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TENSILE AND CHARPY IMPACT BEHAVIOR OF E-GLASS / UNSATURATED POLYESTER LAMINATED COMPOSITE MATERIAL AT ELEVATED TEMPERATURE

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Abstract

Glass fibre reinforced polymer has been widely used in engineering application especially in power generation plant due their properties of low cost-effective product and high strength to weight ratio. The Charpy impact and tensile tests behaviour on E-glass/unsaturated polyester composite materials under variable temperatures ranging from 30°C to 70°C have been investigated in this paper. The laminated composite materials are fabricated by hand layup technique, which is formulated by stacking different layers of fibres immersed in resin. Unsaturated polyester matrix materials reinforced with of E-glass fibres in two forms (mat chopped strand, and woven roving) have been used. Six types of laminated composite are prepared with different layers at constant volume fraction of 30 %. The investigation involved the modulus of elasticity, tensile strength, and the fracture toughness of the indicated laminated composite materials. The temperature effect on the modulus of elasticity, elastic energy, maximum absorbed energy, and delamination's are highlighted. The result shows that the temperature affects the impact performance and the failure mechanism of the composite. The failure mechanism was varied from fibre breakage and delamination at high temperature to matrix cracking at room temperature. Also, the increasing in the laminated layers for the same type of fibres of the composite causes increasing in the elastic modulus, fracture toughness and tensile strength despite of the orientation of the fibres. As well as the mechanical properties of the composite laminated plates decreased with the temperature increases from 30°C to 70°C.

Keywords: Charpy impact test, Elevated temperature, E-glass/unsaturated polyester laminated composite, Tensile test.

1. Introduction

Due to the superb mechanical properties and their high ratio of strength/weight, composites materials have found an expanding application such as aviation and vehicle structures. Specifically, superconducting magnets of fusion reactors, for example, the Thermonuclear Reactor, may utilize enormous amounts of glass fiber reinforced polymer (GFRP) composite overlays as heat insulation, and electrical protection [1, 2].

Glass fiber-reinforced polyester (GFRP) is widely used materials in the manufacturing of wind turbines blades and water tank. During the service, these are subjected to static and dynamic loading, and may include various factors can affect the composite resistance [3].

An impact at low velocity on laminated composites could be led into different types of damages involving delamination, interfacial de-ponding of fiber-matrix, matrix cracking and fiber breakage. This sort of damages is hazardous due to the difficulty of visual detections and the failure can be occurred at loads lower than the design level.

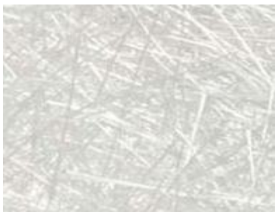
Many studies have been investigated the tensile and impact Behavior of laminated composites at low velocity for example, Masud and Zaman [4] have experimentally investigated the effect corrosive environment, high and low temperature on the fracture toughness of chopped glass fiber reinforced composite. The experiment was done by using single edge notched specimen (SEN). It has been found that the fracture toughness gradually decreases with increasing environmental exposure time and the fracture toughness independent of length of pre-crack notch. Yang and Yao [5] studied the tensile mechanical behaviour of GFRP bars under different temperature. It has been found that there is decreasing in ultimate tensile strength with increasing temperature from -20°C to 300 °C. As well as the tensile elastic modulus and the ultimate tensile strength were linearly decreased below 100°C. Shokrieh et al. [6] have experimentally investigated the glass/epoxy laminated composites under low velocity impact and variable temperature range. The experiment was conducted different energy level also at variable temperature ranging from -30°C to 23°C. It has been found that the mechanism of failure is different which are matrix cracking at room temperature and fiber breakage and delamination at low temperatures. Kumarasamy et al. [7] evaluated experimentally, the tensile performance of GFRP composites at low and high temperature. The mechanical performance of glass fiber epoxy and polyester has been evaluated in static tensile loading.

