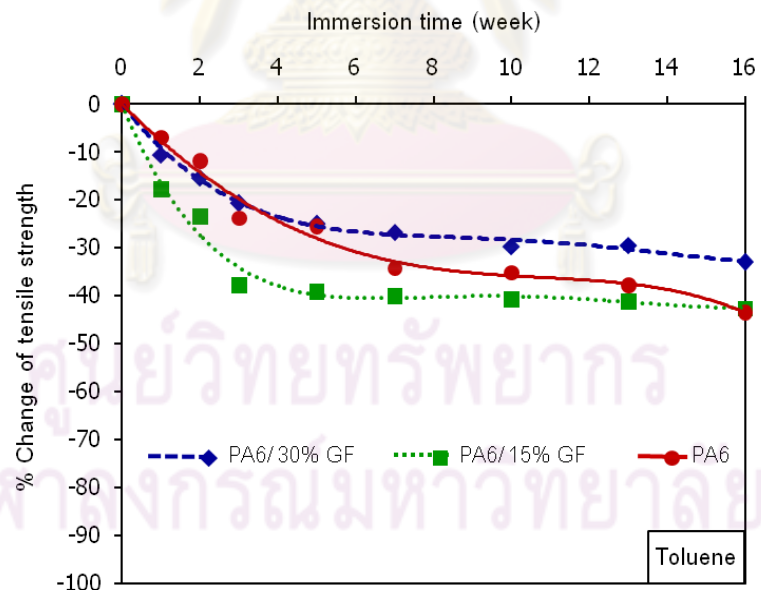


Figure 5.24 Percent change of tensile strength of PA6 and PA6/GF composites immersed in toluene

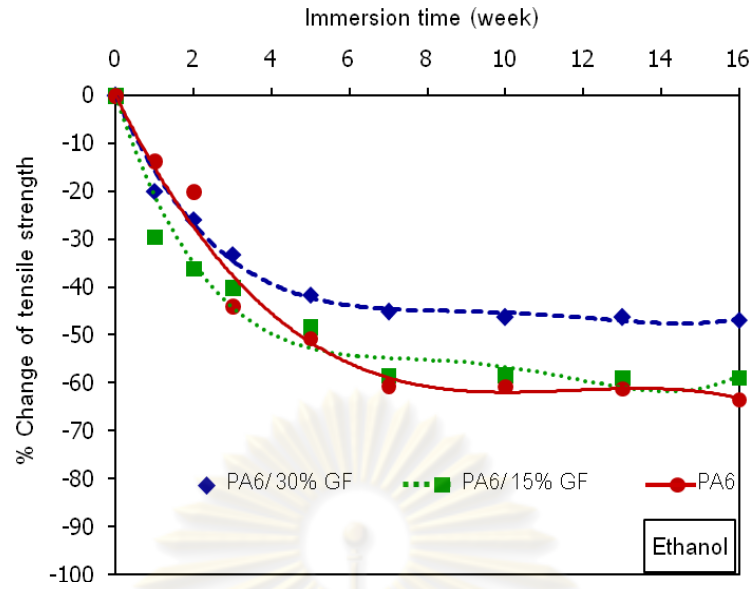


Figure 5.25 Percent change of tensile strength of PA6 and PA6/GF composites immersed in ethanol

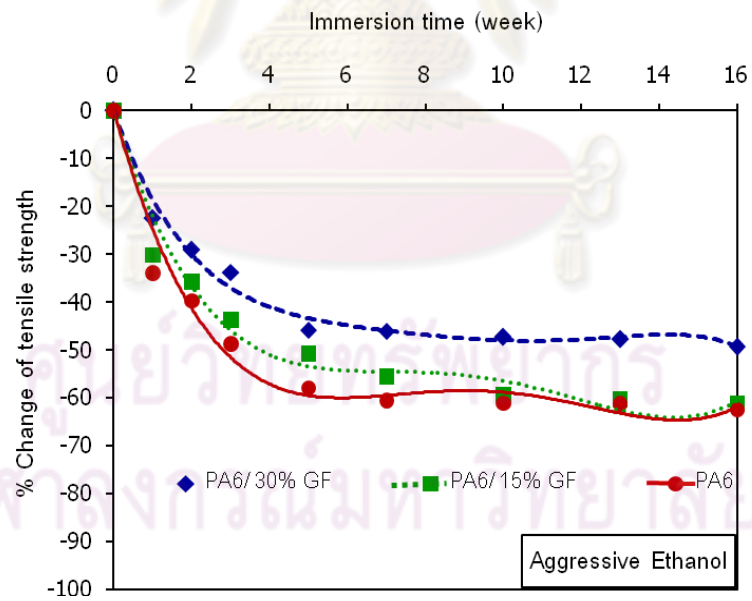


Figure 5.26 Percent change of tensile strength of PA6 and PA6/GF composites immersed in aggressive ethanol

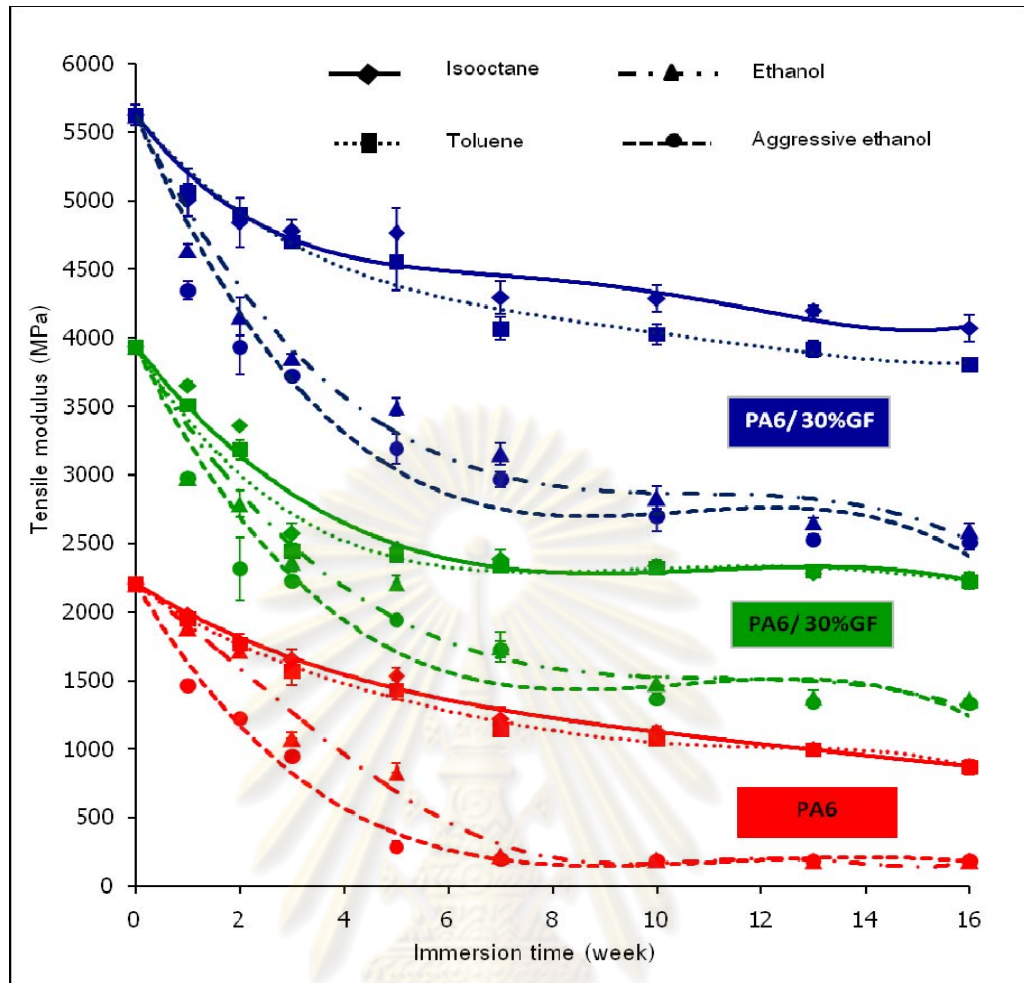


Figure 5.27 Tensile modulus of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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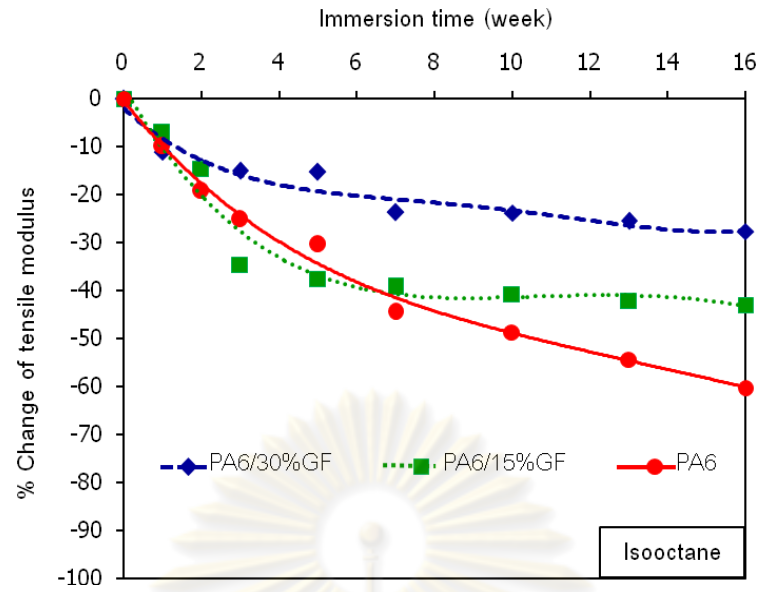


Figure 5.28 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in isooctane

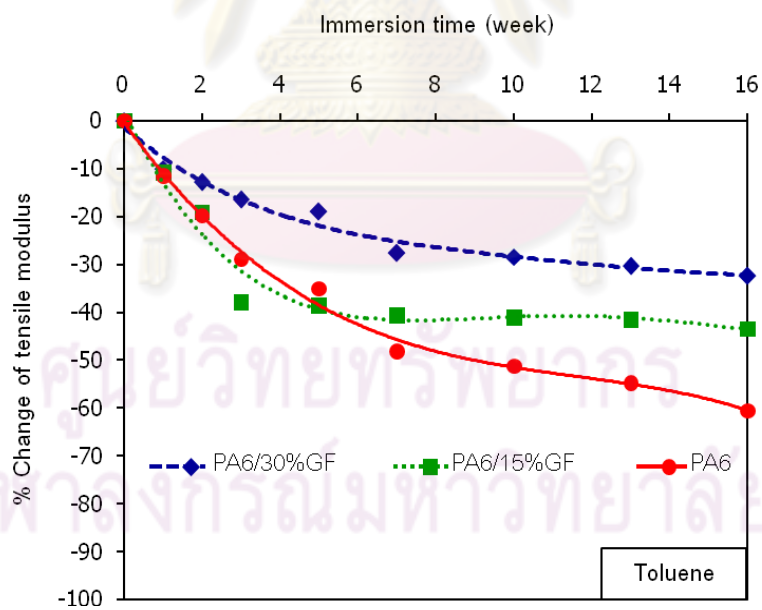


Figure 5.29 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in toluene

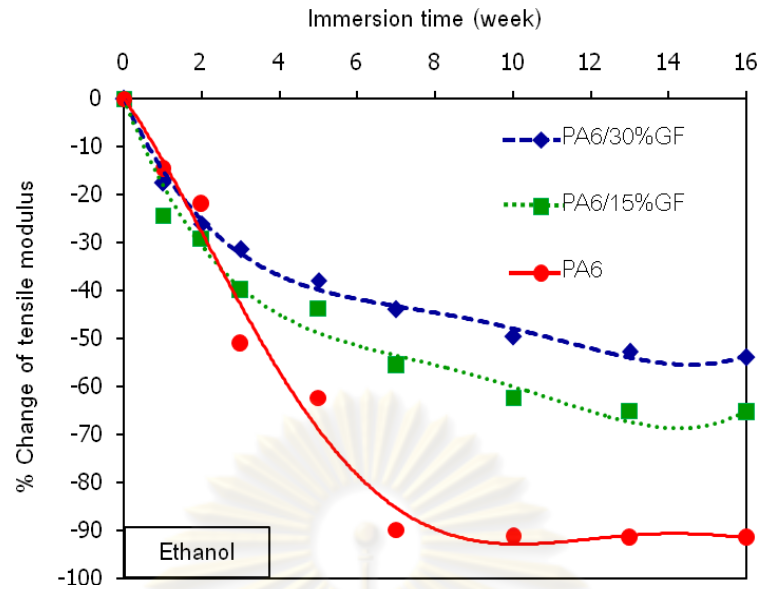


Figure 5.30 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in ethanol

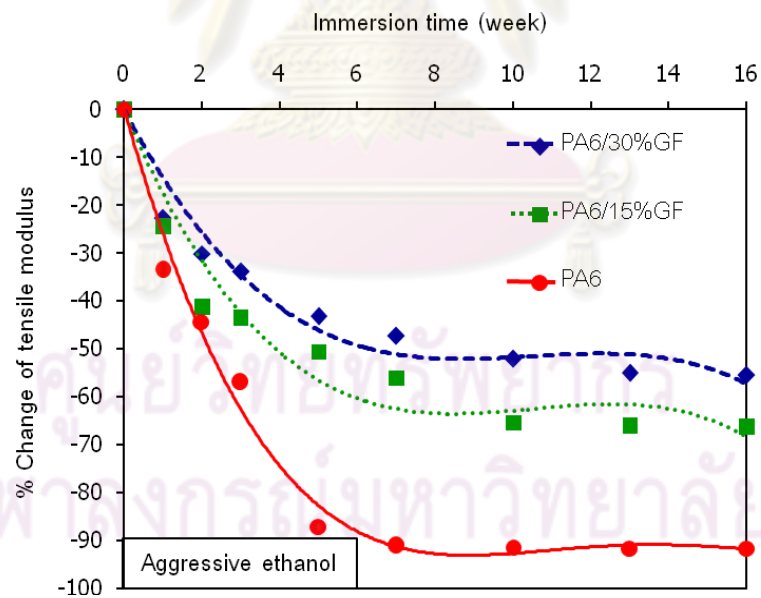


Figure 5.31 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in aggressive ethanol

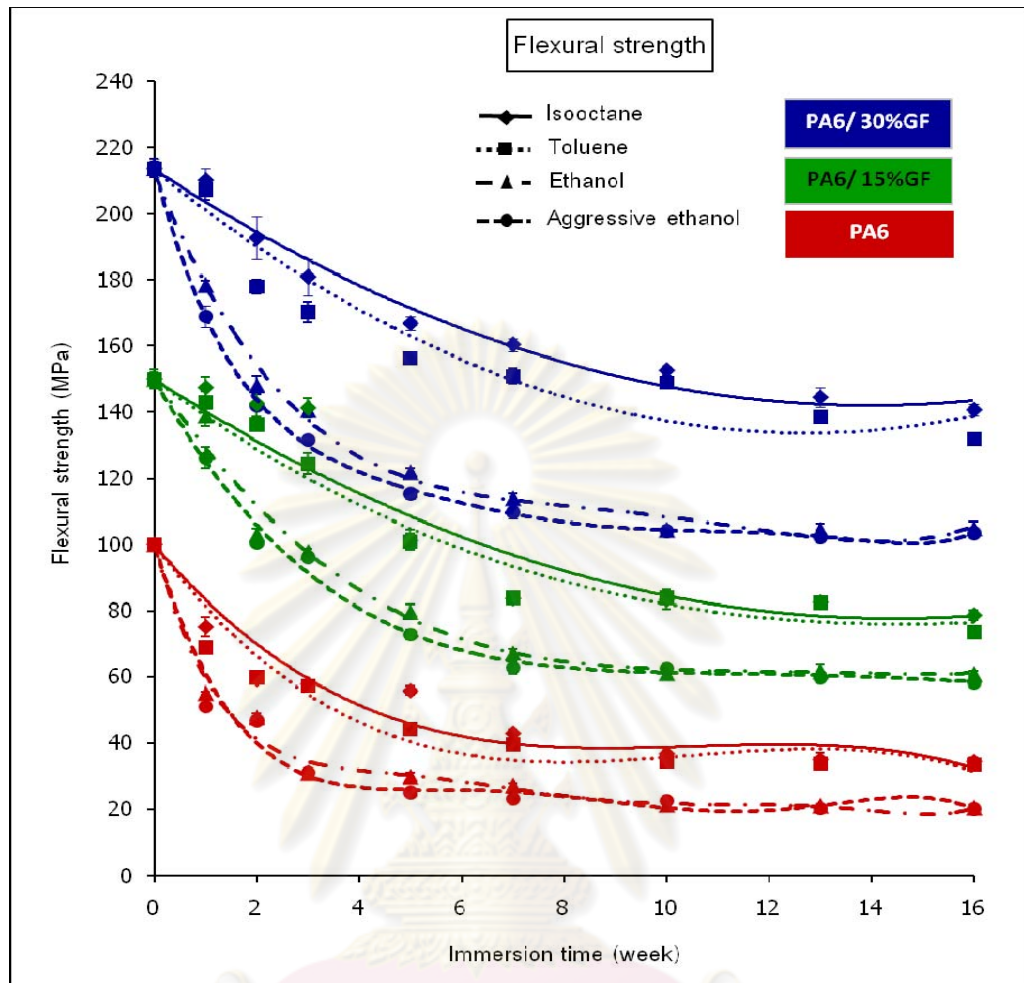


Figure 5.32 Flexural strength of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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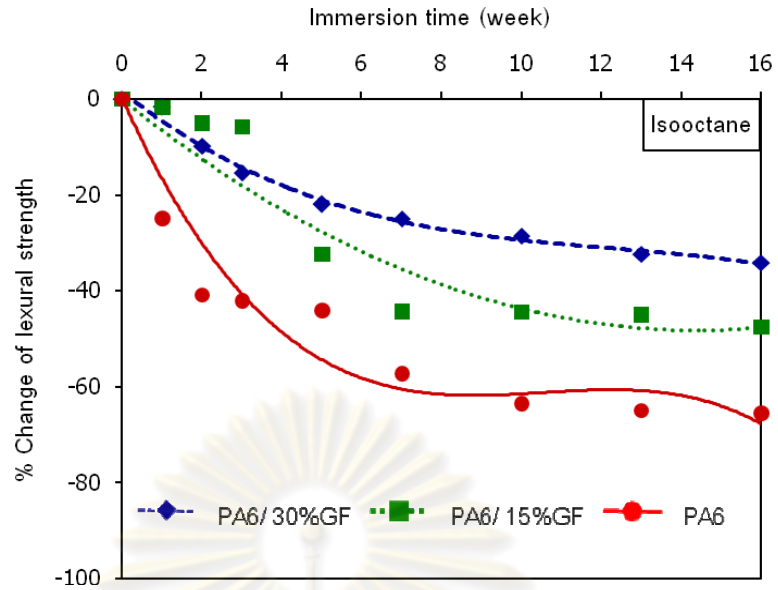


Figure 5.33 Percent change of flexural strength of PA6 and PA6/GF composites immersed in isooctane

