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Effects of High and Low Temperature on the Tensile Strength of Glass Fiber Reinforced Polymer Composites

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Abstract. In this paper, the tensile performance of glass fiber reinforced polymer (GFRP) composites at high and low temperature was experimentally evaluated. GFRP laminates were manufactured using the wet hand lay-up assisted by vacuum bag, which has resulted in average fibre volume fraction of 0.45. Using simultaneous heating/cooling and loading, glass fiber epoxy and polyester laminates were evaluated for their mechanical performance in static tensile loading. In the elevated temperature environment test, the tension mechanical properties; stress and modulus were reduced with increasing temperature from 25^{o}C to 80^{o}C. Results of low temperature environment from room temperature to a minimum temperature of -20^{o}C, indicated that there is no considerable effect on the tensile strength, however a slight decrease of tensile modulus were observed on the GFRP laminates. The results obtained from the research highlight the structural survivability on tensile properties at low and high temperature of the GFRP laminates.

1. Introduction

Fiber reinforced polymer (FRP) composites has been widely accepted in many engineering applications that requires high performance structures. FRP composites holds a huge advantage over traditional or conventional material in term of its mechanical and chemical properties. It has a high fatigue resistance due to its excellent tension handling and can withstand high load tension. FRP composites have a non-elastic structure which can absorb vibration and dissipate it. This property is suitable for bridge structure and aircraft as they are constantly subjected to vibration from the wind. One of the biggest advantage of using FRP composites is their high strength to weight ratio [1]. This will enable manufacturer to produce high strength materials while reducing its overall weight. With the manufacturing cost of FRP composites are decreasing, many manufacturer and engineers are opting FRP composite as a replacement for traditional materials [2]. Because of this FRPs are being considered in the aerospace, marine, construction, automotive, oil and gas industries as well as in wind turbine application.

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There are two type of FRP composite that are widely used in the industries which are carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP). Both of this FRP have their pros and cons but for this research, we will mainly focus on GFRP composites since this materials is low cost and readily available locally compared to CFRP while still having excellent mechanical properties. GFRP has also been extensively used in many applications from the household industry to a high performance structure in the aerospace industry [3]. Despite many advantages offered by the GFRP, one of the critical limitations on the use of GFRP is in high temperature applications. The increasing use of GFRP at low temperature has also draw interest for researcher in studying the behavior and effect of the FRP specimens.

The purpose of this paper is to investigate the effect of hot and cold environment under tensile loading of GFRP epoxy and polyester laminates. The strength of FRP is strongly dependent on temperature, with tensile strength and modulus rapidly decreasing once the temperature exceeds the glass transition temperature [4, 5]. The tensile behavior of FRP composites at high temperature and fire was studied by many researchers using several experimental approach and several fiber/matrix combinations [6-13]. Similar to high temperature, as the composite is exposed to low temperature environment, the strength and modulus might changed. Few studies has been performed to evaluate the mechanical properties of FRP composites at low temperature environment and the results are varies depending on the loading, experimental setting and type of specimens tested [14-17].

This paper evaluates both hot and cold environment on the GFRP specimens made using wet lay-up assisted by vacuum bagging method using an available testing machine fitted with a hot/cold box chamber. The results will provide important insight on the effect of both hot and cold environment to GFRP laminates.

2. Materials and experimental techniques

2.1. GFRP laminates

The GFRP laminates were manufactured from E-glass plain woven fabric (800 g/m^2) and epoxy resin (Bisphenol-a) or polyester resin. The resin did not contain flame retardant fillers or additives. GFRP laminates were manufactured using the wet hand lay-up assisted by vacuum bag. The laminates were then left to cure at room temperature and went through post-cure process in the oven at 80^{o}C for 1 hour. The average fibre volume fraction of the laminates was 0.45 and was determined through burn-off test method following ASTM D2584.