The results showed that the modulus and the tensile properties decreased with temperature increasing from 25ºC to 80ºC. While the temperature has a little influence on the tensile strength when the temperature reduced from room temperature to -20ºC. Mahmood et al. [8] used a graphene with Glass/Epoxy to study the strain and damage. It has been shown that the deposition of rGO on the glass fiber causes marginal increasing of the dynamic moduli (E', E") of the composites and increasing in the delamination resistance and of the flexural strength. Hulugappa et al. [9] investigated the mechanical behaviour of graphite/fly ash cenosphere and glass fabric reinforced epoxy composites. It has been concluded that the graphite is responsible for improving K_{IC} and F_S of glass epoxy composites. Elanchezhian et al. [10] studied the mechanical properties of GFRP and CFRP composite by conducting a test of composite laminates for tensile with different strain rate at different temperature (35ºC, 70ºC). The composites were fabricated by using hand layup technique. It has been found that the tensile and flexural properties of CFRP better than GFRP properties. As well as the mechanical properties of the laminated composite decreased with temperature increased.

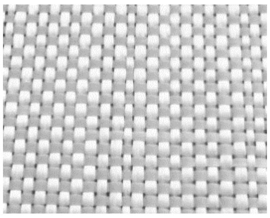
Accordingly, it is found that there is a little attention in the literature regards on the mechanical behaviour of laminated composites with 6, 8, and 10 layers, under tensile and Charpy impact loading testing at elevated temperatures ranging from 30°C to 70°C which are realistic and exist in engineering application. So, the aim of the current investigation is to study the effect temperatures on modulus of elasticity, tensile strength, absorbed energy, and fracture toughness of glass/polyester composites with two forms of E-glass reinforced fibres, woven roving [0, 90] and mat chopped, with a constant volume fraction of 30%.

2. Fabrication of Laminated Composite

The materials used in preparing the samples consist of unsaturated polyester matrix material (Industrial Chemicals & Resins. Co. Ltd) [11], and glass fiber reinforcement materials (Sinoma Jinjing Fiberglass Co., Ltd) in two forms [12], which are E-glass mat chopped strand (the fibers randomly arranged in different orientations) and E-glass woven roving fibers (the fibers arranged in two orientations 0o, and 90 o) as shown in Fig. 1.



(a) E-glass mat chopped fibers.



(b) E-glass woven roving fibers.

Fig. 1. E-glass fibers.

The unsaturated Polyesters are perhaps the most widely used of the thermoset systems, accounting for about 75% of total resin usage. Polyester resins are relatively cheap and quick preparation resins used for low-cost applications. They are macromolecules formed by the condensation polymerization of dibasic acids or anhydrides with dihydric alcohols (glycols). Glass is the most popular fiber used in polymer matrix composites due to its good insulating, high chemical resistance, low cost, and high strength properties [13].

Six types of composite were prepared with a volume fraction of 30%:

- Unsaturated polyester (UP) reinforced with E-glass mat chopped strand fibers with 6, 8, and 10 layers.
- Unsaturated polyester (UP) reinforced with E-glass woven roving fibers with 6, 8, and 10 layers.

The properties of polyester and E-glass (mat chopped strand and woven roving) are the resins and fiber used in this work is shown in Table 1.

Table 1. Properties of the resin and fiber [11, 12].

Materials	**Density (g/cm^3)**	**Modulus of Elasticity (GPa)**	**Strength (MPa)**	**Poisson's Ratio**
Polyester	1.1-1.4	2.1-3.4	34.5-103	0.37-.4
E-glass	2.58	72	3450	0.22

Hand lay-up technique is used to prepare laminated composite plates. It is a molding process where fiber reinforcements are placed by hand then wet with resin. The frame was fabricated from steel plate at the workshop. This technique is an oldest and easiest open moulding method for composite manufacturing processes, laminate panels were fabricated according to *ASTM D5687* [14]. The quantity of fiber exist in the composite is typically considered as a weight fraction or percentage of volume fraction of the composite [15]. The fibers volume fraction could be computed from the equation as follows [16]:

$$v_f = \frac{1}{1+\left(\frac{1-\varphi}{\varphi}\right)\frac{\rho_f}{\rho_m}} \quad (1)$$

where: v_f is the fiber volume fraction, φ is the weight fraction of fiber, ρ_f is the fiber Density (g/cm^3), ρ_m is the matrix density of (g/cm^3).

