Glass Fiber-Reinforced Phenolic Composite

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Abstract

The influence on mechanical properties of E-glass fiber-reinforced phenolic composite was investigated by varying wt % of fiber to resin ratios (20/80, 30/70, 40/60 and 50/50). E-glass fibers of uniform length (25 mm) were mixed with phenolic resin (resol) at room temperature (25°C). The standard test samples of resin-impregnated fibers, for mechanical testing, were made by using die molding technique. The tensile, flexural and impact strengths of these composite materials were evaluated at room temperature using universal testing machines. The random orientation of fibers and non homogeneity of composite was examined by SEM and Digital camera. It was observed that the impact, flexural and tensile strength increase gradually with increase in glass fiber content up to 40% by weight. It was also observed that tensile and impact strength decreased slightly (about 5%) when glass fiber content was increased from 40 to 50% whereas the flexural strength showed a gradual increase.

Keywords: *Polymeric matrix composite, Phenolic resin, E-glass fibers*

Introduction

Glass fiber/phenolic composites are composed of glass fiber as reinforcement and phenolic resin as matrix. Most of the resins used for composites are epoxy, vinylester and polyesters. Although phenolic resins were among the first polymers developed and have been used commercially for about a hundred years but only few publications are seen in which composites were prepared using phenolic resins. [1-6].

Phenolic resins are the products of condensation reaction of phenol and formaldehyde with water as by-product [7]. The phenolics are used as molding materials. During heat and pressure of the molding process, phenolic react to form a cross-linked structure. This structure yields excellent dimensional and thermal stability with superior load-bearing capability at elevated temperatures [8-9]. Because the resin is compatible with a variety of reinforcements (glass fibers, silicon carbide fibers, high silica and quartz fibers, alumina fibers, metal fibers and wires, graphite fibers, boron fibers, aramid fibers and multiphase fibers) and fillers, a wide range of engineering materials with varying properties can be synthesized.

E-glass is a family of glasses with calcium aluminoborosilicate composition and having maximum alkali content of 2.0%. E-glasses are used as a general purpose fiber when strength and high electrical resistivity are required [10]. E-glass fibers are low cost, easy to manufacture, and possess high strength and stiffness with respect to the polymers in which they are reinforced. Also it can be processed easily through die molding, filament winding and hand-lay-up techniques. E-

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glass are available in the form of mats, tapes, cloths, continuous and chopped filaments, roving, and yarns [11].

Margolis reported that normally chopped glass fibers are added in polymeric matrix from 20-50% by weight [12]. It was also reported by Harrington that a combination of reinforcement and fillers that make up about 45 to 65% of molding material formulation can impart specific material and mold processing properties [13]. Similarly Gardner reported that the reinforcements can account for about 40 to 70 wt% of the total composition of composite [14]. In general, physical and mechanical property of the composite is improved with the length of the fiber reinforcements. Typical lengths range from 1/8 to 2 inch. Colclough and Dalenberg used E-glass fibers in 1/2 inch and 1 inch length and put 56% by weight in phenolic resin and tested the tensile, impact and flexural strength. It was found that these mechanical properties show great improvement with the increasing glass fiber length [15, 16].

In this paper, we are presenting mechanical properties of phenolic matrix composite having E-glass as reinforcement varying from 20-50% by weight. Four composites with fiber to resin ratios 20/80, 30/70, 40/60 and 50/50 were prepared by using chopped E-glass fibers of uniform length of 1 inch. The effect of variation of weight percent of E-glass fiber on mechanical properties was examined by the tensile, flexural and impact strengths of these phenolic matrix composites.

Materials And Methodology

Materials

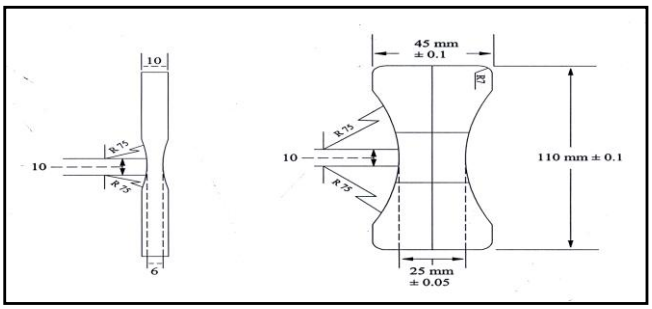
Chopped E-glass fibers of length ~25 mm and diameter ~0.2 mm were purchased from Taiwan Glass Industry, Taiwan. Phenolic resin (resol), in liquid form, was purchased from Shisin Industries, Taiwan. These materials were used without any pretreatment.