2.2. High and low temperature environment test

The static tensile properties were obtained using a 50 kN Testometric M500-30 range computer controlled universal materials testing machine. To simulate a hot/cold temperature environment, a close chamber box was attached to the Testometric machine. The hot/cold box is capable to simulate a hot condition at maximum temperature of 80^{o}C and cold condition at a minimum temperature of -20^{o}C. The size of the specimen was 140 mm x 20 mm with a gauge length of 50 mm. To reduce the slippage problem, tabs from sand paper were introduced on the GFRP specimens. The tensile test was conducted under position control with a crosshead speed of 2 mm/min. The GFRP laminates specimen was tested at room temperature and at both hot/cold environment under simultaneous tensile loading. A total number of 3 specimens were tested at each condition for both GFRP laminates.

3. Results and discussion

The experimental results obtained from the high and low temperature tests for the GFRP polyester and epoxy laminates are presented next.

3.1. High temperature tensile behaviour

From the tensile test results, the stress strain curves were drawn. Figure 1a and 2a show these curve for the GFRP laminates at the four different temperatures considered. The laminate exhibits a linear

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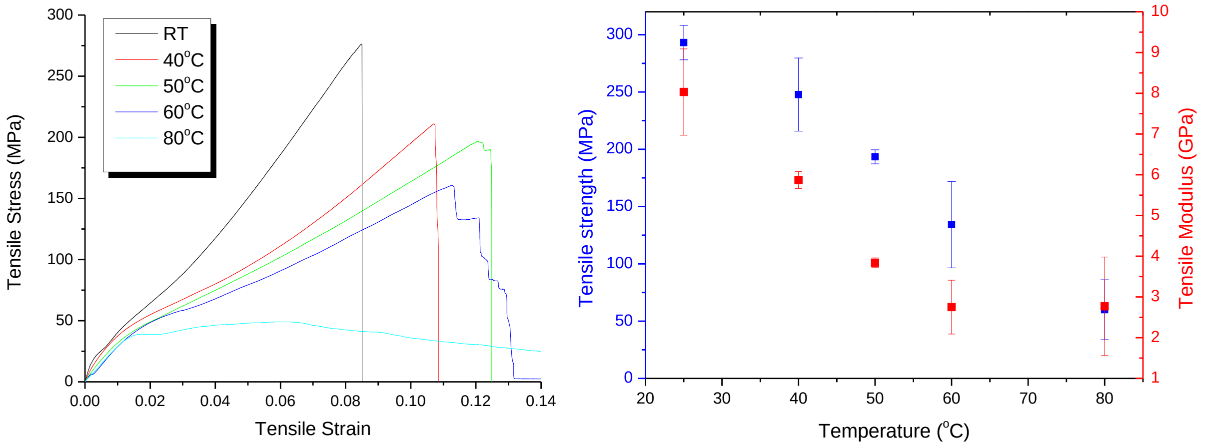
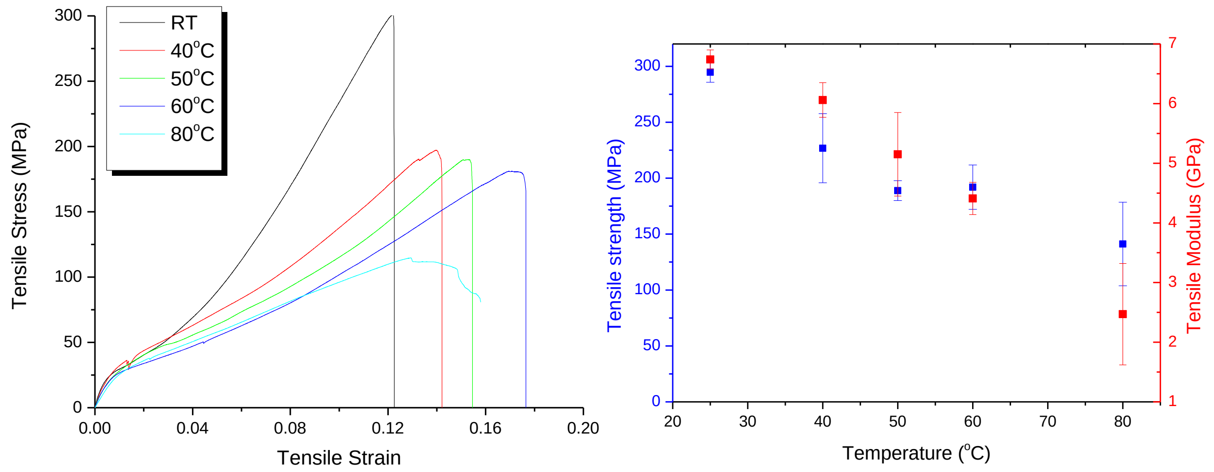
elastic behaviour at room temperature until breakage while at elevated temperatures; the curves show a non-linear region before breakage. The slope of the stress strain curve decrease significantly as the temperature increases.