3. Experimental work

3.1. Tensile test

The mechanical properties have been obtained by tensile test, which were conducted with constant strain rate of 2 mm / min. The specimens were designed according to the ASTM D3039 standard [17], as shown in Fig. 2. The mechanical properties involved modulus of elasticity, and ultimate tensile strength at three different temperature which are 30, 50, and 70°C. The tests were conducted by using a hydraulic test machine equipped with peripheral chamber which is 200 kN *WDW–200 E III*, as shown in Fig. 3. The peripheral chamber was equipped to achieve required testing temperature. The procedure was repeated three times for all the tensile test results of the composite specimens and the average value of the data have been taken. The chamber is spreading oven air to maintain temperature and let sub-ambient temperatures to be reached. The temperature was measured by touch thermometer. The tensile strength and modulus of elasticity of the composite laminates was measured via stress-strain curve, which obtained from a tensile test.

The specimen was placed in the grip of the tensile testing machine and the test was performed by applying tension until it undergoes fracture.

(a) W / UP **(b) Ch / UP.**

Fig. 2. Tensile test specimens.

Fig. 3. WDW–200 E III hydraulic tensile test machine.

3.2. Fracture toughness test

The Charpy impact test is one of the most well-known tests for characterizing the mechanical Behavior of materials. Fracture toughness (K_{IC}) testing carried out on a Gunt WP-400 testing machine shown in Fig. 4, according to ISO-179 standard [18], the specimen of impact was carried out as shown in Fig. 5.

A Charpy test is not sufficient at only one temperature, due to the absorption of energy in fracture decreases with increasing test temperature [2]. The test is performed at 30, 50, and 70°C temperature by heating the samples in a special heated chamber device, and then tested by using impact test machine. The test temperature was monitored by touch thermometer.

Fig. 4. Impact test machine.

Fig. 5. Samples of impact test specimens.

In impact test, the strain energy created in the specimen is supposed equal to the absorbed energy by the specimen when hit by the pendulum. Hence, the amount of strain energy is multiplied by size of specimen to calculating the amount of energy and by using the following equation to calculate the value of fracture toughness [19]:

$$G_c = \frac{U_c}{A} \tag{2}$$

where: G_c is the impact strength (J/m^2), U_c is the strain energy (J), A is the cross-sectional area of specimen (m^2).

Fracture toughness is calculated by El-Kadi and Ellyin [20]:

$$K_c = \sqrt{G_c E} \tag{3}$$

where: E is the elastic modulus (GPs).

4. Results and discussion

It is outstanding that the fiber type and number of fiber layers are mostly in charge of strength enhancement of the composite. Thus, differences in composite strength with different type of fiber and number of loading layer is clear. The difference in values of ultimate tensile strength of Ch / UP and W / UP composite with 6, 8 and 10 layers at 30°C, 50°C and 70°C temperature are shown in Figs. 6, 7, 8, 9, 10 and 11, respectively. The experiment test was repeated three times for all the tensile test of the composite samples and the average value of the results were taken.

The results show that the increasing of the laminated layers for the same type of fibers of the composite will causes increasing the elastic modulus and the tensile strength despite of the orientation of the fibers.

Also, the increasing of fibers participates to strengthening of the composite that reduce the progress of failure through the composite material and decrease the strain to failure. The modulus of elasticity and tensile strength of W/UP is increased by 30% and 19% respectively, while for Ch/UP composite is increased by 17.9 % and 14.6% respectively when the layers increased from 6 to 10 layers as shown in Table 2 and Figs. 6, 7 and 8.