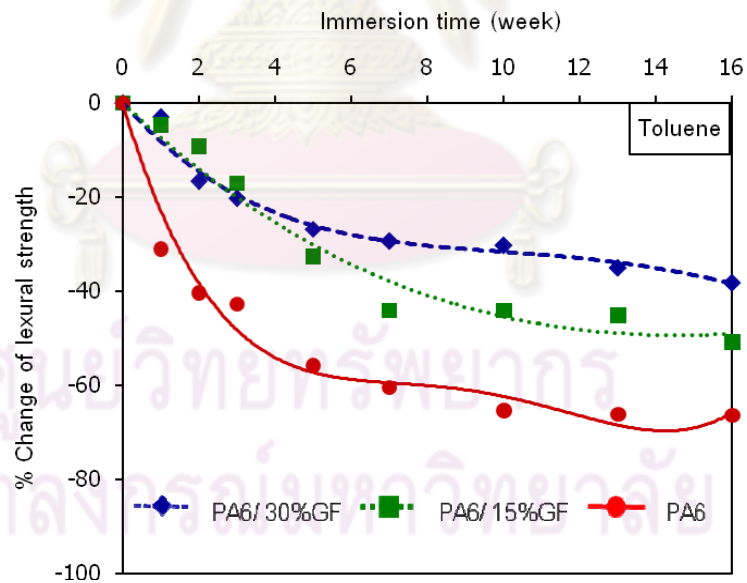


Figure 5.34 Percent change of flexural strength of PA6 and PA6/GF composites immersed in toluene

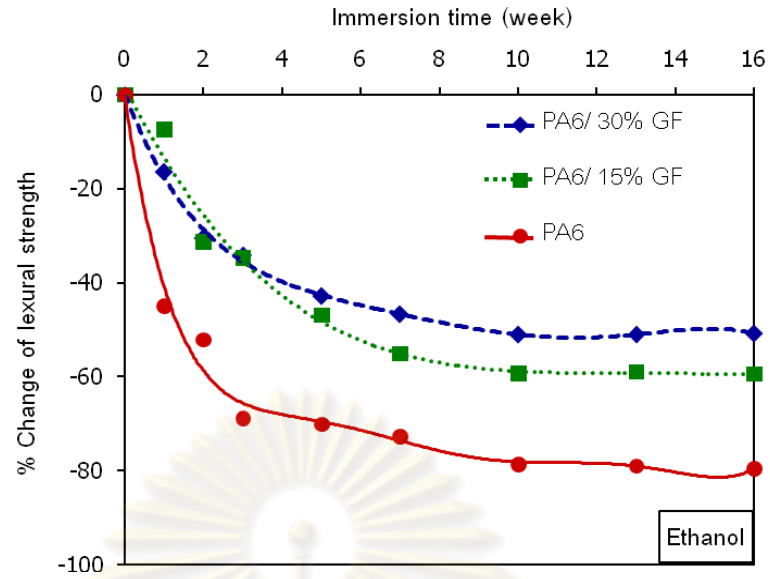


Figure 5.35 Percent change of flexural strength of PA6 and PA6/GF composites immersed in ethanol

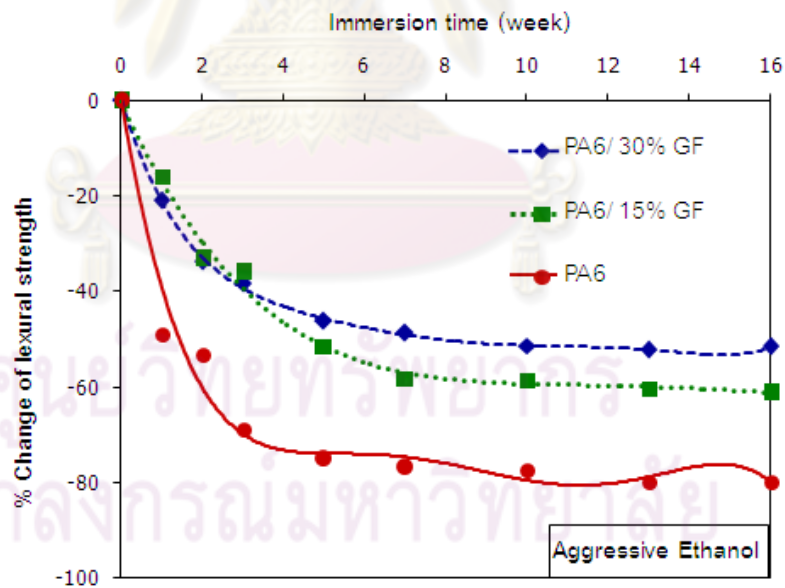


Figure 5.36 Percent change of flexural strength of PA6 and PA6/GF composites immersed in aggressive ethanol

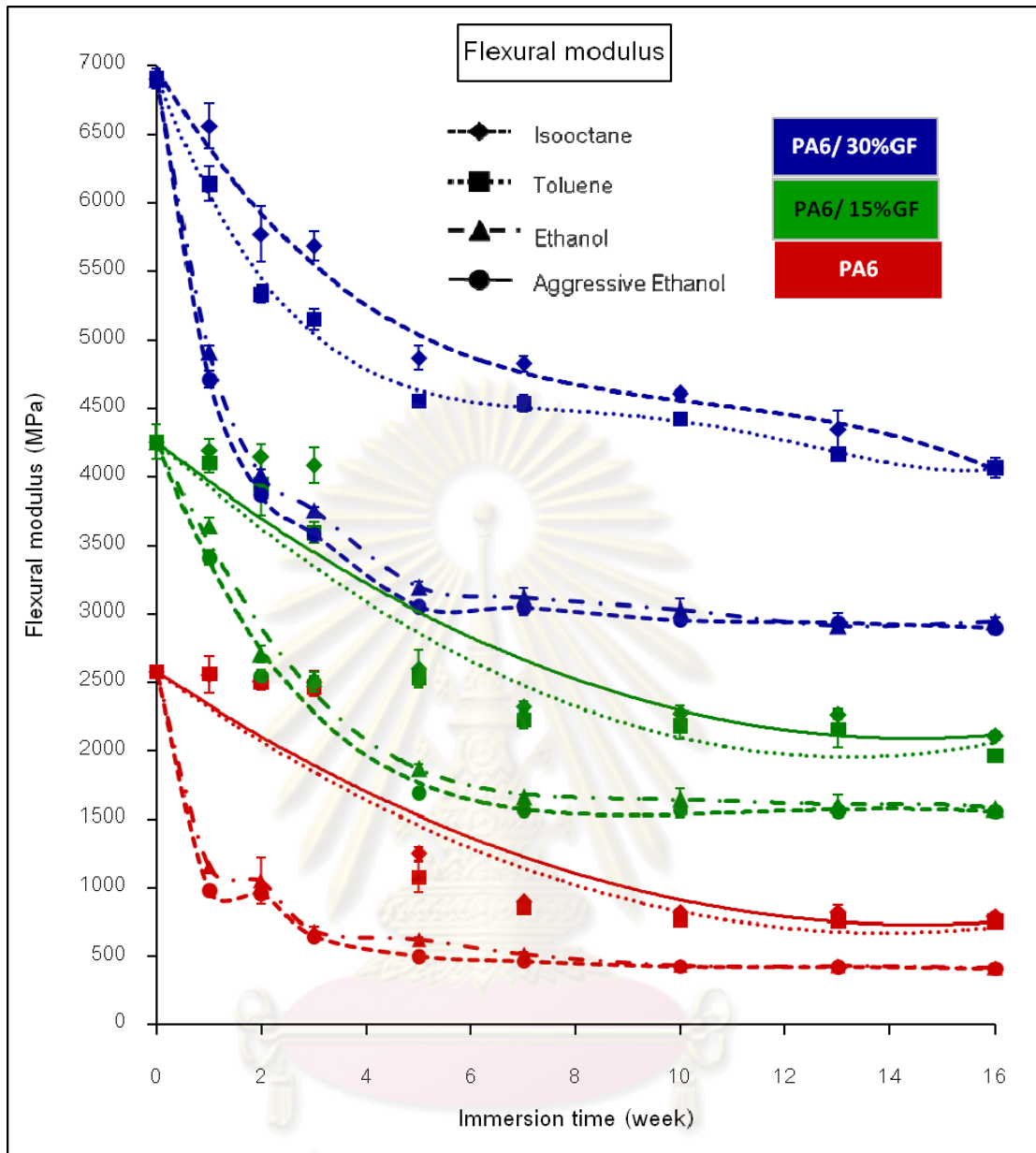


Figure 5.37 Flexural modulus of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

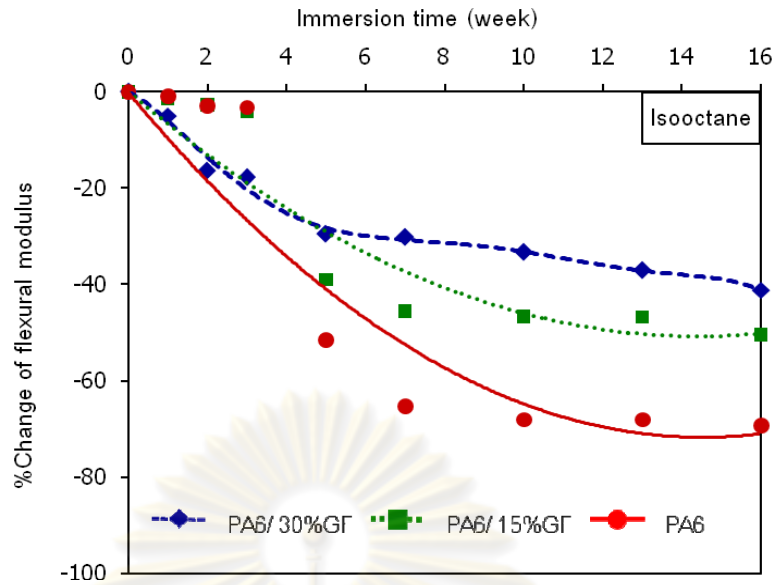


Figure 5.38 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in isooctane

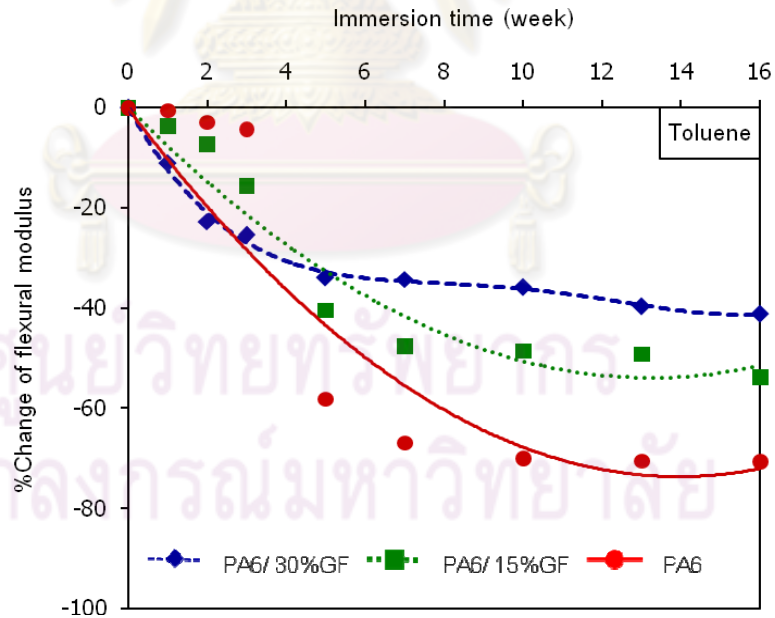


Figure 5.39 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in toluene

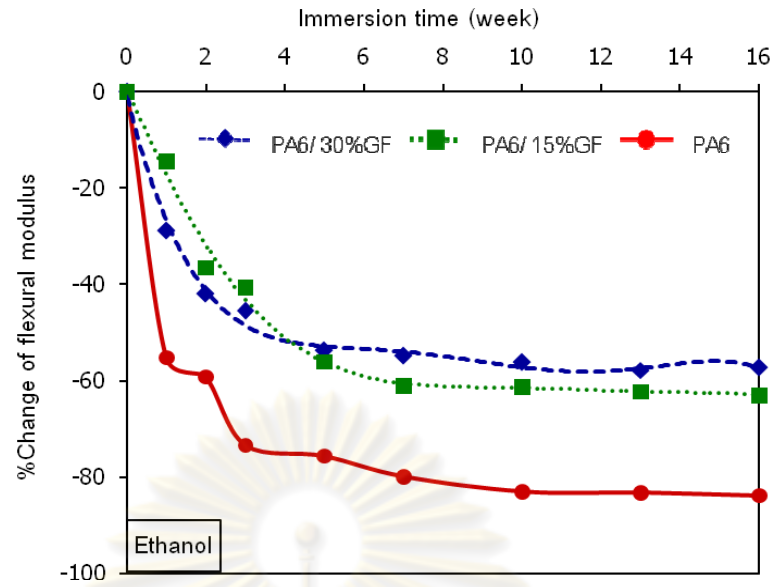


Figure 5.40 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in ethanol

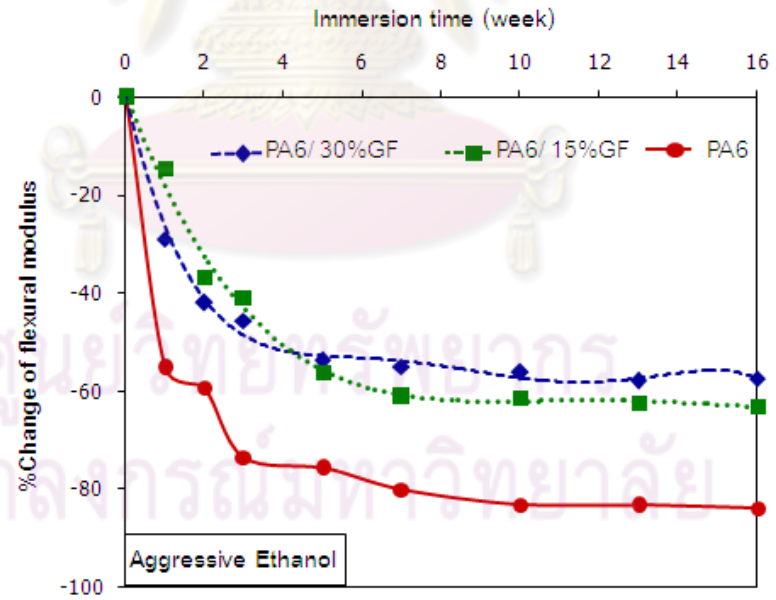


Figure 5.41 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in aggressive ethanol

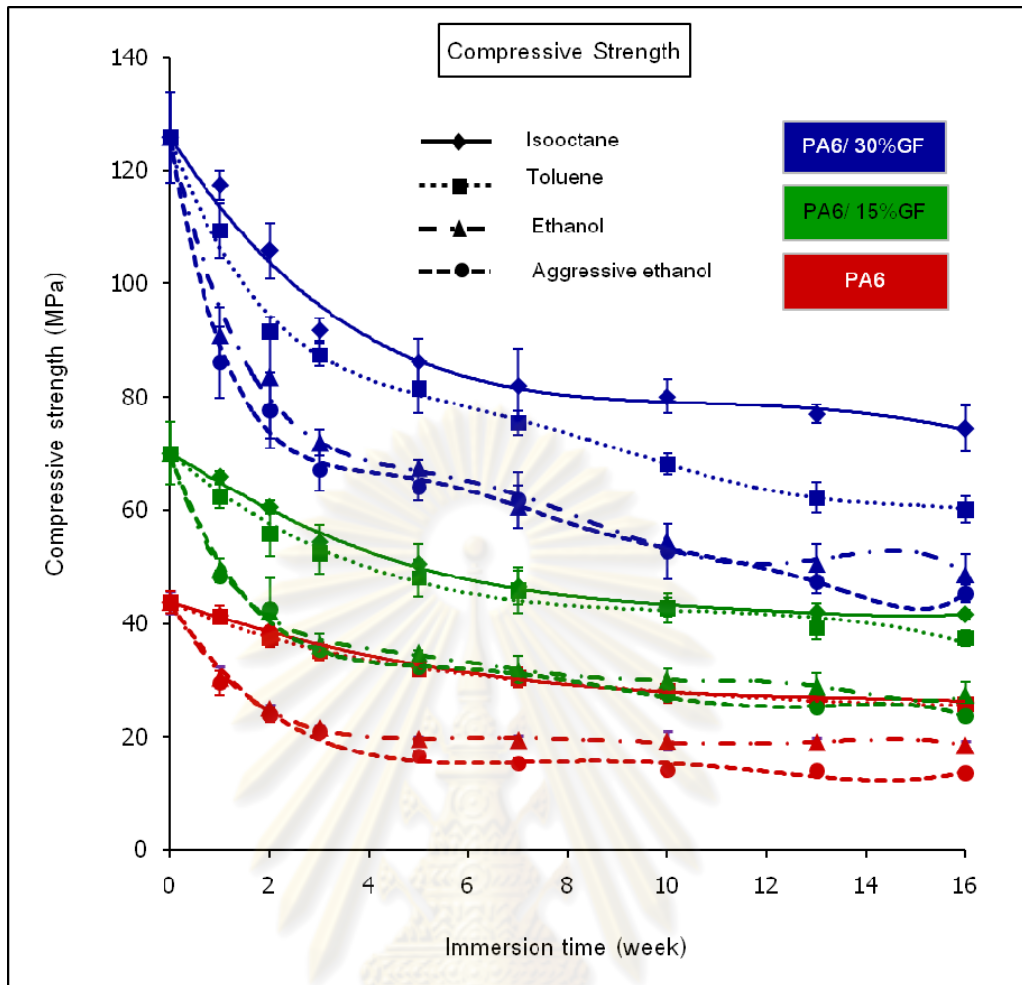


Figure 5.42 Compressive strength of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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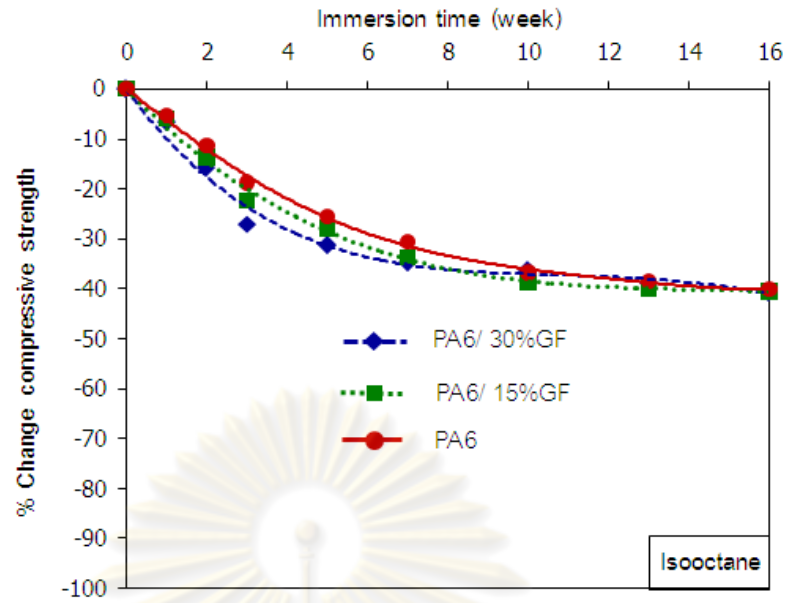


Figure 5.43 Percent change of compressive strength of PA6 and PA6/GF composites immersed in isooctane

