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Research Article

Effect of Moisture Absorption Behavior on Mechanical Properties of Basalt Fibre Reinforced Polymer Matrix Composites

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The study of mechanical properties of fibre reinforced polymeric materials under different environmental conditions is much important. This is because materials with superior ageing resistance can be satisfactorily durable. Moisture effects in fibre reinforced plastic composites have been widely studied. Basalt fibre reinforced unsaturated polyester resin composites were subjected to water immersion tests using both sea and normal water in order to study the effects of water absorption behavior on mechanical properties. Composites specimens containing woven basalt, short basalt, and alkaline and acid treated basalt fibres were prepared. Water absorption tests were conducted by immersing specimens in water at room temperature for different time periods till they reached their saturation state. The tensile, flexural, and impact properties of water immersed specimens were conducted and compared with dry specimens as per the ASTM standard. It is concluded that the water uptake of basalt fibre is considerable loss in the mechanical properties of the composites.

1. Introduction

Nowadays fibre is used for reinforcement in polymer composites for making low cost applications and that should be sustainable in different environments. The percentage of moisture uptake increased as the fibre volume fraction increased due to the high cellulose content. The tensile and flexural properties of hemp fibre reinforced unsaturated polyester composites specimen were found to decrease with increase in percentage of moisture uptake. The water absorption pattern of these composites at room temperature was found to follow Fickian behavior, whereas at elevated temperatures it exhibited non-Fickian behavior [1]. The tensile properties of the specimens immersed in water were evaluated and compared with the dry composite specimens. A decrease in the tensile properties of the composites was demonstrated, indicating a great loss in the mechanical properties of the water-saturated samples compared to the dry samples. The percentage of moisture uptake was also increased as the percentage of the fibre weight increased due to the high cellulose content [2]. According to Gisele Iulianelli, PVC/wood flour composites were prepared by compression molding using sapwood and heartwood from Angelim Pedra as filler. The composites specimens were subjected to water immersion and impact tests. The results showed that the water absorption of all composites increased slightly with increasing immersion time and wood content [3].

Han et al. studied the physical properties of lignocellulosic filler reinforced polyolefin biocomposites like thickness swelling, water absorption, and mechanical properties; polyolefin is used as the matrix polymer and rice-husk flour

Table 1: Notations used.

Sl. number	Notations used	Explanation
1	WM	"Without moisture"
2	NW	"With normal water"
3	SW	"With sea water"

Table 2: Density and voids presented in the composites.

Void content (%)	2–7
Density of composites (g/cm^3)	1.6–1.9

as the reinforcing filler. The mechanical properties of the composites decreased as the filler loading increased, but the composites had an acceptable strength level. It was concluded that these biocomposites are suitable to be used for the interior of bathrooms, wood decks, food packaging, and so forth [4, 5]. Chow investigated the water absorption of epoxy/glass fibre/organomontmorillonite nanocomposites that were prepared by hand layup method. Water uptake of epoxy was reduced by the addition of glass fiber and organomontmorillonite (OMMT). The decrease of water absorption in epoxy is attributed to the increasing of tortuosity path for water penetration in the epoxy composites by the hybrid of glass fiber and OMMT [6]. The water uptakes of hybrid composites are observed to be less than that of unhybridized composites [7].

The basalt fibre composites were manufactured with and without the Gel-coating process and were immersed in a moisture absorption device at 80°C for more than 100 days. The mechanical properties of the moisture absorption composites and the composites which dry after moisture absorption were compared. The mechanical properties degradation of basalt fiber composites according to the result of the measurement of moisture absorption was smaller than that of glass fiber composites by about 20%. In addition, the coefficient of moisture absorption was lower for the case of Gel-coating processing than the composites without the Gel-coating process by about 2% and it was deduced that Gel-coating did not have a significant effect on the mechanical properties. Liu et al. investigated the aging behavior of basalt fibre composites with epoxy and vinyl ester as matrix; the aging results indicate that the interfacial region in basalt composites may be more vulnerable to damage than that in glass composites. Young's modulus and short beam strength of basalt composites decreased in the aging tests, but the tensile strength was relatively stable [8]. The mechanical properties of the moisture absorption composites and the composites which dry after moisture absorption were compared. The mechanical properties degradation of basalt fiber composites according to the result of the measurement of moisture absorption was smaller than that of glass fiber composites by about 20% [9]. Raghavendra et al. studied the effect of moisture on the mechanical properties of GFRP composite fabric material; the presence of moisture in the epoxy matrix, fiber-matrix interface, and the chemical attack of moisture on the glass fibers are thought to be the main reasons for reduced strength of GFRP material in hot-wet condition [10]. Water absorption speeds up evolution of damages inside composites and causes some novel damages. During water or seawater immersion test, properties of the composites are altered because of changes in the matrix, the fibre, and the interface [11–16].

As per literature review, only few authors studied the moisture absorption effect on mechanical properties of basalt fibre composites. In this investigation woven basalt fibre, short basalt fibres, and the surface modified basalt fibres are taken to study the effect of moisture on the mechanical properties of the composites.

2. Experimental Details

2.1. Materials. Basalt fibre was supplied by ASA.TECH, Austria. Unsaturated polyester resin, methyl ethyl ketone peroxides (MEKP), and co-naphthenate were purchased from Sakthi Fibre Glass, Chennai, India. Sodium hydroxide and sulphuric acid were purchased from the United Scientific Company, Madurai, India.

2.2. Treatment of Fibres. The basalt woven fabrics were cut into an approximate size of 35 × 35 cm. The fibre was treated by soaking in two solutions, 1 N NaOH and 1 N H_2SO_4, separately for 24 hours at room temperature. After this, the fibres were washed several times with distilled water to remove any NaOH and H_2SO_4 from the surface of the fibres. Finally, the fibres were dried at room temperature for 24 hours before the composites were prepared.

