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Studies on Mechanical Properties of Bamboo/Carbon Fiber Reinforced Epoxy Hybrid Composites Filled with SiC Particulates

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Abstract - In concern with global environmental awareness, most of the engineering synthetic materials are replaced by natural fiber composites. Bamboo is attracted towards the researchers because of its bio-degradability, high tensile strength, low density and anti-bacterial properties. Many research studies have shown underutilization of these bamboo fibers as a reinforcing material in composite research and its relevant application in product development. Hence there are more possibilities of developing a economical engineering products by utilizing bamboo fibers in composite manufacturing**.** In the present work experimental investigation has been carried out to study the effect of Silicon carbide on bamboo/carbon fibers. The woven hybrid composite laminates were fabricated by using hand lay-up method using L-5 Epoxy resin and K-6 hardener. Bamboo fibers at different wt % are filled in epoxy resin and the effects of Silicon carbide with bamboo/carbon fibers on mechanical and physical properties are studied. On the basis of mechanical testing results, it is found that bamboo/carbon fiber mixed with silicon carbide is giving optimum mechanical properties. The addition of Silicon carbide on bamboo/carbon fibers has improved tensile, flexural strength. The water absorption tests were performed on immersing specimens into three different water conditions, namely normal, distilled and salt water. Specimen preparation and water absorption studies carried out as per ASTM standards. The micro-hardness test result shows that reinforcing SiC in matrix improves micro-hardness of composite. On the basis of overall study the Silicon carbide with bamboo/carbon fiber reinforced epoxy composites is found to be better combination and suitable for fabrication of engineering products.

Keywords - Bamboo fiber, Carbon fiber, Epoxy, Silicon Carbide, Hand layup, Mechanical property, Water absorption test

INTRODUCTION

Natural fiber reinforced composites (NFC's) material is one of the new trends in engineering materials. Cost effectiveness is the key point for manufacturing of engineering products. Availability, completely or partial recyclable and bio-degradable also plays an important role in fabricating engineering components. These NFC's are preferred in most applications due to lower environmental effects and have higher fiber content for equivalent performance, which reduces the amount of more polluting base polymers. Also its lower weight improves fuel efficiency and reduces emissions in automotive applications. Many research studies on the natural fibers such as cotton, coir, sisal, jute, banana, flex, maize, and areca, to list few, have been carried out. The main drawbacks of these natural fibers are hydrophilicity. Most of these are hydrophilic (higher moisture absorption) in nature because of hydroxyl and other polar groups in their constituents [1-4]. Currently, plenty of research material is being generated on the potential of cellulose based fibers as reinforcement for plastics. All researchers who have worked in the area of natural fibers and their composites are agreed that these renewable, abundantly available materials have several drawbacks: poor wettability, incompatibility with some polymeric matrices and high moisture absorption by the fibers [5-6]. Normally cellulose based fibers are used in fabricating natural fiber composites. To develop NFC's, it is vital to understand the chemical composition and the surface adhesive bonding properties of natural fibre. The main constituents of natural fibre include cellulose, hemicellulose, lignin, pectin, ash, waxes and water-soluble substances. Among all the natural fiber reinforcing materials, bamboo appears to be a promising material because it is relatively inexpensive, anti-bacterial and commercially available in the required form [7]. Carbon Fiber Reinforced Polymers (CFRP) is a fiber reinforced polymer made of a plastic matrix reinforced by fine fibers of carbon. Fiber carbon is a lightweight, strong, and robust material used in different industries due to their excellent properties. The mechanical behavior of bamboo/E-glass hybrid composites with Al_2O_3 used as a filler material gives the optimum tensile & flexural strength and the mechanical properties significantly influenced while using bamboo & glass fibre in such layer manner [8]. The composites reinforced with pure carbon fibers can hold the maximum tensile, flexural, impact strength and less water intake percentage, whereas the composites reinforced with carbon and banana fibers shows higher water intake percentage [9]. Bamboo composites having ability to replace petroleum based composite materials in many applications and it leads to increase consumer benefits in various sectors [10]. Bamboo fiber possesses good moisture absorption, soft feel and splendid colors as well as anti bacterial properties. Hence these properties make the fiber popular in home textiles. Bamboo fiber can absorb ultraviolet radiation in various wavelengths; hence it can be used in wallpapers and curtains [11-12]. The main purpose of this study is usage of bamboo fibers in industries for rural development. In this paper, an effect of hybridization of bamboo/carbon fiber reinforced epoxy composites with SiC as filler material is evaluated. The results of the tests help in determining the potential applications of the bamboo/carbon fiber reinforced epoxy composites.