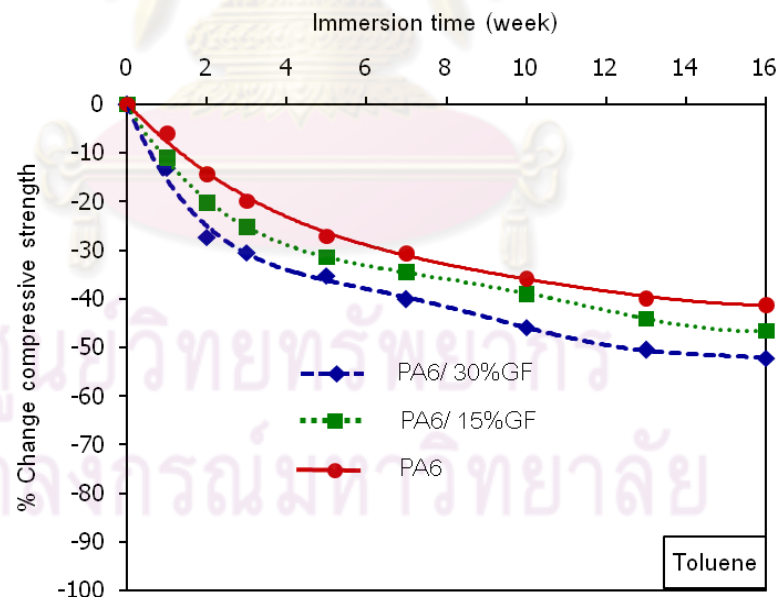


Figure 5.44 Percent change of compressive strength of PA6 and PA6/GF composites immersed in toluene

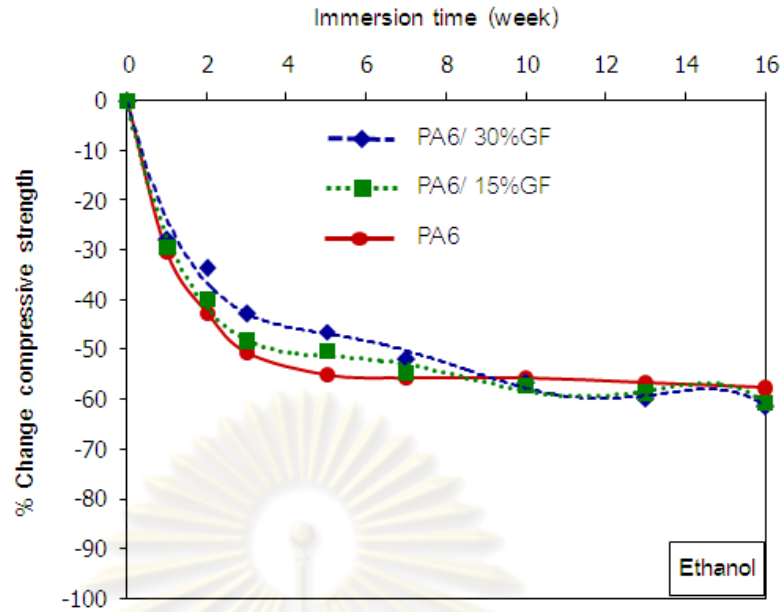


Figure 5.45 Percent change of compressive strength of PA6 and PA6/GF composites immersed in ethanol

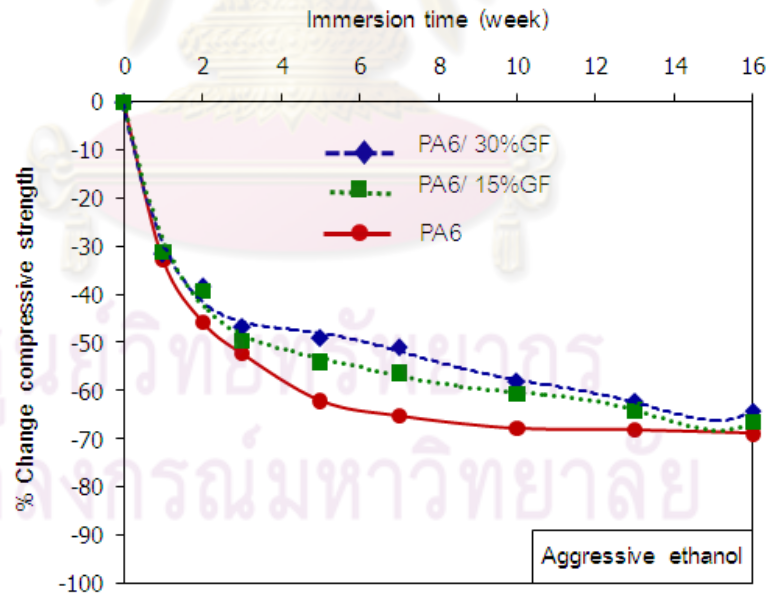


Figure 5.46 Percent change of compressive strength of PA6 and PA6/GF composites immersed in aggressive ethanol

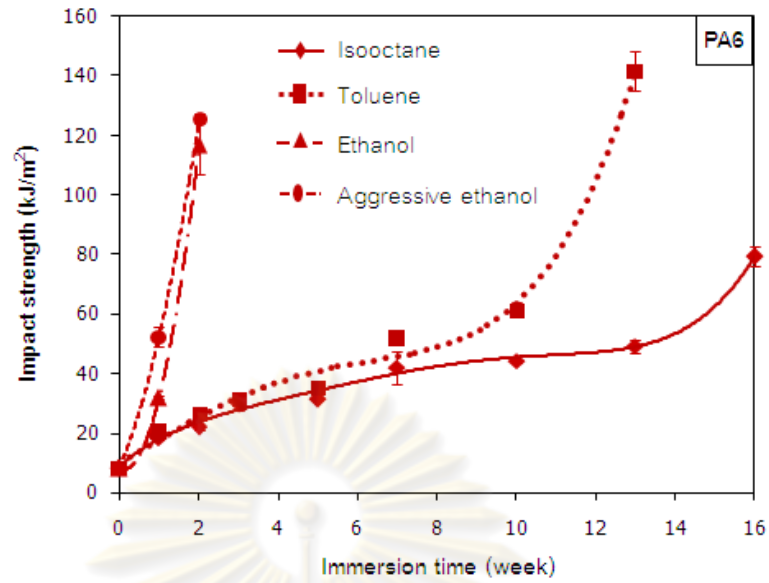


Figure 5.47 Izod impact strength of PA6 after immersed in chemicals of surrogate gasohol

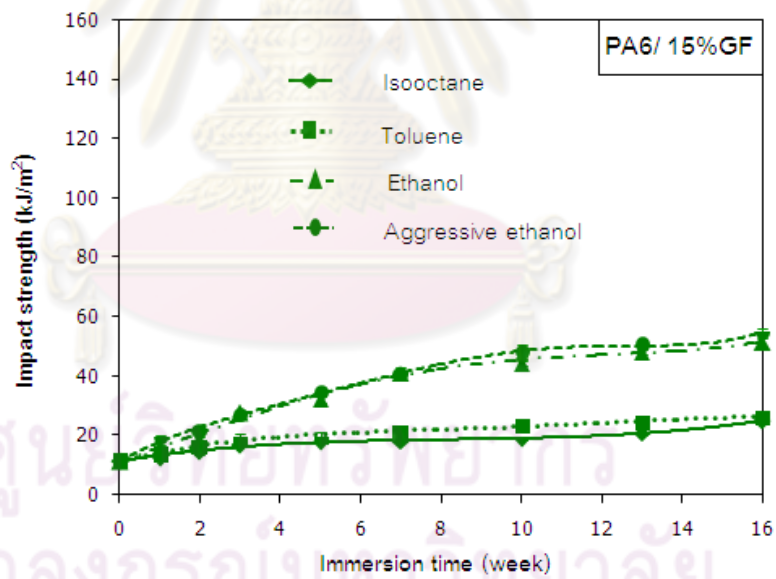


Figure 5.48 Izod impact strength of PA6/ 15%GF after immersed in chemicals of surrogate gasohol

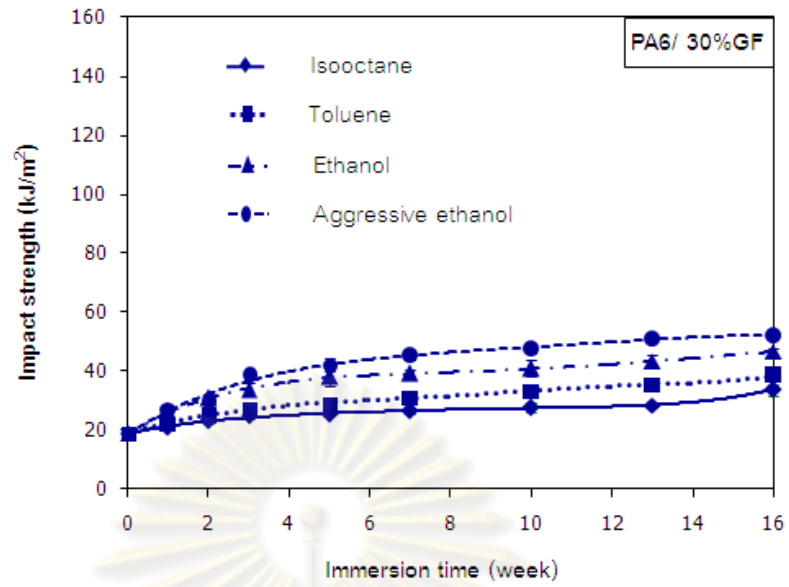


Figure 5.49 Izod impact strength of PA6/ 30%GF after immersed in chemicals of surrogate gasohol

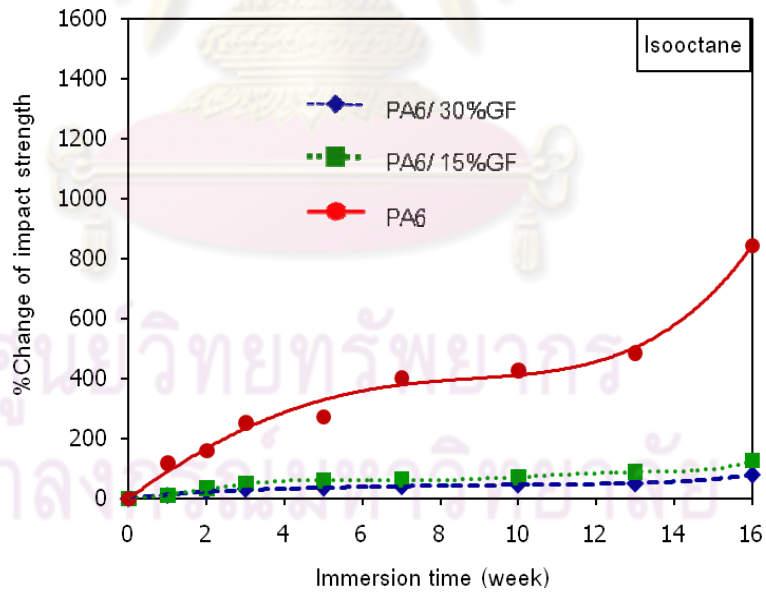


Figure 5.50 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in isooctane

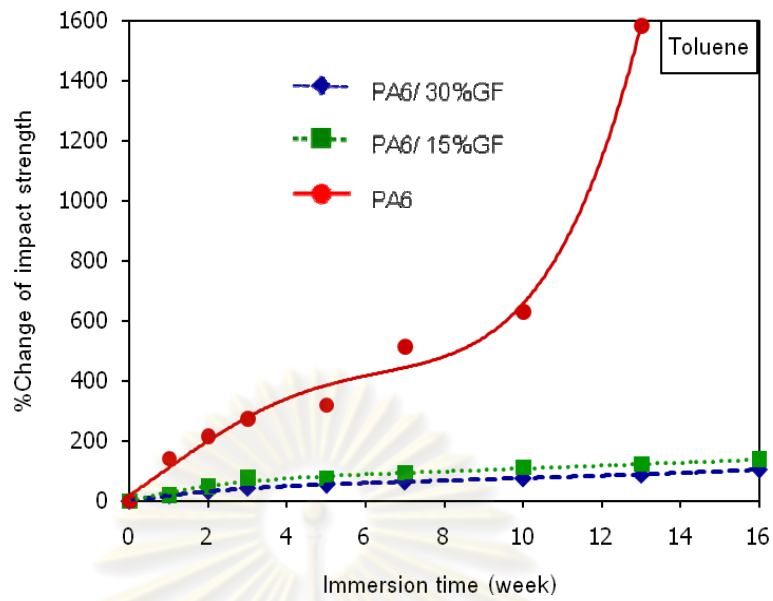


Figure 5.51 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in toluene

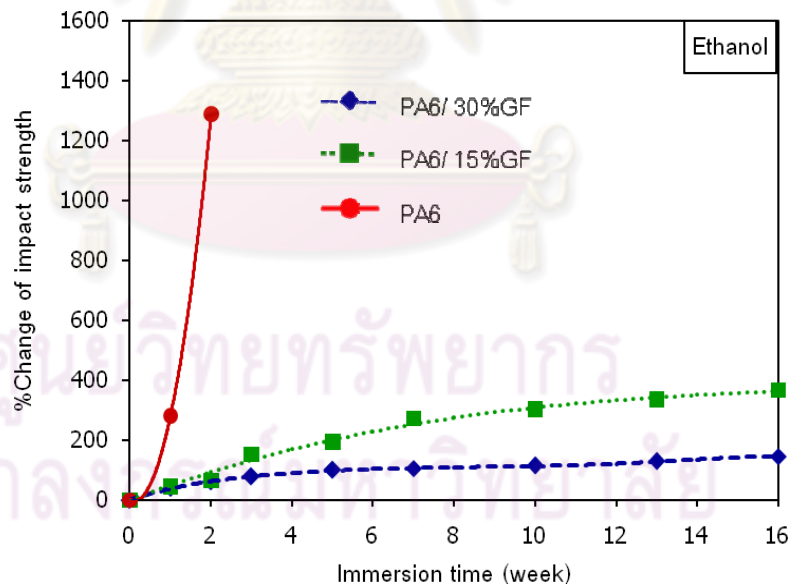


Figure 5.52 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in ethanol

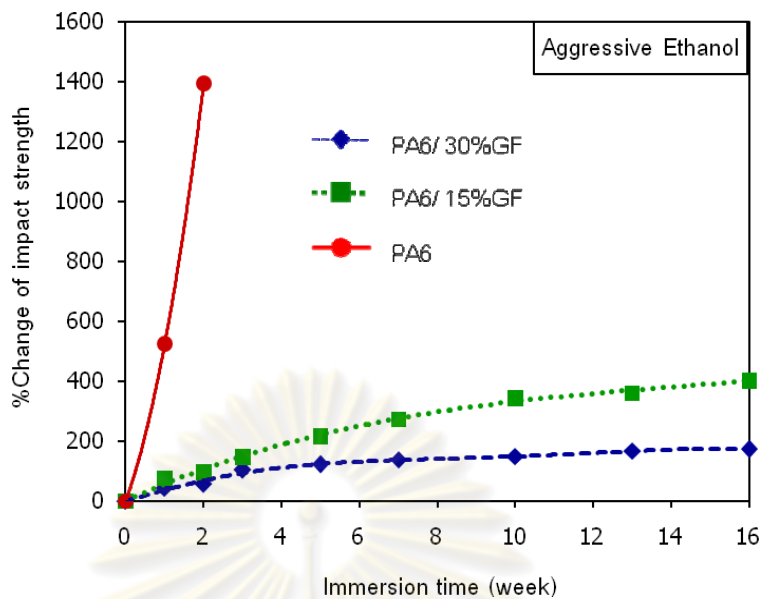


Figure 5.53 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in aggressive ethanol

5.4 Elementary Mechanics of Materials Models

Several theoretical models have been proposed for the prediction of composite properties of a unidirectional fiber-reinforced composite from those of the component fiber and matrix, the longitudinal modulus to be in good agreement with experiments [66].

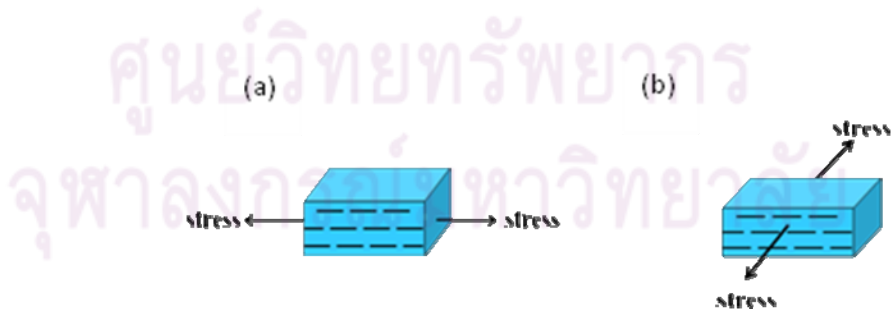


Figure 5.54 Stress direction (a) Rule of mixture (ROM) (b) Inverse rule of mixture (IROM) [67]

Rule of Mixture (ROM) and Inverse Rule of Mixture (IROM) were two important models that can predict. Longitudinal modulus from Rule of Mixture (ROM) is assumed

that the fibers are parallel to the stress applied and the dimensions do not change along the length of the element. Static equilibrium requires that the total force on the specimen must equal the sum of forces acting on the fiber and matrix. Since area fractions are equal to the corresponding volume fraction (V_f) [67,68]; the ROM is give as

$$E_c = V_f E_f + (1-V_f)E_m \quad \dots\dots\dots(5.1)$$

where V_f and $(1-V_f)$ are volume fraction of fiber and polymer matrix, respectively, E_c , E_f , and E_m are the modulus of composite, fiber and polymer matrix, respectively.