The tension strength and elastic modulus as a function of temperature has been plotted to evaluate the effect of elevated temperature for both types of GFRP laminates tested. Figure 1b and 2b show the relationship of the tensile strength and modulus of the surrounding temperature for the two types of GFRP laminates respectively. The curves clearly show that the tensile strength and modulus decreases as the temperature of the surrounding increases. The loss in tensile strength is mainly due to the resin softening of the GFRP laminates. The stiffness loss is attributed to the straightening of woven fibers as the matrix softens.



(a) (b)

Figure 1. GFRP epoxy laminate specimens at elevated temperatures (a) Tensile stress vs strain curves (b) Tensile strength and modulus



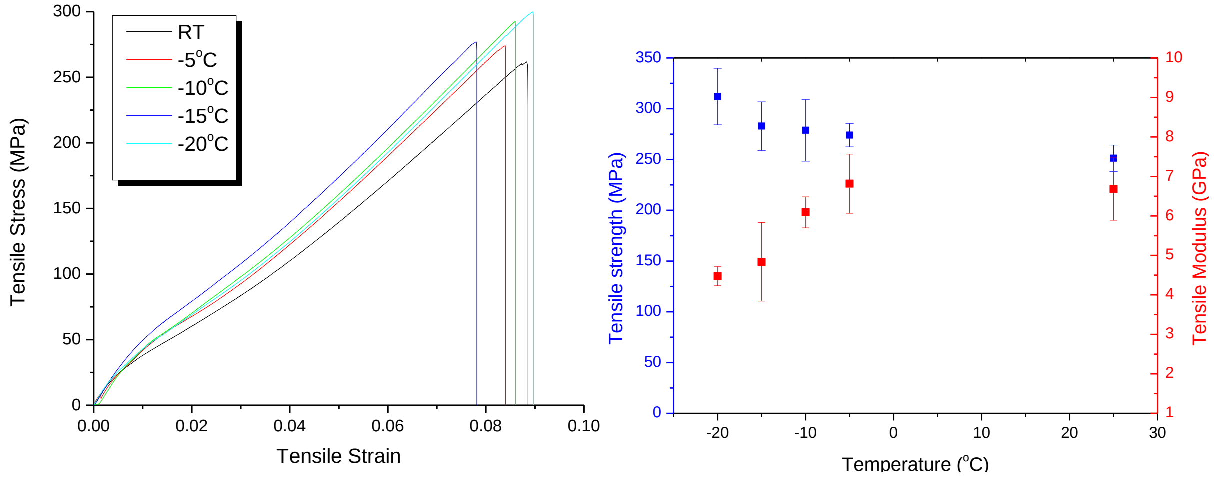
(a) (b)

Figure 2. GFRP polyester laminate specimens at elevated temperatures (a) Tensile stress vs strain curves (b) Tensile strength and modulus

