Study on Influence of Curing Temperature on Tensile Properties of Jute and Hemp Reinforced Hybrid Polymer Composites

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Abstract. Natural fiber reinforced polymer composites seem to be the best alternative material for the expensive and non-renewable synthetic fiber reinforced polymer composite materials. The strength of any composite material is greatly affected by interfacial bonding between matrix and fibers, pre and post curing operations performed. The present work is aimed at investigating the influence of curing temperature on tensile behaviour of Jute and Hemp fibers reinforced epoxy composite. The laminates are cured in a hot air oven for temperatures varying from 30°C to 70°C for the time duration of 8hrs. The maximum tensile strength of 112.89MPa is obtained for a specimen cured at 60°C. As curing temperature increases the rate of polymerization also increases and bubbles that are trapped inside the composite get burst, thus reducing the voids formed during manufacturing. At a curing temperature of 70°C, the tensile strength value reduced to 106.31MPa. At very high temperatures polymers emit some volatile reactants, which may get trapped below the surface leading to reduced strength of composite materials. The present work highlights that the curing temperature greatly influences the tensile behaviour of natural fiber reinforced polymer composite material.

Keywords: Jute, Hemp, Epoxy resin, tensile strength, curing temperature.

1. Introduction
Over the last few years natural fiber reinforced polymer composite materials have become the dominant emerging engineering materials. The modern composite material constitutes a notable percentage of material market covering from routine products to products of advanced applications. While composite material have been well known as material with light weight, the present challenge is to see how cost effectively they can be produced. They force in this direction have resulted in several newer methods of manufacturing currently being used in composite industries.

Many of the composite manufacturing industries have started to realize that the composite material greatly offers higher business opportunities than any other sectors. Thus, the researchers have shown keen interest in the area of commercial applications of composites and they are enabled by the identification of effective and efficient matrix and reinforcement fiber material. Reinforcement for the composite can be in the form of fibers, fabrics, whiskers or particles. Fibers are basically categorized by its length, shape and type. The composite reinforced with particles exhibits no specific orientations and shapes. Whiskers exhibit a desired shape, but they are very small in both length and diameter when compared with fibers. The fibers can be further classified as Synthetic and Natural fiber. The synthetic fibers are one that offers high strength, high performance, and higher specific strength with lower density. But most of the synthetic fibers are not bio-degradable, production of these fibers is extremely tedious, expensive, and also emits some harmful gases like CO, SiO etc. Hence, in concern towards environmental pollution, most of the researchers are in search for newer and effective fiber material that should be environmental friendly, Bio-degradable and possess high strength to weight ratio as alternative for synthetic fibers. Natural fibers are the one that possesses above properties and...
most of these fibers are extracted from plants such as Jute, Hemp, Sisal, PALF, Bamboo, Areca, Banana etc. and from animals such as Kashmir wolf, mohair and angora, fur of sheepskin, rabbit, mink, fox, beaver etc.

In any Fiber Reinforced Composite (FRP) materials its strength is determined by the individual strength of fiber and matrix material and the interfacial adhesion between these two constituents. The orientation, length and volume fraction of fibers and crystalline structure of matrix material will also greatly affect the strength of Polymer Matric Composites (PMC). The internal structure of these materials in turn is dependent on the post and pre curing operations performed during manufacturing of the composite. The polymer curing rate during manufacturing of polymer matrix composites decides the rate of polymerization of polymers, which is also accountable for crystalline structure of the polymer. Quite often PMCs fail as they are manufactured without giving due considerations to the curing temperature. Hence, in the present paper an attempt is directed towards the study of the effect of curing temperature on tensile behaviour of jute and hemp fiber reinforced polymer composites. The prepared composite laminates are cured by placing it in hot air oven for time duration of 8hrs. The curing temperature in the oven was varied from 30°C to 70°C for the step of 10°C. The cured specimens are subjected for tensile test and analysed for intensity of polymerisation using X Ray Diffraction (XRD) method and interfacial bonding between matrix and fiber using Scanning Electron Microscope (SEM).