While longitudinal modulus from Inverse Rule of Mixture (IROM) is assumed that the fiber are perpendicular to the stress applied so that static equilibrium requires that the total force on the specimen must equal the sum of transverse displacements in the fiber and polymer matrix [67,68]; the IROM is give as

$$E_c = \frac{E_f E_m}{(1-V_f)E_f + V_f E_m} \quad \dots\dots\dots (5.2)$$

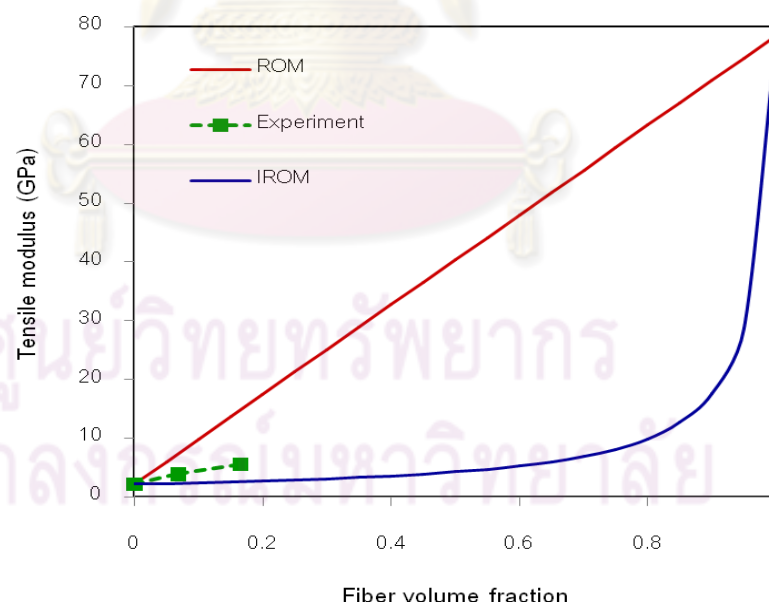


Figure 5.55 Tensile modulus of unsoaked PA6 and PA6/GF composites in this experiment compared with ROM and IROM models

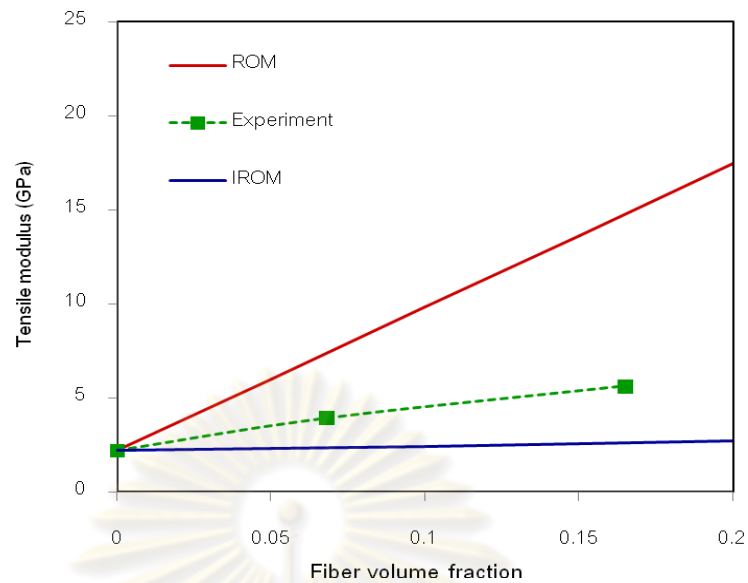


Figure 5.56 Tensile modulus of unsoaked PA6 and PA6/GF composites in this experiment compared with ROM and IROM model (at fiber volume fractions of this experiment)

Figures 5.55-5.56 compared the tensile modulus of PA6 reinforced with glass fiber from this experiment with ROM and IROM models. The result showed that the tensile modulus of PA6 can be improved with the increase of glass fiber content. The tensile modulus of PA6 reinforced with glass fiber was between tensile modulus values calculated by ROM and IROM models. This implies that the glass fiber direction in PA6/GF composite materials were between parallel to the stress (explained by ROM model) and perpendicular to the stress (explained by IROM model). Figure 5.56 showed the tensile modulus of composite material at the fiber volume fractions of this experiment. The result showed the tensile modulus of PA6 reinforced with 30 wt% glass fiber was 5.63 GPa and those calculated by ROM and IROM models were 14.79 and 2.62 GPa respectively. Hence, theoretically it indicated that on average the orientation of glass fiber in the composites was in random orientation with respect to stress applied. Experimentally this random fiber orientation was possible because the PA6/GF composites were prepared with injection molding machine at high injection speed. The injection process cause some of glass fiber to be oriented parallel to the flow direction on the surfaces, while at the center of specimen's cross-section they are oriented

perpendicular to the flow direction [69]. Hence, the tensile modulus of PA6/GF composites in this experiment was acceptable.

Figures 5.57-5.58 compared the tensile modulus of PA6/GF composites of this experiment with ROM and IROM model before and after immersion in chemicals of surrogate gasohol. The results showed that the tensile modulus of PA6/GF composites was in between the values predicted by ROM and IROM models. These results were somewhat expected with the same reasoning discussed above. Hence, the chemicals absorbed in to PA6/GF composites did not affect the random orientation of glass fibers in the composites.

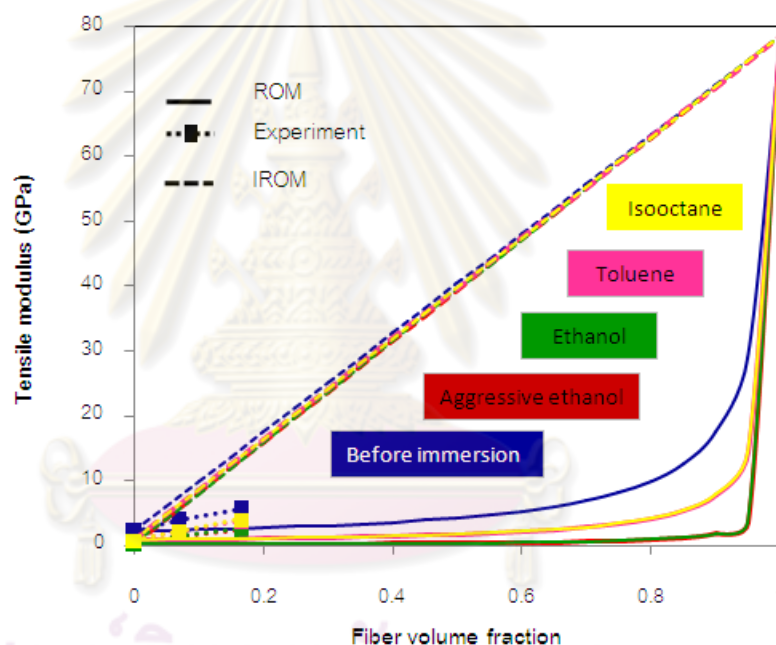


Figure 5.57 Tensile modulus of PA6 and PA6/GF composites of this experiment compared with ROM and IROM model after immersion in chemicals of surrogate gasohol

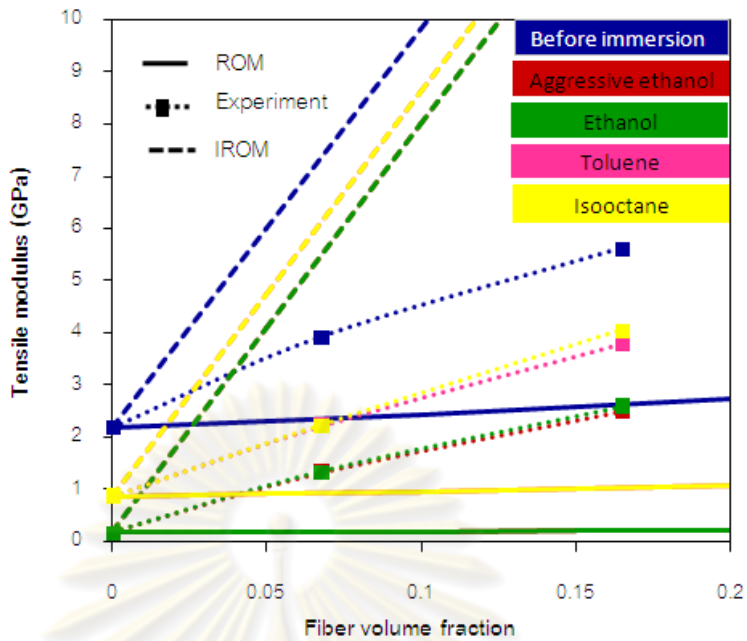


Figure 5.58 Tensile modulus of PA6 and PA6/GF composites of this experiment compared with ROM and IROM model after immersion in chemicals of surrogate gasohol (at fiber volume fraction of experiment)

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The findings obtained in this study can be concluded as the followings:

1. The solvent absorption caused the swelling of PA6. But glass fiber in PA6 provided dimensional stability by restricting the movement of polymer chains, thus reducing the swelling.

2. The glass fiber in PA6/GF composites could improve the heat distortion temperature (HDT) of unsoaked PA6/GF composites because glass fiber could limit the thermal movement of polymer chains and prevent the elastic and plastic deformation.

3. The glass fiber did not affect the glass transition temperature (T_g) of PA6/GF composites. The movement of polymer chains at T_g was from PA6 chains only.

4. The glass fiber could improve the tensile strength, tensile modulus, flexural strength, flexural modulus, compressive strength and Izod impact strength of PA6/GF composites because the good interfacial bonding between PA6 and GF resisted the matrix peeling off from the fiber and stress could transfer over to glass fiber.

5. Orientation of glass fiber in dog bone specimens produced under the condition of this study seemed to be in random position with respect to applied stress (as implied by ROM and IROM models).

6. The chemicals in surrogate gasohol affected both neat PA6 and PA6/GF composites. The thermal and mechanical properties except Izod impact strength of specimens decreased with increasing immersion time or amount of chemicals absorbed. But the effects were reduced in the PA6/GF composites due to lesser mass of PA6 in the PA6/GF composites relative to neat PA6 specimens and because the fiber glass could reduce the movement of polymer chains.

7. Ethanol and aggressive ethanol significantly affected the thermal and mechanical properties of neat PA6 and PA6/GF composites more than isooctane and toluene. This was because water and ethanol in aggressive ethanol are polar chemicals and thus can be absorbed easily by polar amide group in PA6 matrix. On the other

hand, isooctane and toluene are non-polar chemicals; hence, they were not easily absorbed into PA6 matrix.

8. Overall, the effects of gasohol on properties of PA6 were mainly from alcohol component than gasoline component because PA6 could absorb polar materials easier than non-polar materials. Therefore, PA6 and PA6/GF composites should be used with gasohol with low ethanol volume content.

6.2 Recommendations

To further gained insights into the effects of chemicals in gasohol and/or gasohol itself on the thermal and mechanical properties of PA6/GF composites, the following recommendations were suggested:

1. The effects of commercial gasohol on physical, thermal and mechanical properties of PA6/GF composites should be studied for comparison with effects of chemicals in surrogate gasohol used in this experiment.

2. Morphology and orientation of the glass fiber in PA6/GF composites before and after the immersion should be further investigated to gain more understanding on the effects of chemicals in surrogate gasohol and/or actual gasohol on physical, thermal, and mechanical properties of PA6/GF composites.

3. The influence of chemicals of surrogate gasohol at temperature above and below room temperature on the physical, thermal, and mechanical properties of PA6 reinforced with glass fiber should be examined. This experiment should yield better insight into the compatibility of PA6/GF composites with gasohol at real operating conditions of engine.

4. The exact composition of each chemical of surrogate gasohol after being in contact with PA6/GF specimens should be explored by standard tests to determine whether there was any interaction with PA6 or glass fiber. It was also interesting to find out whether any additives in the PA6 matrix could leak out because it might affect the thermal and mechanical properties of PA6/GF composites.

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APPENDICES

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APPENDIX A
THE EXPERIMENTAL DATA OF PHYSICAL PROPERTIES

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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	6.7888	6.8071	7.0092	6.6943	6.8287	6.8256±0.1147
	PA6/GF (15 wt%)	7.5789	7.5234	7.4908	7.5270	7.7368	7.5714±0.0977
	PA6/GF (30 wt%)	8.4333	8.4525	8.4209	8.3947	8.4838	8.4376±0.0327
1	PA6	7.0564	7.1025	7.1948	7.0735	7.1084	7.1071±0.0534
	PA6/GF (15 wt%)	7.8488	7.7885	7.7579	7.8005	8.0066	7.8405±0.0985
	PA6/GF (30 wt%)	8.6835	8.7028	8.6676	8.6386	8.7278	8.6841±0.0339
2	PA6	7.2540	7.2670	7.4582	7.1462	7.2782	7.2807±0.1124
	PA6/GF (15 wt%)	7.9376	7.8754	7.8458	7.8883	8.0910	7.9276±0.0972
	PA6/GF (30 wt%)	8.7467	8.7608	8.7325	8.7035	8.7927	8.7472±0.0331
3	PA6	7.2843	7.2970	7.4885	7.1763	7.3084	7.3109±0.1124
	PA6/GF (15 wt%)	7.9980	7.9355	7.9049	7.9479	8.1549	7.9882±0.0990
	PA6/GF (30 wt%)	8.7916	8.8069	8.7777	8.7485	8.8383	8.7926±0.0334
5	PA6	7.2846	7.2970	7.4888	7.1764	7.3085	7.3111±0.1125
	PA6/GF (15 wt%)	8.0231	7.9631	7.9322	7.9734	8.1846	8.0153±0.1001
	PA6/GF (30 wt%)	8.8158	8.8471	8.8119	8.7863	8.8725	8.8267±0.0335
7	PA6	7.2842	7.3014	7.4912	7.1775	7.3202	7.3149±0.1130
	PA6/GF (15 wt%)	8.0247	7.9617	7.9306	7.9729	8.1856	8.0151±0.1012
	PA6/GF (30 wt%)	8.8342	8.8527	8.8373	8.8067	8.8936	8.8449±0.0319
10	PA6	7.2746	7.2933	7.4846	7.1690	7.3132	7.3069±0.1139
	PA6/GF (15 wt%)	8.0393	7.9750	7.9440	7.9873	8.1996	8.0290±0.1014
	PA6/GF (30 wt%)	8.8348	8.8543	8.8397	8.8079	8.8934	8.8460±0.0314
13	PA6	7.2742	7.2922	7.4832	7.1686	7.3116	7.3060±0.1135
	PA6/GF (15 wt%)	8.0235	7.9601	7.9287	7.9707	8.1852	8.0136±0.1018
	PA6/GF (30 wt%)	8.8380	8.8575	8.8429	8.8111	8.8966	8.8492±0.0314

Week	Material	Mass (g)					Average (g)
		1	2	3	4	5	
16	PA6	7.2737	7.2910	7.4819	7.1683	7.3099	7.3050±0.1131
	PA6/GF (15 wt%)	8.0268	7.9646	7.9348	7.9752	8.1886	8.0180±0.1010
	PA6/GF (30 wt%)	8.8401	8.8575	8.8457	8.8118	8.8969	8.8504±0.0309



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Appendix A2 Mass change

Table A2-1 Mass of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Mass (g)					Average (g)
		1	2	3	4	5	
0	Aggressive Ethanol	6.7582	6.8205	6.7421	6.9603	6.6771	6.7916±0.0956
	Ethanol	6.8659	6.8867	6.8186	6.9262	6.7677	6.8530±0.0615
	Isooctane	6.8077	6.7542	6.7517	6.7820	6.7314	6.7654±0.0297
	Toluene	6.8532	6.7308	6.7872	6.7305	6.9258	6.8055±0.0841
1	Aggressive Ethanol	6.9287	6.9754	6.8887	7.0970	6.8379	6.9455±0.0987
	Ethanol	6.9899	7.0305	6.9435	7.0238	6.9021	6.9780±0.0547
	Isooctane	6.8180	6.7618	6.7593	6.7882	6.7347	6.7724±0.0318
	Toluene	6.8690	6.7465	6.803	6.7469	6.9423	6.8216±0.0842
2	Aggressive Ethanol	7.0950	7.1227	7.0329	7.2215	6.9980	7.0940±0.0866
	Ethanol	7.1131	7.1691	7.0673	7.1185	7.0329	7.1002±0.0521
	Isooctane	6.8220	6.7692	6.7662	6.7959	6.7458	6.7798±0.0296
	Toluene	6.8993	6.7759	6.8298	6.7749	6.9668	6.8493±0.0831
3	Aggressive Ethanol	7.1408	7.1618	7.0712	7.2523	7.0451	7.1342±0.0816
	Ethanol	7.1464	7.2059	7.1019	7.1434	7.0713	7.1338±0.0509
	Isooctane	6.8306	6.7712	6.7698	6.7994	6.7541	6.7850±0.0303
	Toluene	6.9074	6.7833	6.8380	6.7829	6.9758	6.8575±0.0836
5	Aggressive Ethanol	7.1953	7.2044	7.1152	7.2848	7.0983	7.1796±0.0753
	Ethanol	7.1770	7.2432	7.1320	7.1642	7.1054	7.1644±0.0522
	Isooctane	6.8412	6.7851	6.7830	6.8122	6.7623	6.7968±0.0305
	Toluene	6.9134	6.7891	6.8436	6.7885	6.9871	6.8643±0.0856

Week	Chemical	Mass (g)					Average (g)
		1	2	3	4	5	
7	Aggressive Ethanol	7.3398	7.3462	7.2587	7.3922	7.2376	7.3149±0.0646
	Ethanol	7.2915	7.3852	7.2632	7.2410	7.2538	7.2869±0.0580
	Isooctane	6.8555	6.7975	6.7961	6.8254	6.7746	6.8098±0.0313
	Toluene	6.9260	6.8012	6.8554	6.8004	6.9935	6.8753±0.0837
10	Aggressive Ethanol	7.3543	7.3930	7.2966	7.4729	7.2526	7.3539±0.0855
	Ethanol	7.3957	7.4666	7.3589	7.3162	7.3294	7.3734±0.0604
	Isooctane	6.8630	6.8094	6.8030	6.8343	6.7867	6.8193±0.0298
	Toluene	6.9427	6.8195	6.8745	6.8178	7.0109	6.8931±0.0833
13	Aggressive Ethanol	7.3619	7.4037	7.3050	7.4981	7.2595	7.3656±0.0921
	Ethanol	7.4255	7.4793	7.3795	7.3840	7.3403	7.4017±0.0528
	Isooctane	6.8859	6.8264	6.8250	6.8604	6.8068	6.8409±0.0317
	Toluene	6.9575	6.8330	6.8872	6.8294	7.0260	6.9066±0.0846
16	Aggressive Ethanol	7.3686	7.4109	7.3121	7.5096	7.2657	7.3734±0.0940
	Ethanol	7.4353	7.4858	7.3861	7.4196	7.3463	7.4146±0.0524
	Isooctane	6.9021	6.8442	6.8428	6.8715	6.8212	6.8564±0.0312
	Toluene	6.9615	6.8363	6.8908	6.8354	7.0283	6.9105±0.0837

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Table A2-2 Mass of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Mass (g)					Average (g)
		1	2	3	4	5	
0	Aggressive Ethanol	7.5358	7.6150	7.4853	7.5167	7.6153	7.5536±0.0590
	Ethanol	7.5380	7.7000	7.6169	7.5046	7.5567	7.5832±0.0770
	Isooctane	7.6822	7.5820	7.6674	7.5583	7.6644	7.6309±0.0565
	Toluene	7.5531	7.3676	7.5942	7.4106	7.5131	7.4877±0.0957
1	Aggressive Ethanol	7.6723	7.7569	7.6226	7.6504	7.7482	7.6901±0.0598
	Ethanol	7.6403	7.8102	7.7416	7.6225	7.6724	7.6974±0.0777
	Isooctane	7.7147	7.6066	7.6989	7.5939	7.6977	7.6624±0.0573
	Toluene	7.6319	7.4038	7.5867	7.4443	7.5491	7.5232±0.0962
2	Aggressive Ethanol	7.7147	7.8010	7.6644	7.6916	7.7878	7.7319±0.0599
	Ethanol	7.6723	7.8448	7.7788	7.6593	7.7067	7.7324±0.0781
	Isooctane	7.7188	7.6148	7.7050	7.5990	7.7038	7.6683±0.0566
	Toluene	7.6403	7.4118	7.5948	7.4531	7.5563	7.5313±0.0961
3	Aggressive Ethanol	7.7608	7.8475	7.7100	7.7362	7.8312	7.7771±0.0598
	Ethanol	7.7075	7.8835	7.8196	7.6985	7.7452	7.7709±0.0790
	Isooctane	7.7254	7.6218	7.7119	7.6032	7.7083	7.6741±0.0570
	Toluene	7.6469	7.4185	7.6015	7.4596	7.5623	7.5378±0.0961
5	Aggressive Ethanol	7.8275	7.9118	7.7734	7.7986	7.8930	7.8409±0.0597
	Ethanol	7.7534	7.9352	7.8723	7.7497	7.8051	7.8231±0.0799
	Isooctane	7.7355	7.6362	7.7240	7.6163	7.7246	7.6873±0.0564
	Toluene	7.6566	7.4369	7.6113	7.4724	7.5686	7.5492±0.0926

