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].

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

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).

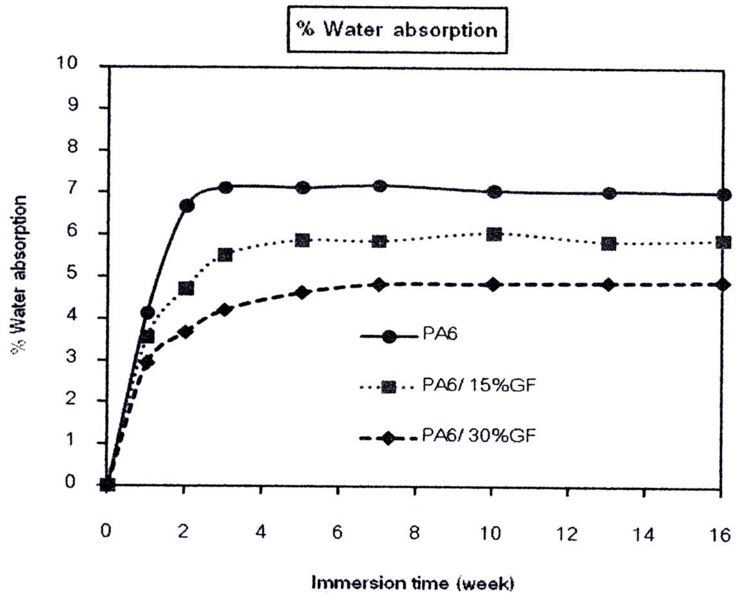

Figure 5.1 Percent water absorption of PA6 and PA6/GF composites

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.

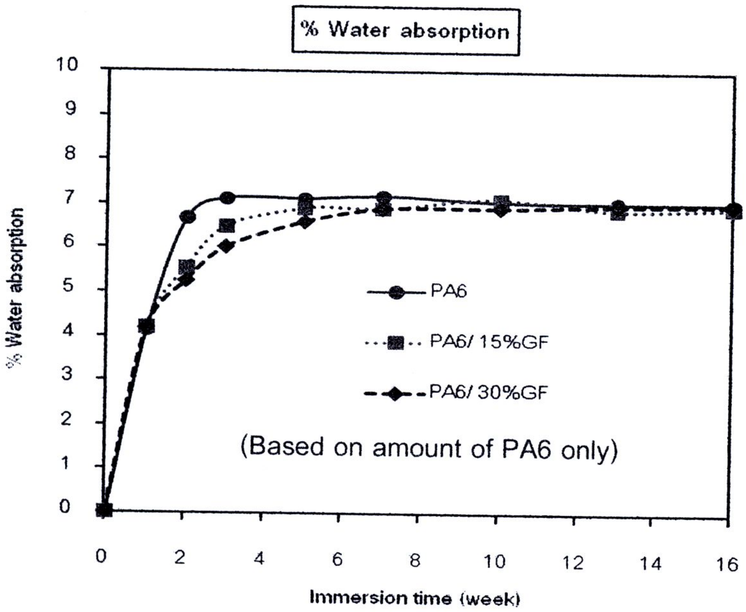

Figure 5.2 Percent water absorption of PA6 and PA6/GF composites based on the amount of PA6 matrix

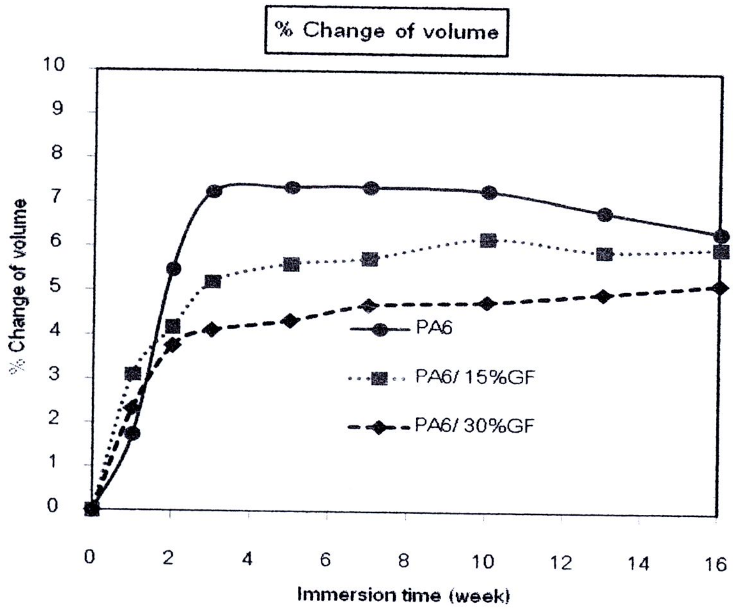

Figure 5.3 Percent volume change of PA6 and PA6/GF composites immersed in water

5.1.2 Mass Change of PA6/GF Composites

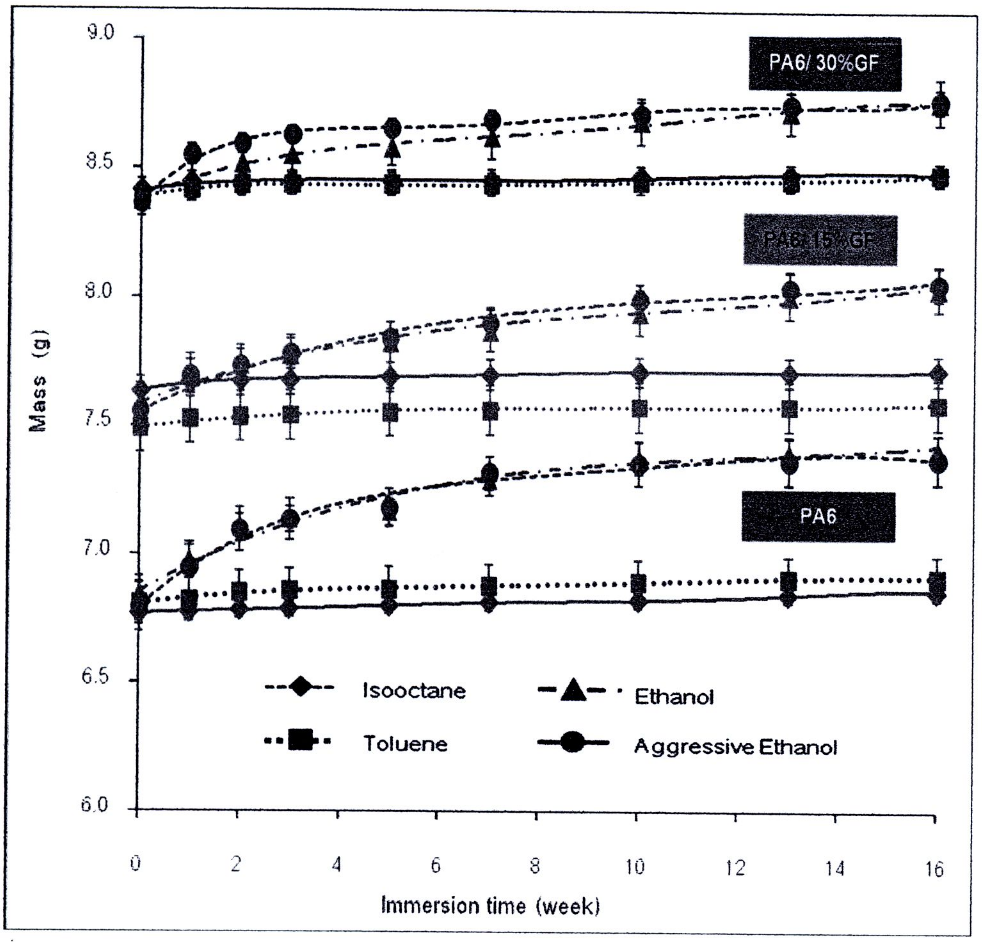

Figure 5.4 Mass of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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 became 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].

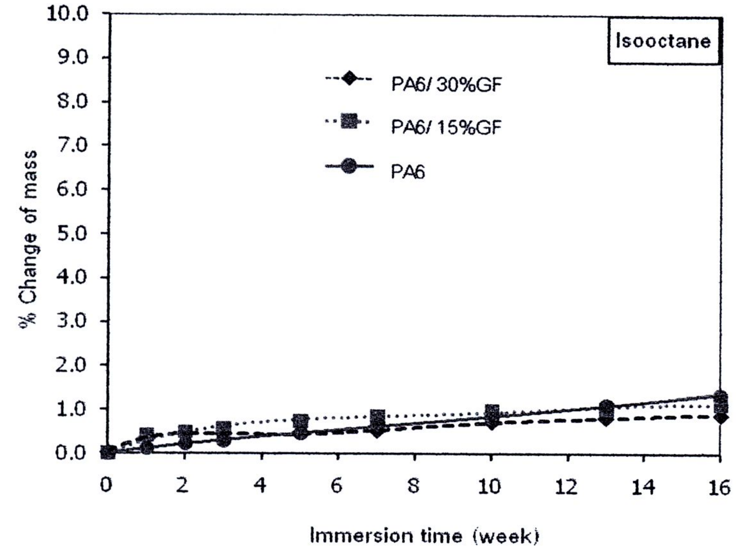

Figure 5.5 Percent mass change of PA6 and PA6/GF composites immersed in isooctane

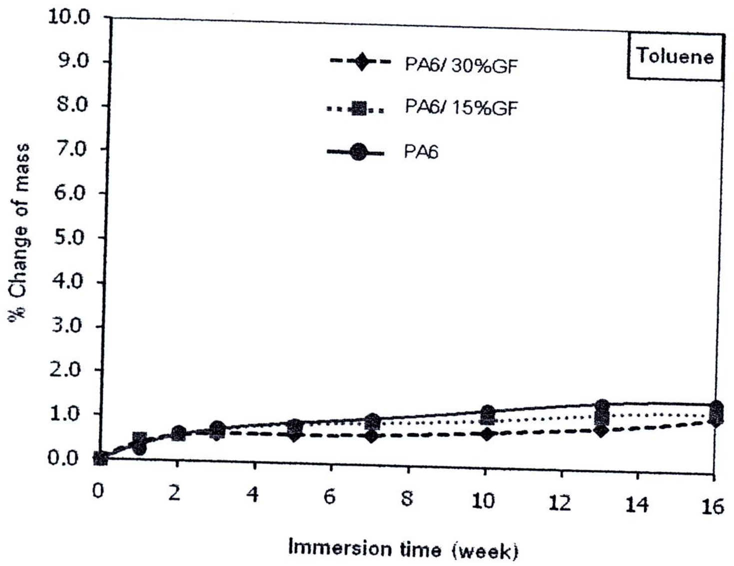

Figure 5.6 Percent mass change of PA6 and PA6/GF composites immersed in toluene

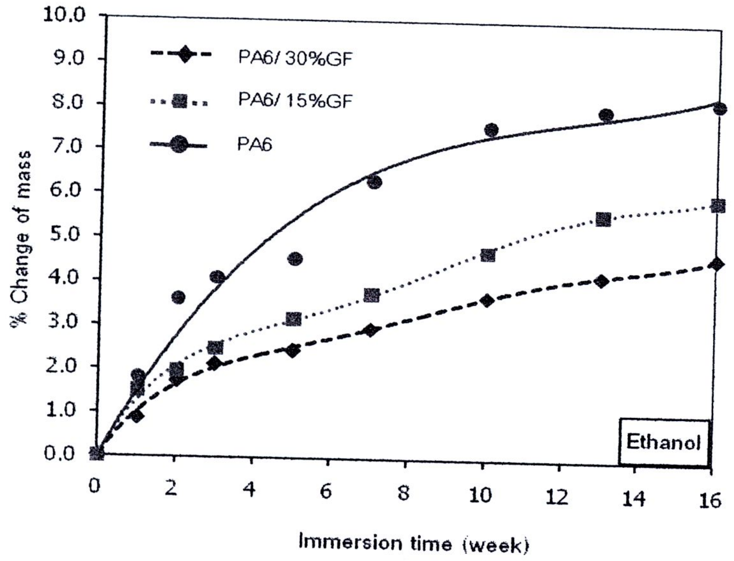

Figure 5.7 Percent mass change of PA6 and PA6/GF composites immersed in ethanol

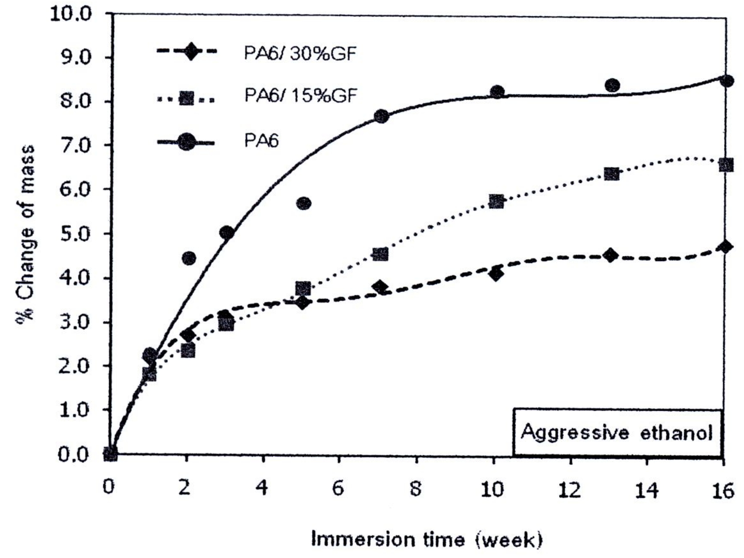

Figure 5.8 Percent mass change of PA6 and PA6/GF composites immersed in aggressive ethanol

