Effect Of Moisture Absorption On Mechanical Properties Of Wood Reinforced Polymer Matrix Composites

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Abstract

The demand for wooden products is continuously increasing in spite of rapid depletion of forest around the globe. Research in the field of green technology is being done to provide wood substitutes which makes use of wood materials mixed with polymer to provide a cost-effective, improved performance and termite resistant wood polymer composites. Wood polymer composites (WPCs) are made by mixing wood saw dust with polymer matrix material, polypropylene in this case. As these materials are mainly meant for use in outdoor applications they are exposed to moisture. In order to use them in such applications, for manufacturers it is necessary to know the effect of moisture on wood polymer composite material.

In this work experiments are conducted which involves exposure of specimens to moisture done for different intervals of time and corresponding drop in tensile and flexural properties are measured. The results of testing shows that the tensile and flexural strength reduces with time when subjected to condition of moisture absorption. The trend of the stress-strain graph obtained from the test conducted was studied. The specimens exposed to water absorption for 21 days show decrease of ultimate tensile strength by 34.38%, Young's modulus by 35.76% and Yield strength by 32.40%. Similar changes were observed with flexural test specimens with decrease of flexural strength by 20.43%, Young's modulus by 40.94% and Yield strength by 36.61%.

Keywords: Wood Polymer Composite, Composite Materials, Water Absorption, Wood Saw Dust, Polypropylene.

1. Introduction

A recent advancement in green technology has given lot of opportunities to the people of this generation to be more concerned about the nature. Global warming has put greatest challenges on human beings to reduce the deforestation and to reuse and recycle things. Green technology minimizes deforestation to a greater extent and the outcome of latest technology can be used for making various types of wood flour composites which are of low cost and come with better benefits. Wood polymer composite is typically comprised of wood or other natural lignocellulose fibres in a thermoplastic matrix. These products have found their way into consumer, automotive, and construction applications, and are experiencing tremendous growth in exterior residential construction applications. The introduction of WPCs in the decking market is mainly responsible for this growth. A direct result of success in the decking market is that products are now being developed and introduced for new exterior applications such as railings, fencing, roofing, and siding. The growth in exterior applications results in a need to understand the durability of WPC.

In plastic based composites, the polymers act as a matrix and flour of wood or other natural flour acts as reinforcement. The reinforcing flour are the main load-carrying component in the composites. It provides high strength and stiffness as well as resistance to bending and breaking under the applied stress. Interface bonding between the fillers and the matrix is the key to transfer the stress from the matrix into the fillers across the interface. The interface adhesion between the polymer matrix and wood fillers can be improved using coupling agents. The coupling agents will form a bond between the wood flour (reinforcement) and the thermo-plastic (matrix) through the improved compatibility and developing a mechanical or chemical bonding. It is very rigid, impermeable and transparent, very resistant to fatigue and bending, chemically inert, and can be recycled. It is moreover an excellent electrical insulator [1].

WPC do not corrode and are highly resistant to rot, decay, and Marine Borer attack, though they do absorb water into the wood fibres embedded within the material. WPC are often considered a sustainable material because they can be made using recycled plastics and the waste products of the wood industry. They can be recycled easily in a new wood-plastic composite, much like concrete. One advantage over wood is the ability of the material to be molded to meet almost any desired shape. A WPC member can be bent and fixed to form strong arching curves. Another major selling point of these materials is their lack of need for paint. They are manufactured in a variety of colors.

