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INFLUENCE OF BIODIESEL AND BLENDED FUELS ON THE TENSILE AND COMPRESSIVE PROPERTIES OF GLASS FIBRE REINFORCED EPOXY COMPOSITES

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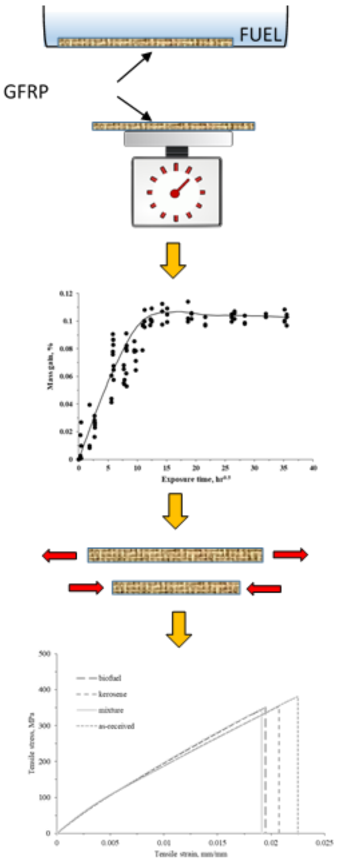
Graphical abstract



Abstract

With the recent usage increase of biodiesel as an alternative fuel source as well as the increase in the utilisation of glass fibre reinforced polymer (GFRP) as structure such as tanks have considerably affected the necessity to study the influence of fuel absorption on the mechanical properties of GFRP composites. Biodiesel is a renewable, efficient and environmentally friendly but possess a high viscosity property. Three main fuel types which consist of aviation fuel, biodiesel and a blend between aviation and biodiesel fuel are used to perform complete immersion of the GFRP specimens. An experimental method is used to investigate the mechanical degradation in term of tension and compression properties of the GFRP composites. The GFRP specimens are aged using immersion bath technique. Vacuum assisted resin transfer moulding (VARTM) is used to manufacture the GFRP specimens with a volume fraction of 0.50 with a void content below 3%. The GFRP specimens were immersed in the fuels until it reaches an equilibrium state before the tensile and compression test was carried out to study the mechanical properties of the immersed specimens. Based on the result obtained, the GFRP specimens that were immersed in all three fuel solution display a slight degradation in term of tensile and compressive strength as well as their Young's modulus when compared to an as-received (standard) specimen. It is concluded, that the GFRP composite was able to resist the fuels corrosive nature as they can retain most of their mechanical strength and the decrement is not significant.

Keywords: GFRP, fuel immersion, mechanical properties, fuel attack, VARTM

Abstrak

Peningkatan dalam penggunaan biodiesel sebagai sumber bahan api alternatif dan juga peningkatan penggunaan polimer bertetulang gentian kaca (GFRP) sebagai struktur seperti tangki telah mewujudkan kepentingan kajian serapan bahan api terhadap sifat mekanikal komposit. Biodiesel adalah sejenis tenaga yang dipebaharui, cekap dan mesra alam tetapi mempunyai sifat kelikatan yang tinggi. Tiga jenis bahan api iaitu, bahan api penerbangan, biodiesel serta campuran bahan api penerbangan digunakan bagi rendaman menyeluruh spesimen GFRP. Kaedah eksperimen digunakan bagi mengkaji penurunan sifat regangan dan mampatan komposit GFRP. Teknik rendaman digunakan dalam proses penuaan spesimen GFRP. Acuan pemindahan resin dengan bantuan vakum (VARTM) digunakan bagi menghasilkan spesimen GFRP dengan pecahan isipadu 0.5 dan kandungan lompang di bawah 3%. Spesimen GFRP direndam sehingga fasa keseimbangan tercapai sebelum ujian regangan dan mampatan dijalankan bagi mengkaji sifat mekanikal spesimen yang telah melalui proses rendaman. Berdasarkan daripada keputusan yang diperolehi, kesemua spesimen GFRP yang direndam di dalam semua jenis bahan api menunjukkan sedikit penurunan pada kekuatan regangan dan mampatan dan juga pada modulus Young apabila dibandingkan dengan spesimen piawai. Kesimpulan dalam kajian ini, komposit GFRP mampu menahan kakisan bahan api apabila kekuatan mekanikal masih dapat dibendung dengan kadar penurunan yang tidak begitu signifikan.