5.1.3 Volume Change of PA6/GF Composites

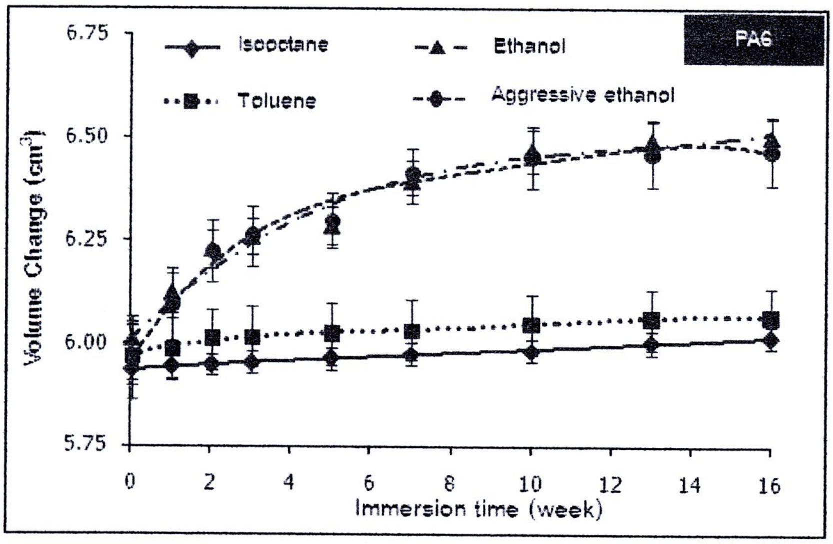

Figure 5.9 Volume of PA6 after immersed in chemicals of surrogate gasohol

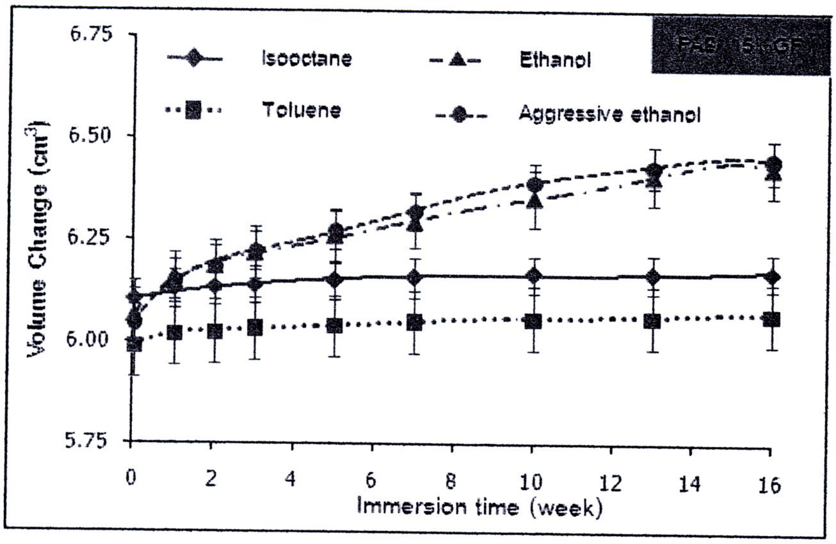

Figure 5.10 Volume of PA6/GF (15 wt%) after immersed in chemicals of surrogate gasohol

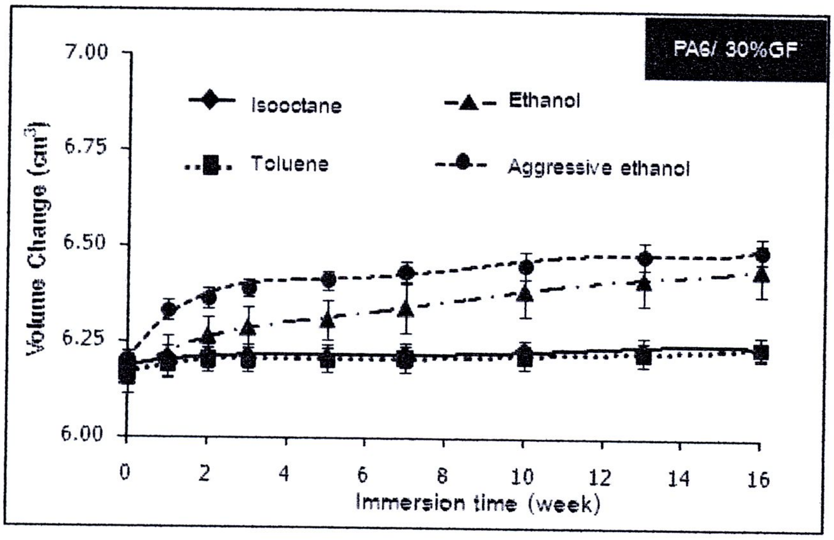

Figure 5.11 Volume of PA6/GF (30 wt%) after immersed in chemicals of surrogate gasohol

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].

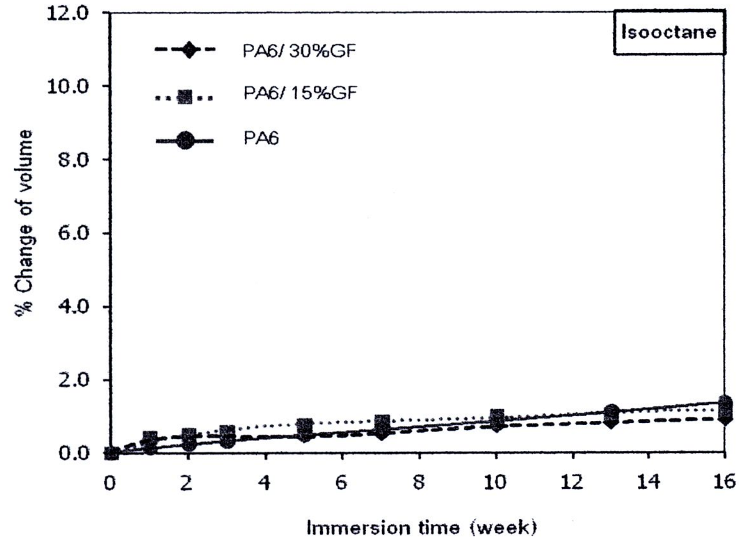

Figure 5.12 Percent volume change of PA6 and PA6/GF composites immersed in isooctane

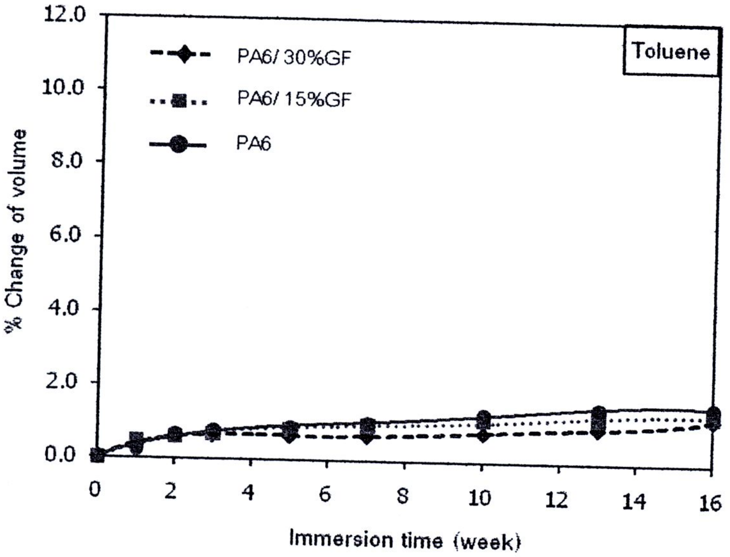

Figure 5.13 Percent volume change of PA6 and PA6/GF composites immersed in toluene

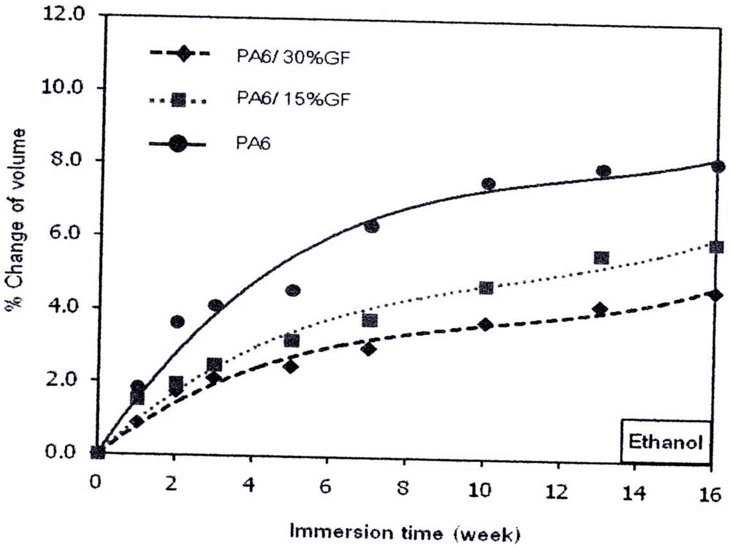

Figure 5.14 Percent volume change of PA6 and PA6/GF composites immersed in ethanol

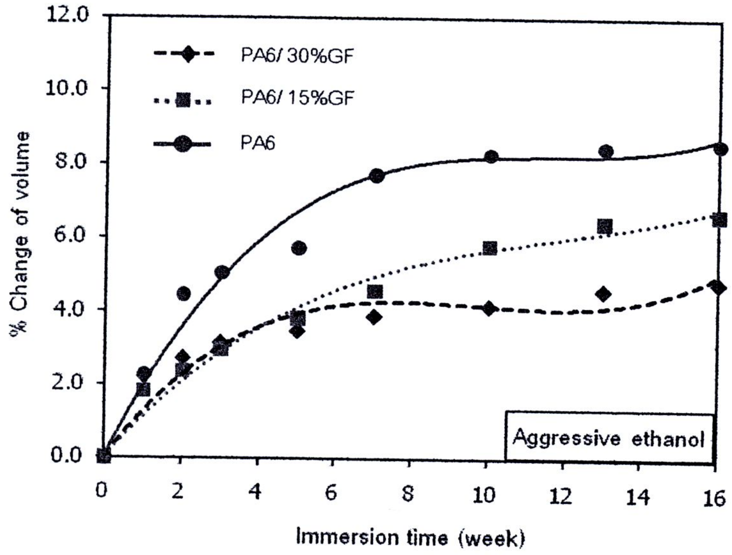

Figure 5.15 Percent volume change of PA6 and PA6/GF composites immersed in aggressive ethanol

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 became 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 unsoakedPA6 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].