Week	Chemical	Mass (g)					Average (g)
		1	2	3	4	5	
7	Aggressive Ethanol	7.8907	7.9696	7.8319	7.8549	7.9477	7.8990±0.0589
	Ethanol	7.8438	7.9821	7.9233	7.7977	7.7952	7.8684±0.0820
	Isooctane	7.7524	7.6433	7.7280	7.6222	7.7359	7.6964±0.0592
	Toluene	7.6678	7.4403	7.6223	7.5835	7.4796	7.5587±0.0960
10	Aggressive Ethanol	7.9903	8.0605	7.9234	7.9424	8.0378	7.9909±0.0591
	Ethanol	7.8568	8.0571	8.0056	7.8701	7.9188	7.9417±0.0870
	Isooctane	7.7600	7.6572	7.7411	7.6331	7.7409	7.7065±0.0571
	Toluene	7.6851	7.4546	7.6374	7.5973	7.4918	7.5732±0.0974
13	Aggressive Ethanol	8.0344	8.1064	7.9649	7.9911	8.0996	8.0393±0.0633
	Ethanol	7.9161	8.1270	8.0774	7.9361	7.9889	8.0091±0.0908
	Isooctane	7.7622	7.6574	7.7449	7.6364	7.7437	7.7089±0.0576
	Toluene	7.687	7.4579	7.6418	7.6012	7.4983	7.5772±0.0965
16	Aggressive Ethanol	8.0483	8.1228	7.9791	8.0076	8.1263	8.0568±0.0666
	Ethanol	7.9584	8.1585	8.0946	7.9594	8.0116	8.0365±0.0879
	Isooctane	7.7683	7.6664	7.7541	7.6441	7.7514	7.7169±0.0572
	Toluene	7.6973	7.4662	7.6506	7.6093	7.5074	7.5862±0.0970

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Table A2-3 Mass of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Mass (g)					Average (g)
		1	2	3	4	5	
0	Aggressive Ethanol	8.3688	8.3692	8.4209	8.3218	8.3381	8.3638±0.0379
	Ethanol	8.4018	8.2692	8.4253	8.3624	8.4041	8.3726±0.0621
	Isooctane	8.4827	8.4007	8.3882	8.3696	8.4088	8.4100±0.0432
	Toluene	8.3427	8.3753	8.3900	8.4471	8.3590	8.3828±0.0401
1	Aggressive Ethanol	8.5524	8.5569	8.6024	8.4995	8.5273	8.5477±0.0382
	Ethanol	8.4832	8.3144	8.4911	8.4403	8.4988	8.4456±0.0767
	Isooctane	8.5108	8.4256	8.4229	8.4034	8.4435	8.4412±0.0414
	Toluene	8.3745	8.4071	8.4218	8.4789	8.3908	8.4146±0.0401
2	Aggressive Ethanol	8.5815	8.5808	8.6515	8.5494	8.5874	8.5901±0.0374
	Ethanol	8.5304	8.3982	8.5495	8.5241	8.8531	8.5171±0.0703
	Isooctane	8.5138	8.4318	8.4272	8.4075	8.4481	8.4457±0.0407
	Toluene	8.3855	8.4190	8.4456	8.4991	8.4119	8.4322±0.0431
3	Aggressive Ethanol	8.6308	8.6201	8.6757	8.5887	8.6094	8.6249±0.0324
	Ethanol	8.5631	8.4309	8.5822	8.5568	8.6158	8.5498±0.0703
	Isooctane	8.5153	8.4330	8.4285	8.4089	8.4497	8.4471±0.0408
	Toluene	8.3878	8.4227	8.4480	8.5013	8.4140	8.4348±0.0430
5	Aggressive Ethanol	8.6590	8.6494	8.7053	8.6161	8.6384	8.6536±0.0330
	Ethanol	8.5910	8.4586	8.6088	8.5852	8.6436	8.5774±0.0702
	Isooctane	8.5171	8.4345	8.4298	8.4106	8.4511	8.4486±0.0409
	Toluene	8.3895	8.4245	8.4499	8.5031	8.4156	8.4365±0.0430

Week	Chemical	Mass (g)					Average (g)
		1	2	3	4	5	
7	Aggressive Ethanol	8.6803	8.6688	8.7490	8.6515	8.6828	8.6865±0.0371
	Ethanol	8.6058	8.4839	8.6316	8.6590	8.7227	8.6206±0.0879
	Isooctane	8.5206	8.4383	8.4337	8.4144	8.4553	8.4525±0.0408
	Toluene	8.3905	8.4253	8.4520	8.5050	8.4178	8.4381±0.0433
10	Aggressive Ethanol	8.6715	8.6908	8.7942	8.6881	8.7076	8.7104±0.0485
	Ethanol	8.6613	8.5462	8.6901	8.7284	8.7879	8.6828±0.0899
	Isooctane	8.5361	8.4536	8.4532	8.4326	8.4736	8.4698±0.0398
	Toluene	8.4024	8.4314	8.4628	8.5153	8.4274	8.4479±0.0434
13	Aggressive Ethanol	8.6994	8.7347	8.8290	8.7352	8.7411	8.7479±0.0483
	Ethanol	8.7051	8.5880	8.7310	8.7697	8.8282	8.7244±0.0892
	Isooctane	8.5454	8.4618	8.4603	8.4405	8.4811	8.4778±0.0404
	Toluene	8.4152	8.4445	8.4749	8.5270	8.4388	8.4601±0.0430
16	Aggressive Ethanol	8.7257	8.7493	8.8447	8.7515	8.7602	8.7663±0.0457
	Ethanol	8.7445	8.6267	8.7683	8.8092	8.8643	8.7626±0.0885
	Isooctane	8.5515	8.4682	8.4670	8.4464	8.4869	8.4840±0.0404
	Toluene	8.4367	8.4682	8.4993	8.5509	8.4622	8.4835±0.0438

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Appendix A3 Volume change

Table A3-1 Volume of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Volume (cm ³)					Average (cm ³)
		1	2	3	4	5	
0	Aggressive Ethanol	5.9154	5.9551	5.8814	6.0550	5.8168	5.9247±0.0794
	Ethanol	6.0854	6.2015	6.1023	6.2078	6.0643	6.1323±0.0675
	Isooctane	5.9376	5.9016	5.8861	5.9694	5.8714	5.9132±0.0399
	Toluene	6.0043	5.8797	5.9229	5.9156	6.0497	5.9544±0.0701
1	Aggressive Ethanol	6.1055	6.1425	6.0473	6.2103	6.0089	6.1264±0.0714
	Ethanol	6.1553	6.2064	6.1373	6.2494	6.1260	6.1828±0.0601
	Isooctane	5.9442	5.9071	5.8977	5.9769	5.8734	5.9199±0.0408
	Toluene	6.0702	5.9049	5.9350	5.8892	6.0293	5.9657±0.0798
2	Aggressive Ethanol	6.3432	6.3323	6.2504	6.3805	6.2328	6.3078±0.0634
	Ethanol	6.3011	6.3463	6.2525	6.2674	6.2407	6.2816±0.0427
	Isooctane	5.9508	5.9127	5.9190	5.9854	5.8714	5.9278±0.0428
	Toluene	6.0483	5.9245	5.9845	5.9122	6.0640	5.9867±0.0693
3	Aggressive Ethanol	6.3863	6.3771	6.2979	6.4207	6.2798	6.3523±0.606
	Ethanol	6.3184	6.3755	6.2843	6.2697	6.2669	6.3030±0.0454
	Isooctane	5.9562	5.9147	5.9211	5.9866	5.8728	5.9303±0.0432
	Toluene	6.0553	5.9281	6.0029	5.9162	6.0825	5.9970±0.0742
5	Aggressive Ethanol	6.4654	6.4381	6.3768	6.4820	6.3502	6.4225±0.0569
	Ethanol	6.3530	6.4262	6.3255	6.3115	6.3272	6.3487±0.0458
	Isooctane	5.9758	5.9369	5.9217	6.0066	5.8939	5.9470±0.0445
	Toluene	6.0603	5.9299	5.9925	5.9409	6.0912	6.0029±0.0714

Week	Chemical	Volume (cm ³)					Average (cm ³)
		1	2	3	4	5	
7	Aggressive Ethanol	6.5743	6.5424	6.4900	6.5603	6.4591	6.5252±0.0488
	Ethanol	6.4943	6.5759	6.4816	6.3890	6.4859	6.4853±0.0663
	Isooctane	5.9692	5.9385	5.9404	6.0264	5.9057	5.9560±0.0453
	Toluene	6.0424	5.9775	5.9981	5.9468	6.0738	6.0077±0.0507
10	Aggressive Ethanol	6.6083	6.6393	6.5909	6.6767	6.5046	6.6039±0.0644
	Ethanol	6.6245	6.6662	6.5958	6.4829	6.5808	6.5900±0.0682
	Isooctane	5.9751	5.9489	5.9259	6.0279	5.9125	5.9581±0.0457
	Toluene	6.0766	5.9610	6.0159	5.9572	6.1067	6.0235±0.0673
13	Aggressive Ethanol	6.6983	6.6204	6.6981	6.4408	6.6422	6.6199±0.1059
	Ethanol	6.6616	6.7026	6.6280	6.5673	6.6099	6.6339±0.0513
	Isooctane	6.0315	5.9680	5.9585	6.0640	5.9490	5.9942±0.0507
	Toluene	5.9682	6.0148	5.9680	6.1574	6.0036	6.0224±0.0783
16	Aggressive Ethanol	6.7166	6.5839	6.7130	6.4460	6.6454	6.6210±0.11
	Ethanol	6.6707	6.7293	6.6259	6.5921	6.6248	6.6485±0.0531
	Isooctane	6.0462	5.9751	5.9654	6.0717	5.9568	6.0030±0.0522
	Toluene	5.9750	6.0017	5.9926	6.1554	6.0054	6.0260±0.0732

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Table A3-2 Volume of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Volume (cm ³)					Average (cm ³)
		1	2	3	4	5	
0	Aggressive Ethanol	6.0286	6.0920	5.9882	6.0134	6.0922	6.0429±0.0472
	Ethanol	6.0304	6.1600	6.0935	6.0037	6.0454	6.0666±0.0616
	Isooctane	6.1458	6.0656	6.1339	6.0466	6.1315	6.1047±0.0452
	Toluene	6.0425	5.8941	6.0754	5.9285	6.0105	5.9902±0.0766
1	Aggressive Ethanol	6.1378	6.2055	6.0981	6.1203	6.1986	6.1521±0.0478
	Ethanol	6.1122	6.2482	6.1933	6.0908	6.1379	6.1579±0.0622
	Isooctane	6.1718	6.0853	6.1591	6.0751	6.1582	6.1299±0.0458
	Toluene	6.1055	5.9230	6.0694	5.9554	6.0393	6.0185±0.0769
2	Aggressive Ethanol	6.1817	6.2408	6.1315	6.1533	6.2302	6.1855±0.0480
	Ethanol	6.1378	6.2758	6.2230	6.1274	6.1654	6.1859±0.0625
	Isooctane	6.1750	6.0918	6.1640	6.0792	6.1630	6.1346±0.0453
	Toluene	6.1122	5.9294	6.0758	5.9625	6.0450	6.0250±0.0769
3	Aggressive Ethanol	6.2086	6.2780	6.1680	6.1890	6.2650	6.2217±0.0479
	Ethanol	6.1660	6.3068	6.2557	6.1588	6.1962	6.2167±0.0632
	Isooctane	6.1803	6.0974	6.1695	6.0826	6.1666	6.1393±0.0456
	Toluene	6.1175	5.9348	6.0812	5.9677	6.0498	6.0302±0.0768
5	Aggressive Ethanol	6.2620	6.3294	6.2187	6.2389	6.3144	6.2727±0.0478
	Ethanol	6.2027	6.3481	6.2978	6.1998	6.2441	6.2585±0.0639
	Isooctane	6.1884	6.1090	6.1792	6.0930	6.1797	6.1499±0.0451
	Toluene	6.1253	5.9495	6.0890	5.9779	6.0549	6.0393±0.0741

Week	Chemical	Volume (cm ³)					Average (cm ³)
		1	2	3	4	5	
7	Aggressive Ethanol	6.3126	6.3757	6.2655	6.2839	6.3582	6.3192±0.0471
	Ethanol	6.2750	6.3857	6.3386	6.2382	6.2362	6.2947±0.0656
	Isooctane	6.2019	6.1146	6.1824	6.0978	6.1887	6.1571±0.0474
	Toluene	6.1342	5.9522	6.0978	6.0668	5.9837	6.0470±0.0768
10	Aggressive Ethanol	6.3922	6.4484	6.3387	6.3539	6.4302	6.3927±0.0472
	Ethanol	6.2854	6.4457	6.4045	6.2961	6.3350	6.3533±0.0696
	Isooctane	6.2080	6.1258	6.1929	6.1065	6.1927	6.1652±0.0457
	Toluene	6.1481	5.9637	6.1099	6.0778	5.9934	6.0586±0.0779
13	Aggressive Ethanol	6.4275	6.4851	6.3719	6.3929	6.4797	6.4314±0.0506
	Ethanol	6.3329	6.5016	6.4619	6.3489	6.3911	6.4073±0.0726
	Isooctane	6.2098	6.1259	6.1959	6.1091	6.1950	6.1671±0.0461
	Toluene	6.1496	5.9663	6.1134	6.0810	5.9986	6.0618±0.0772
16	Aggressive Ethanol	6.4386	6.4982	6.3833	6.4061	6.5010	6.4455±0.0532
	Ethanol	6.3667	6.5268	6.4757	6.3675	6.4093	6.4292±0.0703
	Isooctane	6.2146	6.1331	6.2033	6.1153	6.2011	6.1735±0.0457
	Toluene	6.1578	5.9730	6.1205	6.0874	6.0059	6.0689±0.0776

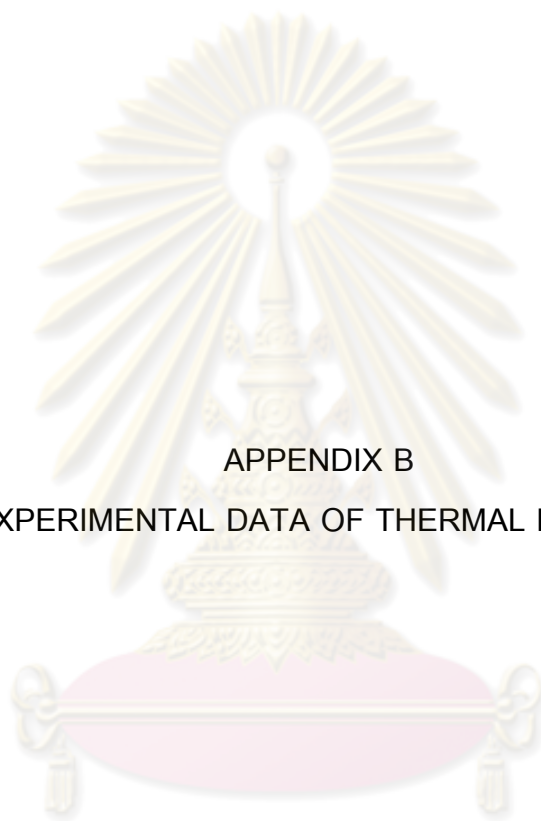
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Table A3-3 Volume of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Volume (cm ³)					Average (cm ³)
		1	2	3	4	5	
0	Aggressive Ethanol	6.1991	6.1994	6.2377	6.1643	6.1764	6.1954±0.0281
	Ethanol	6.1778	6.0803	6.1951	6.1488	6.1795	6.1563±0.0457
	Isooctane	6.2373	6.1770	6.1678	6.1541	6.1829	6.1838±0.0318
	Toluene	6.1343	6.1583	6.1691	6.2111	6.1463	6.1638±0.0295
1	Aggressive Ethanol	6.3351	6.3384	6.3721	6.2959	6.3165	6.3316±0.0283
	Ethanol	6.2376	6.1135	6.2435	6.2061	6.2491	6.2100±0.0564
	Isooctane	6.2579	6.1953	6.1933	6.1790	6.2085	6.2068±0.0304
	Toluene	6.1577	6.1817	6.1925	6.2345	6.1697	6.1872±0.0295
2	Aggressive Ethanol	6.3567	6.3561	6.4085	6.3329	6.3611	6.3631±0.0277
	Ethanol	6.2724	6.1751	6.2864	6.2677	6.3111	6.2625±0.0517
	Isooctane	6.2601	6.1999	6.1965	6.1820	6.2118	6.2100±0.0300
	Toluene	6.1658	6.1904	6.2100	6.2493	6.1852	6.2002±0.0317
3	Aggressive Ethanol	6.3932	6.3853	6.4264	6.3620	6.3773	6.3888±0.0240
	Ethanol	6.2964	6.1992	6.3104	6.2918	6.3351	6.2866±0.0517
	Isooctane	6.2613	6.2007	6.1974	6.1830	6.2130	6.2111±0.0300
	Toluene	6.1675	6.1932	6.2118	6.2510	6.1868	6.2020±0.0316
5	Aggressive Ethanol	6.4140	6.4070	6.4484	6.3823	6.3988	6.4101±0.0245
	Ethanol	6.3169	6.2196	6.3300	6.3126	6.3556	6.3069±0.0516
	Isooctane	6.2626	6.2018	6.1984	6.1843	6.2140	6.2122±0.0301
	Toluene	6.1688	6.1945	6.2132	6.2523	6.1879	6.2033±0.0316

Week	Chemical	Volume (cm ³)					Average (cm ³)
		1	2	3	4	5	
7	Aggressive Ethanol	6.4298	6.4213	6.4807	6.4085	6.4317	6.4344±0.0275
	Ethanol	6.3278	6.2382	6.3468	6.3669	6.4138	6.3387±0.0647
	Isooctane	6.2651	6.2046	6.2013	6.1871	6.2171	6.2150±0.0300
	Toluene	6.1695	6.1951	6.2147	6.2537	6.1896	6.2045±0.0319
10	Aggressive Ethanol	6.4233	6.4376	6.5142	6.4356	6.4500	6.4522±0.0360
	Ethanol	6.3686	6.2840	6.3898	6.4179	6.4617	6.3844±0.0661
	Isooctane	6.2765	6.2159	6.2156	6.2004	6.2306	6.2278±0.0293
	Toluene	6.1782	6.1996	6.2227	6.2613	6.1966	6.2117±0.0319
13	Aggressive Ethanol	6.4440	6.4710	6.5400	6.4705	6.4749	6.4799±0.0357
	Ethanol	6.4008	6.3147	6.4199	6.4483	6.4913	6.4150±0.0656
	Isooctane	6.2834	6.2219	6.2208	6.2063	6.2361	6.2337±0.0297
	Toluene	6.1876	6.2092	6.2316	6.2699	6.2050	6.2206±0.0316
16	Aggressive Ethanol	6.4635	6.4810	6.5516	6.4826	6.4890	6.4935±0.0338
	Ethanol	6.4298	6.3432	6.4473	6.4774	6.5179	6.4431±0.0651
	Isooctane	6.2879	6.2266	6.2257	6.2106	6.2404	6.2382±0.0297
	Toluene	6.2035	6.2266	6.2495	6.2874	6.2222	6.2378±0.0322

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APPENDIX B

THE EXPERIMENTAL DATA OF THERMAL PROPERTIES

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Appendix B1 Heat distortion temperature

