THERMAL AGING OF UNSATURATED POLYESTER COMPOSITE REINFORCED WITH E-GLASS NONWOVEN MAT

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Abstract:

An experiment was carried out using glass fiber (GF) as reinforcing materials with unsaturated polyester matrix to fabricate composite by hand layup technique. Four layers of GF were impregnated by polyester resin and pressed under a load of 5 kg for 20 hours. The prepared composite samples were treated by prolonged exposure to heat for 1 hour at 60–150°C and compared with untreated GF–polyester composite. Different mechanical test of the fabricated composite were investigated. The experiment depicted significant improvement in the mechanical properties of the fabricated composite resulted from the heat treatment. The maximum tensile strength of 200.6 MPa is found for 90°C heat-treated sample. The mechanical properties of the composite do seem to be very affected negatively above 100°C. Water uptake of the composite was carried out and thermal stability of the composite was investigated by thermogravimetric analysis, and it was found that the composite is stable up to 600°C. Fourier transform infrared spectroscopy shows the characteristic bond in the composite. Finally, the excellent elevated heat resistant capacity of glass-fiber-reinforced polymeric composite shows the suitability of its application to heat exposure areas such as kitchen furniture materials, marine, and electric board.

Keywords:

Glass fiber, Polyester, Composite, Mechanical Properties

1. Introduction

Composite materials are special type of materials in which two different materials known as matrix and reinforcement are combined together to obtain their synergistic effects on the end products. Composite materials are one of the most significant inventions of the material sciences and widely used in furniture, packaging, assembly boards, paneling, fencing, kitchen to civil constructions, automobile and marine industries, military purposes, and even space or aircraft manufacturing. So, composites are a versatile and valuable family of materials that can be used in many fields with high quality and low cost applications. The excellent mechanical properties of synthetic fibers made them a versatile choice for different applications [1]. Fiber-reinforced composites were successfully used for many decades for all engineering applications. Glass-fiber-reinforced polymeric (GFRP) composites were most commonly used in the manufacture of composite materials because of their low cost, high tensile strength, high chemical resistance, and insulating properties. The matrix comprised organic, polyester, thermostable, vinylester, phenolic, and epoxy resins. Owing to suitable compositions and orientation of fibers, desired properties and functional characteristics of GFRP composites were equal to those of steel, their stiffness was higher than that of aluminum, and their specific gravity was one quarter of the steel. The various glass fiber (GF) reinforcements such

as long longitudinal, woven mat, chopped fiber (distinct), and chopped mat in the composites have been produced to enhance the mechanical and tribological properties of the composites [2-3]. GF-reinforced unsaturated polyester resin (UPR) composite materials have become the alternatives of conventional structural materials, such as wood and steel, in some applications, because of its good mechanical properties. Mechanical properties of fiber-reinforced UPR composites depend on the properties of the constituent materials, the nature of the interfacial bonds, the mechanisms of load transfer at the interphase, and the adhesion strength between the fiber and the matrix [4].

The usefulness of composite materials is determined by their mechanical properties and establishes the shelf life of the composite. The properties of the composite may vary because of the change in microstructures of reinforcement, matrix, different loading conditions, and surrounding environment such as heat [5,6], moisture [7-9], and corrosive environment [10]. Generally, applying the GFRP materials in construction is subjected to different temperatures. Changes in temperatures greatly influence the properties of the composite. Belaid et al. [11] investigated the effect of accelerated thermal aging on glass/polyester composite at constant temperature 80°C for different periods. Their result showed that with the increase of aging time, elastic modulus decreases. Bisht and Chauhan [12]

performed an experiment on E-glass-reinforced unsaturated polyester composite against different temperatures. They observed that tensile strength of the composite decreases with the increase in temperature. Increased temperature causes oxidation and mechanical creep in polyester, which causes degradation, and this takes place in composite materials because of its thermal expansion coefficient [13-15]. Thermal degradation of the composite is the crucial issue while applying in constructions, automotive, and marine. The problem of fire that may result in the mentioned areas, the composite materials should resist at higher temperature initially to allow some time to take preventive measures. Hence, extensive study on thermal aging of the glass composite is required. The objective of this experiment is to investigate the influence of various temperature levels on GF-reinforced unsaturated polyester composite. Four plies of GF were reinforced to polyester resin and its response to different mechanical properties of the fabricated composite by temperature variations were determined and exhibited in this study. Thermal analysis of the composite was done to determine the degradation of the composite.