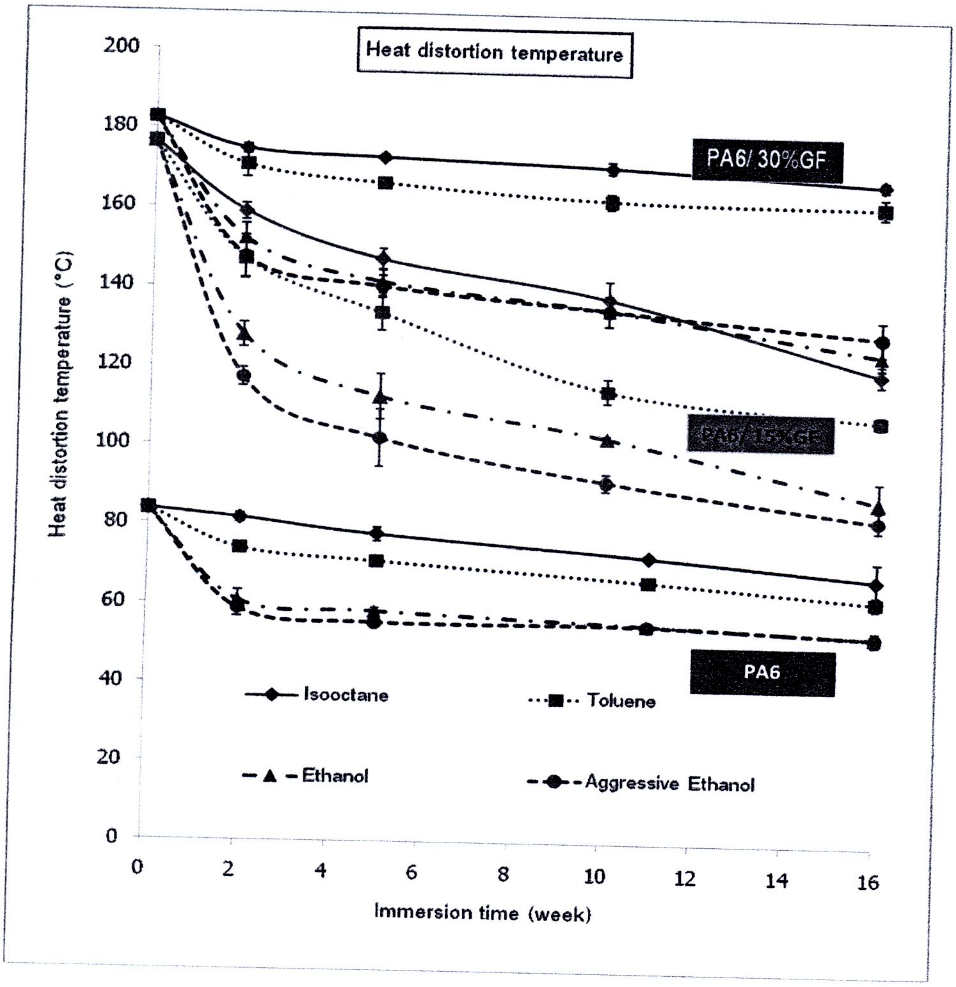

Figure 5.16 Heat distortion temperatures of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

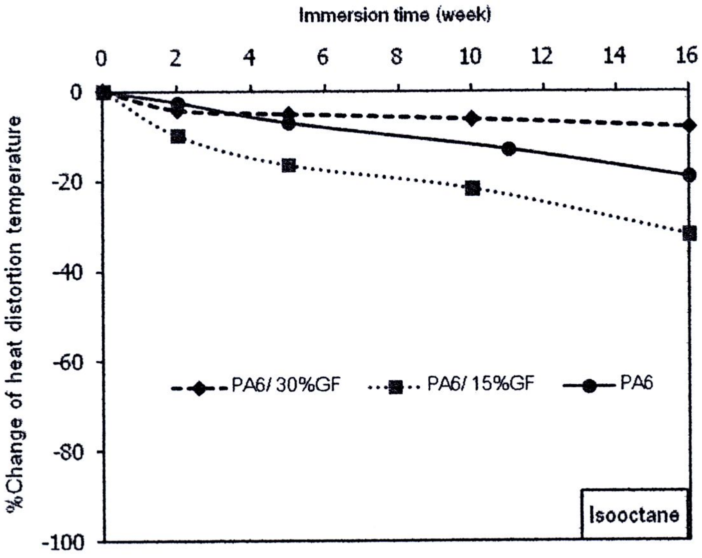

Figure 5.17 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in isooctane

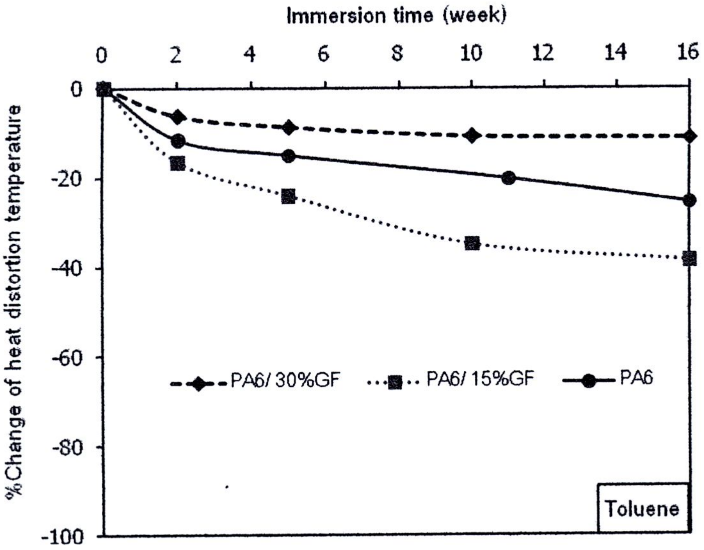

Figure 5.18 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in toluene

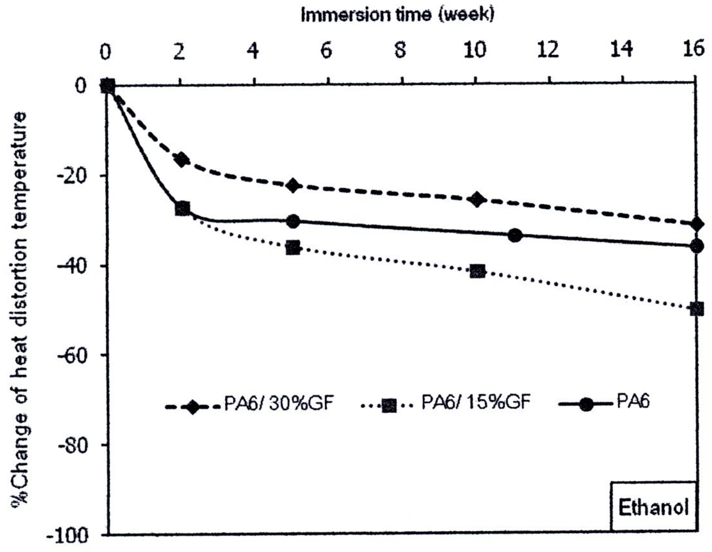

Figure 5.19 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in ethanol

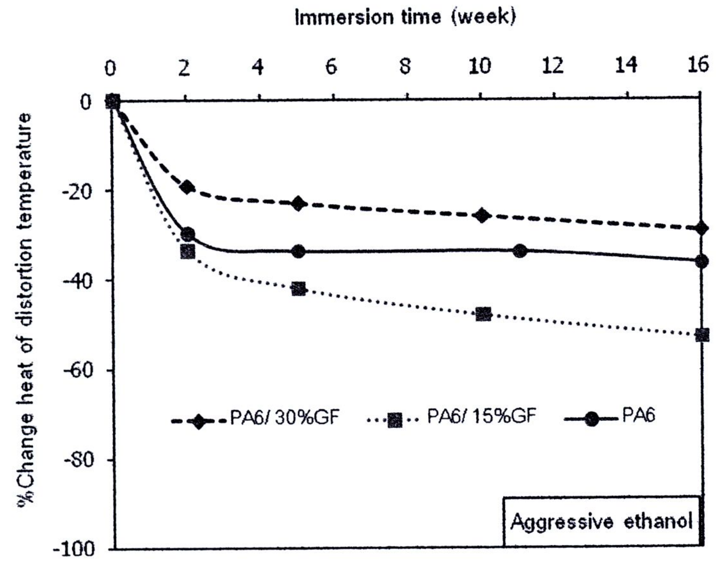

Figure 5.20 Percent change heat distortion temperature of PA6 and PA6/GF composites immersed in aggressive ethanol

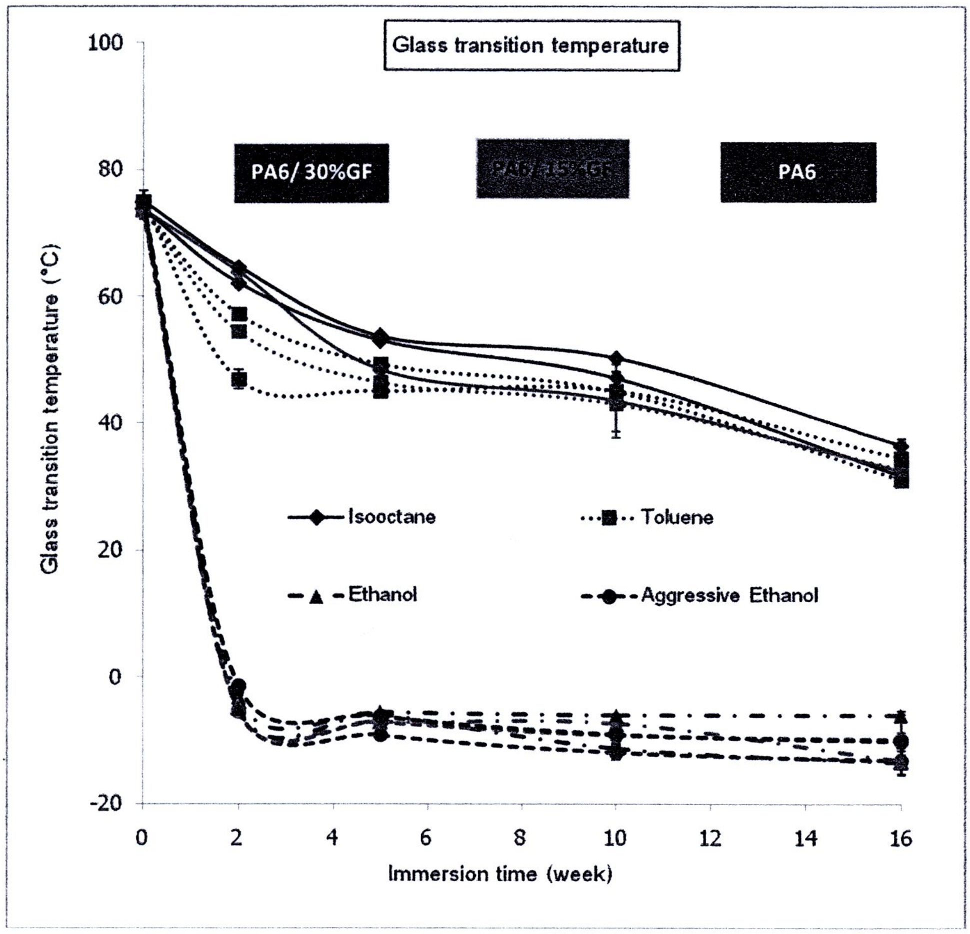

Figure 5.21 Glass transition temperatures of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

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 °C and decreased to around -5 °C and -6 °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.

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 at15 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/m^2 to 19.08 kJ/m^2, 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 from 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.

$$-[\,NH - (CH_2)_5 - CO\,]_n + [H_2O]_n \longrightarrow -[\,NH_2 - (CH_2)_5\,]_n + -[\,(CH_2)_5 - COOH\,]_n$$

From the reaction, the hydrogen in H_2O molecules formed hydrogen bonding to (-NH-) groups in polymeric chain of PA6 leading to amide groups(–NH_2). 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 decease 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].