2. EXPERIMENTAL PROCEDURES

2.1. MATERIALS

Bidirectional Bamboo fiber mats of thickness 0.2 mm are purchased from Champs Agro Unit, Thane (W), Maharashtra, India. Carbon fibers in woven mat form of 200 gsm are supplied by Suntech Fiber Private Limited, Bangalore. Epoxy L - 12 and Hardener is K-6 are supplied by Yuje Enterprises, Malleshwaram West, Bengaluru, India. Silicon carbide was purchased from Sapna Abrasives, Bangalore, India. Table 1 and Table 2 indicate Physical properties of Bamboo fiber and Carbon fiber respectively.

Table 1. Physical properties of Bamboo fiber

Physical Property	Bamboo Fiber
Density (g/cm^3)	1.1
Elongation at break (%)	11
Cellulose content (%)	45-50
Lignin content (%)	20-30
Tensile strength (MPa)	350-500
Elastic modulus (GPa)	85-87

Table 2. Physical properties of Carbon fiber

Physical Property	Carbon Fiber
GSM	200
Orientation	Plain-woven fabric
Tensile strength (GPa)	3.4
Tensile modulus (GPa)	230
Density (g/cc)	1.8
Elongation (%)	1.5

2.2. SPECIMEN FABRICATION

An attempt has been made to fabricate composites by using bamboo, carbon and a hybrid of bamboo/carbon fiber reinforced epoxy with SiC particulates. The mechanical properties like tensile, flexural and hardness are analyzed. Water absorption behaviour is also analyzed.

2.2.1. PREPARATION OF EPOXY-HARDNER AND SiC MIXTURE

For preparing each laminates 350 g of Epoxy-Hardener mixture is taken. For preparing this mixture the ratio is 10:1 (For every 10 g of epoxy 1 g of hardener is taken). Then this mixture is stirred thoroughly for some time. Then 6% of SiC is added to the mixture for the last laminate in order to study the effect of filler material in composites.

2.2.2. FABRICATION METHOD

In this present work, hand layup method is used for fabricating composite laminates. Hand lay-up technique is the simplest method of composite processing. The processing steps are very simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of fiber to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats are cut as per the mold size and placed at the surface of mold after perspex sheet has been placed over it. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed.

3. TESTING OF COMPOSITES

The mechanical properties are carried out by different instruments for the fabricated composites. Table 3 shows the laminates designations. The thickness of each layer of carbon is 0.4 mm and each layer of bamboo is 0.27 mm. As per ASTM standard, the thickness of each laminates is nearly 3 mm, So as to maintain the ASTM standard, considering 9 layers of bamboo fiber for laminate L1 (Only bamboo fiber and epoxy-hardener mixture), for laminate L2 6 layers of carbon fiber is taken (Only carbon fiber and epoxy-hardener mixture), for laminate L3 5 layers of bamboo and 4 layers of carbon fiber is taken (Mixture of bamboo/carbon and epoxy-hardener mixture) and for laminate L4 5 layers of bamboo and 4 layers of carbon fiber with 21 g of filler material (Mixture of bamboo/carbon, epoxy-hardener with SiC mixture).

Table 3. Laminates designations

Sequence	Composition
L1	B+B+B+B+B+B+B+B+B
L2	C+C+C+C+C+C
L3	B+C+B+C+B+C+B+C+B
L4	B+C+B+C+B+C+B+C+B (SiC)

3.1. TENSILE TEST

The tensile test is conducted by cutting the composite sample according to ASTM D638 (specimen dimensions is 216 × 19 × 3 mm^3). The computerized testing machine (UTM) was utilized. Composite specimens with different fiber combinations are tested, which are shown in Fig. 1. In each case, three samples are tested and the average is determined and noted. When the tensile load is applied to the specimen the system automatically calculates ultimate strength, ultimate load, and displacement and strain rate. The graph related to the above values is simultaneously plotted by the computer. The specimen is held in the grip and load is applied and the corresponding elongations are noted. The load is applied until the specimen breaks, ultimate tensile strengths are noted. Tensile stress and strain are recorded and load vs. displacement graphs are generated.