Kata kunci: GFRP, rendaman bahan api, sifat mekanikal, serangan bahan api, VARTM

1.0 INTRODUCTION

With the depletion of fossil fuel, there is a need for alternative fuel, and currently, biodiesel fuel is becoming popular due to it being a renewable fuel [1-4]. For biodiesel to be used in the current engine system, its properties have to be similar or better than the currently used diesel fuel. This is to ensure that the readily available engine can be used without any major modification [5]. Biodiesel also is environmentally friendly since it does not contain sulphur and is produced from plant oil or animals fats [6, 7]. Biodiesel can be corrosive in nature when subjected to humidity due to the formation of acidic compound [8]. Metals can corrode when reacted to this compound [9]. Another type of fuel which is gaining attention especially in the aviation industry is a blend between kerosene and biodiesel. A study was carried out on the compatibility of a couple of blended biodiesel with Jet-A fuel. It was found that blends that have about 10-20 % of methyl ester in the composition have similar properties with the current aviation fuel [10].

Glass fibre reinforced polymer (GFRP) composite shows an irreversible degradation due to moisture absorption from the environment [11, 12]. This may pose a serious problem if the degradation has a significant effect on the mechanical properties of GFRP, especially for critical parts. One of the parts that are currently being fabricated from GFRP is storage tanks such as underground storage tanks and fuel tanks [13]. GFRP is utilized as fuel tanks in various industries such as marine, automotive and aerospace industries [14-16]. This due to its inert state and has high corrosion resistance to chemical compared to steels besides being much lighter than metals [17]. The effect of moisture absorption in fibreglass composite in term of its mechanical properties were studied by a group number of researchers [18-27].

Sala [22] has investigated the effect of several types of fluid on the mechanical properties of composite materials. Sala used water, Skydrol, fuel and dichloromethane as the solvent for the absorption set-up. It was found that the composite materials underwent plasticization which reduces its fatigue properties. Moreover, specimens that were immersed in Jet-A fuel showcase a reduction in compressive strength. A study was conducted on the absorption rate of glass fibre composite and found that specimens that have imperfection such as cracks absorb more moisture compared to standard specimens [26]. Recently, few researchers have investigated the effects of water and salt solution on a civil structure made from GFRP [28, 29]. It was discovered that the structure underwent degradation in mechanical properties. The GFRP structure shows a decrease in interlaminar strength after being subjected to water and salt solutions. A similar finding was observed by Hu, Li [30] and Chakraverty, Mohanty [31]. This reduction in strength was due to the plasticiser effect on the polymer [32, 33]. Bazli, Ashrafi [34] discovered that the GFRP specimens that were subjected to seawater losses about 17 – 23% in flexural strength. This reduction was due to the formation of blisters on the surface of the composites. The blisters will deform the resin and thus degrading the composite mechanical properties [35]. Based on this, the GFRP composites may experience some form of degradation when subjected to fuel. Damage to the GFRP structure may lead to other system or structure failure and this could cause tragedies if the GFRP structure is a critical part in a system. Thus, this paper investigates the resistance of GFRP toward fuel attack based on its mechanical properties.

2.0 METHODOLOGY

2.1 Material Used and Fabrication Method

For this research, 800 g/m^2 E-glass plain woven fabric and two-part epoxy resin was used. For this study, the epoxy resin that was used is EpoxAmite 100 epoxy and is supplied by Smooth-On. This epoxy is a two-part resin system with part A being the epoxy and part B is the hardener. This epoxy resin is room temperature cured while the mixing ratio is 100g of part A with 28.4g of part B. The properties of both E-glass and the epoxy resin are shown in Table 1. The GFRP laminate that is used in the research were manufactured using an in-house set-up vacuum assisted resin transfer moulding (VARTM). The manufactured GFRP were left to cure at room temperature before underwent post-cure in the oven at 70°C for 2 hours. The dimension of the specimen for the tensile test is 250 x 25 x 2.5 mm while for the compression test, the specimen dimensions are 130 x 25 x 2.5 mm. The fibre volume fraction of the laminate was determined using ASTM D2734 and ASTM D3171 for resin burn off method and acid digestion method respectively. The average fibre volume fraction of the GFRP laminate was 0.51 for both burn-off and acid digestion method. The average void content of the laminate was 2.27% which is below 3% and it was calculated according to ASTM D3171.