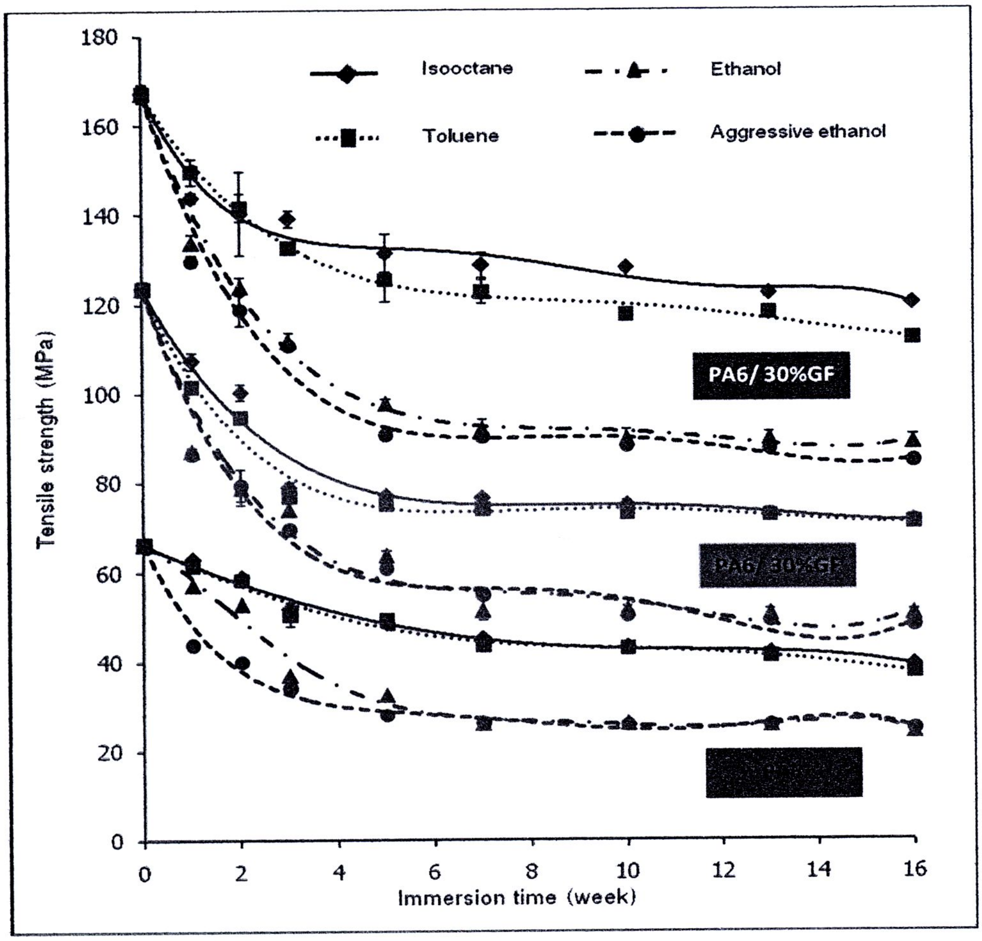

Figure 5.22 Tensile strength of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

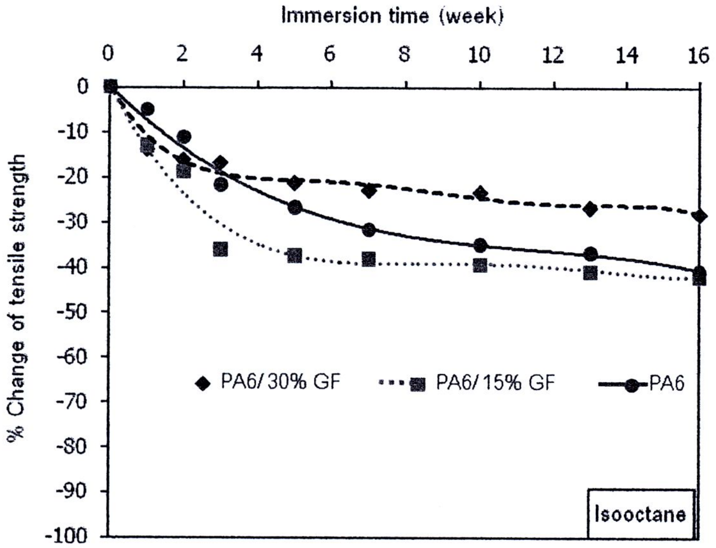

Figure 5.23 Percent change of tensile strength of PA6 and PA6/GF composites immersed in isooctane

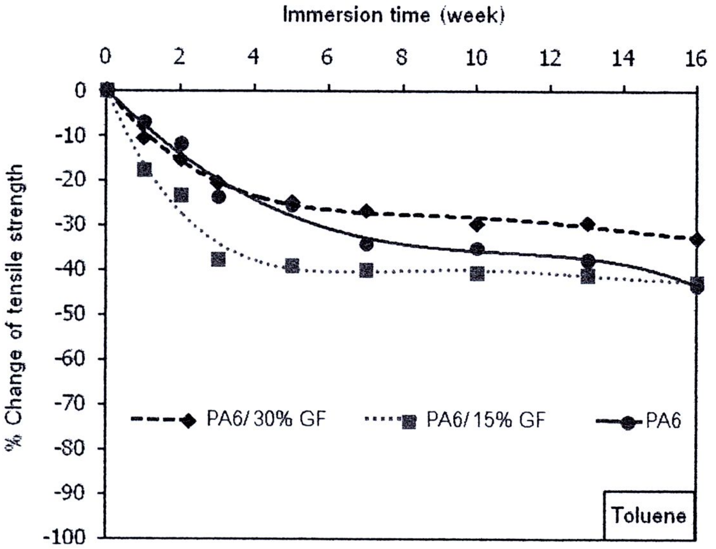

Figure 5.24 Percent change of tensile strength of PA6 and PA6/GF composites immersed in toluene

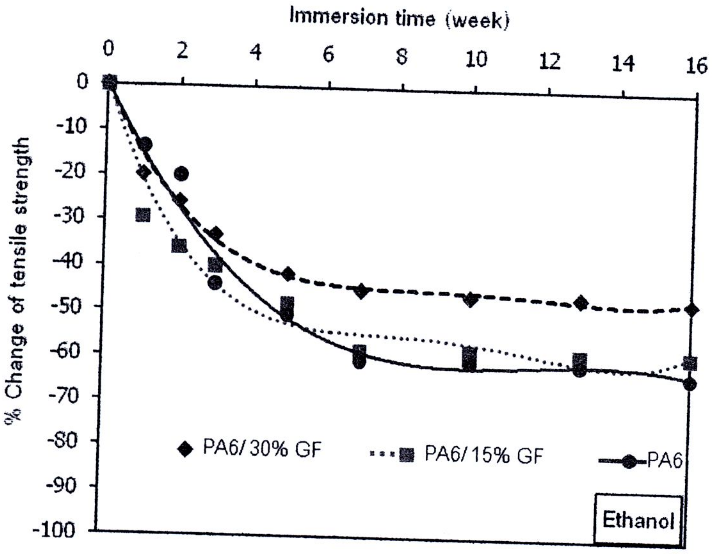

Figure 5.25 Percent change of tensile strength of PA6 and PA6/GF composites immersed in ethanol

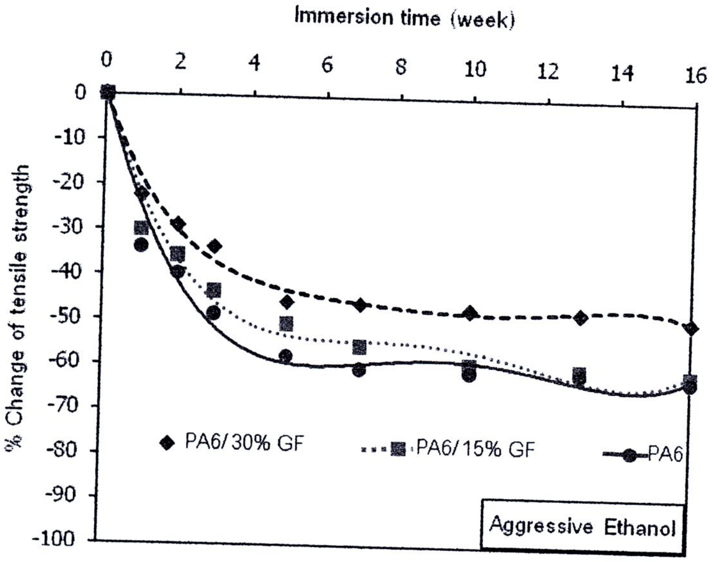

Figure 5.26 Percent change of tensile strength of PA6 and PA6/GF composites immersed in aggressive ethanol

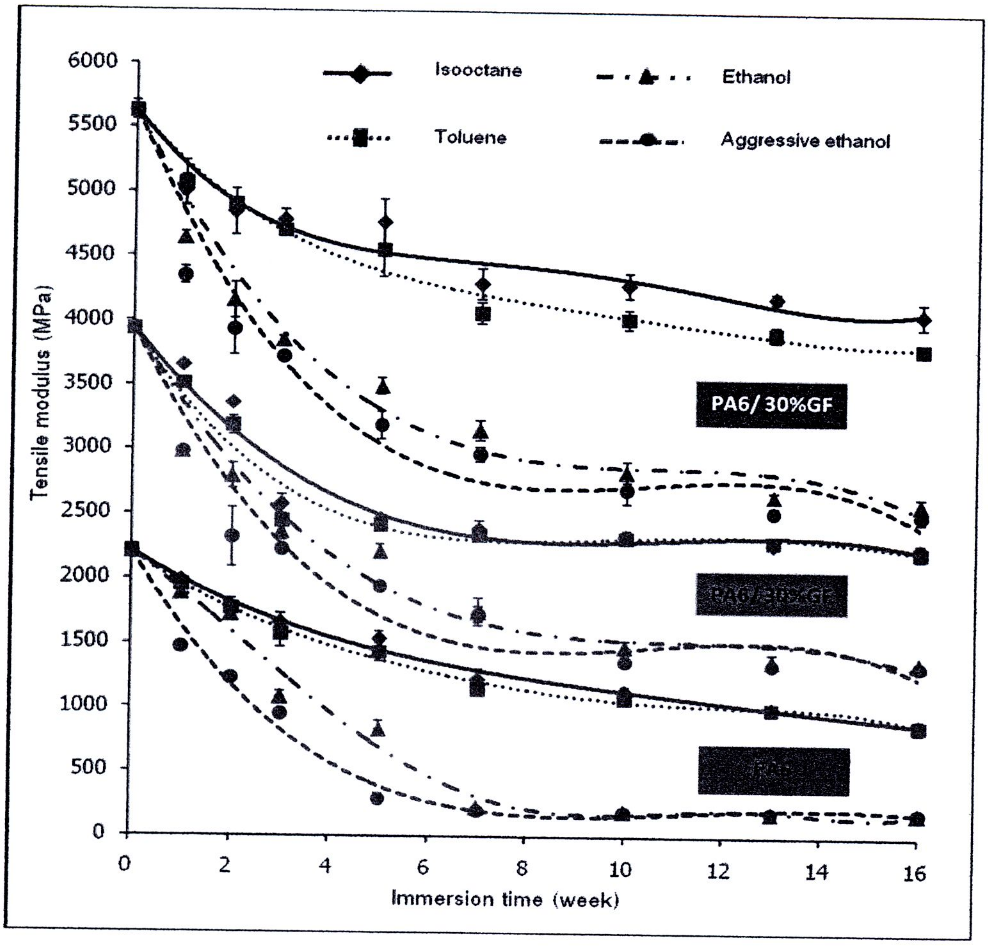

Figure 5.27 Tensile modulus of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