Table 4. Tensile properties of composites

Sequence	Break Load (N)	Tensile Modulus (N/mm^2)	Ultimate Tensile strength (N/mm^2)
L1	57.87	589.804	32.45
L2	9288.1	2580.73	162.94
L3	11.77	2293.97	150.48
L4	9423	1912.39	165.32

3.2. FLEXURAL TEST

The samples are cut to the dimensions as per ASTM standards for flexural testing. The test specimen geometry is width 8 mm, length 80mm, thickness 3 mm. The test is conducted at a strain rate of 1mm/minute. The test specimens are as shown in Fig. 2. Flexural test is done using a three point bend setup. The distance between the two supports are maintained at 100 mm. The ultimate load carrying capacity of the composite laminates is recorded.

3.3. HARDNESS TEST

Shore durometer hardness (Shore-D) for this research to study the hardness of the surface of the sample material. The ASTM test method designation is ASTM D2240 (26×26 × 3 mm^3). The specimens are shown in Fig. 3. The Shore hardness is measured with an apparatus known as a Durometer and consequently is also known as 'Durometer hardness'. The hardness value is determined by the penetration of the Durometer indenter foot into the sample. Because of the resilience of rubbers and plastics, the indentation reading my change over time, so the indentation time is sometimes reported along with the hardness number.

3.4. WATER ABSORPTION TEST

The water absorption tests were performed on immersing specimens into three different water conditions, namely normal, distilled and salt water. Specimen preparation and water absorption studies carried out as per ASTM D570 (Specimen dimension is 30x28x3 mm^3). Specimens were immersed in normal (pH=7), distilled (pH=6.5) and salt (pH=8) shown in Fig. 4, water at room temperature, i.e., 23

°C. After specific time intervals (every 2 hours days), specimens were removed from the container, their surface moisture was removed by tissue paper. The content of water absorption by the specimen was measured using a precise digital balance machine. The percentage of water uptake is calculated by the following equation.

$W (\%) = (W_1 – W_2)/ W_1$

W_1 = initial weight of specimen g

W_2= specimen weight after N hours of water soaking, g

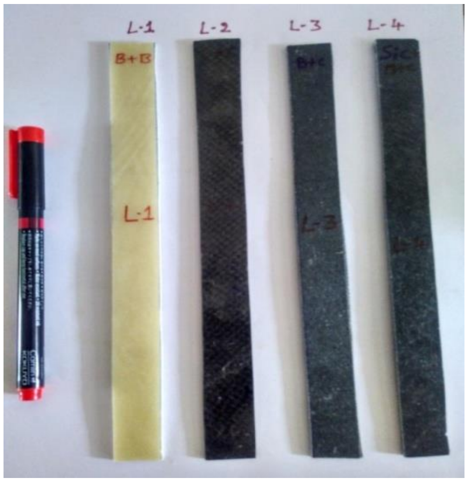

Fig. 2. Tensile test specimens

Fig. 3. Flexural test specimens

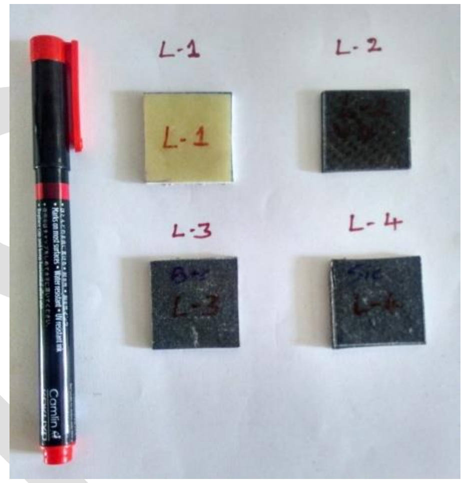

Fig. 4. Hardness test specimens

Fig. 4. Test specimens immersed in normal, distilled and salt water

4. RESULTS AND DISCUSSION

4.1. TENSILE PROPERTIES

The composites laminates L1, L2, L3, and L4 are fabricated according to ASTM standards and tested in UTM machine to obtain tensile properties. The properties like break load; tensile modulus and ultimate strength are listed in Table 4.The stress vs. strain graph is shown in Fig. 5. It is observed that the laminate L4 consisting of filler material gives the maximum tensile strength of 165.32 MPa and the laminate L1 gives the least tensile strength of 32.45 Mpa. Laminates L2 and L3 which is the combination of bamboo/carbon hybrid composites shows the better result than L1 which is the combination of pure bamboo layers. Among all the combinations, addition of filler material SiC to the bamboo/carbon hybrid composites L4 shows the better result than L1, L2 and L3.