Table 1 Properties of 800 g/m^2 E-glass woven roving and epoxy resin

E-glass		
Specification	**Warp yarn**	**Weft yarn**
Tex	2400	2400
Fibre diameter (μm)	24	24
Count of cloth (root/cm)	1.8	1.8
Breaking Strength (N) ≥	4600	4400
Epoxy Resin		
Properties		
Cure Time	20 – 25 hours	
Specific Gravity	1.10 g/c.c	
Ultimate Tensile (ASTM D638)	27000 psi	
Tensile Modulus	452000 psi	
Compressive Strength	10500 psi	
Compressive Modulus	104000 psi	

2.2 Immersion Setup

Three different glass container was used to store the fuel solutions, and the specimens were immersed in the container. The container was stored at room temperature in the composite laboratory. The three fuel solution that is used for this research is kerosene or Jet-A fuel, biodiesel fuel where the feedstock is palm oil based and an 80% kerosene with 20% biodiesel volume based ratio blend fuel. The ratio for the blend fuel mixture was found to have similar properties to pure kerosene fuel as reported by Azad, Uddin [36]. The kerosene fuel was obtained from a local government agency and the biodiesel fuel was supplied by Kurnia Kebal Sd. Bhd.

The procedure and the calculation for the moisture absorption curve were based on ASTM D5229. The steps are as follows. Firstly, the dry weight specimen were measured before being submerged into the fuel solutions. After a certain period of time, the specimens were taken out of the container and the moist is dried out using kitchen towel before weighing it again. The steps was repeated until a weight of the specimen remained constant as that indicated the specimen had reached a saturation state. A high precision analytical balance was used to weigh the specimens. The specimens were immersed for 2 months to obtain their absorption curve. The immersion setup was repeated four times with 5 specimens for each fuel to increase the accuracy of the data.

2.2 Tensile and Compression Test

The mechanical properties of the immersed specimens were tested using tensile and compression test. Based on tensile and compression test, the maximum stress for both tensile and compression, the Young's modulus as well as the force need to break the specimen can be obtained [37, 38]. The tensile and compression test were carried out using Instron Universal Testing Machine (UTM) which coupled with Bluehill Universal program. For tensile test, the extension rate was 2 mm/min while for compression test, the compression rate was 1.5 mm/min. The overall setup of using the Instron machine is shown in Figure 1. Both tensile and compression test setup is similar with one exception where no extensometer was used for compression test. Tensile and compression test were carried out on immersed specimens that have reach saturation state.

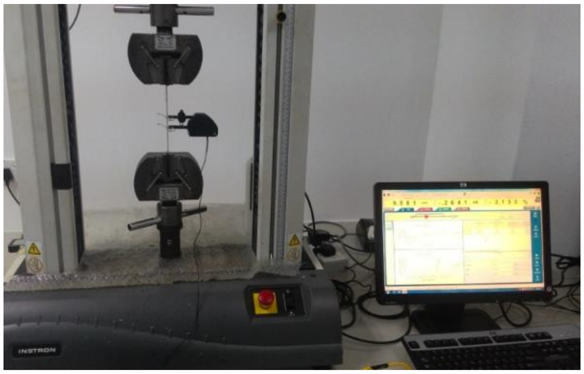


Figure 1 Overall setup of Instron machine with extensometer attached to the GFRP specimens

3.0 RESULTS AND DISCUSSION

For a diffusion curve to be classified as a Fickian curve, several conditions have to be satisfied. The first condition is that the diffusion shows a linear uptake at the beginning of the curve. The second condition is that same material with different thickness has an absorption curve that can be superimposed. The final condition is that the diffusion rate will slow down before reaching an equilibrium state.

Figure 2 shows the fuel uptake curve for GFRP laminate in biodiesel fuel. Based on the absorption behaviour, the GFRP laminate displays a classic Fickian absorption curve. The specimen reaches the equilibrium state at approximately 10 hr$^{0.5}$ which is about 4 days. The specimens gain about 0.14% of mass due to the penetration of the fuel molecules. A similar absorption curve can be seen for both kerosene and blended fuel mixture as shown in Figure 3 and Figure 4. Based on Figure 3, the maximum fuel uptake for the GFRP specimen is about 0.33%. The specimens reach its equilibrium state after being immersed at approximately 10 $hr^{0.5}$. While for blended fuel mixture, it reaches saturation state at approximately 15 $hr^{0.5}$ of immersion period with a mass gain of 0.11% as shown in Figure 4.