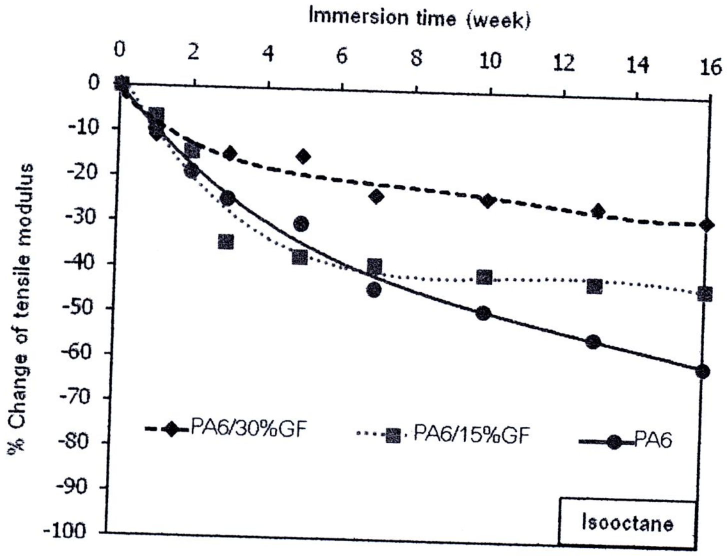

Figure 5.28 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in isooctane

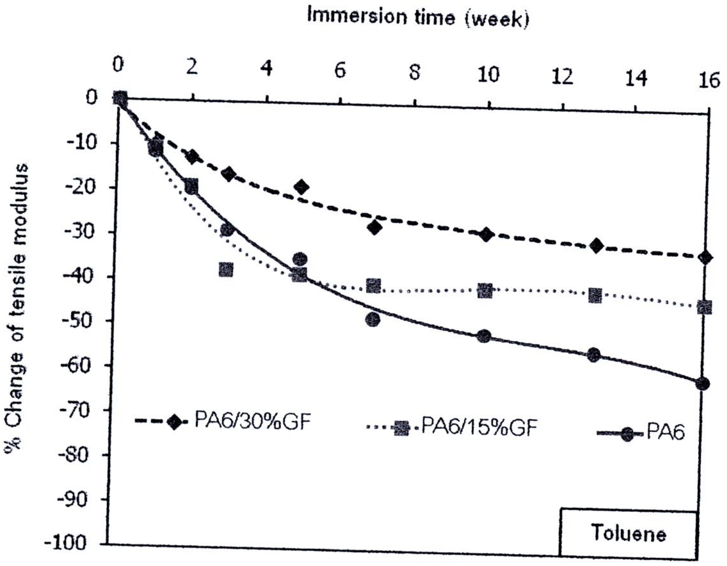

Figure 5.29 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in toluene

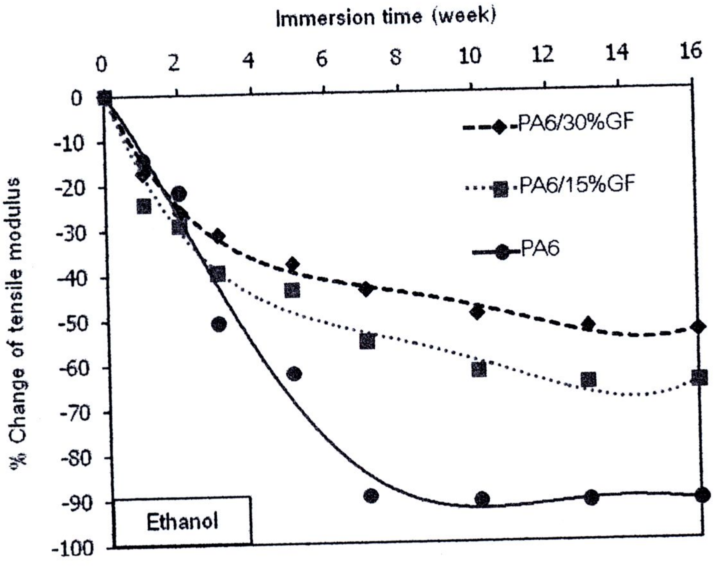

Figure 5.30 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in ethanol

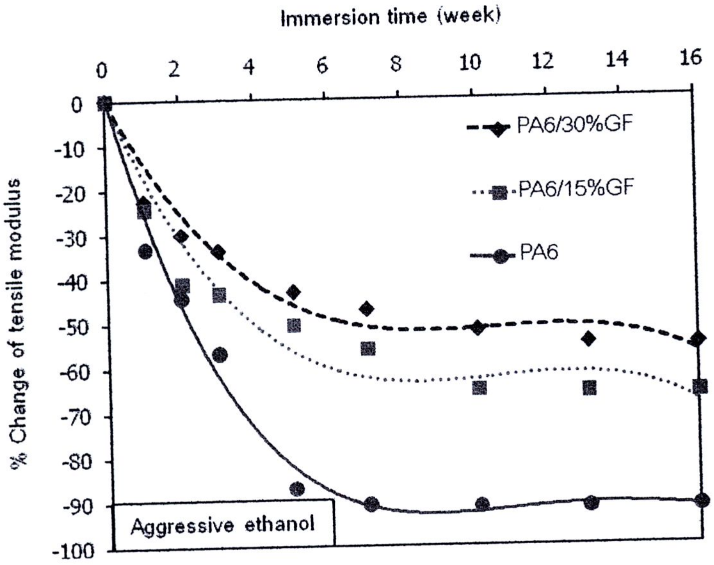

Figure 5.31 Percent change of tensile modulus of PA6 and PA6/GF composites immersed in aggressive ethanol

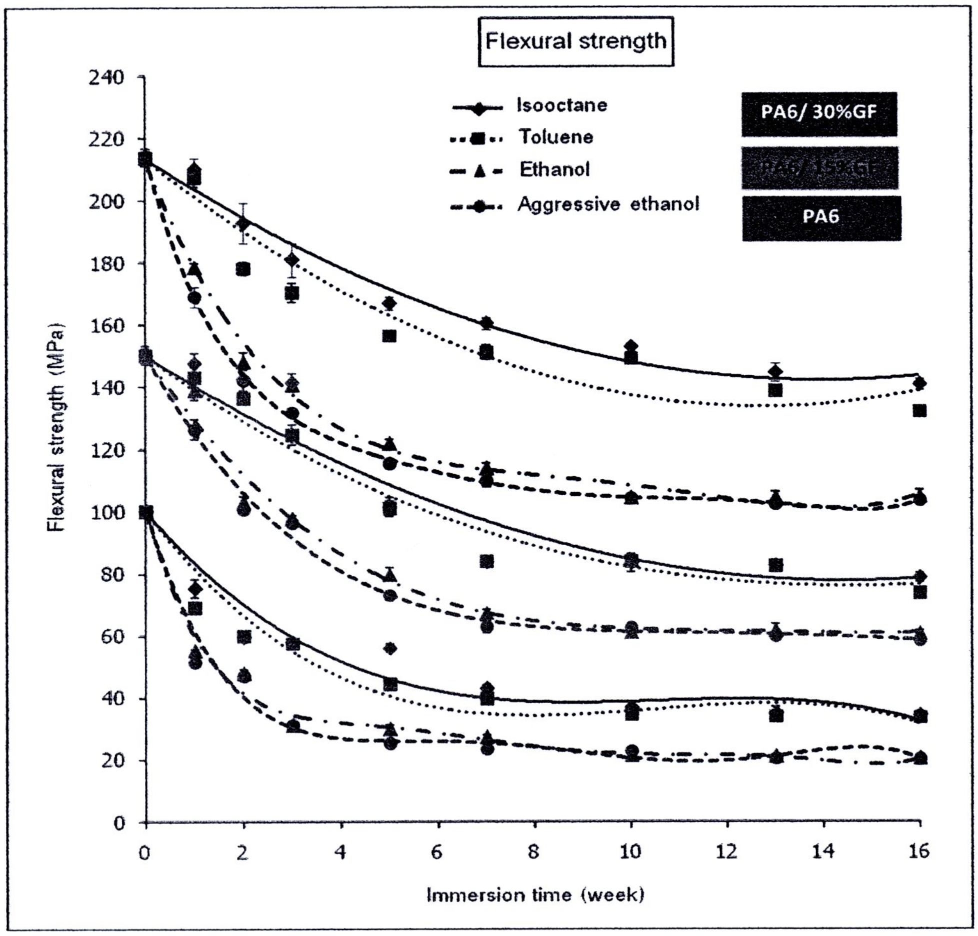

Figure 5.32 Flexural strength of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

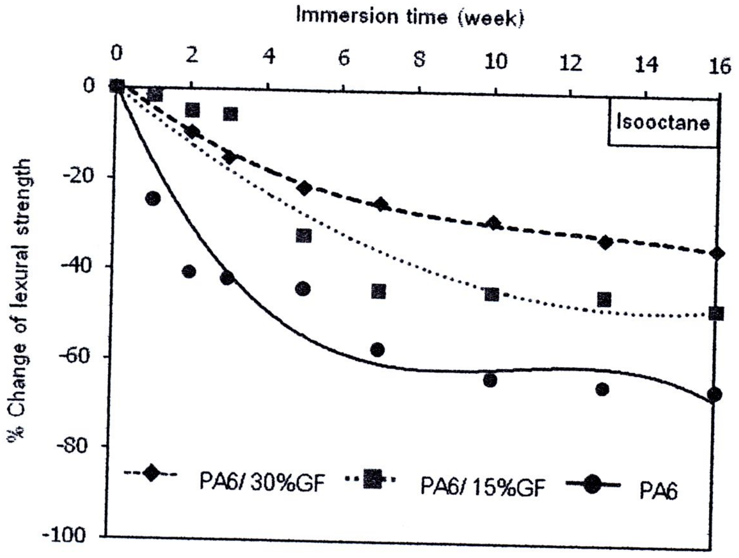

Figure 5.33 Percent change of flexural strength of PA6 and PA6/GF composites immersed in isooctane

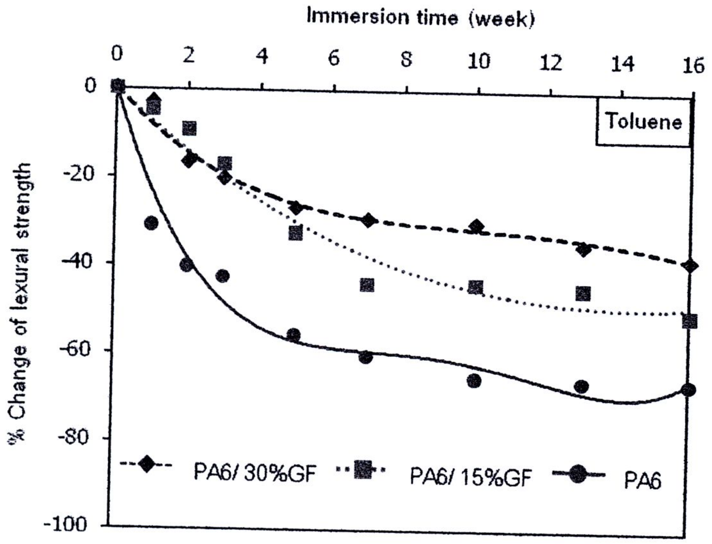

Figure 5.34 Percent change of flexural strength of PA6 and PA6/GF composites immersed in toluene

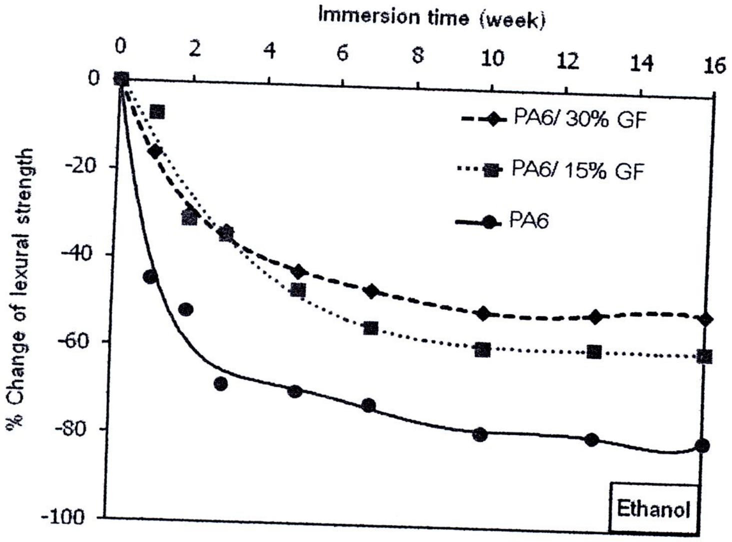

Figure 5.35 Percent change of flexural strength of PA6 and PA6/GF composites immersed in ethanol