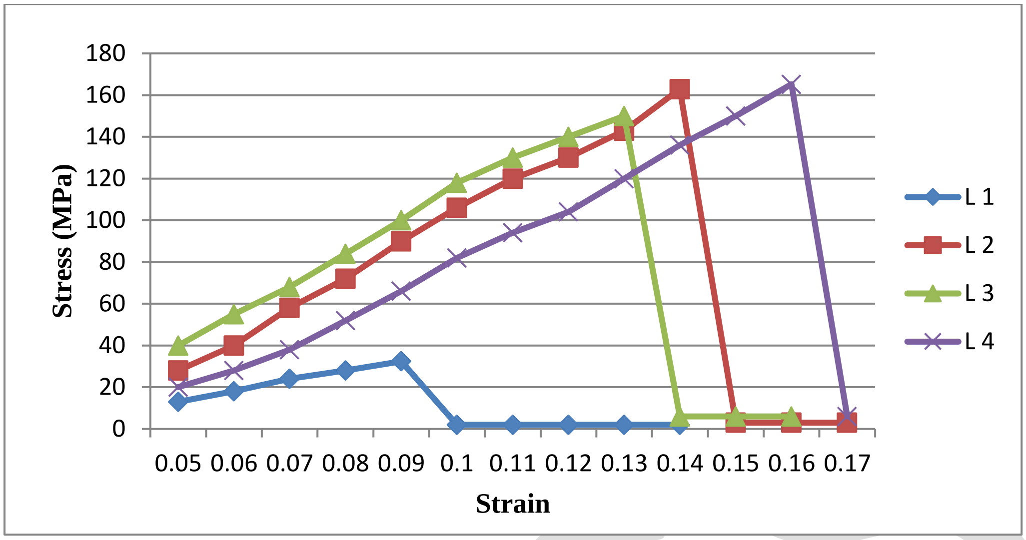

Fig. 5. Stress vs. strain graph for tensile test

4.2. FLEXURAL PROPERTIES

The flexural strength of the laminates was determined using the three-point bending machine as per ASTM D790. The load vs. displacement graph is shown in Fig. 6. The laminate L2 shows more flexural strength which is about 562 MPa. The laminate L1 shows less flexural strength of 362 MPa because it consists of pure bamboo fiber only. The laminate L3 having both natural and synthetic fibres gives a flexural strength of 381 MPa. And laminate L4 of strength 425 MPa, which gives better result next to the L2. Fig. 7 indicates the flexural strength of different laminates.

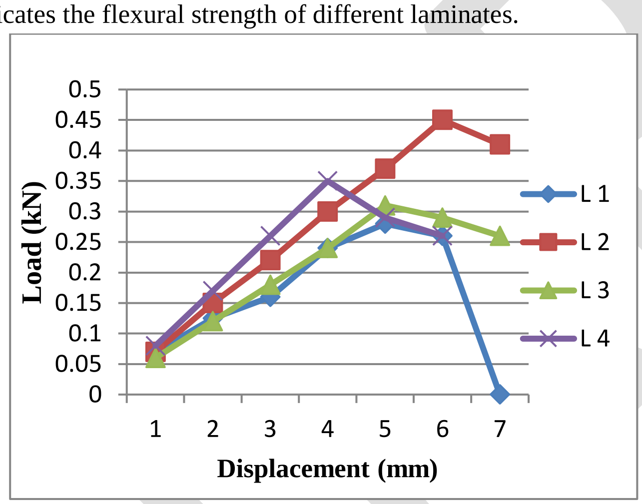

Fig. 6. Load vs. displacement for flexural strength

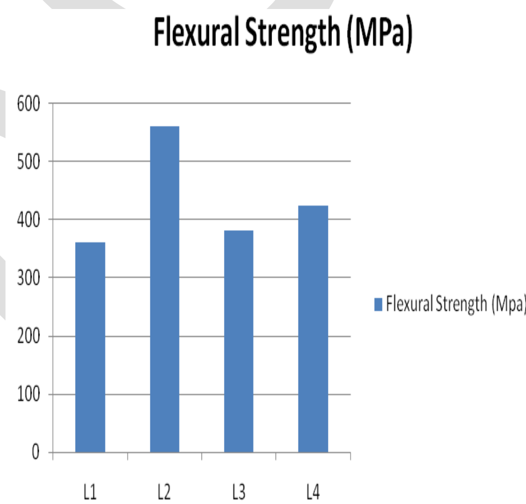

Fig. 7. Flexural strength of laminates

4.3. HARDNESS PROPERTY

In this study the hardness test has been conducted on Shore-D hardness testing instrument. It can be seen that the laminate L4 consisting of filler material as the highest hardness value among the other laminates. The hardness values for different laminates are shown in Fig. 8.