As well as the results showed that the tensile strength and the elastic modulus of laminated composite reinforcing with E-glass woven roving fiber is greater than the composite reinforced with E-glass mat chopped fiber. The modulus of elasticity increased by 20%, 19.3% and 8%, while the tensile strength increased by 30%, 10%, and 5%, when reinforcing with 6, 8 and 10 layers, respectively. This result due to the fiber orientation, which plays an important factor in an increasing the tensile strength and elastic modulus of the laminated composites. This finding agrees with the finding of Ali [21].

Figures 9, 10 and 11, shows the ultimate tensile strength of laminated composites at 30°C, 50°C and 70°C temperature. The mechanical properties such as tensile strength and modulus of elasticity of the composite laminated plates decreased with the temperature increasing from 30°C to 70°C, as shown in Table 2.

In fiber-reinforced polymer matrix composites, the magnitude thermal expansion coefficient of the matrix is normally greater than thermal expansion of the fibers. Due to high temperature of operation condition, it will lead to the matrix to brittleness. The specimens become more brittle at 70°C and a higher loss in tensile strength of about 15% and 12% for Ch / UP and W / UP respectively, while the reductions in elastic modulus about 80% and 90% for Ch / UP and W / UP respectively was found. The samples tested at 70°C show a little loss in the strength, the load bearing capacity losses are decreased at the elevated temperature. This behaviour is due to the progressive loss in stiffness of composite material and makes unsaturated polyester composites more brittle. As the temperature raises, the resin of the GRFP will be softening, which cause a loss in the tensile strength. In addition, the glass fiber will be straightening which cause losses in the stiffness.

The experimental Charpy impact test has been done at three different temperature, which are 30°C, 50°C and 70°C. The fracture toughness has been calculated for all the laminated composite plates as shown in Fig. 12. The fracture toughness of laminated composite is increasing with increasing in the number of layers. The fracture toughness of W / UP composite is increased by 50%, while for Ch / UP is increased by 47% when the layers increased from 6 to 10 layers. The increasing in fracture toughness was due to high fiber-matrix bonding and high modulus of elasticity. The main reason of this increasing is due to the material resistance to the crack propagation, which is impede crack propagation through the layers.

The experiment Charpy impact test results show that the impact performance is affected by the temperature. Also, the fracture toughness of composite laminated plates was decreased with temperature increasing from 30°C to 70°C as shown in Fig. 12, by 46%, 26% for 6 layers, by 28%, 25% for 8 layers and by 27%, 31% for 10 layers for W / UP and Ch / UP laminated composite, respectively.

When the temperature increased, the stiffness will decrease due to the brittle occurred. The ability of material to absorb the energy before the fracture called toughness. The formation of microcracks and growth is considered to be one of energy absorption mechanism. The thermal expansion coefficient of the matrix is normally an order of magnitude greater than that of the fibers. An increase in temperature will cause the matrix to be brittle. Thus, Heat annealing led to an increasing in the crystallinity and a reduce in the fracture toughness. Fracture toughness is a matrix govern property with couple of intricacies from fiber bridging, in this way, due to the decreasing in microcrack formation with increasing temperature led to a decrease in matrix toughness. The composite is unequal to absorb as much energy before complete sample failure at elevated temperatures.

Figure 13 (a) and (b) show the fracture surface of W/UP and Ch/UP specimens after the test. Failure is not occurred over the fiber reinforcements of the samples. Rather, delamination failures of the samples are found in one side of all samples. The matrix material fail was observed beside the weak interface planes, which are between the plies of E-glass fiber reinforcements. Due to geometrical constrains at large bend angles of the specimen, lead to the delamination failure by shear stress.

Table 2. Experimental results of the elastic modulus in (GPa).

