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EFFECT OF HARDENER ON MECHANICAL PROPERTIES OF CARBON FIBRE REINFORCED PHENOLIC RESIN COMPOSITES

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Abstract

In this paper the effect of hardener on mechanical properties of carbon reinforced phenolic resin composites is investigated. Carbon fibre is one of the most useful reinforcement materials in composites, its major use being the manufacture of components in the aerospace, automotive, and leisure industries. In this study, carbon fibres are hot pressed with phenolic resin with various percentages of carbon fibre and hardener contents that range from 5-15%. Composites with 15% hardener content show an increase in flexural strength, tensile strength and hardness. The ultimate tensile strength (UTS), flexural strength and hardness for 15% hardener are 411.9 MPa, 51.7 MPa and 85.4 HRR respectively.

Keywords: Composites, Thermoset, Resin, Carbon Fibre.

1. Introduction

Carbon fibres are gradually becoming the most advanced material after the introduction of composite-bodied Corvette in 1953. The unique features of carbon fibre are low density, high strength, lightweight, high modulus and high stiffness leading to the development of new industrial applications. Carbon fibre processes include controlled oxidation, carbonization and graphitization of carbon-rich organic precursors. Carbon fibres are usually grouped according to the modulus band: high strength (HS), intermediate modulus (IM), high modulus (HM) and ultra high modulus (UHM). In 1993, the United States consumption of carbon fibres was 2.8 million kg per year [2].

Carbon fibres are commonly used in the following sectors: (1) High technology areas including aerospace and nuclear engineering; (2) General engineering and transportation sector, including engineering components such as bearing, gears, cams, fan blades and automobile bodies; (3) Sporting goods such as golf clubs and bicycles [9].

Phenolic resins are the oldest synthetic polymers used commercially around the beginning of the 20th century. These thermoset resins have typically been cured at high temperatures (140-180^{o}C) and usually high pressures. Commonly, phenolic resin is used in a broad range of applications such as paints, adhesives, and composites. There are two types of phenolic resin, the resole type and the novolac type, depending on the method of synthesis and the catalysts used. Phenolic resin provides intermolecular hydrogen bonding as a domain driving force to interact with hydroxyl, carbonyl, amide, ester, and other hydrogen-bonding functional groups [1].

Hexamine, also called hexamethylenetetramine or methenamine (INN), is a heterocyclic organic compound that can be prepared by reacting formaldehyde and ammonia. Important area for use of hexamine is in the production of powdery or liquid preparations of phenolic resins and phenolic resin moulding compounds, where hexamine is added as a hardening component. These phenolic resins are used as binders, in brake and clutch linings, abrasive products, non-woven textiles, formed parts produced by moulding processes, and fireproof materials [11]. This paper discusses the effect of hardener on mechanical properties of carbon fibre reinforced phenolic resin composites.

2. Material and Experimental Methods

Carbon fibre of type 12 K was used to produce carbon composites. The volume fraction of long carbon fibre was 40 percent. Phenolic resin was used as a matrix and hexamine as the hardener. The hardener was also varied from 5-15%. Figure 1 illustrates the chemical structure of the hexamine. Phenolic resin was supplied by Satya Cashew Chemicals, India. The mixture were hot pressed under a pressure which varies between 100-150 kg/cm^3 and temperature between 150-200^{o}C. The composites were then post cured for 8 hours at 230^{o}C. Figure 4.2 shows the flow diagram of carbon fibre reinforced phenolic resin composites preparation by impregnation method.

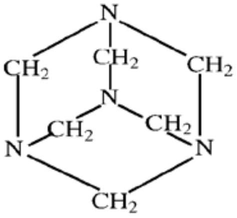

Fig. 1. Chemical Structures of the Hexamine-Hardener.

The mechanical tests were carried out to obtain the best amount of hardener for the composites. The tests that were carried out are flexural, tensile and hardness tests.

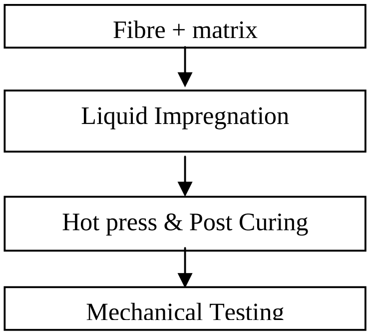

Fig. 2. Flow diagram of composites preparation by impregnation [4].