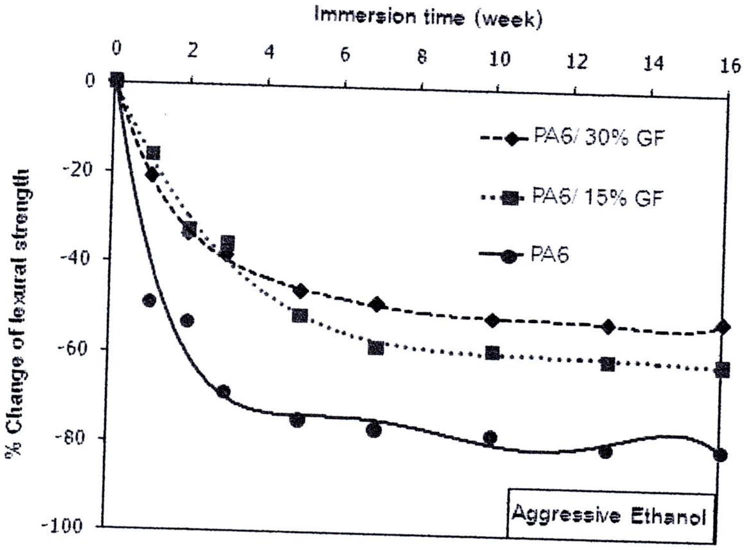

Figure 5.36 Percent change of flexural strength of PA6 and PA6/GF composites immersed in aggressive ethanol

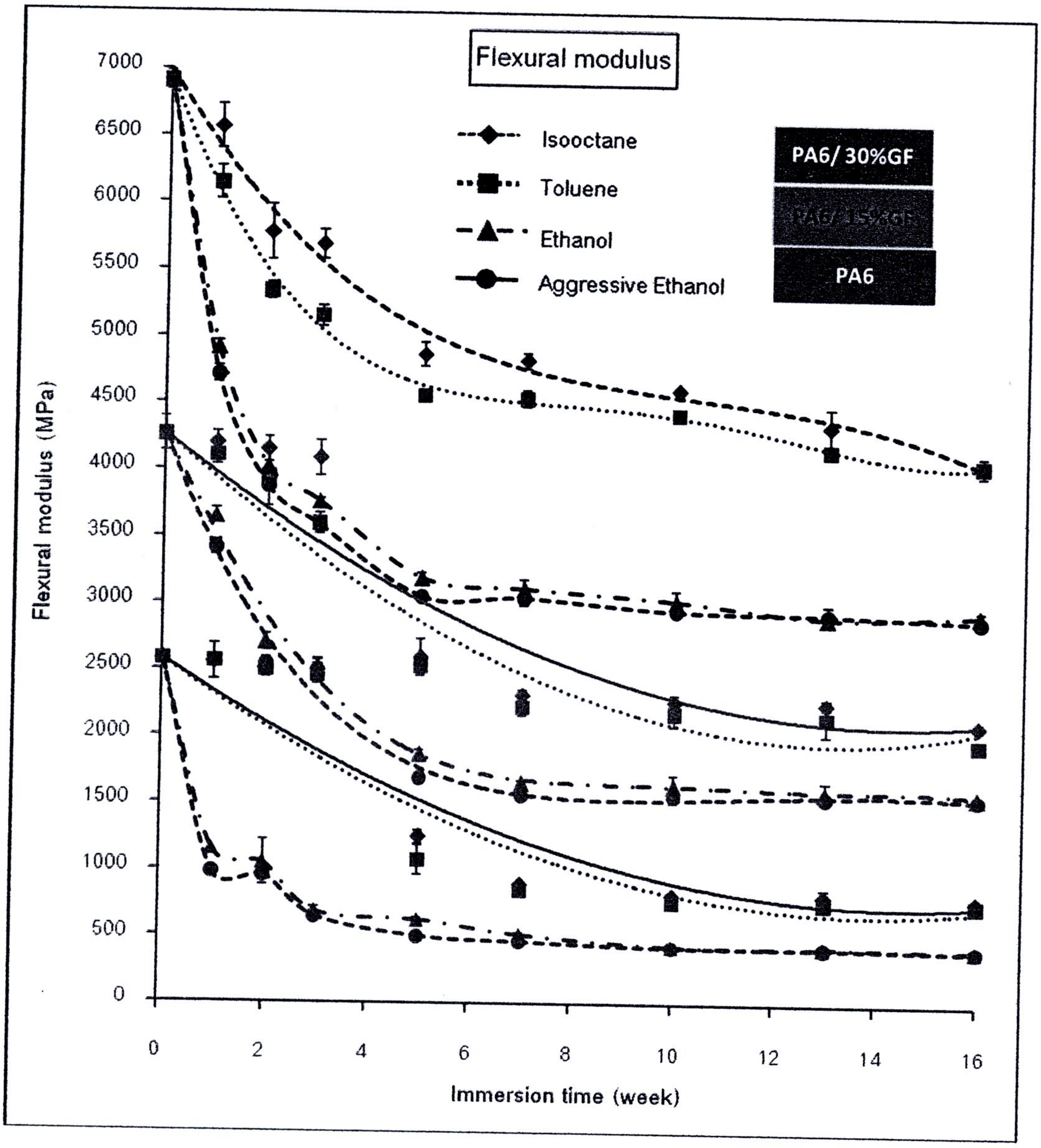

Figure 5.37 Flexural modulus of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

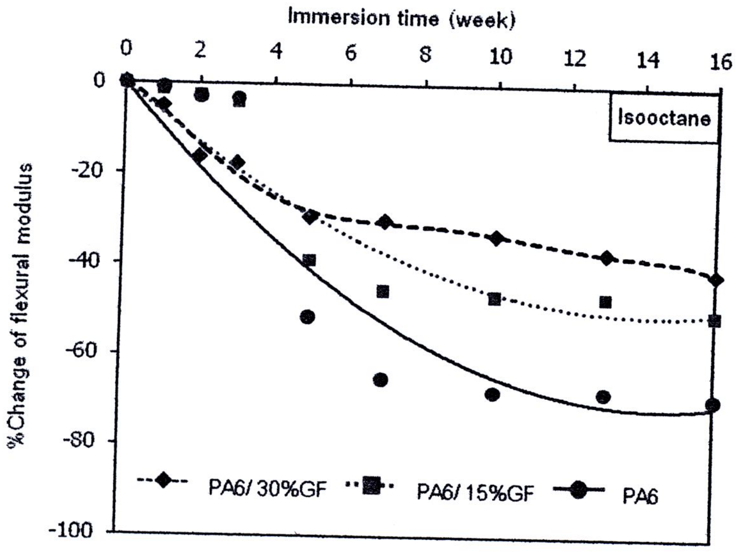

Figure 5.38 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in isooctane

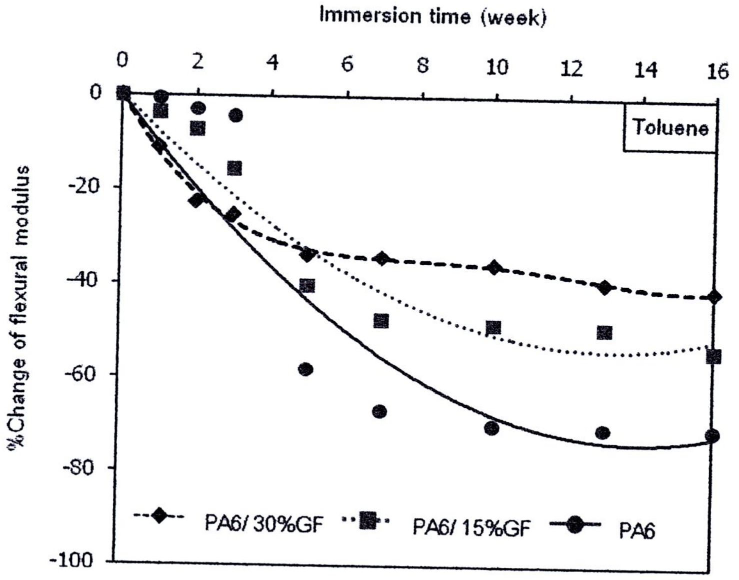

Figure 5.39 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in toluene

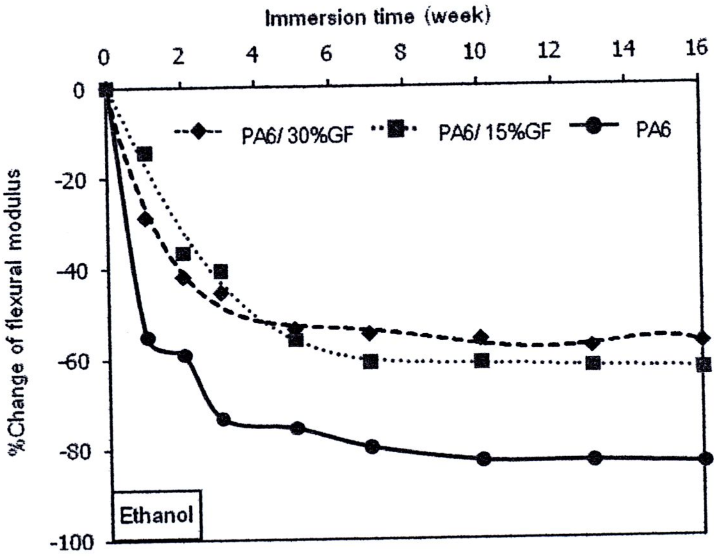

Figure 5.40 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in ethanol

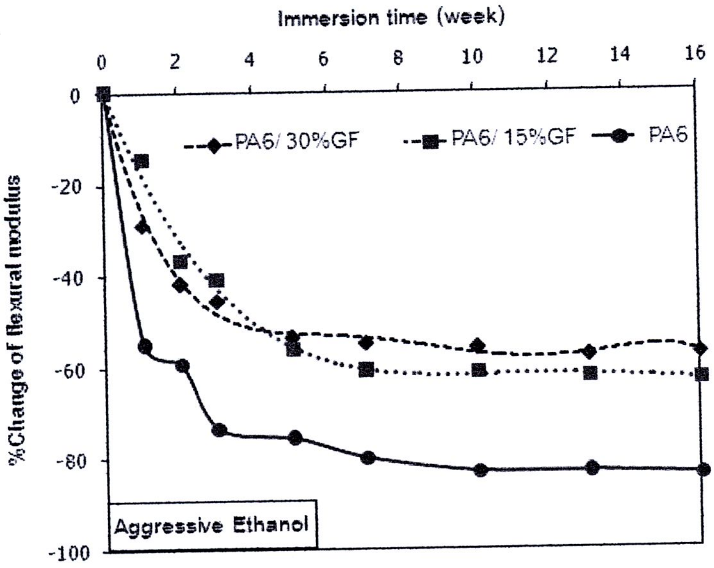

Figure 5.41 Percent change of flexural modulus of PA6 and PA6/GF composites immersed in aggressive ethanol