Table B1-1 Heat distortion temperature of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Heat distortion temperature (°C)			Average (°C)
		1	2	3	
0	Aggressive Ethanol	83.9	82.9	84.5	83.77±0.81
	Ethanol				
	Isooctane				
	Toluene				
2	Aggressive Ethanol	59.7	56.5	60.2	58.80±2.01
	Ethanol	60.1	58.7	63.7	60.83±2.58
	Isooctane	82.8	80.8	81.1	81.57±1.08
	Toluene	74.3	73.4	74.2	73.97±0.49
5	Aggressive Ethanol	56.7	55.2	54.5	55.47±1.12
	Ethanol	58.2	57.4	59.2	58.27±0.90
	Isooctane	78.4	79	75.9	77.77±1.64
	Toluene	69.7	71.7	71.8	71.07±1.18
10	Aggressive Ethanol	54.4	56.2	55.4	55.33±0.90
	Ethanol	54.9	55.1	56.3	55.43±0.76
	Isooctane	73.3	72.7	72.3	72.77±0.50
	Toluene	68.2	66	65.8	66.67±1.33
16	Aggressive Ethanol	54.4	51.2	53.9	53.17±1.72
	Ethanol	53.9	53.6	52.2	53.23±0.91
	Isooctane	70.7	70	62.5	67.73±4.55
	Toluene	64.3	61.9	60.6	62.27±1.88

Table B1-2 Heat distortion temperature of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Heat distortion temperature (°C)			Average (°C)
		1	2	3	
0	Aggressive Ethanol	176.3	176.5	176.7	176.5±0.20
	Ethanol				
	Isooctane				
	Toluene				
2	Aggressive Ethanol	119.4	117.5	114.8	117.23±2.31
	Ethanol	125.9	126.4	131.6	127.97±3.16
	Isooctane	160.1	156.5	160.1	158.90±2.08
	Toluene	150.2	150	141.2	147.13±5.14
5	Aggressive Ethanol	95.2	101.6	109.6	102.13±7.21
	Ethanol	115.1	116.6	105.9	112.53±5.79
	Isooctane	145.3	150.2	146.5	147.33±2.55
	Toluene	129.2	134.5	137.8	133.83±4.34
10	Aggressive Ethanol	92.4	89.1	93.2	91.57±2.17
	Ethanol	103	102	103.3	102.77±0.68
	Isooctane	142.4	138	133.5	137.97±4.45
	Toluene	118.3	112.3	113.7	114.77±3.14
16	Aggressive Ethanol	82.1	85.7	80.5	82.77±2.66
	Ethanol	81.5	91.1	89.8	87.47±5.21
	Isooctane	122.7	119.2	117.6	119.83±2.61
	Toluene	109.4	108.5	106.2	108.03±1.65

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Table B1-3 Heat distortion temperature of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Heat distortion temperature (°C)			Average (°C)
		1	2	3	
0	Aggressive Ethanol	181.8	183	183.2	182.67±0.76
	Ethanol				
	Isooctane				
	Toluene				
2	Aggressive Ethanol	153.2	147	142.7	147.63±5.28
	Ethanol	149.5	156.5	150.5	152.17±3.79
	Isooctane	174.1	176.1	174.2	174.80±1.13
	Toluene	174	171.2	167.4	170.87±3.31
5	Aggressive Ethanol	142.3	141.9	137.3	140.50±2.78
	Ethanol	140.5	144.9	139.7	141.70±2.80
	Isooctane	173.1	173.8	172.1	173.00±0.85
	Toluene	166	166.9	166.6	166.50±0.46
10	Aggressive Ethanol	134.4	135.9	134.9	135.07±0.76
	Ethanol	130.8	136.8	137.7	135.10±3.75
	Isooctane	172.8	170.3	170.1	171.07±1.50
	Toluene	162.1	164.9	161.1	162.70±1.97
16	Aggressive Ethanol	130.3	133	124.6	129.30±4.29
	Ethanol	125.5	127.7	121.2	124.80±3.31
	Isooctane	167.5	169.1	166.7	167.77±1.22
	Toluene	161.6	164.8	159.8	162.07±2.53

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Appendix B2 Glass transition temperature

Table B2-1 Glass transition temperature of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Glass transition temperature (°C)		Average (°C)
		1	2	
0	Aggressive Ethanol	72.60	74.70	73.65±1.48
	Ethanol			
	Isooctane			
	Toluene			
2	Aggressive Ethanol	-5.20	-5.10	-5.15±0.07
	Ethanol	-3.10	-3.40	-3.25±0.21
	Isooctane	61.60	62.40	62.00±0.57
	Toluene	57.10	57.30	57.20±0.14
5	Aggressive Ethanol	-8.00	-10.30	-9.15±1.63
	Ethanol	-5.10	-6.50	-5.80±0.99
	Isooctane	52.90	53.10	53.00±0.14
	Toluene	49.60	49.00	49.30±0.42
10	Aggressive Ethanol	-11.20	-12.70	-11.95±1.06
	Ethanol	-11.80	-10.80	-11.30±0.71
	Isooctane	47.90	46.40	47.15±1.06
	Toluene	45.50	44.40	44.95±0.78
16	Aggressive Ethanol	-11.70	-14.70	-13.20±2.12
	Ethanol	-14.90	-12.20	-13.55±1.91
	Isooctane	30.60	32.70	31.65±1.48
	Toluene	31.70	30.50	31.10±0.85

Table B2-2 Glass transition temperature of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Glass transition temperature (°C)		Average (°C)
		1	2	
0	Aggressive Ethanol	72.90	74.50	73.70±1.13
	Ethanol			
	Isooctane			
	Toluene			
2	Aggressive Ethanol	-5.80	-5.10	-5.45±0.49
	Ethanol	-4.00	-5.40	-4.70±0.99
	Isooctane	63.60	63.90	63.75±0.21
	Toluene	54.60	54.30	54.45±0.21
5	Aggressive Ethanol	-6.70	-7.60	-7.15±0.63
	Ethanol	-6.10	-7.90	-7.00±1.27
	Isooctane	48.10	48.60	48.35±0.35
	Toluene	46.20	46.50	46.35±0.21
10	Aggressive Ethanol	-10.90	-7.60	-9.25±2.33
	Ethanol	-6.60	-8.00	-7.30±0.99
	Isooctane	47.60	39.40	43.50±5.80
	Toluene	46.20	39.90	43.05±4.45
16	Aggressive Ethanol	-10.60	-9.00	-9.80±1.13
	Ethanol	-12.50	-13.90	-13.20±0.99
	Isooctane	31.30	33.80	32.55±1.77
	Toluene	34.50	31.10	32.80±2.40

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Table B2-3 Glass transition temperature of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Glass transition temperature (°C)		Average (°C)
		1	2	
0	Aggressive Ethanol	76.10	73.70	74.90±1.70
	Ethanol			
	Isooctane			
	Toluene			
2	Aggressive Ethanol	-1.40	-1.30	-1.35±0.07
	Ethanol	-5.70	-4.30	-5.00±0.99
	Isooctane	64.50	64.70	64.60±0.14
	Toluene	45.80	48.00	46.90±1.56
5	Aggressive Ethanol	-6.30	-5.90	-6.10±0.28
	Ethanol	-6.00	-5.20	-5.60±0.57
	Isooctane	53.50	53.90	53.70±0.28
	Toluene	45.30	44.90	45.10±0.28
10	Aggressive Ethanol	-9.30	-8.80	-9.05±0.35
	Ethanol	-5.60	-6.40	-6.00±0.57
	Isooctane	50.60	49.90	50.25±0.49
	Toluene	46.50	43.80	45.15±1.91
16	Aggressive Ethanol	-10.70	-9.60	-10.15±0.78
	Ethanol	-5.60	-6.50	-6.05±0.64
	Isooctane	35.70	37.20	36.45±1.06
	Toluene	36.30	32.60	34.45±2.62

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APPENDIX C
THE EXPERIMENTAL DATA OF MECHANICAL PROPERTIES

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Appendix C1 Tensile Strength

Table C1-1 Tensile strength of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Tensile Strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	66.50	65.36	65.62	66.76	66.71	66.27±0.61
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	43.85	43.35	43.56	44.41	44.22	43.88±0.44
	Ethanol	57.35	57.64	56.83	57.39	56.96	57.23±0.33
	Isooctane	62.71	62.82	62.96	63.51	62.70	62.94±0.34
	Toluene	61.78	61.25	62.38	60.63	62.15	61.64±0.71
2	Aggressive Ethanol	40.49	39.50	40.15	39.87	39.81	39.96±0.37
	Ethanol	52.19	53.17	53.91	53.11	53.64	53.00±0.64
	Isooctane	59.61	58.83	60.47	57.41	57.97	58.86±1.23
	Toluene	58.21	59.00	58.38	58.25	58.11	58.39±0.36
3	Aggressive Ethanol	34.29	33.92	33.94	33.95	34.02	34.02±0.18
	Ethanol	37.07	37.58	36.01	38.38	36.45	37.10±0.93
	Isooctane	51.82	52.81	49.87	52.93	51.88	51.86±1.22
	Toluene	48.65	47.50	51.28	54.23	50.85	50.50±2.60
5	Aggressive Ethanol	28.41	27.60	28.23	27.42	28.04	27.94±0.42
	Ethanol	33.42	31.92	33.11	31.41	33.48	32.67±0.94
	Isooctane	48.55	49.65	49.87	47.48	47.17	48.55±1.22
	Toluene	49.57	48.18	47.66	48.47	47.43	48.26±0.84

Week	Chemical	Tensile Strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	26.18	26.80	26.64	25.86	25.63	26.22±0.50
	Ethanol	26.03	26.34	26.10	26.00	26.31	26.16±0.16
	Isooctane	46.97	44.26	46.61	44.46	44.30	45.32±1.35
	Toluene	43.11	43.66	43.31	43.70	44.05	43.57±0.37
10	Aggressive Ethanol	25.79	25.52	25.90	25.45	26.28	25.79±0.33
	Ethanol	25.81	25.74	25.97	26.22	26.65	26.08±0.36
	Isooctane	43.48	43.13	42.51	43.53	42.88	43.12±0.43
	Toluene	43.79	42.24	43.00	42.99	42.95	43.00±0.55
13	Aggressive Ethanol	26.57	26.92	24.76	25.24	25.00	25.70±0.98
	Ethanol	25.88	25.79	25.83	25.50	25.79	25.76±0.15
	Isooctane	41.50	42.03	41.44	41.94	42.54	41.89±0.44
	Toluene	41.07	40.86	41.96	41.64	40.46	41.20±0.60
16	Aggressive Ethanol	25.23	24.45	25.78	24.65	24.42	24.91±0.59
	Ethanol	24.59	23.86	24.04	24.29	24.29	24.26±0.30
	Isooctane	40.20	38.87	39.11	38.83	39.09	39.22±0.57
	Toluene	38.55	35.96	36.81	38.32	37.77	37.48±1.08

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Table C1-2 Tensile strength of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Tensile Strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	123.09	125.89	120.73	123.75	123.71	123.43±1.85
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	87.52	85.86	87.74	85.28	85.20	86.32±1.23
	Ethanol	87.35	87.60	86.33	86.21	87.78	87.05±0.73
	Isooctane	109.97	106.14	108.7	105.29	106.31	107.22±1.86
	Toluene	101.87	101.29	100.18	103.55	100.50	101.48±1.33
2	Aggressive Ethanol	80.23	76.18	82.47	82.75	75.14	79.35±3.52
	Ethanol	83.93	77.25	81.86	74.15	77.13	78.86±3.95
	Isooctane	100.43	98.5	99.50	99.43	102.99	100.17±1.71
	Toluene	93.58	93.81	95.76	96.15	93.63	94.59±1.26
3	Aggressive Ethanol	69.93	69.62	70.62	69.55	68.39	69.62±0.93
	Ethanol	75.27	72.65	72.87	74	75.35	74.03±1.28
	Isooctane	78.42	77.60	80.37	79.88	78.56	78.96±1.13
	Toluene	77.27	76.85	76.23	76.53	77.32	76.84±0.47
5	Aggressive Ethanol	61.25	60.38	60.33	61.32	61	60.86±0.48
	Ethanol	64.05	64.64	64.17	62.52	63.97	63.87±0.80
	Isooctane	77.09	77.46	77.06	77.57	76.88	77.21±0.29
	Toluene	74.96	75.92	74.92	75.06	74.45	75.06±0.53

Week	Chemical	Tensile Strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	53.50	56.93	55.71	54.53	54.16	54.97±1.36
	Ethanol	47.71	53.78	51.30	51.99	52.00	51.36±2.24
	Isooctane	76.12	76.98	76.3	77.46	75.36	76.44±0.81
	Toluene	72.35	75.23	74.25	74.74	73.47	74.01±1.12
10	Aggressive Ethanol	50.36	50.60	49.89	50.39	50.30	50.31±0.26
	Ethanol	50.54	52.05	51.50	52.64	50.98	51.54±0.83
	Isooctane	73.49	74.84	75.15	74.47	76.29	74.85±1.02
	Toluene	72.73	73.23	72.96	73.03	73.83	73.16±0.42
13	Aggressive Ethanol	49.80	48.34	48.43	49.81	48.96	49.07±0.71
	Ethanol	50.58	50.31	51.96	50.55	50.44	50.77±0.67
	Isooctane	73.82	71.93	72.42	72.55	73.31	72.81±0.75
	Toluene	71.82	73.59	73.43	70.53	73.52	72.58±1.36
16	Aggressive Ethanol	48.14	47.94	48.06	47.85	47.96	47.99±0.11
	Ethanol	51.44	50.58	49.22	51.79	50.70	50.75±0.99
	Isooctane	71.44	72.09	72.38	69.69	71.78	71.48±1.06
	Toluene	70.59	68.93	70.93	71.9	71.81	70.83±1.20

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Table C1-3 Tensile strength of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Tensile Strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol						167.11±2.16
	Ethanol	164.61	165.27	168.81	167.28	169.56	
	Isooctane						
	Toluene						
1	Aggressive Ethanol	129.35	127.20	128.95	131.23	130.88	129.52±1.62
	Ethanol	132.51	133.26	133.12	133.79	136.27	133.79±1.68
	Isooctane	144.03	143.66	142.86	143.34	144.80	143.74±1.01
	Toluene	150.76	151.35	151.77	149.34	145.44	149.73±2.89
2	Aggressive Ethanol	118.04	119.00	118.86	122.08	115.17	118.63±2.47
	Ethanol	125.97	120.73	124.80	125.00	123.09	123.92±2.06
	Isooctane	140.13	132.86	149.84	131.47	146.36	140.13±9.33
	Toluene	141.45	137.43	140.92	142.39	145.00	141.44±3.16
3	Aggressive Ethanol	109.74	110.10	110.18	112.67	110.89	110.72
	Ethanol	112.36	114.35	110.55	109.62	111.95	111.77±1.81
	Isooctane	139.12	138.87	136.24	139.18	141.56	138.99±1.89
	Toluene	133.15	132.62	132.28	133.19	131.64	132.58±0.65
5	Aggressive Ethanol	91.74	89.38	87.17	92.50	92.14	90.59±2.26
	Ethanol	96.49	97.64	98.78	98.12	97.50	97.70±0.84
	Isooctane	136.00	130.24	128.77	125.93	135.01	131.19±4.25
	Toluene	120.89	132.23	119.88	126.75	126.84	125.32±5.03

Week	Chemical	Tensile Strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	91.37	90.29	89.61	89.76	89.99	90.20±0.70
	Ethanol	92.96	93.06	89.62	88.76	94.03	91.69±2.33
	Isooctane	127.73	124.83	127.60	130.54	131.81	128.50±2.74
	Toluene	118.93	121.42	122.58	126.22	123.34	122.50±2.66
10	Aggressive Ethanol	88.05	87.74	87.74	86.94	89.73	88.04±1.03
	Ethanol	88.44	88.69	88.05	91.55	92.21	89.79±1.94
	Isooctane	127.60	127.04	127.46	128.49	128.64	127.85±0.62
	Toluene	118.31	115.65	118.44	117.07	117.72	117±1.14
13	Aggressive Ethanol	87.75	87.56	86.59	86.89	88.17	87.39±0.64
	Ethanol	89.22	88.29	90.11	91.77	89.71	89.82±1.28
	Isooctane	122.34	121.99	122.73	122.76	120.86	122.14±0.78
	Toluene	118.3	118.17	117.9	116.58	118.43	117.88±0.75
16	Aggressive Ethanol	83.38	87.37	83.89	80.89	87.92	85.69±2.93
	Ethanol	86.49	90.46	90.06	88.61	88.78	88.88±1.56
	Isooctane	119.75	119.56	119.09	120.63	120.56	119.92±0.66
	Toluene	111.9	112.81	112.2	111.04	112.54	112.10±0.68

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Appendix C2 Tensile Modulus

Table C2-1 Tensile Modulus of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Tensile Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	2229	2207	2215	2213	2192	2204±22
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	1484	1410	1448	1475	1505	1464±37
	Ethanol	1867	1908	1904	1824	1906	1882±37
	Isooctane	1995	1997	2002	1955	1974	1985±20
	Toluene	1949	1951	2000	1987	1924	1949±47
2	Aggressive Ethanol	1240	1194	1231	1236	1232	1227±19
	Ethanol	1689	1727	1698	1756	1727	1719±27
	Isooctane	1700	1858	1777	1737	1826	1780±64
	Toluene	1732	1791	1778	1777	1761	1768±22
3	Aggressive Ethanol	963	943	903	947	980	947±33
	Ethanol	1068	1137	1013	1103	1062	1077±47
	Isooctane	1699	1673	1571	1711	1648	1649±78
	Toluene	1496	1479	1560	1738	1565	1567±102
5	Aggressive Ethanol	361	325	315	329	295	325±24
	Ethanol	884	731	875	778	878	829±70
	Isooctane	1519	1493	1605	1591	1463	1534±62
	Toluene	1487	1493	1367	1471	1343	1432±71

Week	Chemical	Tensile Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	178	192	200	208	195	195±13
	Ethanol	227	224	223	215	225	223±5
	Isooctane	1298	1156	1320	1182	1155	1222±80
	Toluene	1146	1126	1121	1177	1147	1144±22
10	Aggressive Ethanol	197	182	195	181	190	189±7
	Ethanol	187	195	186	189	196	191±5
	Isooctane	1150	1148	1094	1172	1088	1130±37
	Toluene	1106	1065	1063	1051	1090	1075±22
13	Aggressive Ethanol	175	183	182	197	184	184±8
	Ethanol	182	183	181	185	190	184±4
	Isooctane	1029	990	990	990	1022	1004±20
	Toluene	964	995	1063	964	994	996±40
16	Aggressive Ethanol	204	172	169	166	206	184±19
	Ethanol	182	196	182	184	182	185±6
	Isooctane	848	863	890	877	890	874±18
	Toluene	885	777	901	879	903	869±52

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Table C2-2 Tensile modulus of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Tensile Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	3945	3943	3984	3908	3908	3937±28
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	2975	2960	2979	3019	2962	2979±24
	Ethanol	3012	2984	2998	2970	2932	2979±31
	Isooctane	3643	3702	3633	3655	3638	3654±28
	Toluene	3490	3491	3487	3559	3533	3512±32
2	Aggressive Ethanol	2250	2350	2340	2326	2318	2317±39
	Ethanol	2786	2767	2862	2886	2638	2788±97
	Isooctane	3373	3362	3340	3352	3379	3361±16
	Toluene	3119	3127	3197	3185	3298	3186±72
3	Aggressive Ethanol	2226	2250	2233	2207	2229	2229±18
	Ethanol	2457	2369	2371	2344	2268	2362±68
	Isooctane	2493	2492	2649	2603	2631	2573±76
	Toluene	2384	2461	2471	2488	2425	2446±42
5	Aggressive Ethanol	1928	1956	1951	1961	1926	1944±16
	Ethanol	2258	2247	2247	2147	2176	2215±50
	Isooctane	2488	2402	2485	2446	2472	2459±36
	Toluene	2426	2423	2410	2416	2406	2416±8