2. Literature Survey

The work is done on the wood polymer composite to understand its behaviour with moisture. J. Bhaskar et al., [2] tried to understand the changes in WPCs stability and durability performance, microstructure of the composites using pine wood filler and concluded that the reinforcing flour are the main load-carrying component in the composites. K. Hardinnawirda and I. SitiRabiatull Aisha [3] studied the effect of filler content on the mechanical properties and water intake of the composites. Several percentage of filler loadings were used (10, 15, 20 and 25 wt %) in order to gain insights into the effect of filler content on the mechanical properties and water intake of the composites. From the results, the tensile strength of the RH filled UPR composites found to decrease as the filler loading increased. Sandeep Tamrakar, Roberto A and Lopez Anido [4] investigated the water absorption and behaviour and durability of extruded wood polymer polypropylene composites (WPC) material used in Z-section sheet piles. After about 28 days of immersion, water and surface of specimen became oily and water became more turbid and dark. S. Migneault et al., [5] studied the effects of processing method and fibre size on the structure and properties of Wood Plastic Composites (WPCs). WPC parts were manufactured using extrusion or Injection Molding (IM) and fibres with different length to diameter (L/D) ratios. The IM process resulted in better composite physical and mechanical properties than the extrusion process, but higher density was obtained with the extrusion process. A.K. Bledzki et al., [6] studied the compounding techniques, namely two-roll mill, high-speed mixer and twin-screw extruder. It was shown that twin-screw extruder compounded composites had higher mechanical properties than those compounded in a two-roll mill or a high-speed mixer. Behzad Kord [7] investigated water absorption and thickness swelling of wood plastic composites manufactured from wood flour and virgin and/or recycled plastics, namely high density polyethylene and polypropylene. Wood flour was mixed with different virgin or recycled plastics at 25% and 50% by weight fibre loading. The results indicated that the water absorption and thickness swelling of composites containing polypropylene is lower than those of polyethylene.

3. Preparation of WPC

The reinforcement material used in the composite is mixture of wood saw dust and matrix material used is polypropylene. Polypropylene has an excellent resistance to stress, low specific gravity and good mechanical properties such as excellent impact strength. It has a melting point of 160-165º C and has low density (0.85 g/cm3 with amorphous, 0.95 g/cm3 with crystalline) and higher stiffness and strength.

The wood saw dust was collected and was dried to remove the moisture gained during the grinding and handling, to maintain the moisture content of about 1-2%. Similarly, the virgin polypropylene granules were also dried to remove all the moisture during washing. Then the wood saw dust was compounded with virgin polypropylene in the co-rotating twin-screw extruder. The extruder consists of extruding zones and a die head as well as different feeding hoppers for wood saw dust and plastics. The wood saw dust and the plastic were fed through separate feeders at the extruder. The plastic was firstly fed from the main feeding hopper at the end of the extruder and then the wood saw dust was fed through a feeder that is located between first zone and the main feeder of the extruder. The extruded part coming out from the die head was then passed through a water shower. Finally extruded wood polymer composite panels were obtained (Figure 3.1).

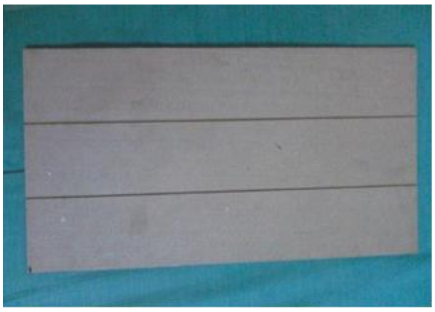

Figure 3.1 Extruded WPC boards

4. Preparation of Specimens

The Specimens were prepared from the extruded board. ASTM standard dimension was followed for both tensile and flexural specimen. For Tensile test specimen, ASTM D3039 standard was followed and for flexural test specimen, ASTM D790 was followed. Specimens were cut out from the extruded board using precision diamond tip wood cutter. The irregular surfaces of the test specimen were made into smooth and fine surface by carrying on finishing operations. Sand paper of fine grade was used to polish the surface of the specimen and irregular shapes if any were cut using proper cutting techniques.

5. Moisture Absorption Test

The specimens were completely immersed in a water bath for different intervals of time. Water penetrated inside the composite material through the surface of the specimens, causing changes in physical and chemical properties of the material. The weight increase in specimens due to water absorption was noted down. Also the changes in surface properties were observed and noted down. In the testing performed, tap water was used for immersion and test was carried out at room temperature conditions. Specimens were placed in a plastic container filled with tap water up to the brim. After every 24 hours the specimens were taken out and weighed separately. This procedure was carried out for 3 weeks and the readings were tabulated. A graph of increase in percentage weight of the specimen was plotted against the duration in days.

The weight increments were tabulated in the Table 5.1. The final weight of the specimens and percentage increment in weights are given for durations of 7days, 14 days and 21 days. In Table 5.2 the trend line for water absorption curve of tensile and flexural specimens are given. From this trend line the percentage increment at any time t within the duration of 21 days can be found.