Preparation of composites

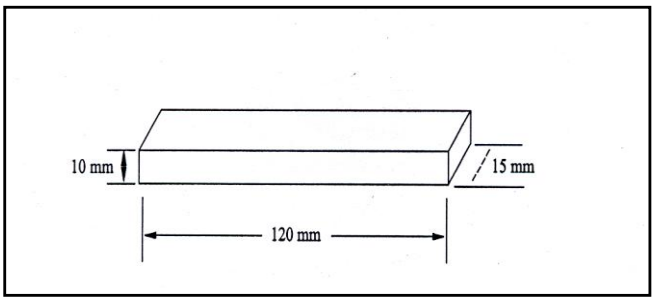
The glass fibers were hand mixed with resin in different fiber to resin ratios, 20/80, 30/70, 40/60 and 50/50, to prepare different composition composites. After thoroughly mixing glass fibers with resin, the resin-impregnated fibers were partially cured at 90 ± 5 ºC for one hour in an electrically heated oven. This material was later used for making compression molded test specimens for mechanical testing.

Preparation of testing samples

Samples for mechanical properties were prepared by using an electrically heated hydraulic press (Shanghai Press, China) of 100 tons capacity. The exact dimensions of specimens for tensile test are given in Fig.1 (a) and for impact and bend test are given in Fig.1 (b). The specimens for bend and impact tests were of the same size. The special features of pressure, time and temperature of the press were used to get the best quality samples using compression molding dies of standard size.



(a)



(b)

Fig.1: Dimensions of specimens (a) tensile specimen (b) Impact and bend specimen

The dies were pre-heated up to 150°C on the heated bed of press before putting resin-impregnated fibers into the die-cavity. The dies were kept under pressure of 25 MPa while maintaining the temperature of die at about 150°C for 20 minutes to cure the sample into the die-cavity.

Mechanical testing

The tensile, flexural and impact strengths of these composite materials were evaluated at 25 °C according to standard procedures [17-19]. Tensile testing of specimens was carried out on a universal tensile testing machine [Shimadzu Corporation Kyoto, Japan] having capacity of 500 KN. Fig.2 shows the die molded tensile sample and breaking fixture used to test tensile strength. While Fig.3 shows the press used for the purpose. The tensile strength of samples was calculated using Equation (1)

$$S = P/ BD \qquad (1)$$

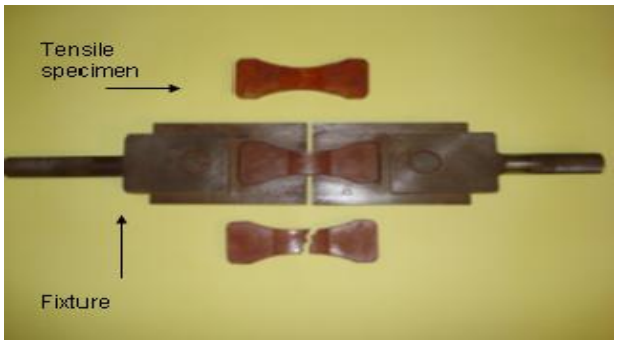


Fig.2: Tensile specimen and its breaking fixture

Fig.3: Press used for tensile testing

where S = tensile strength [N/mm² = MPa], P = load KN or Newton, B = width of sample (25 mm), D = thickness of sample (6 mm).

Flexural strength of the composites was tested on a universal flexural machine [Shimadzu Corporation Kyoto, Japan] having capacity of 200 tons. The Flexural strength of samples was calculated using Eq.2.

$$S = 3PL/ 2BD^2 \qquad (2)$$

where S = flexural strength [N/mm² = MPa], P = load (KN or Newton), B = width of sample (15 mm), D = thickness of sample (10 mm), L = span length of flexural fixture (100 mm).