Material's type	**6 layers**			**8 layers**			**10 layers**		
	30°C	**50°C**	**70°C**	**30°C**	**50°C**	**70°C**	**30°C**	**50°C**	**70°C**
Ch / UP	6.02	5.18	3.36	6.97	6.08	4.62	8.71	5.47	4.61
W / UP	7.58	6.27	3.84	8.64	6.79	5.37	9.24	7.04	6.55

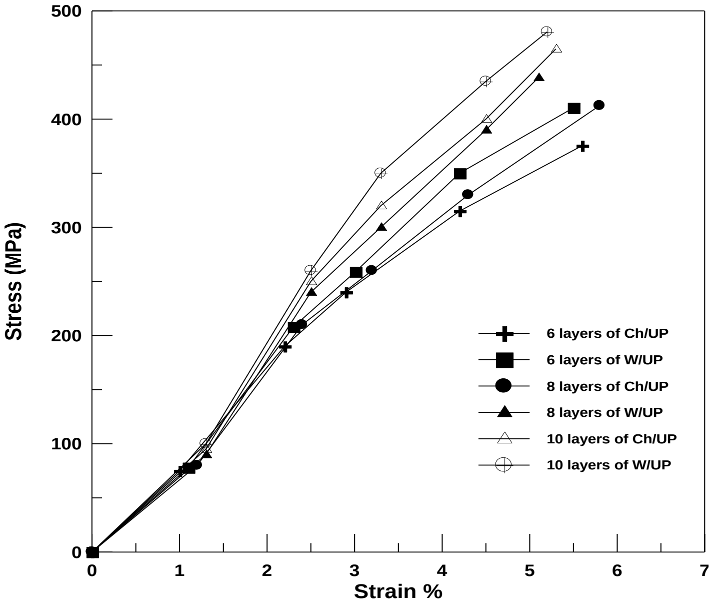


Fig. 6. Stress-strain diagram of laminated composites tested at 30°C temperature.

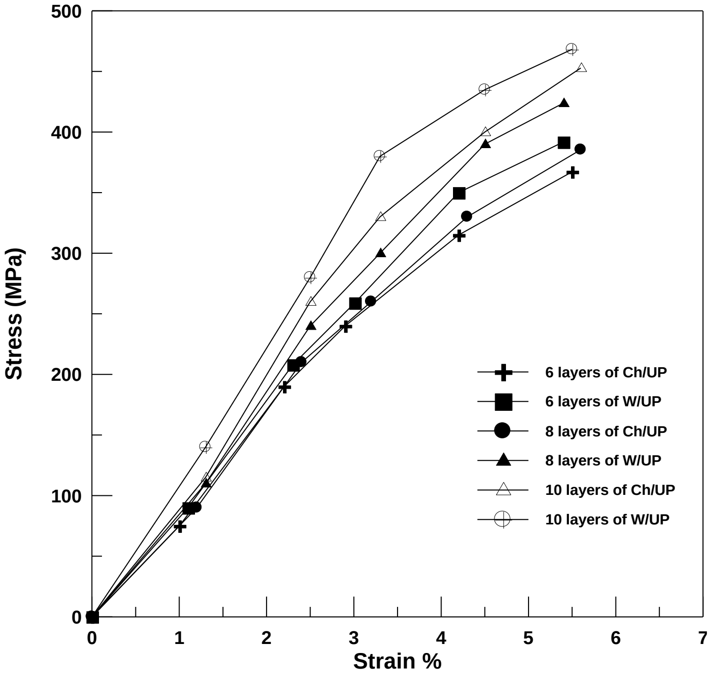


Fig. 7. Stress-strain diagram of laminated composites tested at 50°C temperature.