Table 5.1 Average change in percentage weight of WPC

Number of days	As received	7 days		14 days		21 days	
Specimen Type	Weight (gm)	Weight (gm)	% increase	Weight (gm)	% increase	Weight (gm)	% increase
Tensile	45.82	47.29	3.21	48.20	5.19	48.74	6.37
Flexural	20.96	21.77	3.86	22.27	6.25	22.57	7.68

Table 5.2 Trend line equation of specimen

Specimen type	Trend line equation
Tensile	$y = -0.0092x^2 + 0.4803x + 0.2849$
Flexural	$y = -0.0109x^2 + 0.5761x + 0.3596$

The water absorption curve was obtained for tensile and flexural specimen by plotting percentage increment in weight along y-axis against duration in days along x-axis. The curve of both tensile and flexural specimen followed a non-linear trend. The trend line equations of water absorption curve are given in Table 5.2., which is obtained from the plotted tensile (Figure 5.1) and flexural (Figure 5.2) plots.

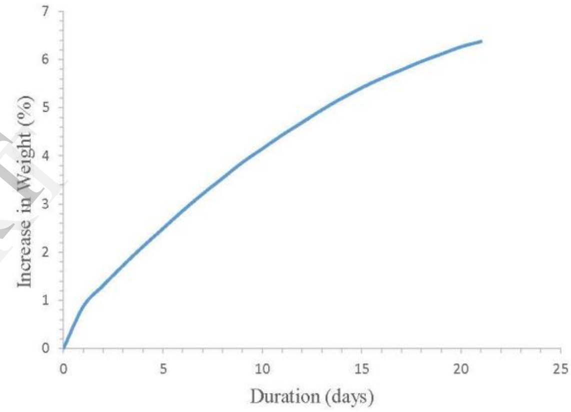

Figure 5.1 Water absorption curve for tensile specimen

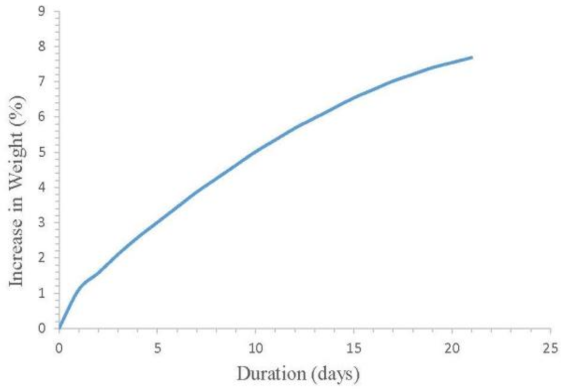

Figure 5.2 Water absorption curve for Flexural specimen

6. Results and Discussion

All the data obtained from the tests were tabulated. The stress-strain data was plotted for all the test specimens. Then the parameters were compared with each other to understand the performance. The tensile test data and flexural test data were separately dealt.

6.1. Tensile Test Results

The specimens which were exposed moisture were subjected to tensile loading. The standard tensile testing procedure was followed. Universal Testing Machine (UTM) from BISS (Bangalore Integrated System Solutions) was used for testing the specimens. The tensile test results were tabulated in Table 6.1. For different exposure durations the values of ultimate tensile strength, strain at failure, Young's modulus and toughness were calculated. The reduction in parameters were compiled and were shown in the bar graphs. The graph of stress-strain data was plotted for all the specimens.

The following inference can be made from the graph shown in Figure 6.1. With subsequent periods of exposure, the curve becomes more flat indicating the decrease in tensile strength. As a result for any given value of stress, the strain value increases with increase in number of days of immersion.

Table 6.1 Tensile test results for water absorbed specimens

Exposure Duration	Ultimate tensile strength MPa	Yield Strength MPa	Young's Modulus GPa
As received	12.68	11.38	3.33
7 days	11.23	9.74	2.74
14 days	9.80	8.41	2.26
21 days	8.32	7.69	2.14