Impact strength of composites was tested on universal impact testing machine [Shimadzu Corporation Kyoto, Japan] having capacity of 29.4 Joules. The following Equation (3) was used to calculate impact strength of specimens:

$$S = \text{Impact energy/Area of Sample} \qquad (3)$$

where S = impact strength [MPa.mm], impact energy is in joule and the area (width x thickness) of the sample is in mm².

Results and Discussion

We have studied the effects of variation of E-glass fiber on the mechanical properties of phenolic matrix composites. Fig.4-6 represents graphically the trends of tensile, impact and bending strengths of phenolic matrix composite by variation of the glass fiber content. The tensile, flexural and impact strengths of phenolic matrix composites were examined by producing fifteen test samples of each composite. The average result of tensile, flexural and impact strength for each composite are shown in Table 1. The variation in the strength values in a composite of same composition was observed which was due to the complexity in the fiber/matrix mixing process and due to the fact of random orientation of the fibers resulting in inhomogeneous samples. This fact is revealed from Scanning Electron Micrograph (Fig.7) and from a digital camera macrograph

(Fig.8) of one of the samples taken after grinding the surface of specimen on emery papers. This shows random orientation of fibers, which was due to the fact that chopped glass fibers were used in making composites, and these could not be aligned into the die during compression molding.

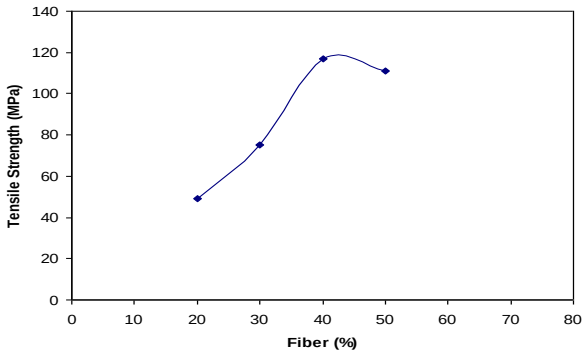


Fig.4: Effect of E-glass fiber content on tensile strength of composite.

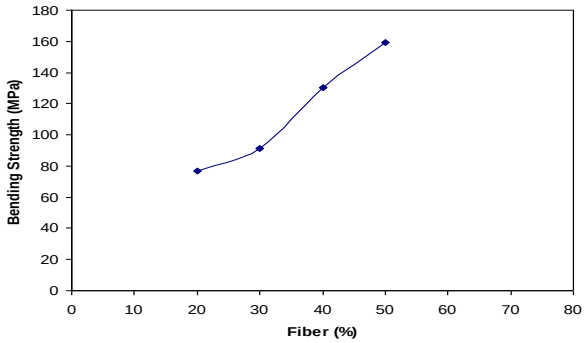


Fig.5: Effect of E-glass fiber content on impact strength of composite.

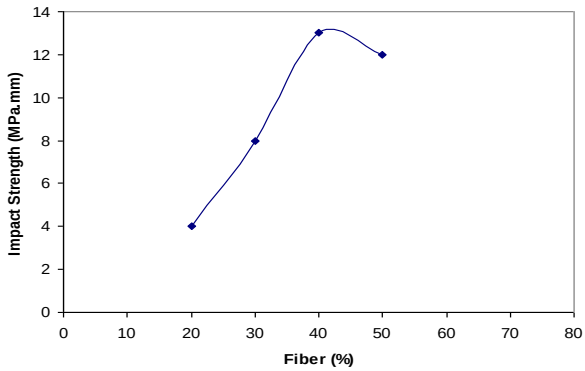


Fig.6: Effect of E-glass fiber content on bending strength of composite.