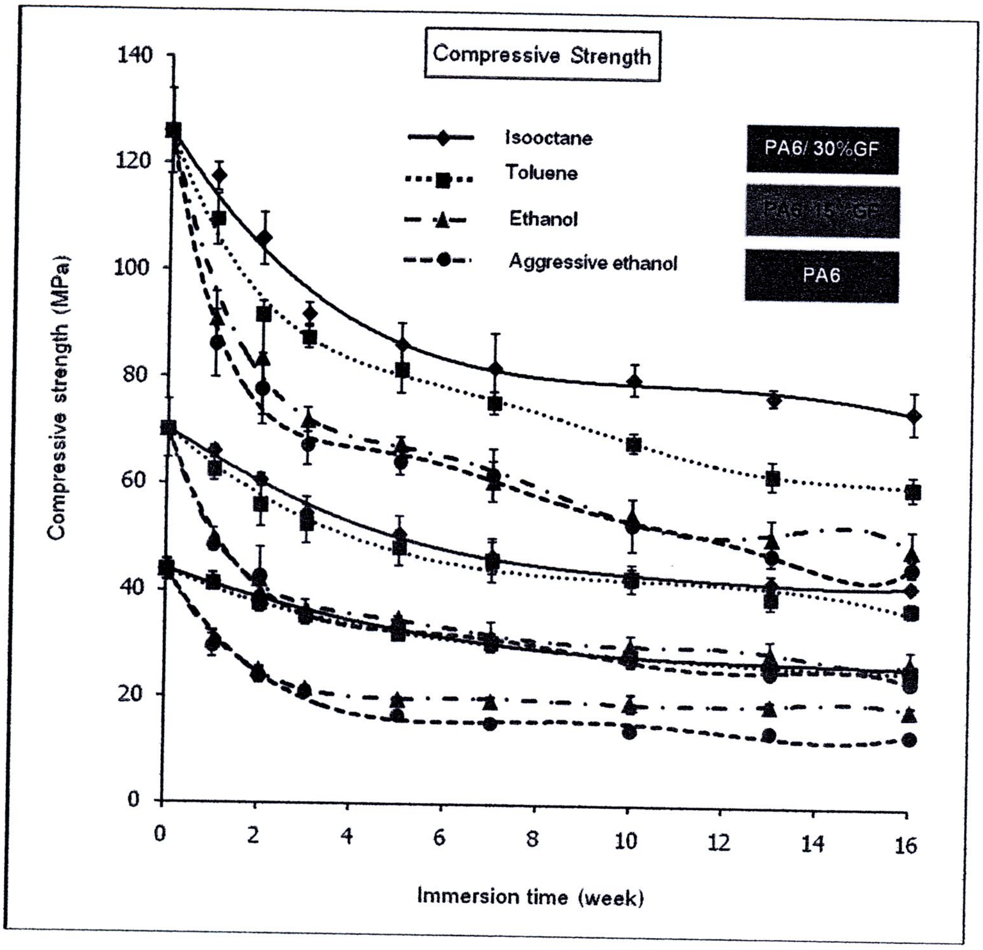

Figure 5.42 Compressive strength of PA6 and PA6/GF composites after immersed in chemicals of surrogate gasohol

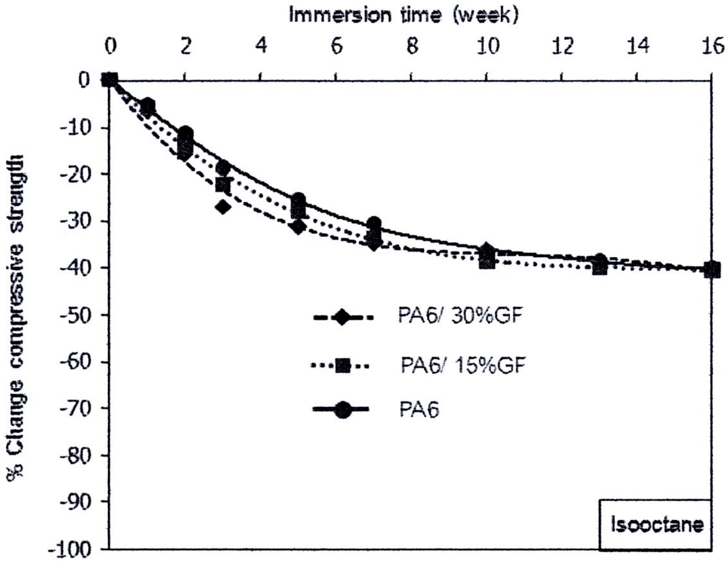

Figure 5.43 Percent change of compressive strength of PA6 and PA6/GF composites immersed in isooctane

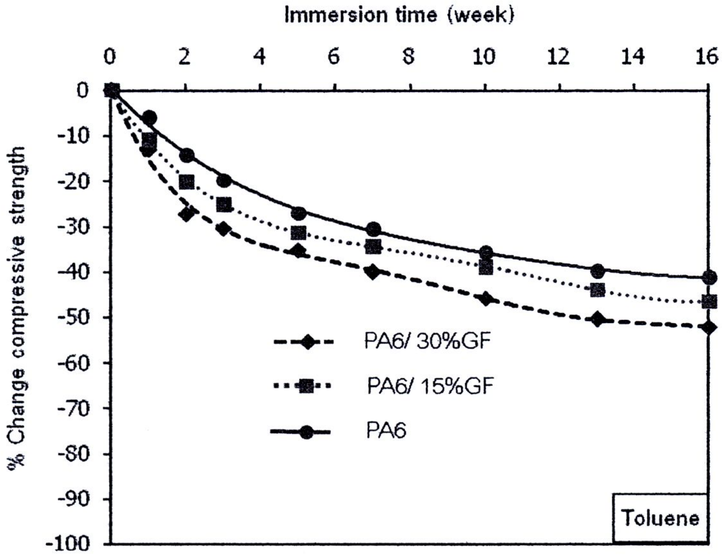

Figure 5.44 Percent change of compressive strength of PA6 and PA6/GF composites immersed in toluene

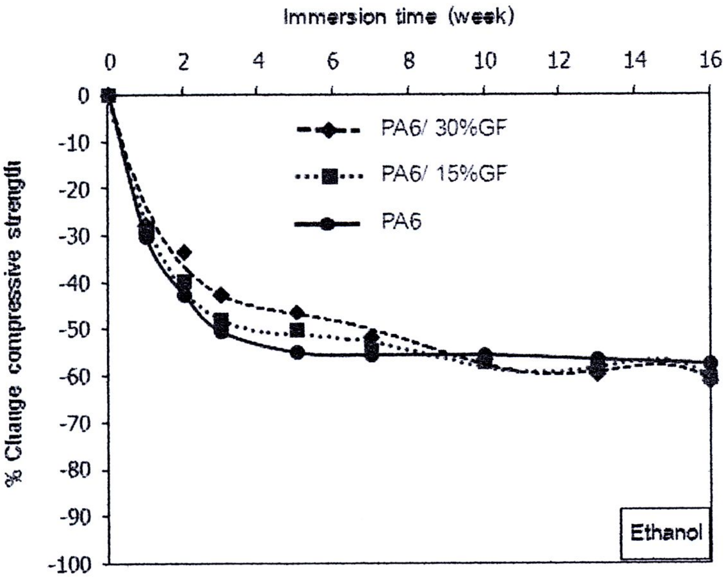

Figure 5.45 Percent change of compressive strength of PA6 and PA6/GF composites immersed in ethanol

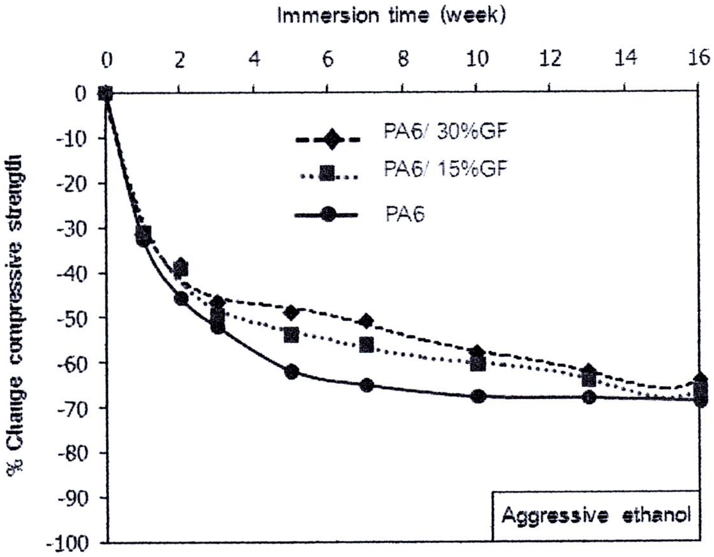

Figure 5.46 Percent change of compressive strength of PA6 and PA6/GF composites immersed in aggressive ethanol

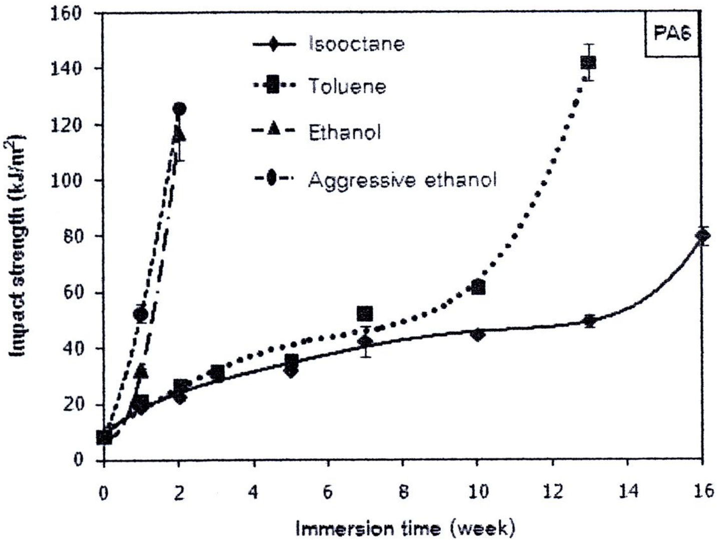

Figure 5.47 Izod impact strength of PA6 after immersed in chemicals of surrogate gasohol

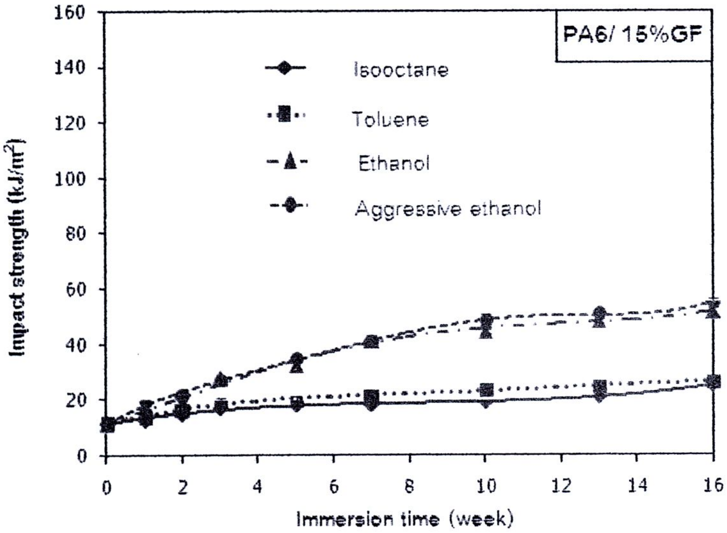

Figure 5.48 Izod impact strength of PA6/ 15%GF after immersed in chemicals of surrogate gasohol

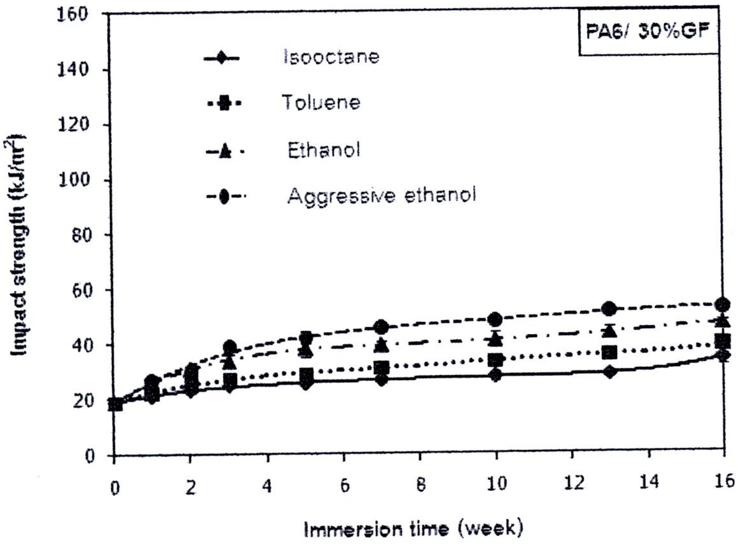

Figure 5.49 Izod impact strength of PA6/ 30%GF after immersed in chemicals of surrogate gasohol