Week	Chemical	Tensile Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	1760	1766	1761	1728	1628	1728±58
	Ethanol	1671	1879	1711	1623	1849	1746±112
	Isooctane	2306	2360	2392	2417	2472	2389±62
	Toluene	2307	2334	2308	2337	2393	2336±35
10	Aggressive Ethanol	1370	1333	1395	1309	1411	1364±42
	Ethanol	1452	1516	1522	1417	1493	1480±44
	Isooctane	2403	2273	2316	2322	2346	2332±48
	Toluene	2322	2286	2295	2319	2386	2322±39
13	Aggressive Ethanol	1367	1334	1348	1331	1327	1342±16
	Ethanol	1350	1335	1351	1472	1359	1374±56
	Isooctane	2305	2360	2392	2416	2471	2389±62
	Toluene	2307	2272	2303	2307	2307	2299±15
16	Aggressive Ethanol	1344	1340	1336	1302	1344	1333±18
	Ethanol	1363	1369	1349	1351	1362	1359±9
	Isooctane	2261	2184	2279	2205	2287	2243±46
	Toluene	2201	2140	2245	2245	2295	2225±58

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Table C2-3 Tensile modulus of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Tensile Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol						5626±76
	Ethanol	5622	5592	5757	5601	5560	
	Isooctane						
	Toluene						
1	Aggressive Ethanol	4246	4388	4347	4319	4424	4345±68
	Ethanol	4646	4632	4642	4598	4694	4642±40
	Isooctane	5007	5005	4890	5135	4991	5006±123
	Toluene	5067	5260	4897	5152	4951	5066±170
2	Aggressive Ethanol	3792	4094	4123	4001	3660	3934±201
	Ethanol	4253	3956	4072	4270	4247	4160±139
	Isooctane	4840	4785	4865	4723	4973	4837±108
	Toluene	4905	4907	4868	4877	4962	4904±42
3	Aggressive Ethanol	3715	3694	3764	3737	3718	3725±26
	Ethanol	3827	3876	3822	3870	3887	3856±30
	Isooctane	4823	4778	4880	4655	4756	4779±83
	Toluene	4735	4705	4697	4668	4706	4702±24
5	Aggressive Ethanol	3281	3101	3217	3300	3062	3192±106
	Ethanol	3446	3538	3400	3576	3516	3495±64
	Isooctane	4956	4694	4712	4522	4938	4764±182
	Toluene	4664	4555	4749	4270	4534	4555±181

Week	Chemical	Tensile Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	3029	3013	2982	2892	2924	2968±58
	Ethanol	3074	3231	3140	3090	3236	3154±77
	Isooctane	4306	4124	4323	4456	4259	4294±120
	Toluene	4113	4136	3961	3998	4146	4071±85
10	Aggressive Ethanol	2784	2855	2653	2616	2595	2701±113
	Ethanol	2864	2726	2941	2787	2861	2836±82
	Isooctane	4234	4308	4274	4166	4455	4287±96
	Toluene	3983	4048	3924	4118	4066	4028±75
13	Aggressive Ethanol	2506	2547	2476	2530	2580	2528±40
	Ethanol	2694	2624	2628	2668	2678	2659±31
	Isooctane	4185	4223	4192	4235	4141	4195±37
	Toluene	3902	3978	3925	3959	3823	3917±60
16	Aggressive Ethanol	2567	2452	2530	2532	2458	2508±51
	Ethanol	2528	2623	2649	2551	2621	2594±52
	Isooctane	3978	4146	4036	3987	4198	4069±98
	Toluene	3781	3810	3784	3832	3817	3805±22

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Appendix C3 Flexural Strength

Table C3-1 Flexural strength of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Flexural Strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	99.05	100.83	101.02	100.70	99.53	100.23±0.88
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	50.61	51.16	51.39	52.49	50.89	51.31±0.72
	Ethanol	55.74	55.50	54.91	55.46	54.42	55.21±0.53
	Isooctane	70.01	76.87	76.49	76.90	76.33	75.32±2.98
	Toluene	68.01	68.88	69.18	70.11	69.53	69.14±0.78
2	Aggressive Ethanol	46.78	46.96	48.57	46.07	47.78	47.10±1.06
	Ethanol	45.89	49.97	49.13	46.85	47.96	47.98±1.14
	Isooctane	59.26	59.75	58.04	59.83	59.50	59.28±0.73
	Toluene	59.90	60.59	60.38	59.79	58.73	59.87±0.72
3	Aggressive Ethanol	31.16	31.31	31.53	31.08	31.49	31.31±0.20
	Ethanol	31.22	31.52	30.77	30.86	31.74	31.22±0.42
	Isooctane	58.42	58.65	57.82	56.45	58.95	58.06±0.99
	Toluene	56.07	59.73	57.75	56.56	57.03	57.43±1.43
5	Aggressive Ethanol	25.72	24.89	25.26	24.55	25.53	25.19±0.48
	Ethanol	30.58	30.52	30.04	29.40	28.41	29.99±1.18
	Isooctane	56.57	54.43	56.02	57.67	55.39	56.02±1.41
	Toluene	45.04	44.27	42.17	46.56	43.62	44.33±1.63

Week	Chemical	Flexural Strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	23.55	22.80	23.96	23.93	22.67	23.38±0.55
	Ethanol	27.18	27.98	27.72	27.15	26.83	27.37±0.47
	Isooctane	42.07	42.59	44.89	43.18	41.35	42.82±1.34
	Toluene	39.74	39.27	39.05	39.94	40.16	39.63±0.46
10	Aggressive Ethanol	22.58	22.19	22.94	23.42	22.49	22.72±0.47
	Ethanol	21.71	22.91	20.62	21.15	21.18	21.51±0.87
	Isooctane	37.39	36.05	36.97	37.28	35.69	36.68±0.76
	Toluene	34.73	35.43	34.31	35.20	34.00	34.73±0.69
13	Aggressive Ethanol	19.96	20.44	20.46	20.57	20.58	20.40±0.26
	Ethanol	21.34	20.99	21.05	20.99	21.31	21.14±0.17
	Isooctane	33.64	33.20	35.13	36.11	37.71	35.16±1.84
	Toluene	34.28	33.96	33.46	33.52	34.42	33.93±0.44
16	Aggressive Ethanol	19.62	20.73	20.01	20.16	21.10	20.33±0.59
	Ethanol	20.34	20.65	20.05	21.32	20.52	20.57±0.47
	Isooctane	34.96	33.42	34.26	35.68	34.58	34.58±0.84
	Toluene	33.71	33.67	33.68	33.86	33.55	33.70±0.11

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Table C3-2 Flexural strength of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Flexural Strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	149.78	148.77	154.20	150.60	149.12	150.49±2.19
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	124.74	128.32	126.75	121.88	130.29	126.40±3.25
	Ethanol	140.67	136.22	143.12	135.92	138.77	138.94±3.04
	Isooctane	150.33	145.38	142.88	149.19	149.84	147.53±3.25
	Toluene	145.93	141.36	139.74	142.84	145.94	143.16±2.76
2	Aggressive Ethanol	99.86	102.87	99.77	99.60	101.18	100.66±1.39
	Ethanol	100.12	103.99	102.86	103.83	104.75	103.11±1.80
	Isooctane	145.98	144.17	141.09	136.51	145.25	142.60±3.88
	Toluene	130.43	132.11	142.82	143.10	133.71	136.43±6.07
3	Aggressive Ethanol	97.73	97.24	96.52	95.37	94.86	96.34±1.22
	Ethanol	98.08	97.82	98.88	98.54	96.43	97.95±0.94
	Isooctane	139.82	140.32	138.00	144.63	144.12	141.38±2.87
	Toluene	124.26	124.81	122.73	126.57	124.90	124.65±1.38
5	Aggressive Ethanol	70.72	72.85	74.47	74.27	72.53	72.97±1.52
	Ethanol	78.35	80.29	77.87	82.78	79.82	79.82±1.94
	Isooctane	96.65	100.72	104.65	102.80	102.77	101.52±3.06
	Toluene	102.02	100.92	100.59	100.83	101.47	101.17±0.58

Week	Chemical	Flexural Strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	60.98	63.80	60.98	63.13	65.88	62.95±2.07
	Ethanol	66.63	68.77	67.79	68.05	65.90	67.43±1.15
	Isooctane	84.52	84.67	83.86	81.83	83.88	83.75±1.13
	Toluene	83.26	83.22	85.46	85.85	82.77	84.11±1.43
10	Aggressive Ethanol	63.56	62.76	63.12	60.85	62.25	62.51±1.04
	Ethanol	61.01	61.03	60.84	61.76	61.03	61.13±0.36
	Isooctane	85.33	83.54	84.97	84.70	79.17	83.54±2.54
	Toluene	82.74	86.99	82.60	86.11	81.68	84.03±2.36
13	Aggressive Ethanol	60.41	60.01	60.45	60.18	58.38	59.89±0.86
	Ethanol	62.72	63.58	59.16	63.07	60.00	61.71±1.99
	Isooctane	82.48	83.35	82.22	82.20	82.56	82.56±0.47
	Toluene	83.45	84.24	76.05	83.28	85.45	82.49±3.70
16	Aggressive Ethanol	58.80	58.25	58.07	58.03	59.50	58.53±0.62
	Ethanol	62.02	60.49	60.56	60.34	61.26	60.93±0.70
	Isooctane	79.60	78.52	78.22	76.74	80.62	78.74±1.47
	Toluene	74.55	73.77	72.22	74.76	73.87	73.83±1.00

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Table C3-3 Flexural strength of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Flexural Strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	209.68	215.26	211.97	216.28	215.99	213.84±2.89
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	164.57	165.91	172.58	172.32	170.18	169.11±3.69
	Ethanol	179.36	177.97	177.23	178.25	180.15	178.71±1.15
	Isooctane	206.41	211.48	208.79	215.78	208.37	210.16±3.62
	Toluene	205.19	210.29	203.13	208.22	210.55	207.48±3.24
2	Aggressive Ethanol	142.09	142.66	144.16	141.80	140.00	142.14±1.50
	Ethanol	145.88	149.84	145.45	148.46	151.91	148.31±2.71
	Isooctane	200.48	184.60	194.46	196.52	188.14	192.84±6.41
	Toluene	176.84	179.53	175.53	180.79	178.23	178.20±2.07
3	Aggressive Ethanol	133.80	132.23	131.35	129.06	132.72	131.83±1.78
	Ethanol	141.37	140.69	141.06	140.18	140.35	140.73±0.49
	Isooctane	173.17	180.76	185.83	186.15	178.95	180.97±5.37
	Toluene	173.02	171.92	165.20	170.32	171.88	170.47±3.10
5	Aggressive Ethanol	115.78	115.13	115.66	115.44	115.19	115.44±0.28
	Ethanol	121.79	122.94	120.03	123.05	122.39	122.04±1.23
	Isooctane	169.31	167.24	165.85	164.27	168.15	166.96±1.97
	Toluene	158.48	155.79	156.97	156.26	154.93	156.48±1.34

Week	Chemical	Flexural Strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	107.77	111.97	110.31	109.50	109.83	109.88±1.51
	Ethanol	111.96	113.80	116.33	114.61	113.44	114.03±1.61
	Isooctane	159.44	160.68	162.84	161.25	157.83	160.41±1.89
	Toluene	147.22	153.05	151.85	152.62	150.28	151.01±2.37
10	Aggressive Ethanol	104.01	104.88	104.30	104.07	104.34	104.32±0.34
	Ethanol	103.66	105.60	107.71	102.70	105.66	105.07±1.95
	Isooctane	153.99	154.45	151.99	152.16	151.35	152.79±1.35
	Toluene	151.48	148.09	147.61	148.64	149.97	149.16±1.57
13	Aggressive Ethanol	104.61	103.46	103.39	104.21	103.18	103.77±0.61
	Ethanol	105.13	104.45	105.45	103.78	104.70	104.70±0.64
	Isooctane	142.62	146.14	144.66	148.74	141.36	144.71±2.91
	Toluene	139.58	136.94	137.74	139.83	139.71	138.76±1.33
16	Aggressive Ethanol	103.06	100.92	103.50	103.68	101.84	102.60±1.18
	Ethanol	103.43	104.00	105.14	107.48	103.34	104.68±1.72
	Isooctane	142.42	141.94	138.72	139.03	142.01	140.82±1.79
	Toluene	132.64	129.73	133.22	133.49	131.30	132.08±1.56

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Appendix C4 Flexural Modulus

Table C4-1 Flexural modulus of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Flexural Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	2544	2558	2601	2602	2586	2578±26
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	1032	961	958	959	991	980±32
	Ethanol	1154	1153	1154	1159	1158	1156±3
	Isooctane	2517	2502	2490	2470	2795	2555±135
	Toluene	2633	2677	2679	2632	2695	2663±29
2	Aggressive Ethanol	968	972	947	943	970	957±14
	Ethanol	1072	1031	1078	1036	1041	1052±21
	Isooctane	2506	2566	2461	2543	2453	2506±50
	Toluene	2504	2475	2523	2478	2534	2503±26
3	Aggressive Ethanol	651	635	655	650	649	648±9
	Ethanol	702	647	720	678	658	681±30
	Isooctane	2577	2502	2408	2490	2500	2495±60
	Toluene	2554	2410	2514	2382	2477	2467±71
5	Aggressive Ethanol	514	479	523	497	509	505±17
	Ethanol	643	634	626	629	611	629±12
	Isooctane	1238	1251	1207	1320	1240	1251±42
	Toluene	1159	1227	1154	1154	1103	1160±44

Week	Chemical	Flexural Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	469	462	476	479	461	469±7
	Ethanol	520	543	522	496	502	516±18
	Isooctane	884	921	913	892	865	895±22
	Toluene	845	841	854	856	873	854±13
10	Aggressive Ethanol	440	414	444	430	422	430±13
	Ethanol	429	419	437	428	472	437±21
	Isooctane	814	853	830	814	814	825±17
	Toluene	785	764	785	764	775	775±10
13	Aggressive Ethanol	435	429	425	427	418	427±6
	Ethanol	421	435	421	447	434	432±11
	Isooctane	750	876	866	799	827	824±51
	Toluene	772	743	758	788	746	761±19
16	Aggressive Ethanol	415	424	417	410	409	415±6
	Ethanol	419	412	416	427	416	418±5
	Isooctane	767	776	809	793	821	793±22
	Toluene	740	761	753	760	773	757±12

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Table C4-2 Flexural modulus of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Flexural Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	4068	4234	4419	4355	4213	4258±136
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	3390	3421	3492	3409	3339	3410±55
	Ethanol	3721	3603	3691	3610	3611	3647±55
	Isooctane	4319	4096	4154	4207	4205	4196±82
	Toluene	4213	4072	4121	4082	4027	4103±70
2	Aggressive Ethanol	2575	2609	2545	2507	2509	2549±44
	Ethanol	2609	2755	2680	2740	2742	2705±61
	Isooctane	4136	4055	4244	4064	4234	4146±90
	Toluene	3752	3708	4027	4251	3988	3945±221
3	Aggressive Ethanol	2605	2558	2451	2470	2429	2503±76
	Ethanol	2527	2543	2515	2543	2506	2527±16
	Isooctane	4012	3998	3965	4187	4260	4084±131
	Toluene	3606	3509	3521	3675	3662	3595±77
5	Aggressive Ethanol	1711	1671	1653	1699	1740	1695±34
	Ethanol	1881	1903	1831	1870	1870	1871±26
	Isooctane	2516	2630	2711	2737	2415	2602±135
	Toluene	2415	2594	2517	2571	2573	2534±72
7	Aggressive Ethanol	1544	1560	1541	1562	1618	1565±31
	Ethanol	1677	1674	1653	1663	1641	1661±15
	Isooctane	2330	2351	2300	2275	2358	2323±35

Week	Chemical	Flexural Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
	Toluene	2232	2158	2280	2283	2198	2230±54
10	Aggressive Ethanol	1585	1591	1608	1489	1559	1567±47
	Ethanol	1599	1710	1595	1583	1758	1649±80
	Isooctane	2271	2321	2304	2289	2181	2273±54
	Toluene	2140	2367	2162	2122	2158	2190±100
13	Aggressive Ethanol	1606	1549	1555	1539	1565	1563±26
	Ethanol	1648	1653	1541	1677	1508	1605±76
	Isooctane	2222	2288	2262	2258	2315	2269±35
	Toluene	1939	2150	2202	2256	2263	2162±132
16	Aggressive Ethanol	1573	1573	1518	1542	1591	1559±29
	Ethanol	1585	1563	1561	1591	1584	1577±14
	Isooctane	2117	2068	2090	2129	2151	2111±33
	Toluene	1980	1996	1934	1983	1946	1968±26

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Table C4-3 Flexural modulus of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Flexural Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	7001	6817	6919	6864	6924	6905±69
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	4634	4775	4764	4692	4678	4709±60
	Ethanol	4943	4854	4870	4953	4936	4911±45
	Isooctane	6341	6548	6519	6807	6594	6562±167
	Toluene	5981	6302	6205	6083	6131	6140±122
2	Aggressive Ethanol	3855	3843	3926	3878	3848	3870±34
	Ethanol	3959	4030	3975	4039	4059	4012±43
	Isooctane	5826	5796	5615	5553	6076	5773±205
	Toluene	5363	5272	5365	5264	5408	5334±63
3	Aggressive Ethanol	3618	3569	3520	3577	3625	3582±42
	Ethanol	3746	3799	3770	3744	3750	3762±23
	Isooctane	5777	5641	5813	5564	5628	5685±106
	Toluene	5165	5039	5240	5127	5193	5153±76
5	Aggressive Ethanol	3059	3060	3069	3033	3039	3052±15
	Ethanol	3245	3208	3155	3218	3150	3195±42
	Isooctane	4968	4933	4760	4789	4884	4867±90
	Toluene	4583	4594	4517	4506	4592	4558±43

Week	Chemical	Flexural Modulus (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	2977	3066	3001	3105	3079	3046±54
	Ethanol	3008	3095	3153	3168	3161	3117±67
	Isooctane	4722	4855	4845	4857	4849	4826±58
	Toluene	4448	4596	4509	4544	4592	4538±62
10	Aggressive Ethanol	2984	2950	2966	2946	2947	2959±16
	Ethanol	2917	3104	3048	3053	3029	3030±69
	Isooctane	4610	4626	4576	4634	4586	4606±25
	Toluene	4479	4403	4405	4440	4404	4426±33
13	Aggressive Ethanol	2887	2898	2939	2924	3047	2939±64
	Ethanol	2990	2922	2924	2963	2943	2948±29
	Isooctane	4322	4170	4286	4453	4514	4349±137
	Toluene	4148	4196	4172	4127	4197	4168±31
16	Aggressive Ethanol	2870	2855	2937	2912	2933	2901±37
	Ethanol	2888	2876	2885	2994	2926	2914±49
	Isooctane	4371	4405	4347	4256	4380	4352±57
	Toluene	4112	4118	4075	3944	4081	4066±71