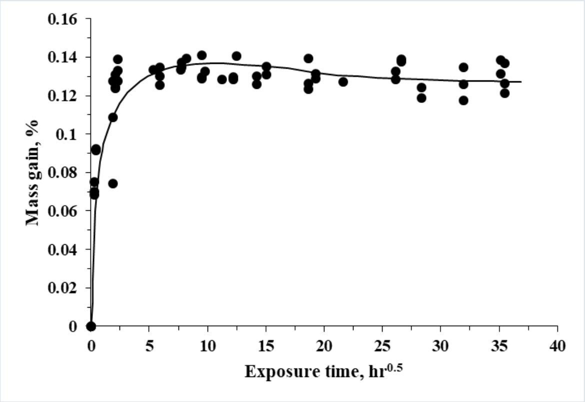


Figure 2 Biodiesel fuel uptake of GFRP laminate

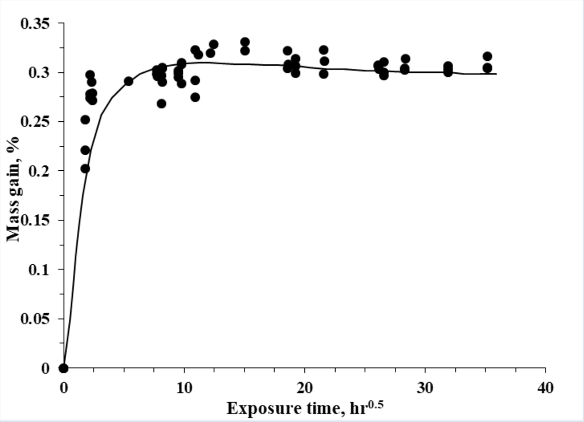


Figure 3 Absorption curve of GFRP laminate when being immersed in the kerosene fuel solution

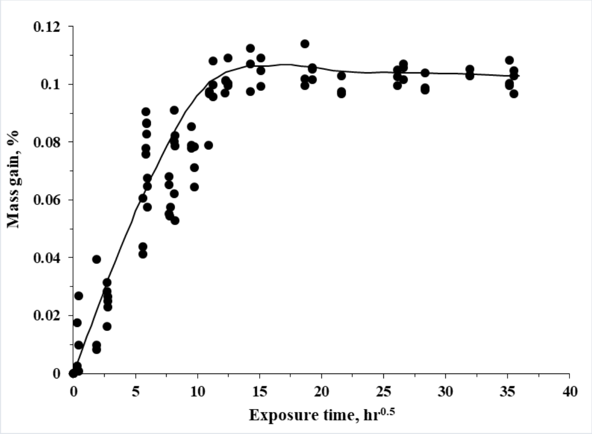


Figure 4 GFRP laminate fuel uptake for blended fuel mixture

The GFRP laminates was subjected to different fuel solution for a period of 15 $hr^{0.5}$ which is about 9 days where the GFRP laminates reach a saturation fuel uptake state. The saturated specimens were tested using tensile and compression test to examine the effect of fuel uptake on its mechanical properties. The tests were carried out based on ASTM D3039 for tensile test and ASTM D3410 for compression test. The tensile stress-strain curve for GFRP specimen after reaching an equilibrium state in four different environment condition was plotted and is shown in Figure 5. The four environment conditions are biodiesel fuel solution, kerosene (JET-A) fuel solution, blended fuel mixture and a standard specimen for as-received conditions. According to Figure 5, the standard as-received specimens have the highest tensile stress which is 363.86 MPa while specimens immersed in blended fuel mixture exhibit the lowest tensile stress which is 344.14 MPa. The specimens that were immersed in kerosene and biodiesel respectively have maximum tensile stress of 347.30 MPa and 344.73 MPa. The decrease in maximum tensile stress in the GFRP specimens are due to the weakening of interlaminar bonds and the formation of microvoids as reported by Genanu [39] and Loos, Springer [40]. El Afif and Grmela [41] reported that the fuel molecule that penetrated into the polymer network will induce internal stress which results in some irreversible degradation; thus reducing the tensile strength of the material. However, the loss in tensile strength for the immersed specimens was not significant as the immersed GFRP specimens were able to retain most of its strength and only experience slight decrement.