2. Experimental

2.1. Materials

Unsaturated polyester and methyl ethyl ketone peroxide (MEKP) were supplied by Polyolefin Co. Limited; Singapore and E-glass nonwoven mat of GSM 300 was purchased from Saint-Gobain Vetrotex, India. The resin liquid solidify when hardener additives MEKP is added, which is transparent liquid. For the fabrication of GFRP, 5% MEKP were added to each 100 gm of polyester resin at room temperature. The polyester resin used in this experiment has the density of 1.35 g/cm^3 , and the composite were fabricated by using 60% polyester resin with 40% glass nonwoven mat. The properties of the used E-glass fiber are shown in Table 1.

2.2. Methods

2.2.1 Method of Composite Fabrication

The composite specimens were prepared by hand lay-up techniques followed by cold compression curing method. UPR and MEKP hardener were taken in a beaker. They were then mixed well and made ready for laminating glass-reinforced mats.

At first, a melot paper was placed on dried bottom part. Then some of the prepared resin mixture was spread evenly on the paper. After that, a piece of nonwoven glass was placed on the resin mixture and a part of resin mixture was spread on the mat. Another piece of glass fabric was placed and similarly rest of the resin mixture was spread on the mat and so on. A melot paper was placed on the mat following which top part of the open mold was kept on the paper. The prepared samples were allowed to cure under pressure at room temperature. The manufacturing process of GFRP by hand lay-up process is shown in Figure 1.

The microscopic view at $1000\times$ zoom for both the nonwoven glass mat as well as fabricated composite is shown in Figure 2. Figure 2(a) provides information about fiber alignment within different layers of nonwoven mat. Figure 2(b) shows the composite surface and glass–polyester interaction within the composite system. The figure also indicates some bubbles formed in between the layers during fabrication. The bubble-formed segments had been omitted from the mechanical test specimen to get precise results. In addition, it is also observed that the distribution of fibers within the matrix is not uniform.

2.2.2 Mechanical Testing of Composite

Tensile tests were conducted according to the ASTM D 638-01 using a Universal Testing Machine (Hounsfield series, model: INSTRON 1011, UK) with a cross-head speed of 10 mm/min . The dimensions of the test specimen were (ISO 14125) $60 \text{ mm} \times 15 \text{ mm} \times 2 \text{ mm}$. Izod impact test for different fabricated composites were carried out according to ASTM D-256. The length and width of the samples used in impact test were 61.5 and 12.7 mm , respectively.

Table 1: Packet label properties of E-glass fiber as received

Properties	E-glass
Density (gm/cc)	2.56
Young's Modulus (mN/m ²)	55.7
Specific Gravity	2.56
Tensile Strength (mN/m ²)	442
Refractive Index	1.55
Softening Point °C	845
Specific heat capacity J/g °C	0.81

Figure 1: Hand lay-up manufacturing of GFRP

a)

b)

Figure 2: Microscopic view of (a) glass fiber (1000×) and (b) composite (1000×)

2.2.3 Water Absorption Test

The GFRP samples (20 mm × 10 mm × 2 mm) were cut from the bulk sample and kept in standard temperature for water absorption test. Then the samples were immersed in a static water bath at 25°C for different time periods (up to 1,800 min). Before immersion in water, the specimens were dried in an oven at 105°C, cooled in a desiccators using silica gel, and weighed. After certain periods of time, samples were taken out from the bath and wiped using tissue paper, then weighed. Water uptake was determined according to ASTM D 570 by using the following formula-

$$\text{Water absorption} = \frac{W_a - W_b}{W_b} \times 100 \quad (1)$$

where W_a is the weight after water immersion and W_b is the weight before immersion.

2.2.4 Thermogravimetric Analysis

Thermogravimetric analysis (TGA) is a method of thermal decomposition useful in assessing the relative thermal stability of the composites, which observes the changes in physical and chemical properties of materials as a function of increasing temperature and time. The thermal property of the GFRP was measured by TGA under nitrogen atmosphere. The weight loss of the GFRP materials was recorded using TG 6 thermogravimetric analyzer (Perkin Elmer) with a flow rate of 10 mL/min and a scan rate of 10°C/min over a temperature range from room temperature to 600°C.

3. Results and discussion

Nonwoven glass mat was reinforced in thermoset polyester matrix by hand lay-up process with the fabric content of 40%.

The mechanical properties such as tensile strength, tensile modulus, and elongation at break were evaluated. Shear strength and hardness of the fabricated composite were also reported in this experiment. Of the five samples, four samples designated as HT 60, HT 90, HT 120, and HT 150 were heat treated from 60 to 150°C for one hour and the last one was untreated. The impact of heat on different samples was compared to the untreated sample.