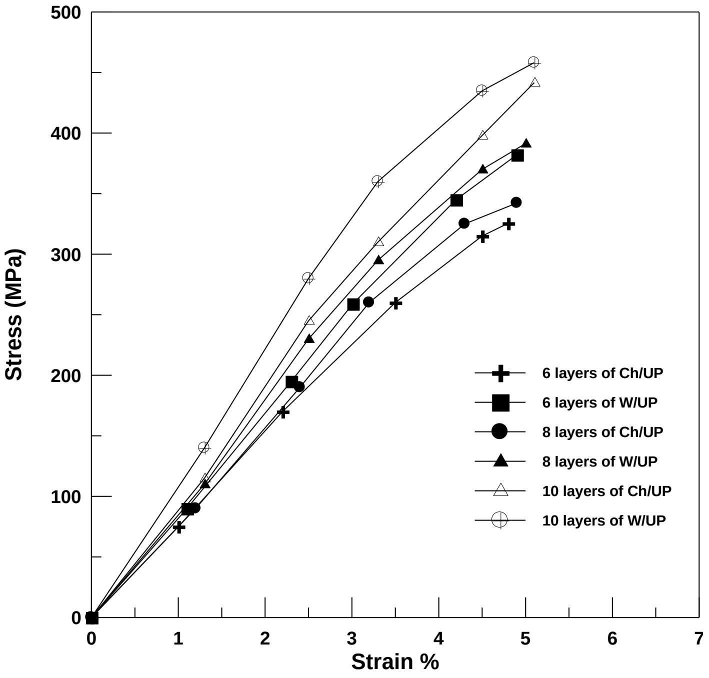


Fig. 8. Stress-strain diagram of laminated composites tested at 70°C temperature.

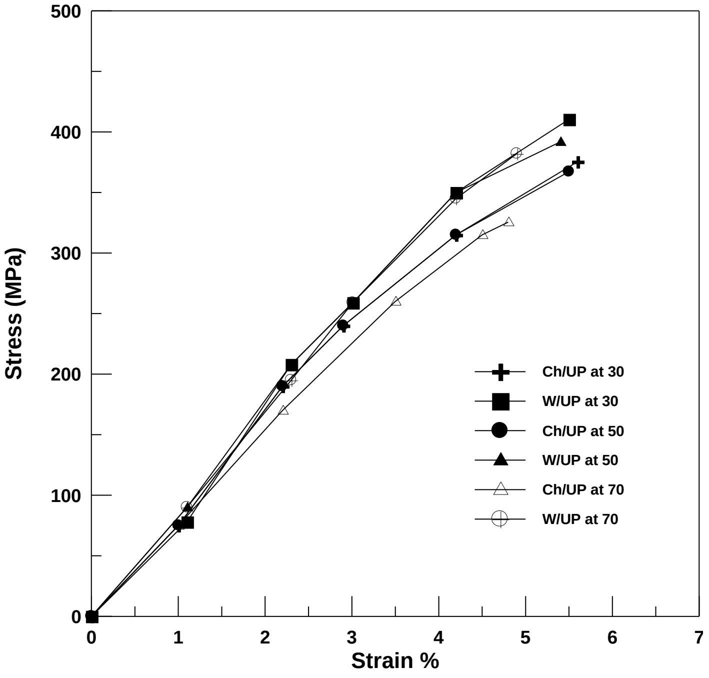


Fig. 9. Stress-strain diagram of laminated composites tested at different temperature with 6 layers of fibers.