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Appendix C5 Compressive Strength

Table C5-1 Compressive strength of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Compressive strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	43.24	43.53	47.18	42.88	42.34	43.83±1.92
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	32.73	30.54	27.09	28.55	28.88	29.56±2.16
	Ethanol	27.82	32.62	30.82	29.77	31.46	30.50±1.82
	Isooctane	41.31	41.42	40.49	41.38	42.07	41.33±0.56
	Toluene	42.14	39.89	41.12	40.34	42.53	41.20±1.13
2	Aggressive Ethanol	23.61	24.62	24.39	24.91	21.81	23.87±1.25
	Ethanol	24.87	24.67	25.88	25.63	24.67	25.14±0.57
	Isooctane	38.00	39.94	38.73	38.54	38.90	38.82±0.71
	Toluene	38.35	40.07	36.43	37.24	35.76	37.57±1.70
3	Aggressive Ethanol	21.13	21.48	21.05	20.59	20.62	20.97±0.38
	Ethanol	21.27	22.18	21.64	21.27	21.81	21.63±0.39
	Isooctane	35.01	36.06	36.68	34.99	35.26	35.60±0.74
	Toluene	33.20	36.06	35.32	34.10	37.03	35.14±1.53
5	Aggressive Ethanol	17.55	16.81	16.80	16.11	16.08	16.67±0.61
	Ethanol	19.93	19.84	19.40	20.08	19.21	19.69±0.37
	Isooctane	34.16	31.82	31.34	33.09	32.53	32.59±1.11
	Toluene	30.63	32.15	31.73	32.19	33.01	31.94±0.86

Week	Chemical	Compressive strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	15.11	15.72	15.26	16.45	13.95	15.30±0.92
	Ethanol	20.44	18.58	19.50	19.80	18.86	19.44±0.74
	Isooctane	30.89	29.19	32.78	31.17	28.28	30.46±1.76
	Toluene	29.96	30.23	32.44	28.62	30.92	30.43±1.40
10	Aggressive Ethanol	13.48	14.00	15.90	13.84	13.62	14.17±0.99
	Ethanol	18.62	19.67	20.84	20.67	17.01	19.36±1.59
	Isooctane	28.72	26.12	29.94	25.88	27.98	27.73±1.73
	Toluene	28.26	28.40	28.61	28.85	26.65	28.15±0.87
13	Aggressive Ethanol	13.22	13.35	14.77	13.98	14.76	14.02±0.74
	Ethanol	18.44	19.82	19.72	17.91	19.29	19.04±0.83
	Isooctane	27.76	26.96	25.86	25.45	28.88	26.98±1.40
	Toluene	26.39	26.19	25.93	27.51	25.80	26.36±0.68
16	Aggressive Ethanol	12.98	13.42	13.57	14.03	14.47	13.69±0.57
	Ethanol	18.77	19.10	17.43	18.36	19.02	18.54±0.68
	Isooctane	26.70	26.24	26.36	25.95	26.23	26.30±0.27
	Toluene	26.26	24.40	26.61	25.85	25.65	25.75±0.84

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Table C5-2 Compressive strength of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Compressive strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	70.51	70.17	63.41	67.91	78.42	70.08±5.45
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	49.16	52.25	47.99	47.66	44.56	48.32±2.78
	Ethanol	51.46	51.00	50.43	46.75	47.91	49.51±2.06
	Isooctane	66.58	67.09	66.33	65.09	64.44	65.91±1.10
	Toluene	63.79	59.63	61.59	65.16	62.13	62.46±2.12
2	Aggressive Ethanol	41.86	44.49	43.37	40.12	43.28	42.63±1.68
	Ethanol	35.87	42.69	39.76	51.79	40.44	42.11±5.94
	Isooctane	61.60	61.68	60.60	59.47	59.16	60.50±1.17
	Toluene	54.05	54.23	61.33	58.65	51.29	55.91±4.02
3	Aggressive Ethanol	36.16	39.25	34.99	34.66	31.56	35.32±2.78
	Ethanol	34.31	38.76	34.36	37.00	36.93	36.27±1.91
	Isooctane	55.43	53.13	54.62	58.54	50.51	54.45±2.96
	Toluene	54.76	56.13	49.76	47.57	53.85	52.41±3.60
5	Aggressive Ethanol	35.04	26.99	34.72	34.09	30.65	32.30±3.45
	Ethanol	35.06	34.37	34.98	34.54	35.26	34.84±0.37
	Isooctane	55.70	52.30	48.99	47.07	48.52	50.52±3.47
	Toluene	49.31	53.33	45.69	46.26	45.94	48.11±3.27

Week	Chemical	Compressive strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	30.08	32.83	32.74	28.69	29.39	30.74±1.93
	Ethanol	29.87	32.69	29.76	35.79	30.44	31.71±2.57
	Isooctane	45.43	43.13	44.62	48.54	50.51	46.45±3.01
	Toluene	44.05	44.23	51.33	48.65	41.29	45.91±4.02
10	Aggressive Ethanol	26.96	27.49	28.93	27.43	27.13	27.59±0.78
	Ethanol	31.96	31.50	30.93	27.25	28.41	30.01±2.06
	Isooctane	45.70	42.30	42.99	41.07	42.52	42.92±1.71
	Toluene	43.79	39.63	41.59	46.59	42.13	42.75±2.61
13	Aggressive Ethanol	25.17	27.07	23.99	24.35	25.71	25.26±1.22
	Ethanol	29.39	29.51	29.81	25.12	30.96	28.96±2.23
	Isooctane	42.57	40.88	43.72	40.23	42.96	42.07±1.46
	Toluene	36.95	42.31	38.69	39.26	38.94	39.23±1.94
16	Aggressive Ethanol	24.37	24.02	23.17	22.98	23.68	23.64±0.58
	Ethanol	27.11	25.56	25.16	29.80	29.73	27.47±2.22
	Isooctane	42.09	40.61	41.87	41.13	42.56	41.65±0.78
	Toluene	36.79	36.63	38.59	36.16	39.13	37.46±1.31

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Table C5-3 Compressive strength of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Compressive strength (MPa)					Average (MPa)
		1	2	3	4	5	
0	Aggressive Ethanol	132.52	130.60	126.93	112.19	127.19	125.89±8.01
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	82.25	81.22	95.21	81.99	90.38	86.21±6.26
	Ethanol	94.35	84.46	97.31	89.59	88.75	90.89±5.02
	Isooctane	119.91	115.64	114.97	120.34	116.08	117.39±2.53
	Toluene	101.06	111.26	109.49	113.00	112.23	109.41±4.85
2	Aggressive Ethanol	78.99	78.75	71.57	71.51	87.53	77.67±6.62
	Ethanol	74.89	96.89	92.37	72.69	80.42	83.45±10.71
	Isooctane	102.15	111.86	105.38	100.19	109.62	105.84±4.91
	Toluene	91.03	92.93	91.56	89.64	92.52	91.54±1.30
3	Aggressive Ethanol	68.22	71.83	68.64	61.82	65.42	67.18±3.76
	Ethanol	72.07	73.23	72.25	74.11	68.22	71.98±2.25
	Isooctane	93.94	94.01	91.50	89.82	90.06	91.87±2.03
	Toluene	90.41	87.23	87.28	87.76	84.73	87.48±2.02
5	Aggressive Ethanol	66.93	66.16	60.52	63.27	64.15	64.21±2.54
	Ethanol	68.35	68.16	67.55	65.07	68.10	67.44±1.36
	Isooctane	90.65	84.74	89.68	85.83	80.69	86.32±4.02
	Toluene	85.85	75.49	78.79	82.18	85.24	81.51±4.39

Week	Chemical	Compressive strength (MPa)					Average (MPa)
		1	2	3	4	5	
7	Aggressive Ethanol	65.95	66.89	56.77	56.64	63.17	61.89±4.92
	Ethanol	55.99	59.91	58.46	65.50	63.32	60.64±3.80
	Isooctane	76.52	89.27	84.04	73.93	86.50	82.05±6.57
	Toluene	78.01	74.02	73.55	73.95	77.66	75.44±2.20
10	Aggressive Ethanol	50.26	58.98	51.41	58.05	48.14	52.78±4.85
	Ethanol	51.96	58.47	53.00	52.70	57.16	54.66±2.94
	Isooctane	84.23	77.06	77.36	80.57	81.49	80.14±3.00
	Toluene	65.59	67.81	68.84	70.64	67.97	68.17±1.83
13	Aggressive Ethanol	49.34	48.77	48.01	46.54	44.32	47.40±2.01
	Ethanol	47.44	51.72	52.37	46.92	54.71	50.63±3.35
	Isooctane	75.96	79.30	77.76	76.81	75.08	76.98±1.63
	Toluene	60.61	61.28	66.74	59.95	62.64	62.24±2.70
16	Aggressive Ethanol	47.84	44.89	45.61	43.68	44.66	45.34±1.56
	Ethanol	53.63	50.46	45.92	48.72	44.51	48.65±3.63
	Isooctane	74.32	80.11	71.32	70.01	76.42	74.44±4.04
	Toluene	62.92	59.56	58.74	57.34	62.14	60.14±2.34

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Appendix C6 Impact Strength

Table C6-1 Impact strength of PA6 immersed in chemicals of surrogate gasohol

Week	Chemical	Impact Strength (kJ/m ²)					Average (kJ/m ²)
		1	2	3	4	5	
0	Aggressive Ethanol	8.86	9.54	6.61	9.39	7.59	8.40±1.26
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	49.57	55.91	52.27	49.12	55.44	52.46±3.17
	Ethanol	32.41	30.91	32.47	32.26	31.89	31.99±0.64
	Isooctane	18.36	17.78	19.17	18.03	18.44	18.36±0.53
	Toluene	20.07	20.07	21.17	19.64	20.27	20.24±0.57
2	Aggressive Ethanol	127.03	123.33	127.54	124.41	125.86	125.63±1.76
	Ethanol	117.63	121.99	100.03	124.40	119.29	116.67±9.65
	Isooctane	21.16	22.11	21.25	22.67	21.94	21.83±0.63
	Toluene	26.16	26.37	26.71	26.75	26.76	26.55±0.27
3	Aggressive Ethanol	-	-	-	-	-	-
	Ethanol	-	-	-	-	-	-
	Isooctane	27.65	28.57	32.12	28.52	31.41	29.65±1.98
	Toluene	31.07	33.08	28.82	30.80	33.12	31.38±1.80
5	Aggressive Ethanol	-	-	-	-	-	-
	Ethanol	-	-	-	-	-	-
	Isooctane	30.73	32.25	31.52	31.17	30.99	31.33±0.59
	Toluene	35.82	36.43	35.44	34.15	34.60	35.29±0.92

Week	Chemical	Impact Strength (kJ/m ²)					Average (kJ/m ²)
		1	2	3	4	5	
7	Aggressive Ethanol	-	-	-	-	-	-
	Ethanol	-	-	-	-	-	-
	Isooctane	39.57	39.25	35.87	45.90	49.74	42.07±5.61
	Toluene	50.78	52.33	50.86	50.56	53.87	51.68±1.41
10	Aggressive Ethanol	-	-	-	-	-	-
	Ethanol	-	-	-	-	-	-
	Isooctane	43.59	43.91	44.96	44.46	44.21	44.23±0.52
	Toluene	60.87	62.49	58.29	60.69	64.80	61.43±2.41
13	Aggressive Ethanol	-	-	-	-	-	-
	Ethanol	-	-	-	-	-	-
	Isooctane	49.90	50.73	45.53	49.67	50.12	49.19±2.08
	Toluene	147.22	148.06	137.07	143.19	132.20	141.55±6.79
16	Aggressive Ethanol	-	-	-	-	-	-
	Ethanol	-	-	-	-	-	-
	Isooctane	78.82	77.64	79.79	84.36	75.57	79.24±3.27
	Toluene	-	-	-	-	-	-

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Table C6-2 Impact strength of PA6/GF (15 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Impact Strength (kJ/m ²)					Average (kJ/m ²)
		1	2	3	4	5	
0	Aggressive Ethanol	10.70	10.80	10.83	10.74	11.77	10.97±0.45
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	19.35	19.85	19.83	19.09	18.48	19.32±0.57
	Ethanol	16.34	14.83	15.54	15.67	16.57	15.79±0.69
	Isooctane	11.80	12.02	11.66	12.53	12.43	12.09±0.38
	Toluene	13.21	13.11	13.18	13.08	13.29	13.17±0.09
2	Aggressive Ethanol	22.28	20.63	20.60	21.58	22.44	21.51±0.88
	Ethanol	17.22	19.93	17.42	17.28	18.94	18.16±1.22
	Isooctane	13.37	14.26	16.02	15.49	13.75	14.58±1.14
	Toluene	18.09	15.24	16.04	15.38	16.85	16.32±1.18
3	Aggressive Ethanol	27.55	27.40	27.13	26.25	27.61	27.19±0.56
	Ethanol	27.00	27.37	27.06	28.38	28.15	27.59±0.64
	Isooctane	16.62	17.15	16.60	16.02	15.95	16.47±0.50
	Toluene	20.33	20.69	19.81	18.29	19.09	19.47±1.02
5	Aggressive Ethanol	34.44	34.08	33.76	36.98	33.95	34.64±1.33
	Ethanol	32.76	31.58	29.98	33.92	32.52	32.15±1.47
	Isooctane	17.39	18.17	17.91	17.21	17.28	17.59±0.42
	Toluene	21.07	18.45	18.71	18.67	21.58	19.35±1.49

Week	Chemical	Impact Strength (kJ/m ²)					Average (kJ/m ²)
		1	2	3	4	5	
7	Aggressive Ethanol	40.09	42.19	40.85	39.86	41.66	40.93±1.00
	Ethanol	42.73	39.44	42.09	41.53	38.87	40.93±1.69
	Isooctane	17.60	18.09	17.86	17.93	17.90	17.87±0.18
	Toluene	22.92	21.87	19.27	22.53	19.88	21.29±1.63
10	Aggressive Ethanol	47.43	47.72	51.78	48.23	47.64	48.56±1.83
	Ethanol	44.79	43.99	44.33	44.94	42.97	44.20±0.78
	Isooctane	18.39	17.89	19.13	19.56	18.95	18.78±0.65
	Toluene	22.86	23.33	22.01	23.46	24.43	23.22±0.88
13	Aggressive Ethanol	50.44	49.87	50.56	50.79	50.31	50.39±0.34
	Ethanol	46.72	47.97	48.47	48.30	48.25	47.94±0.71
	Isooctane	21.45	20.51	21.20	20.00	20.09	20.65±0.65
	Toluene	24.51	24.71	24.12	24.59	24.25	24.44±0.24
16	Aggressive Ethanol	55.22	54.84	56.24	54.38	54.84	55.11±0.70
	Ethanol	53.24	52.53	49.46	51.19	49.70	51.22±1.67
	Isooctane	24.42	25.10	24.81	24.94	24.87	24.83±0.25
	Toluene	26.41	26.26	26.23	26.83	25.12	26.17±0.64

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Table C6-3 Impact strength of PA6/GF (30 wt%) composite immersed in chemicals of surrogate gasohol

Week	Chemical	Impact Strength (kJ/m ²)					Average (kJ/m ²)
		1	2	3	4	5	
0	Aggressive Ethanol	18.44	19.80	19.23	18.82	19.10	19.08±0.51
	Ethanol						
	Isooctane						
	Toluene						
1	Aggressive Ethanol	27.47	27.89	27.51	26.21	27.85	27.38±0.69
	Ethanol	26.05	26.25	27.66	25.95	27.40	26.66±0.80
	Isooctane	21.67	20.86	20.56	20.71	21.48	21.05±0.49
	Toluene	22.55	21.19	22.13	22.85	23.17	22.38±0.77
2	Aggressive Ethanol	30.24	29.86	29.07	30.60	29.32	29.82±0.63
	Ethanol	30.19	31.23	30.74	31.21	30.83	30.84±0.43
	Isooctane	22.20	22.45	23.45	24.78	23.63	23.30±1.03
	Toluene	24.25	24.53	24.77	25.21	24.75	24.70±0.35
3	Aggressive Ethanol	37.20	38.57	38.07	38.63	40.48	38.59±1.20
	Ethanol	31.56	34.83	31.87	34.90	36.51	33.93±2.14
	Isooctane	25.26	23.63	26.43	23.77	24.94	24.81±1.15
	Toluene	26.33	27.67	27.83	28.89	26.49	27.44±1.05
5	Aggressive Ethanol	44.04	44.38	42.37	41.50	38.98	42.26±2.18
	Ethanol	37.09	42.00	35.12	35.86	41.23	38.26±3.15
	Isooctane	25.40	25.24	24.85	26.08	26.39	25.59±0.63
	Toluene	27.73	28.19	29.83	28.98	30.52	29.05±1.15

Week	Chemical	Impact Strength (kJ/m ²)					Average (kJ/m ²)
		1	2	3	4	5	
7	Aggressive Ethanol	47.65	44.43	45.55	44.38	44.78	45.36±1.37
	Ethanol	39.71	37.82	37.66	40.16	40.65	39.20±1.37
	Isooctane	26.14	26.47	25.89	25.71	28.77	26.60±1.25
	Toluene	31.46	30.29	31.80	31.19	30.63	31.08±0.61
10	Aggressive Ethanol	49.27	46.30	47.64	45.37	49.18	47.55±1.73
	Ethanol	43.42	43.39	41.61	38.21	37.74	40.88±2.75
	Isooctane	30.26	25.94	26.21	28.85	27.22	27.70±1.83
	Toluene	34.57	33.24	31.47	32.60	34.78	33.33±1.38
13	Aggressive Ethanol	50.29	50.74	52.06	50.48	51.10	50.93±0.70
	Ethanol	43.36	43.58	43.22	46.25	40.93	43.47±1.89
	Isooctane	28.25	28.31	29.65	28.21	28.24	28.53±0.63
	Toluene	34.10	35.55	35.56	36.28	36.56	35.61±0.95
16	Aggressive Ethanol	52.12	51.91	53.11	51.90	50.69	51.95±0.86
	Ethanol	45.29	45.68	48.00	46.75	48.00	46.74±1.26
	Isooctane	33.23	30.74	34.30	34.99	35.85	33.82±1.97
	Toluene	37.47	39.93	38.01	39.56	38.61	1.07

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย



APPENDIX D
PRESENTATION

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

1. Siriporn Kaensri and Varun Taepaisitphongse. 2010. Influences of Chemicals in Surrogate Gasohol on Mechanical Properties of Glass Fiber Reinforced Nylon 6 Composites. Proceeding of PCT-1st Polymer Conference of Thailand: 438-442
2. Varun Taepaisitphongse and Siriporn Kaensri. 2011. Influences of Chemicals in Surrogate Gasohol on Mechanical and Thermal Properties of Glass Fiber Reinforced Nylon 6 Composites. Proceeding of 5th Srinakharinwirot Vichakarn: SWU5-1168



ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

VITA

Miss Siriporn Kaensri was born in Prachinburi, Thailand, on January 4th, 1986. She received her high school diploma in 2003 from Triamudomsuksanomklao Kabinburi School, Prachinburi. She received the Bachelor of Engineering Degree with a major in Chemical Engineering from the Faculty of Engineering, Burapha University, Chonburi, in 2007. She continued her study for a Master's Degree in Chemical Engineering at the Department of Chemical Engineering Faculty of Engineering, Chulalongkorn University, Bangkok, in 2008.



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