The literature emphasises that pre and post curing of polymer composite changes the internal structure of the matrix material, which in turn responsible for change in mechanical behaviour of the composite material. Aare Aruniit et. al [1] made preliminary studies on particle reinforced composites by checking its mechanical and physical behaviour in order to examine the influence of various post curing factors. According to their study, the material cured at 60° C – 80° C possess higher strength. Further increase of temperature and curing time leads to raise in glass transition temperature and brittleness of material and hence loses its strength. Yizhuo Gu et. al [2] conducted investigation on curing behaviour and temperature distribution of carbon Fibre/Epoxy Composite using rapid heating method. They stated that the high uniformity of temperature was shown by the carbon fabric preform heated by oven with a low heating rate. The addition of non-isothermal resin leads to increase in heat absorption ability of the resin and curing reaction heat. Hence, increases the difficulty of controlling temperature in the composite material. R. J. C. carbas et. al [3] conducted experimental studies on effect of curing temperature on glass transition temperature of epoxy based polymer composite. According to their investigation, the composite cured below its glass transition temperature performs better than naturally cured composite material. The percentage of crosslinking increases with increase of curing temperature and further reduces the free volume by allowing to escapes the gases entrapped during manufacturing. Further increase in curing temperature of the composites above its glass transition temperature ($T_g$) leads to oxidative crosslinking and thermal degradation of composite and also there is a chance of network degradation with it and responsible for change in properties of composite.

2. Materials and Methodology
The details of materials used, processing and the experimental procedures followed during the work are discussed below:

2.1 Epoxy Resin (L 12)
Lopox L12 is a commonly used engineering liquid unchanged epoxy resin used for making most of the engineering composites. Lopox L12 posses medium viscosity and it can be used with various hardeners. Hardener K6 is a commonly used hardener for lapox L12 resin to accelerate the rate of curing and to harden the liquid epoxy polymer. Epoxy resin offers better manufacturing flexibility, adhering ability and excellent mechanical property, improved resistance to osmosis, high resistance to fatigue, micro cracking and lower degradation from water ingress.
Table 1. Properties of Lapox L12 [4]

| Property                     | Values  |
|------------------------------|---------|
| Tensile strength (MPa)       | 20      |
| Flexural strength (MPa)      | 130-150 |
| Impact strength (MPa)        | 17-20   |
| Young’s modulus (MPa)        | 4400-4600 |
| Compressive strength (MPa)   | 110-120 |

2.2 Natural fiber (Jute)

The fiber that occurs naturally is commonly known as natural fibers, whereas the fibers that are made by man are commonly known as synthetic fibers. Fibres can be in bundles such as the fiber that are obtained from fruits, leaf and bast stem etc. Bast fibres are obtained from the stems of various dicotyledonous plants and are also referred to as ‘soft’ fibres to distinguish them from leaf fibres [5].

2.2.1 Jute Fibers: After the cotton the second largest fiber used commonly is the jute. It normally grows to a height of 3-4 m almost of equal strength throughout its length. Jute fiber has higher percentage of cellulose along with lignin and pectin. Corchorus capsularis has a globular shaped pod whereas Corchorus olitorius is cylindrical [6-7]. The retting process is used for separating fibre bundles from the stem. The fibre exits throughout the length of the stem in the form of an annular meshwork composed of more than one fibre layer.

![Figure 1. Jute plant and Fiber (Source: Textileschool.com)](image)

3.2.2 Hemp

Similar to jute, kenaf, ramie and flax hemp is a natural bast fiber with highest percentage of cellulose. Hence, hemp fibers are stronger and durable among most of the natural textile fiber. It is yellowish grey to deep brown in colour and fibers grow to the length of 4 to 6 feet. The diameter of the hemp fiber varies from 4µm to 800 µm. The mean tensile strength is up to 4200 GPa and modulus up to 180 GPa and these value starts to decrease as the diameter of the fiber increases. The mean tensile and modulus value decreases to 10 MPa and 2 GPa respectively for the fiber length of 800 µm. [8]

![Figure 2. Hemp plant and Fiber (Source: Textileschool.com)](image)
2.3 Preparation of Specimen
The fibers extracted from the plants consist of impurities and fatty’s at its surface. Hence, it is necessary to remove such impurities and to make the surface rough for improving the adhering ability of fibers with resin materials. All of these are possible by subjecting fibers for alkaline treatment. Fibers were treated with 5% NaOH solution for 3 to 4hrs, followed by washing with distilled water and dried completely under sunlight for 4-5hrs or in an hot air oven in order to remove any moisture content present in the fibers. The treated fibers are weaved in the form of mat and ready to use as reinforcement for making composite laminates. The laminates are made by traditional hand lay-up method because of its low cost, simple, efficient manufacturing method with no size limitations, and produce a high glass surface finish on both sides.

The specimens are prepared with a volume fraction of 40:60 with respect to fiber and matrix. A polypropylene (PP) mould of dimension 150 x 100 x 4 mm3 is used for composite fabrication. In order to ensure easy removal of laminate from the mould, a layer of wax was coated on the surface of the mould. Nearly 15 to 20 ml of cobalt naphthenate (as promoter) and dimethyl aniline (as accelerator) are added to resin in order to accelerate the rate of polymerisation. Benzoyl peroxide catalyst is added just before the resin is poured into the mould. The amount of catalyst to be added depends on the rate at which the hardening has to occur. Finally specimens are cut from laminates according the American Society for Testing and Materials (ASTM) standards.