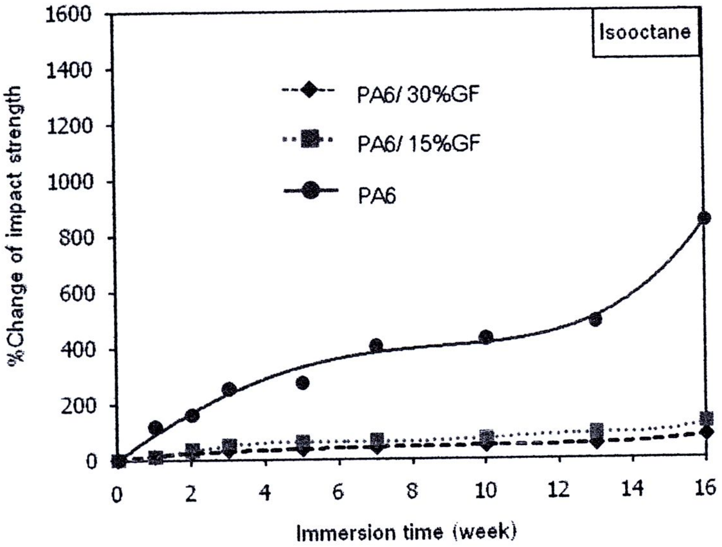

Figure 5.50 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in isooctane

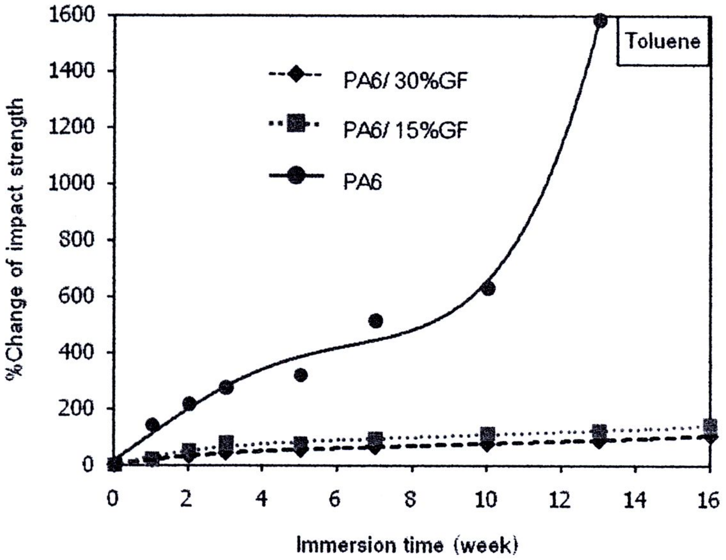

Figure 5.51 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in toluene

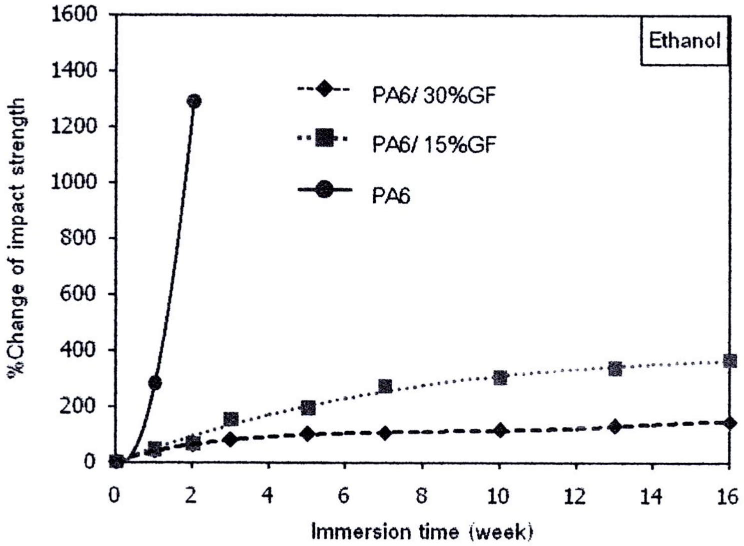

Figure 5.52 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in ethanol

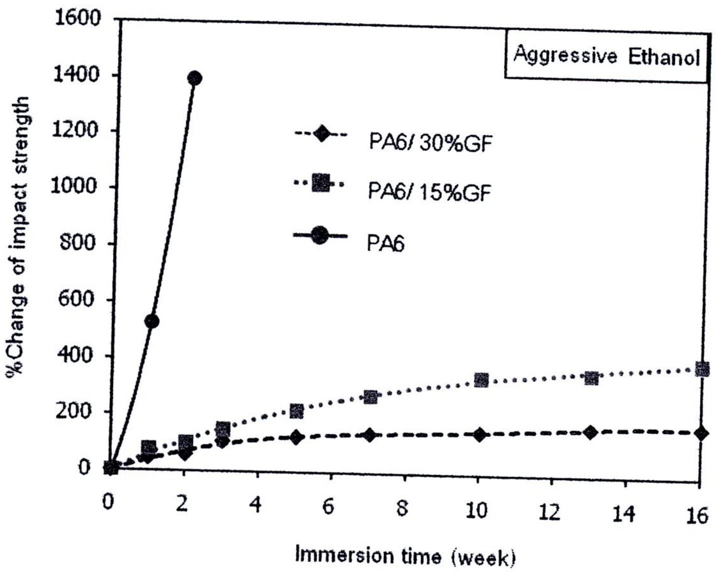

Figure 5.53 Percent change of Izod impact strength of PA6 and PA6/GF composites immersed in aggressive ethanol

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].

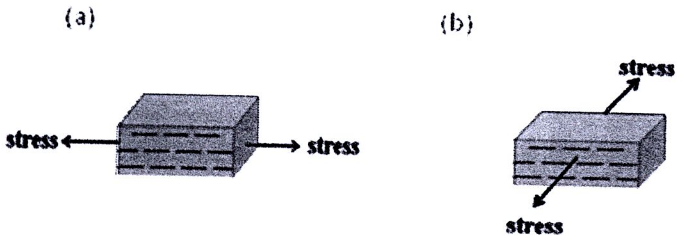

Figure 5.54 Stress direction (a) Rule of mixture (ROM) (b) Inverse rule of mixture (IROM) [67]

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

$$E_c = V_f E_f + (1-V_f)E_m \quad \text{.................................(5.1)}$$

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

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

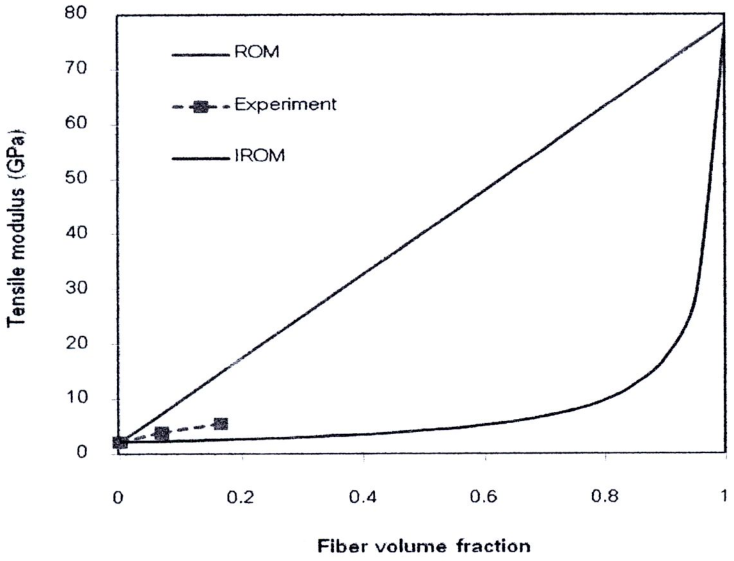

Figure 5.55 Tensile modulus of unsoaked PA6 and PA6/GF composites in this experiment compared with ROM and IROM models

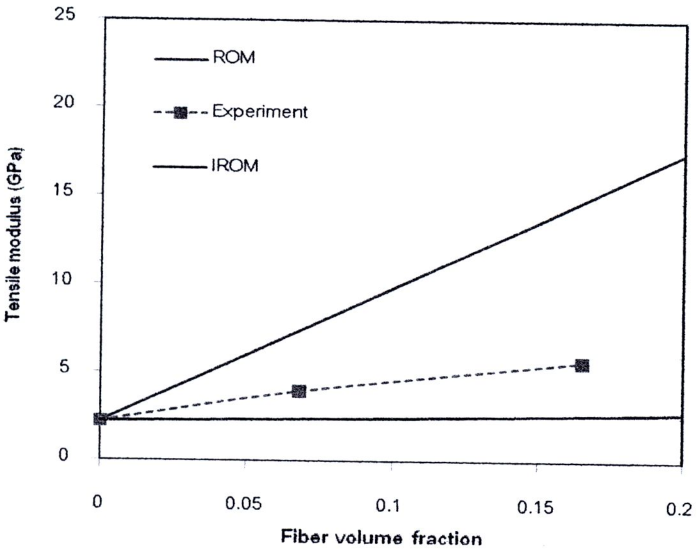

Figure 5.56 Tensile modulus of unsoaked PA6 and PA6/GF composites in this experiment compared with ROM and IROM model (at fiber volume fractions of this experiment)

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.

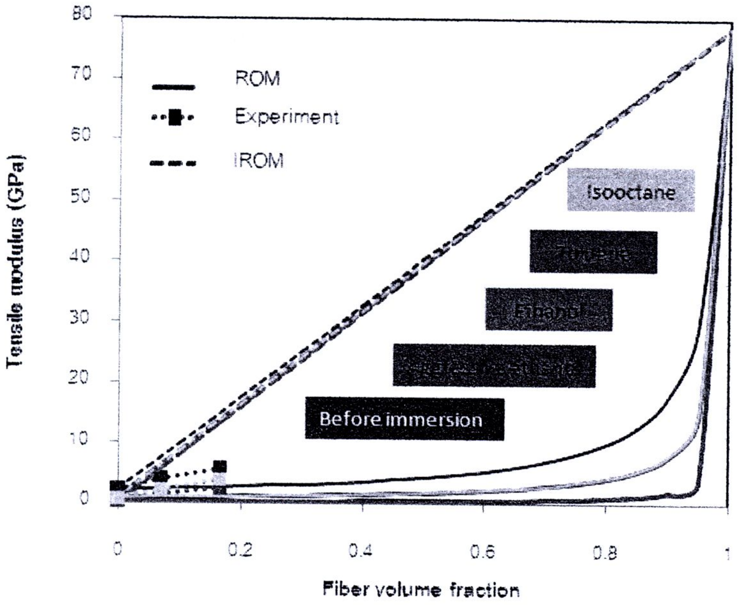

Figure 5.57 Tensile modulus of PA6 and PA6/GF composites of this experiment compared with ROM and IROM model after immersion in chemicals of surrogate gasohol

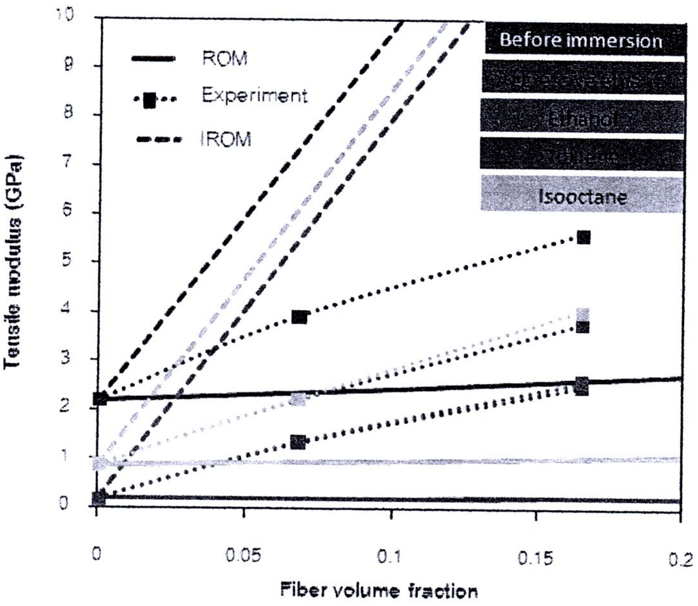

Figure 5.58 Tensile modulus of PA6 and PA6/GF composites of this experiment compared with ROM and IROM model after immersion in chemicals of surrogate gasohol (at fiber volume fraction of experiment)