2.1 Tensile test

The specimens were cut from the samples in accordance to the ASTM D638-type 5. Tensile tests were carried out using INSTRON Universal Testing Machine 5566, under a load cell of 1kN. The gauge length was marked at 10 mm. The crosshead speed was set to 5mm/min and the grip distance was set to 45mm. Seven specimens were used and the average of five results was taken as the value.

2.2 Flexural test

The flexural strength and modulus of the composites were measured by three-point bending test based on ASTM D790. Samples for these tests were in a size of 124mm x 12mm x 3mm. An INSTRON Universal Testing Machine 5566 was operated at a crosshead speed of 3mm/min with a support span of 70mm.

2.3 Hardness test

A Rockwell hardness tester (Mitutoya ATK-600) was used to measure the hardness of each sample under a load of 60kg (HRR) following ASTM D 785 standard method. The diameter of the ball shaped indenter was 12.7 mm (1/2 inch). Seven specimens were used and the average of five results was taken as the final value.

3. Results and Discussions

3.1 Tensile test

Ultimate tensile strength (UTS) is a measure of stress applied to a specimen until failure (break). In this study, three different percentages of hardener, namely, 5, 10 and 15% were used to obtain the best formulation for composites with 40%

carbon fibre loading. The effect of hardener on tensile strength is shown in Figure 3. as shown in this Figure, the maximum strength achieved by using 15% hardener compared to composites with 10% and 5% hardener. The UTS value for 15% hardener is 412 MPa and this value decreases to 349 MPa (10% HR) before decreasing proportionally with the decreasing in percentages of hardener to 310 MPa for 5% hardener. The curing reaction of thermosetting resins leads to a cross-linking network after chemical reaction with an appropriate curing agent (hardener). During curing process, a multiple complex chemical and physical changes occur as the material changes from a viscous liquid to a hard solid [5]. It is also known that modulus and strength increases with degree of cross-linking and molecular weight [8]. The presence of hardener enhances the cross linking thus increases the tensile strength.

The usage of long fibres in the composites, had also affected the strength. Long fibre-reinforced laminates are important because of its high strength and stiffness. It is also generally accepted that good mechanical properties of the composites largely depend on the fibre-matrix and or the fibre-matrix-filler interfacial adhesion, since the load transfer from the matrix to the fibres would require a good bonding at the interface. This verifies the results obtained from this experiment, where 15% of hardener improves the mechanical properties. Therefore, increase in hardener also increased the strength and modulus as shown both in Figure 3 and Figure 4 [6].

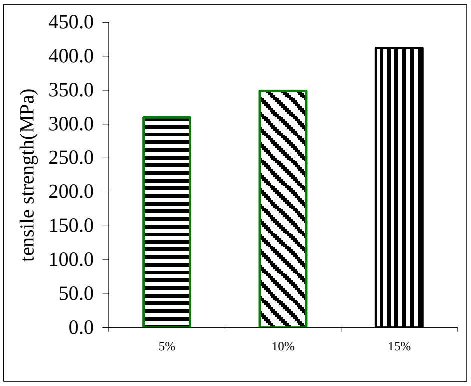

Fig. 3. Effect of Hardener on Tensile Strength.

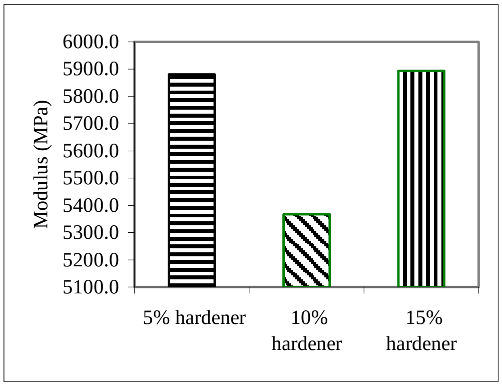

Fig. 4. Effect of Hardener on Tensile Modulus.