3. Results and discussion
The study of tensile behaviour for jute and hemp fiber reinforced composite has been conducted as per ASTM standards for knowing tensile properties of the considered composite.

3.1 Tensile Test
The tensile test samples were prepared as per ASTM D-638 (165*19*6) type 1 standard. The prepared samples are tested using computerised universal testing machine at the rate of 0.3mm per minute and at a load of 1kN. The testing was continued until the failure of the specimen occurred. The results of the tensile test are put forth in the form of stress-strain curves. Table 2, shows the test results of jute and hemp fiber reinforced laminated composites with fiber cured at various temperature. The results are averaged values of 5 samples.

| Fiber temperature (°C) | Maximum load (kN) | Maximum stress (MPa) | Young’s modulus (GPa) |
|------------------------|-------------------|----------------------|----------------------|
| 30                     | 5.56              | 71.35                | 4.79                 |
| 40                     | 5.98              | 76.79                | 5.66                 |
| 50                     | 7.49              | 96.12                | 6.11                 |
| 60                     | 8.29              | 112.89               | 7.04                 |
| 70                     | 7.33              | 106.31               | 6.61                 |

From the above table, it was observed that the specimen cured at temperature 60°C has highest load bearing capacity of 8.29kN, maximum tensile strength of 112.89MPa and young’s modulus of 7.01GPa. It is found that the tensile strength is increased by 63.2% than the specimen cured at room temperature. Figure 3 shows stress strain curve for different curing temperatures.
1. 30°C

![Stress-Strain Plot](image1.png)

2. 40°C

![Stress-Strain Plot](image2.png)

3. 50°C

![Stress-Strain Plot](image3.png)

4. 60°C

![Stress-Strain Plot](image4.png)

5. 70°C

![Stress-Strain Plot](image5.png)

**Figure 3.** Strain-Strain curve for different curing temperatures

The strength of any composite materials is greatly influenced by interfacial bonding between matrix and fibers, the degree of polymerization and cross-linking greatly influences the interfacial bonding between matrix and fibers. With increasing of curing temperature, free radicals and developing polymer chains become more fluid as a consequence of decreased in viscosity and they react to a greater extent, resulting in a more complete polymerization reaction and greater cross-linking. The increase in the degree of polymerization of composites leads to improved mechanical properties and
increased wear resistance. Hence the tensile strength increases as curing temperature increases up to 60°C.

As curing temperature increases to 70°C, the tensile strength starts to decrease and its value reduces to 106.31MPa. At very high temperature polymers may undergo condensation type of chemical reactions, which emits some volatile reactants. Higher the external temperature on polymer materials leads to advanced curing at the surface such that forming a very hard impermeable surface. Hence, there may be the chances of trapping of volatiles released during condensation reaction. Such trapped volatiles may leads to excessive voids inside the composites and further there may be a chances of delamination, thus reduces the strength of composite material. Figure 4 shows the Scanning Electron Microscope (SEM) images and Figure 5 shows the XRD test result of specimen at the point of breakage of specimen cured at temperature of 60°C.

![Figure 4. SEM Photography at a point of failure of specimen](image1)

![Figure 5. X-Ray Diffraction image of specimen cured at 60°C](image2)
Above SEM images shows the breakage of fibers at the point of failure instead of pull out of fibers from matrix material, which clearly explains about a rigid adhesion between fiber and matrix. The XRD test results of specimen cured at 60°C shows maximum intensity count when compared to other curing temperature and hence it can be stated that crystals are densely packed due to higher degree of polymerization.

4. Conclusion
The strength of PMC depends on the curing temperature during its manufacturing and hence this paper highlights the results of the attempt made to study the influence of curing temperature on the tensile properties of jute and hemp hybrid polymer composites. The jute and hemp fiber reinforced composite material was manufactured by curing them at various temperatures. Experimental investigations have revealed that the specimen cured at 60°C temperature exhibit the maximum tensile strength of 112.89MPa and Young’s Modulus of 7.04 GPa than the other specimens cured at various temperatures. Further increase in temperature decreases the strength of the composite. The present study suggests that the curing temperature greatly influences the tensile behaviour of natural fiber reinforced polymer composite. The rate of curing also affects the crystalline structure of the polymer, where the height of the peak is related to the size of crystal size.

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