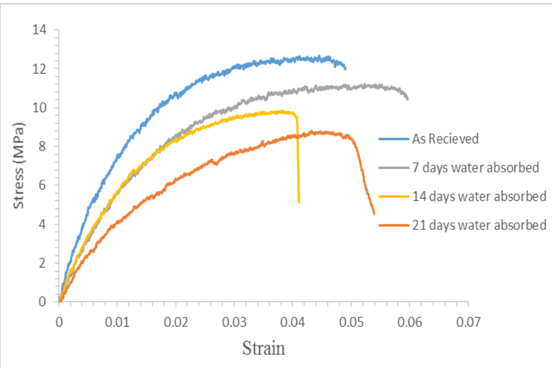

Figure 6.1 Stress-Strain Curve for Tensile Specimen

6.2. Flexural Test Results

The specimens which were exposed moisture was also subjected to flexural loading. The load was applied on the mid-point of the specimen using three point bending machine. The flexural test results were tabulated in Table 6.2 for different exposure durations of water absorption test. The values of ultimate tensile strength, Young's modulus and Yield strength were calculated. The reduction in parameters were compiled and are shown in the bar graphs. The graph of stress-strain data is plot for all the specimens.

The following inference can be made from the graph. From Figure 6.2, with subsequent periods of immersion, the curve becomes more flat indicating the decrease in tensile strength. In terms of stress and strain, for any given value of stress, the strain value increases with increase in number of days of immersion or for given value of stain, the stress induced decreases.

Table 6.2 Flexural test results for water absorbed specimens

Exposure Duration	Ultimate tensile strength MPa	Yield Strength MPa	Young's Modulus GPa
As received	22.76	18.52	3.44
7 days	21.46	16.87	2.69
14 days	19.86	15.61	2.17
21 days	18.11	11.74	2.03

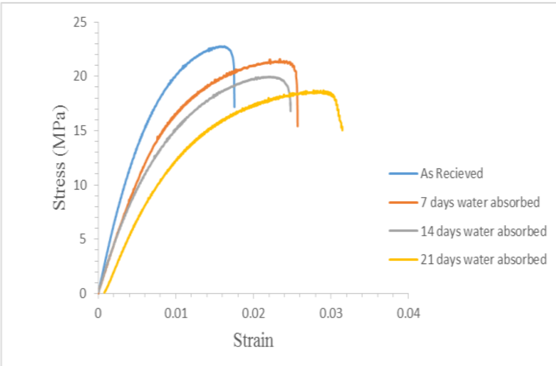

Figure 6.2 Stress-Strain Curve for Flexural Specimen

7. Conclusions

The properties such as tensile or flexural strength, Young's modulus and Yield strength decreases with number of days of immersion. This can be attributed to the following reasons. The wood sawdust and polypropylene composite when comes in contact with water, it will undergo changes in its microstructure. The filler material, wood sawdust is polar in nature while the matrix constituent polypropylene is non-polar. This results in improper interfacial adhesion. In addition to this the presence of hydroxyl groups in the cellulose wood particles is responsible for its inherent hydrophilic nature. As a result, it becomes difficult to mix hydrophilic wood with hydrophobic polypropylene. When the natural filler composites are exposed to the moisture, the hydrophilic sawdust wood swells and this lead to the micro-cracking of brittle thermosetting resin.

As the composite cracks, the capillarity becomes active. Hence, the water molecules are actively attracted to the interface which in turn results in the de-bonding of filler and matrix. The high cellulose in the wood contributes to more water penetration into the interface through micro-cracks induced by swelling on fillers. This causes the interfacial bonding to weaken resulting in decrease in tensile strength and flexural strength. The hydrophilic nature of wood flour causes the water absorption and thickness swelling in wood plastic composites manufactured (the plastics have negligible water absorption). It is well established that the water uptake in natural fibres is mainly due to their hydroxyl groups on cellulose or hemi-cellulose that can react with water and increase gap between the cellulose chains. After drying composites, there is no longer adhesion at the matrix and wood particles interface. Cracks formed in the plastics and the interfacial gap contributes to penetration of water into the composite at a later exposure.

For water absorbed tensile specimens, Ultimate Tensile strength decreased by 11.43% for 7 days, 22.71% for 14 days and 34.38% for 21 days. Young's modulus decreased by 17.82% for 7 days 32.19% for 14 days and 35.76% for 21 days. Yield strength was decreased by 14.41% for 7 days, 26.10% for 14 days and 32.40% for 21 days. Flexural strength decreased by 5.71% for 7 days, 12.74% for 14 days and 20.43% for 21 days. Young's modulus decreased by 21.76% for 7 days 36.85% for 14 days and 40.95% for 21 days. Yield strength decreased by 10.50% for 7 days, 15.71% for 14 days and 36.61% for 21 days.

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