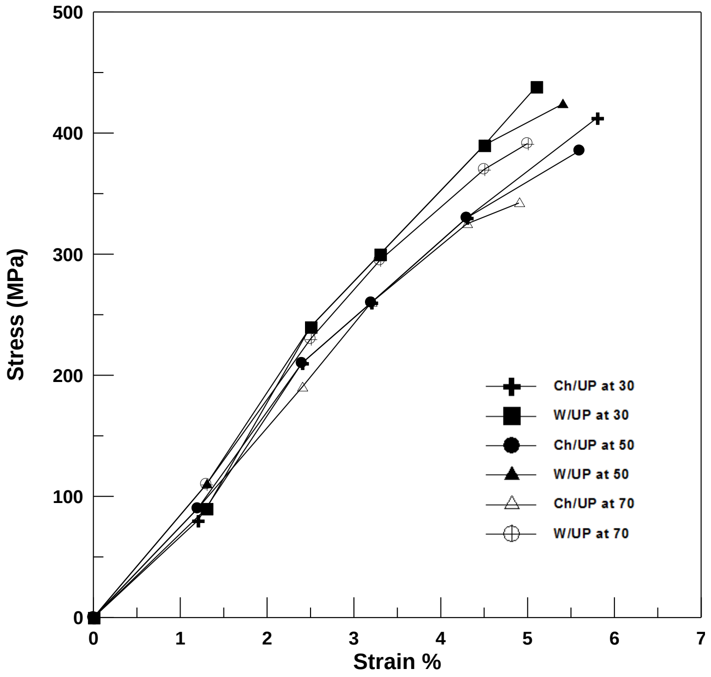


Fig. 10. Stress-strain diagram of laminated composites tested at different temperature with 8 layers of fibers.

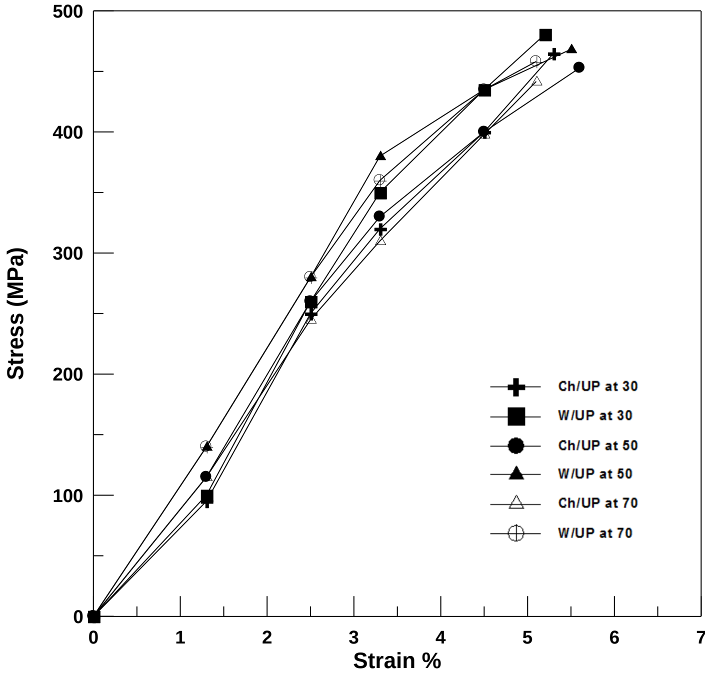


Fig. 11. Stress-strain diagram of laminated composites tested at different temperature with 10 layers of fibers.