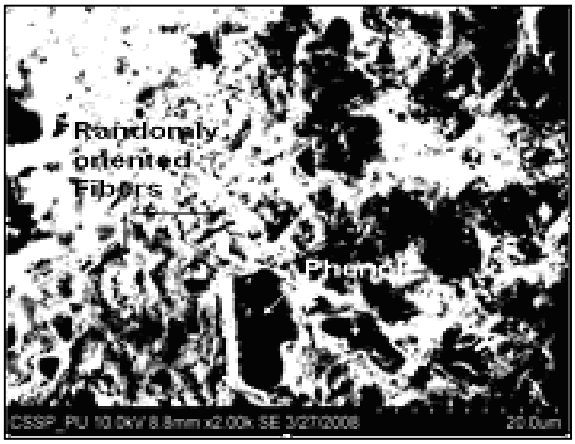


Fig.7: SEM image showing random orientation of glass fibers in a molded sample.

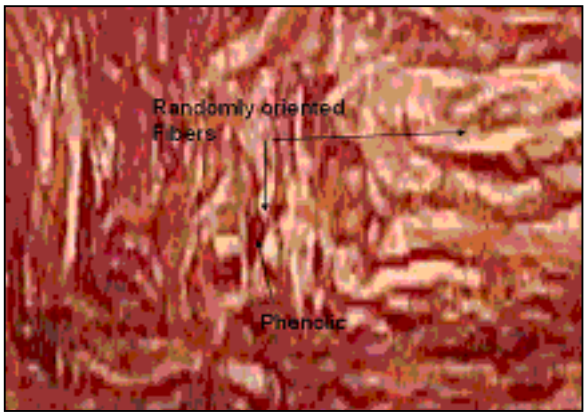


Fig.8: Digital Camera Photograph of random orientation of glass fibers revealed after grinding a portion of sample.

Glass Fiber (Wt %)	Tensile strength (MPa)	Flexural strength (MPa)	Impact Strength (MPa.mm)
20	49 ± 6	77± 6	4± 2
30	75± 6	91± 6	8± 2
40	117± 6	130± 6	13± 2
50	111± 6	159± 6	12± 2

Table 1: Average tensile, impact and bend strengths of composites.

Because of the random orientation of fibers in the samples, a variation in mechanical properties was observed and therefore a computed average was taken from fifteen samples presented in Table1 which shows a gradual increase in tensile strength when wt% of glass fibers is increased up to 40%. However the composite having 50 wt% glass fibers has tensile strength little lower than the composite having 40 wt% glass fibers. This slight decrease in tensile strength from 117 to 111 MPa is probably due to the relative decreasing amount of resin in this composite as the resin provides the adhesion force against the shear fracture of fiber/matrix interface under tensile load. A similar lower value of 110 MPa has been reported for 56 wt% glass fibers in phenolic matrix composite [15, 16].

Another inference that could be drawn from Table1 is that average flexural strength of composite having 20 wt% glass fibers was 77 MPa. As the glass fiber content was increased to 30 wt%, flexural strength increased to 91 MPa. A further increase in glass fibers from 40 wt% to 50 wt% increased the flexural strength from 130 to 159 MPa. This infers that by increasing the glass fiber content in the phenolic matrix, the flexural strength of composite increases gradually. It is worth noting that the tensile strength of composite having 50 wt% glass fibers was reduced whereas the flexural strength did not reduce and rather a further increase was observed. This continuous increase in the flexural strength with the increase in the glass fiber wt% is due to the fact that in the flexural strength testing the load is applied in the transverse direction to the fibers and hence no shear fracture occurs between the glass fibers and matrix.

The average impact strength of composites is also mentioned in Table1.The average impact strength of composite having 20 wt% glass fibers is 4 MPa.mm. As the glass fibers concentration increased to 30 wt%, impact strength increased to 8 MPa.mm. An increasing trend is seen up to 40 wt% glass fibers but a slight decrease occurred at 50 wt%. This slight decrease in impact strength with the increase in glass fibers is due to lesser amount of resins between the glass fibers. This reduction of resin film between the fibers increases the tendency to fracture and showed lesser resistance towards impact load.

Conclusions

The tensile, flexural and impact strengths of phenolic matrix composites increased gradually by the increase in the E-glass fiber content up to 40 wt%. A slight decrease (5 %) in tensile and impact strength is observed when the glass fiber content is increased from 40 to 50 wt%. The flexural strength did not show such a downward trend. This behavior is due to the different molecular response of the material to the different types of modes of tests performed.

Acknowledgement

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