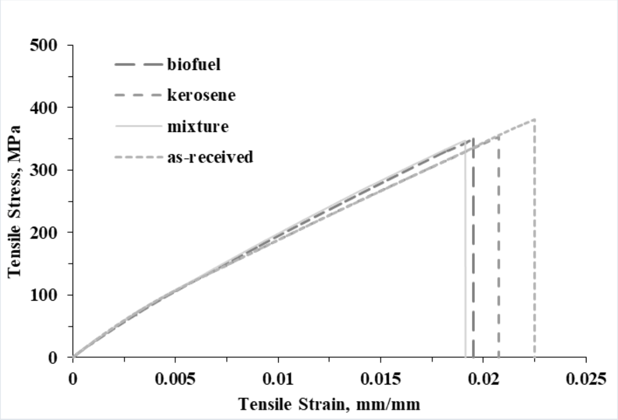


Figure 5 Tensile stress-strain curve for GFRP laminate composite

The comparison of the maximum tensile stress and Young's modulus between the GFRP specimens at different environmental conditions are shown in Figure 6. The immersed specimens show a slightly brittle behaviour as can be seen in Figure 5 and Figure 6. This has directly affected Young's modulus as the Young's modulus for the immersed specimens had a slight decrement when compared to the as-received specimens. The Young's modulus for the as-received specimens is 22.76 GPa while for biodiesel, kerosene and blended fuel mixture are 19.90 GPa, 19.21 GPa and 19.58 GPa respectively. The brittle behaviour is due to the penetration of the fuel molecule that constrained the polymer network mobility as reported by Sperling [42]. Thus resulting in the material to lose its elasticity slightly. Similar behaviour was also reported by Genanu [39].

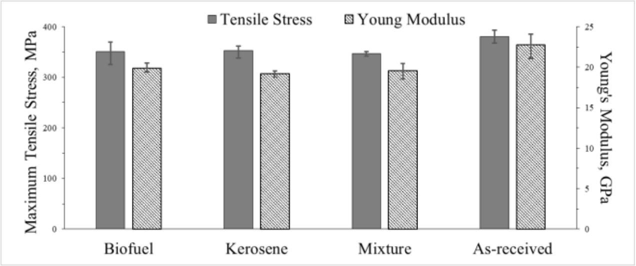


Figure 6 The comparison between maximum tensile stress and Young's modulus of GFRP laminate specimens at different environmental conditions

The percentage difference for both average tensile strength and Young's modulus for GFRP laminate under various environmental conditions is presented in Table 2 and Table 3 respectively. Based on the tabulated data, the decrement in term of tensile strength and Young's modulus for GFRP laminate was not significant as the tensile strength decrease within 6% while the Young's modulus decrement is within 15%. A similar result we obtained by Meissner and Pearson [43] and Jasim and Jawad [44].

Table 2 The average tensile strength and its percentage change for GFRP laminate under different conditions

Condition	Average Tensile Strength (MPa)	Limit		Percentage Different (%)
		Maximum	Minimum	
as-received	363.86	13.01	13.01	0
biodiesel	344.73	18.98	24.96	-5.26
kerosene	347.30	8.87	14.45	-4.55
blended fuel	344.14	3.23	5.15	-5.42

Table 3 The average Young's modulus and percentage different for GFRP laminate under different conditions

Condition	Average Young's Modulus (GPa)	Limit		Percentage Different (%)
		Maximum	Minimum	
as-received	22.76	1.31	1.67	0
biodiesel	19.90	0.60	0.47	-12.56
kerosene	19.21	0.34	0.40	-15.62
blended fuel	19.58	0.88	1.03	-13.99

The GFRP specimens underwent compression test, and the compression stress-strain curves are plotted in Figure 7. Similar behaviour to the tensile stress-strain curve was observed for the compressive stress-strain curve where the immersed GFRP specimens experience a slight decrement in their maximum compressive stress. The compressive stress of GFRP specimens after being immersed in biodiesel, kerosene and blended fuel mixture are 101.24 MPa, 95.66 MPa, and 97.01 MPa respectively while the as-received specimen's compressive stress is 108.95 MPa. The decrement in compressive stress is due to the degradation caused by the fuel molecules when diffusing into the polymer network. Some of the damage that may occur is the formation of new voids and micro-cracks which is induced by the internal stress, which is reported by Genanu [39] and Loos, Springer [40].

The comparison in term of the GFRP specimen's maximum compressive stress and Young's modulus for different environmental conditions are shown in Figure 8. Based on the plotted graph, the immersed specimens shows a slight decrement in their Young's modulus as compared to the as-received specimens. The Young's modulus for the as-received specimen, biodiesel immersed specimen, kerosene immersed specimen, and blended fuel mixture immersed specimen are 3.12 GPa, 2.70 GPa, 2.77 GPa, and 2.77 GPa respectively. The decrease in Young's modulus for the immersed specimens is mainly due to the increase in the cross-linkage force of the polymer network where the fuel molecules that is penetrated in the polymer network. A similar result was obtained by Genanu [39] and Sperling [42].