3.1 Evaluation of Tensile Properties

Tensile strength of GFRP before and after exposure to heat is shown in Figure 3. Effects of heat on the composite were recorded and found that tensile strength increases with the increase in heat and reaches to the maximum of 200.6 MPa. A substantial amount of increase in tensile strength of about 48% is observed compared to untreated sample when exposed to heat at 90°C. The same effect is reported by the researcher [16-18]. Tensile strength seems to be deteriorating above the temperature of 100°C and reaches the bottommost point (123.3 MPa) at 150°C. This may be due to the reorientation of the internal fiber architecture of the reinforcement during heat treatment. This results in changes in the crystallinity of the resin structures in heat treatment. Thus the fibers are pulled out from the UPR. Exposure of the GFRP samples to 60 and 120°C shows almost similar amount of tensile strength around 180 MPa, which is also around 33% higher than its counterpart. Changes in tensile modulus against different temperature are presented in Figure 4. The overall trend of the tensile modulus is almost similar to that of the tensile strength after different heat exposure. Tensile modulus of GFRP starts to increase with the increase in heat, and maximum tensile modulus is found to be 2.4 GPa at 90°C. This is 77.82% higher when compared to untreated sample. Lowest tensile modulus of the GFRP is recorded at 150°C after 56.03% decrease from the highest modulus. Decreases in modulus can be attributed to

the hydrolysis of the resin and bond degradation due to the heat of the composite samples.

3.2 Evaluation of Impact Strength

Figure 5 depicts the impact properties of GFRP in terms of heating. No specific trend is observed in impact strength with different temperature ranges. Sample treated at 90°C shows the highest impact strength of 155.178 kJ/m². Controversially, sample treated with 150°C shows dramatic fall in impact strength by 43.83% compared to untreated sample. Almost zero change in absorbed energy is found in the sample treated in initial temperature. It is interesting to observe that the exposure of GFRP to high temperature reduces the toughness to 78.125 kJ/m², which is far below the untreated sample. This can be attributed to arise of crack and flaws in the glass because of the brittleness of GF. The impact load imposed on the composite samples causes the flat fracture in the fiber, which reduces the energy-absorbing capacity of the samples. In addition, extreme temperature leads to delamination of the composite at large extent as well as fiber matrix debonding [19, 20].

3.3 Water absorption

Figure 6 depicts the water uptake (wt %) of the composite against soaking time. The figure shows that composite samples appear to be saturated within the time frame used for this experiment. It is noted that GFRP showed very little amount of water absorption up to 60 min. Then it gradually increase with some fluctuations till 1,000 min at which it reaches the peak (0.5%) and becomes saturated afterwards (0.52%). High temperature causes microcracking of polyester assisted by osmotic process, which leads to an increase in water flux from outside to the inside of microcracks. In this case, water molecules first enter the open space produced by microvoids that was formed by cavities and cracks in the matrix. In addition, tiny droplets of water may diffuse inside the interface because of the capillarity that may increase the weight of the composites. During prolonged immersion of the samples into water, the hydrophilic group of GF and polyester resin are attracted and chemical reaction takes place. As a result, weight reduction of composite materials may happen [21].

3.4 Thermogravimetric Analysis

Both the polyester resin and composite have been analyzed by thermogravimetry. TGA determines the weight loss because of volatilization and decomposition or gain by gas absorption or chemical reaction. Figure 7 shows that the degradation of composites takes place in two significant stages. The weight loss of unreacted polyester resin or other impurities occurred at the first stage between 40 and 370°C. The weight loss of cured polyester resin occurred at the second stage between 370 and 480°C. In the first stage of decomposition at 370°C, the residual mass of resin is about 72%, and in the second stage at 480°C, the residual mass is nearly 5%. For composite material, the decomposition begins around at 50°C and residual mass decreases to 80% at 340°C. In the second step, the residual mass of the composite is

Figure 3: Tensile strength of GFRP

Figure 4: Tensile modulus of GFRP

Figure 5: Impact strength of GFRP

Figure 6: Water uptake percentage of GFRP

almost 40% at 600°C, which is much higher than the resin. This can be attributed to the thermal stability of GF below 1,000°C. Same result was reported by researcher [22].

Figure 7: TGA curve for the glass composite and polyester resin

4. CONCLUSIONS

The effect of different temperature on GFRP was experimentally investigated. This is of important interest in various applications in order to warranty the service life of GFRP exposed to heat. The GFRP were found to be temperature sensitive. Treatment of the composite below 100°C shows highest increase in their different mechanical properties, whereas above the boiling temperature, there is significant loss of their mechanical properties. Water absorption test shows that the weight of the composite materials may increase due to penetration and diffusion of water molecules. TGA investigation depicts that the degradation of matrix and composite is above the service temperature 150°C. The thermal degradation takes place in two stages: first between 40 and 50°C and the second between 340 and 370°C.

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