3.2 Flexural test

Flexural strength is the stress on the surface of the specimens which should be accompanied by the breaking of the specimen. Three-point test is designed for materials that break at relatively small deflection [4]. Figure 5 shows that at 40% fibre loading, the flexural strength increases as the amount of hardener increases in the composites. The strength of composites increases with hardener content, namely, 29.7 MPa, 50.2 MPa and 51.7 MPa for 5%, 10% and 15% respectively. Similarly, as the amount of hardener increases the cross links between the resin and the fibres are enhanced, thus contribute to a better flexural strength.

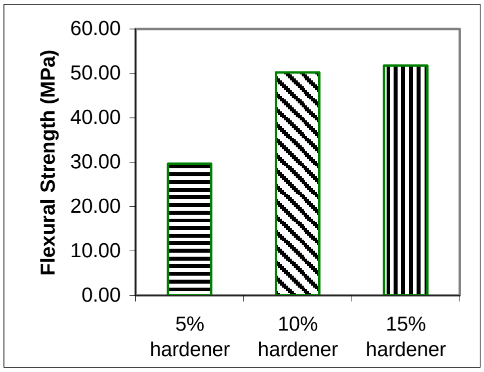

Fig. 5. Effect of Hardener on Flexural Strength.

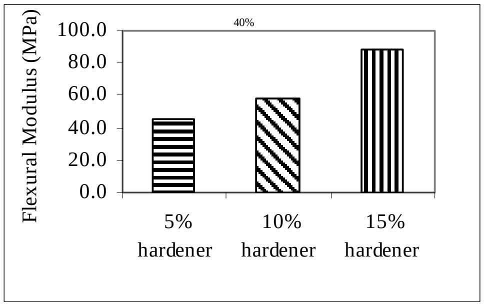

Fig. 6. Effect of Hardener on Flexural Modulus.

The same trend is observed for flexural modulus. An increase of 5%, 10% and 15% in hardener content, at 40% fibre loading, are 45.0 MPa, 58.4 MPa and 88.4 MPa respectively (as shown in Figure 6). This indicates that increasing the hardener content improves the modulus [5]. The composite with 15% hardener and 40% fibres content gives the highest modulus at 88.4 MPa. Again the improvement in cross-linking could contribute to this increase in flexural modulus.

3.3 Hardness test

Hardness is a resistance to penetration, wear, a measure of flow stress and resistance to cutting and scratching [10]. Figure 7 shows that increasing the hardener, increases the hardness of the specimens. It is generally known that, when fibres or other types of reinforcement are incorporated into a resin, the presence of the reinforcement can affect the curing process; this can affect the properties of the cured resin [3]. Figure 7 shows that increasing the hardener content have also improved the hardness value. The increment of the hardness value for 40% fibre loading are from, 83.9HRR, 83.5 HRR and 85.4 HRR for 5, 10 and 15% hardener content respectively. This shows that the mixture of hardener and the resin are highly homogeneous if the percentages of hardener are increased. Increasing the hardener content restricted the percentage of resin available for the cross linking and resulted in a rigid interface, thus improves the hardness. However, for 10% hardener content, similar to the results obtained on tensile modulus, there was a reduction in the hardness due to the preparation problem.

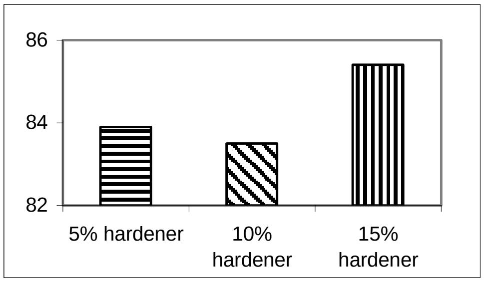

Fig. 7. Hardness at Different Percentages of Hardener and Fibre Loading.

4. Conclusion

In this study, the effect of hardener on mechanical properties of carbon reinforced phenolic resin composites has been examined. According to obtained results it can be concluded that:

- In tensile, flexural and hardness test analysis, increasing the hardener to 15% are found to improve the strength and hardness. This shows that cross linking between the resin and hardener are maximum at this percentage.
- The ultimate tensile strength (UTS), flexural strength and hardness for 15% of hardener are 411.9 MPa, 51.7 MPa and 85.4 HRR respectively.

This phenolic resin composite can achieve the standards of industrial applications especially in the area of automotive design with lower weight compare to metal counterparts.

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