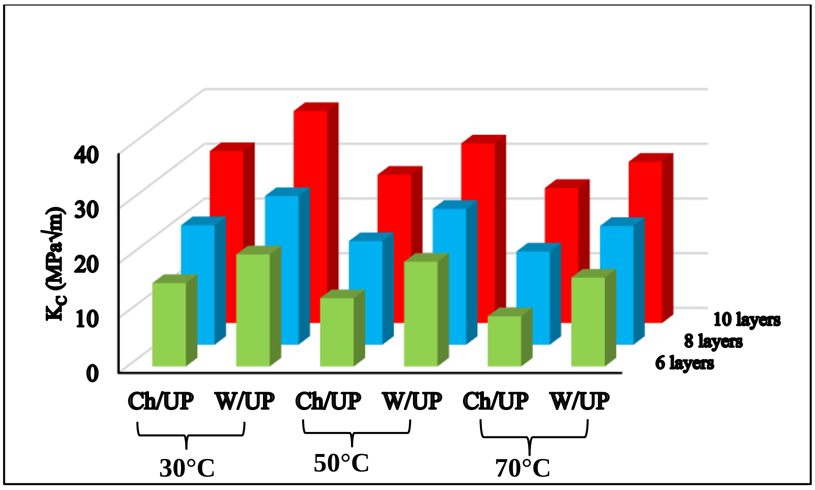
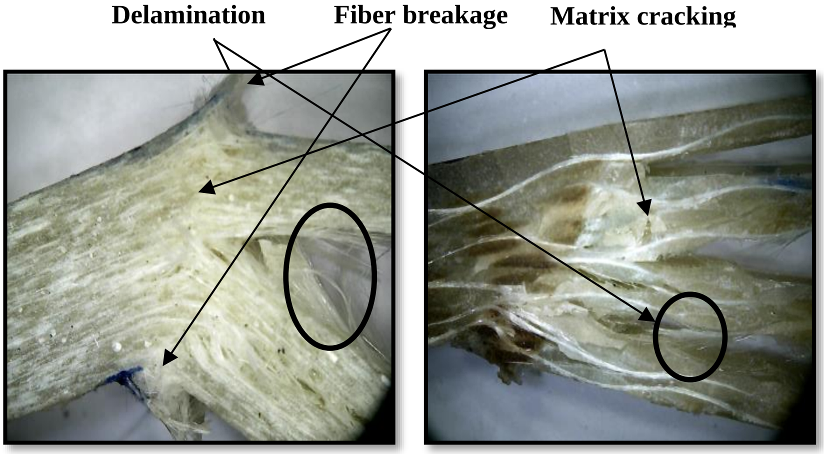


Fig. 12. Experimental results of fracture toughness of the laminated composite materials at various temperatures for 6, 8 and 10 layers.



(a) Unsaturated Polyester matrix reinforced with E-glass mat chopped fibers.

(b) Unsaturated Polyester matrix reinforced with E-glass woven roving fibers.

Fig. 13. Fracture failures of GFRP.

5. Conclusions

The tensile strength and impact behaviour of unsaturated polyesters reinforced with two forms of E-glass, which are woven roving [0, 90] and mat chopped at different temperature, have been investigated. The tests have been done at three different temperature, which are 30°C, 50°C and 70°C. The following conclusions can be considered from this research:

- The unsaturated polyester matrix reinforcement with E-glass woven roving fiber has a greater module of elasticity, tensile strength, and fracture toughness than that of E-glass mat chopped fiber.
- The increasing the laminated layers for the same type of fiber of the composite will increase the modulus of elasticity, tensile strength, and fracture toughness regardless of the orientation of fiber.
- The mechanical properties of the laminated composite decreased with temperature increased from 30°C to 70°C.
- Failure mechanism is varied from fiber breakage and delamination at high temperatures to matrix cracking at room temperature.

Recommendation for a future work

There are many research points should be considered in the future work to have full understanding about the behaviour of suggested material such as:

- Study of the effect of varying volume fraction on the mechanical properties of laminated composite materials.
- Study of the effect of varying matrix materials by using thermoplastic polymer.
- Study of the effect of varying fiber reinforcement materials like using carbon fibers.
- Study of the effect of very low temperature on the behaviour of such composite materials.

Nomenclatures

A	Cross- sectional area of specimen, m^2
E	Modulus of elasticity, GPs
G_C	Impact strength, J/m^2
K_{IC}	Fracture toughness, MPa$\sqrt{}$m
U_C	Strain energy, J
v_f	Fiber volume fraction

Greek Symbols

φ	Weight fraction of fiber
ρ_m	Matrix density, g/cm^3
ρ_f	Fiber density, g/cm^3

Abbreviations

CFRP	Carbon fiber reinforced polymer
Ch / UP	E-Glass mat chopped fibers reinforced with unsaturated polyester
GFRP	Glass Fiber Reinforced Polymer
UP	Unsaturated polyester
W/UP	E-Glass woven roving fibers reinforced with unsaturated polyester

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