3.2. Low temperature tensile behaviour

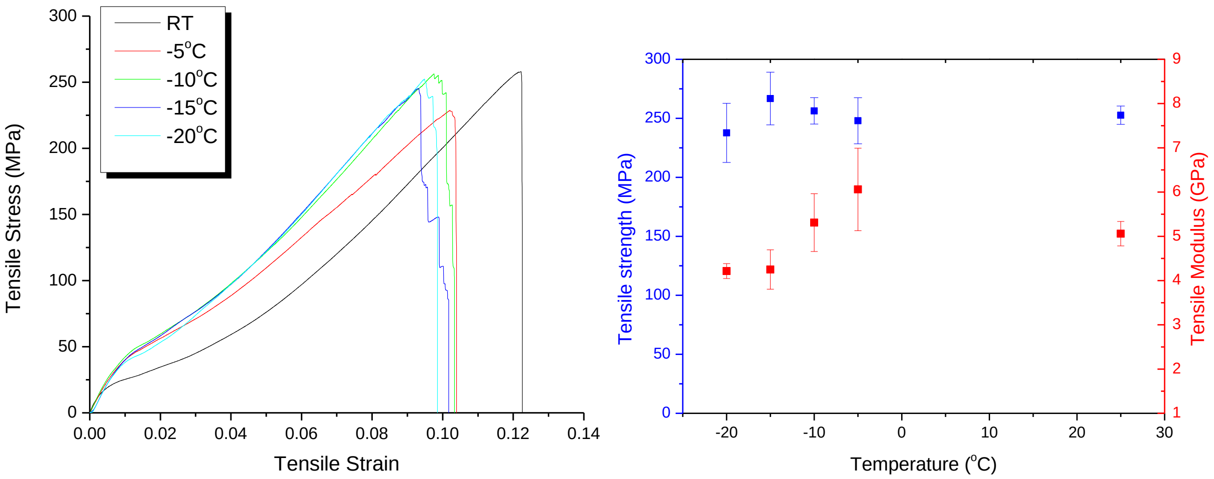
From the tensile test results, the stress strain curves are plotted. Fig. 3a and 4a show these curve for the GFRP laminate at the four different temperatures considered. The GFRP laminates exhibits a linear elastic behavior until breakage. The slope of the stress strain curve increases slightly as the temperature decreases. Both types of GFRP specimens show brittle behaviour as the strain to failure decrease at lower temperature.

The tension strength and elastic modulus as a function of temperature has been plotted to evaluate the effect of low temperature environment for both types of GFRP laminates tested. Figure 3b and 4b show the relationship of the tensile strength and modulus of the surrounding temperature for the two types of GFRP laminates respectively. The curves show that there is no considerable effect on the tensile strength. However, a slight increase of tensile modulus from room temperature to -5°C was observed and slight decrease from -5°C to -20°C was observed on the GFRP laminates.



(a) (b)

Figure 3. GFRP epoxy laminate specimens at low temperature surrounding (a) Tensile stress vs strain curves (b) Tensile strength and modulus



(a) (b)

Figure 4. GFRP polyester laminate specimens at low temperature surrounding (a) Tensile stress vs strain curves (b) Tensile strength and modulus

4. Conclusions

The high and low temperature properties of GFRP laminates during tensile loading have been evaluated in this paper. Both tensile strength and modulus of the GFRP composites decrease as the temperature of the surrounding increases. The loss in tensile strength is mainly due to the resin softening of the composites tested. The stiffness loss is attributed to the straightening of woven fibers as the matrix softens. Results of low temperature environment indicated that there is no considerable effect on the tensile strength tested between room temperature to a minimum of -20°C. However, a slight increase of tensile modulus from room temperature to -5°C was observed and slight decrease from -5°C to -20°C was observed on the GFRP laminates. GFRP laminates also have shown a brittle behavior as the surrounding temperature decreases. The results obtained from the research highlight the structural survivability on tensile properties at low and high temperature environment of the GFRP laminates.

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