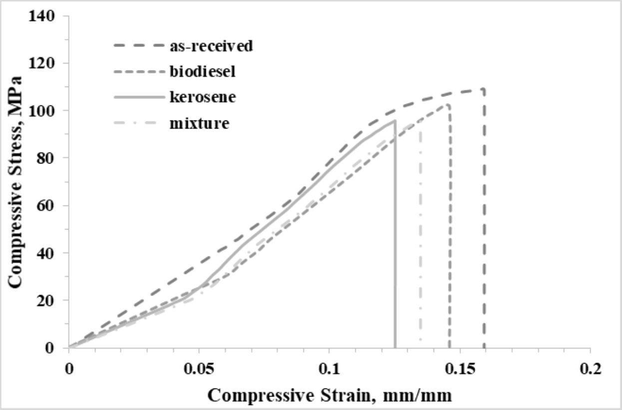


Figure 7 Compressive stress-strain behaviour of GFRP laminate under different environment conditions

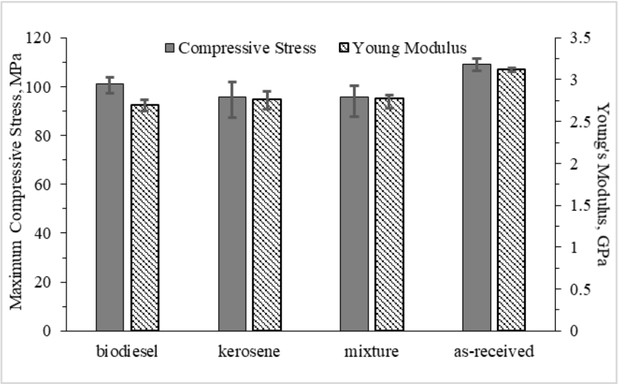


Figure 8 Comparison of compressive stress and Young's modulus of different GFRP laminate specimens under various conditions

The percentage difference in term of average compressive strength and average Young's modulus were tabulated as in Table 4 and Table 5 respectively. It is observed that the percentage difference for average compressive strength is within 12% of decrement while for the average Young's modulus is within 13% of decrement. The decrement in term of compressive strength and Young's modulus for GFRP after being immersed in different fuel solution is not significant as the specimen retain most of its mechanical properties.

Table 4 Percentage of change in term of average compressive stress for GFRP laminate under different conditions

Condition	Average Compressive Strength (MPa)	Limit		Percentage Different (%)
		Maximum	Minimum	
as-received	108.95	2.37	2.50	0
biodiesel	101.24	2.64	3.94	-7.08
kerosene	95.66	6.22	8.51	-12.20
blended fuel	97.01	4.81	8.01	-10.96

Table 5 Percentage of change in term of average Young's modulus for GFRP laminate under different conditions

Condition	Average Young's Modulus (GPa)	Limit		Percentage Different (%)
		Maximum	Minimum	
as-received	3.12	0.02	0.03	0
biodiesel	2.70	0.06	0.07	-13.65
kerosene	2.77	0.09	0.12	-11.28
blended fuel	2.77	0.05	0.11	-11.18

4.0 CONCLUSION

The influence of three different types of fuel solution on the mechanical properties of GFRP was studied in this paper. The absorption curve of the GFRP laminate after being immersed in fuel solutions was obtained, and it can be concluded that the absorption behaviour exhibit a classic Fickian sorption curve. Specimens that were subjected to biodiesel and kerosene fuel solution reaches equilibrium state after being immersed for a period of 100 hours while for specimens immersed in blended fuel mixture reaches saturation state after a period of 225 hours. The specimens that reach the equilibrium state were tested under tensile and compression loading at room temperature to investigate their mechanical properties. All of the immersed specimens had a slight decrement in tensile, compression and their respective modulus compared to an as-received specimen. The slight decrement is because of the permanent damage caused by the penetration of the fuel molecule into the specimen which induces internal stress. The internal stress causes the formation of new voids as well as micro-cracks. Besides that, the immersed specimens show slight brittle behaviour. This is due to the increase of the cross-linkage force of the polymer network. The increase in cross-linkage force was because of the fuel molecule that diffuses into the network. Nonetheless, it is concluded that the decrement in the mechanical properties is not significant as the GFRP laminates retain most of their strength. This shows that the GFRP are able to resist and survive against fuel attack. For future work, further investigation on the interlaminar bond between the fibre and matrix after reaching saturation state when being fully immersed is proposed. This is to deepen the understanding of how fuel degrades the glass fibre epoxy composite.

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