4.4. WATER ABSORPTION TEST

In water absorption studies, specimens were immersed into three different types of water conditions, which were normal, distilled and salt water to signify the real-life conditions. From the results it was observed that water absorption can be reduced by the hybridization of bamboo/carbon composites. Water absorption is shown in Fig. 9-11. Laminate L1 shows higher water absorption behaviour and pure synthetic fiber combination L2 having less water absorption capacity. Also absorption is more in distilled water because of purity of water. In salt water the salt molecules inhibit the activity of water molecules and rests on the surface of the laminate.

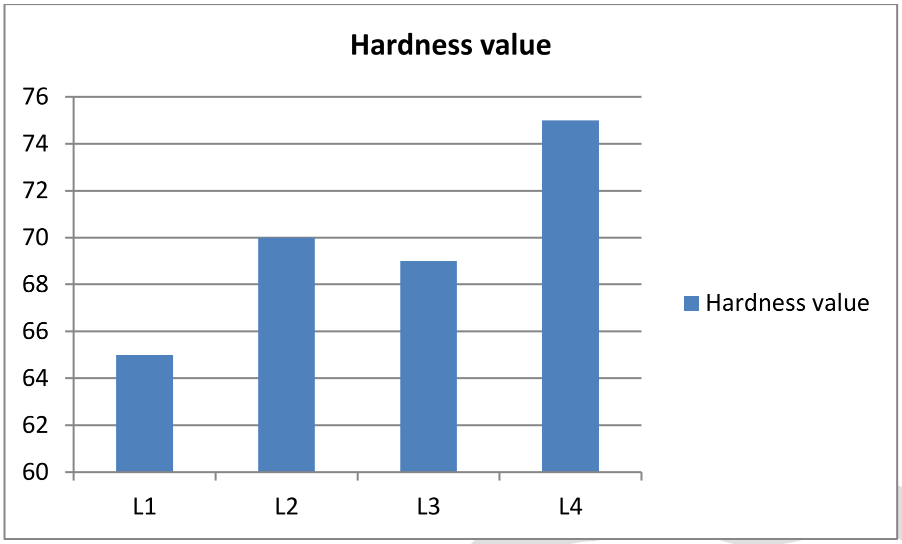

Fig. 8. Hardness value for different laminates

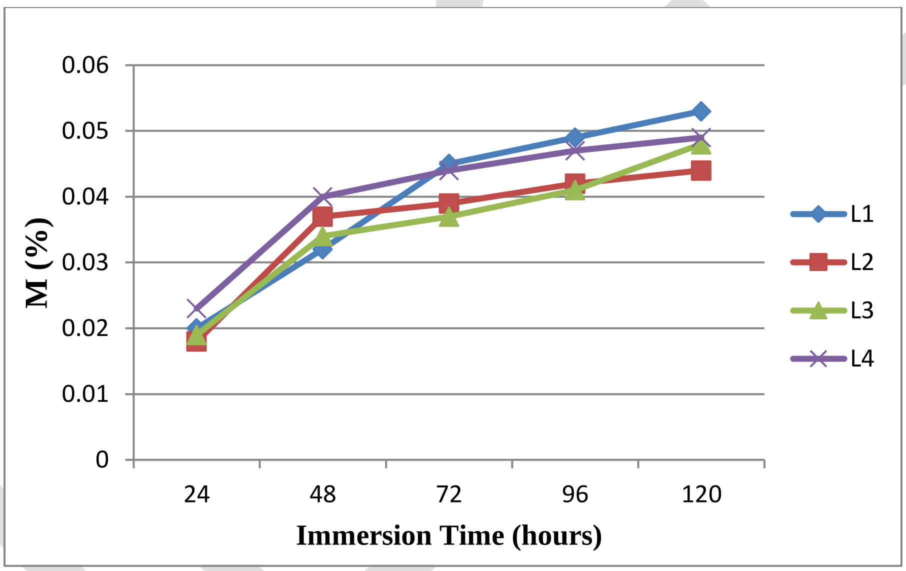

Fig. 9. Water absorption of composites in distilled water

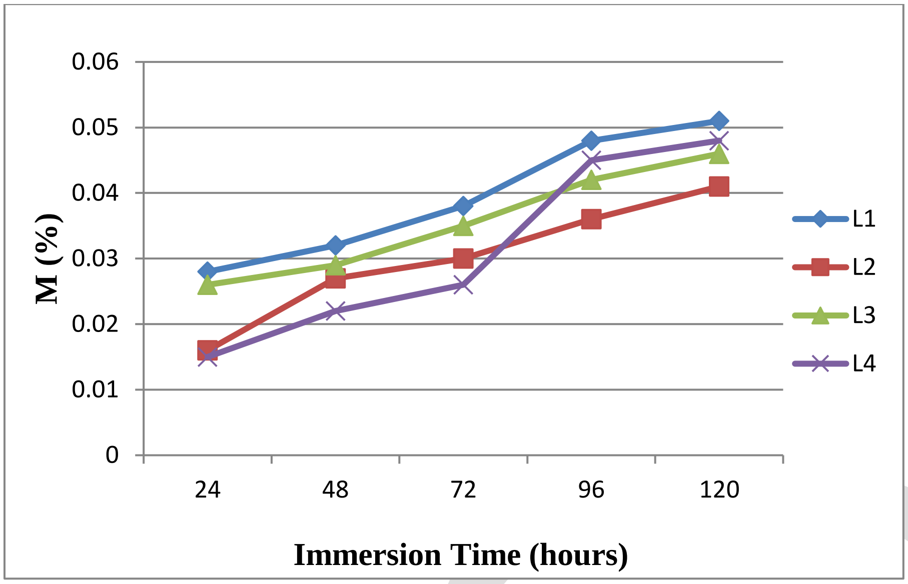

Fig. 10. Water absorption of composites in normal water

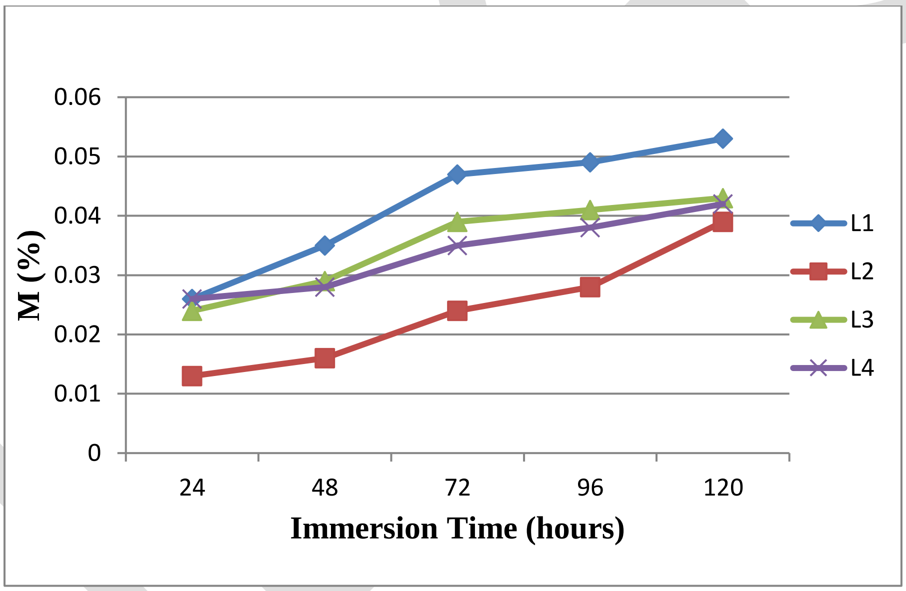

Fig. 11. Water absorption of composites in salt water

CONCLUSION

This current research work presents the studies on the effect of silicon carbide on hybridization of bamboo/carbon reinforced epoxy composites using hand layup method. From the tests, the following conclusions are made:

- The tensile and flexural strength of L4 laminate is high, which is very economical and environmental friendly as compared to the synthetic laminate L2.
- The laminate L1 shows very poor results when compared with laminates L2 and L3 mainly because the laminate L1 only consists of bamboo (natural) fibres.
- The incorporation of bamboo in carbon fibre composites enhances the mechanical properties and it leads to the increase of the utilization of naturally available bamboo fiber.
- Silicon carbide can be added in order to develop the components which are under the load of tensile and flexural with the proper proportion in order to develop economic class of materials.

- From the water absorption test, the laminate L1 is having higher water absorption behaviour as compared to other laminates and also the absorption is more in distilled water for the laminate L1.
- Hardness results show that the laminate consisting of SiC filler material shows the superior results compared to other laminates.

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