2.3. Processing. The compression moulding techniques were used to prepare the basalt fibre composites. The basalt fibre reinforced polymer matrix composites were fabricated by using compression moulding techniques. The general polyester resin was used as a matrix. For a proper chemical reaction, cobalt peroxide and methyl ethyl ketone were used as an accelerator and catalyst, respectively. These are weighed to take the corresponding 1 : 1 amount of general polyester resin. The curing of polyester resin was done by incorporation of one volume percent methyl ethyl ketone peroxide (MEKP) catalyst. One volume percent cobalt naphthenate (accelerator) was also added. For achieving homogeneous condition of the mixture, the stirring process was carried with the use of stirrer. Then, this resin mixture was used to fabricate the composites using compression moulding technique. The samples are allowed to cure for about 3 to 4 hours at room temperature. Similar procedure was adapted for the preparation of the short basalt fibre reinforced polymer composites and surface treated basalt fibre. For the fabrication of woven fabric composites, 78% of fibre was used and for the short fibre composites, 68% of fibre was used. Notations used, typical properties of resin and Fiber presented in the Tables 1, 3, and 4 respectively.

2.4. Mechanical Tests. Test specimens were cut from the composite plates as per the ASTM standard. A tensile test was performed to determine the stress-strain behaviour of the

Table 3: Typical properties of the unsaturated polyester resin.

Appearance	Pale yellowish clear liquid
Viscosity at 25°C	500–600 cps
Volatile content	34–36%
Acid value	23–27 mg KOH/gm
Density at 25°C	1.12–1.13
Cross linking mixture	1.5% catalyst and 1.5% accelerator
Gel time at 25°C	15–25 min
Tensile strength	50 N/mm^2
Elongation at break	1.8%
Flexural strength	110 N/mm^2

Table 4: Typical mechanical properties of the basalt fiber with epoxy-resin system.

ILSS	80 MPa
Compressive strength	1300 MPa
Tensile strength	1700 MPa
Flexural strength	2000 MPa

basalt fibre reinforced polymer composites. This was done using a UTM with a cross head speed of 2 mm/min according to ASTM D3039. The 3-point bending test is used to find the flexural modulus, flexural strength, and strain at break of the basalt fibre reinforced polymer composites. Flexural test is conducted on universal testing machine Sandeep Polyplast made with cross head speed of 2 mm/min according to ASTM 790-98. The sample dimensions are 127 mm × 13 mm × 3 mm and the span length of 100 mm is maintained. Impact test is used to find out the energy required to break the specimen. The unnotched Izod impact test is conducted to study the impact energy according to the ASTM D256. The unnotched specimens are kept in cantilever position and the pendulum swings around to break the specimen. The impact energy (J/cm^2) is calculated. The sample dimensions are 65 mm × 13 mm × 3 mm; five samples are taken for each test and the results are averaged.

2.5. Water Absorption Behavior of Polymer Composites. The effect of water absorption on basalt fibre reinforced unsaturated composites was investigated. The samples for tensile, flexural, and impact tests specimens were used to a size of 150 × 20 × 3 mm^3, 162 × 13 × 3 mm^3, and 60 × 13 × 3 mm^3, respectively. All specimens that were to be tested were measured for their initial weight in dry condition. Water absorption tests were conducted by immersing the specimens in a normal water and sea water bath at room temperature for different time periods. After immersion for 24 h, the specimens were taken out from the water and all the surface water was removed with a tissue paper. The specimens were weighted with an accuracy of 0.001 mg on a digital balance. The specimens were weighed regularly until they reached the saturation limits. Similarly, the specimens were immersed in sea water also and the same procedure was conducted. The moisture absorption was calculated by weight difference.

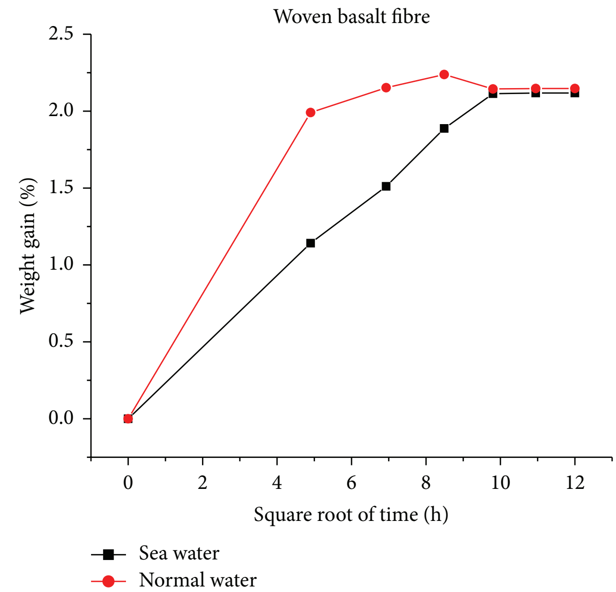

Figure 1: Woven basalt fibre composites in normal and sea water conditions.

The percentage of weight gain of the samples was measured at different time intervals and the moisture content versus square root of time was plotted. Table 2 presents the range of density and voids for both short basalt fibre and woven basalt fibre composites.

3. Result and Discussion

The moisture uptake of basalt fibre polymer composites presented in Figure.

The water absorption behavior of the composites mainly depends on the voids present in the composites, interfacial adhesion between the fibre and matrix, and type of fibres reinforced. The woven basalt fibre composites show higher absorption in normal water compared to sea water. In normal water there are sudden increases in water absorption at the initial stage. After that it gradually increases the rate of water gain. In most of the cases, water uptake reached the saturation limit in about 10 root hours. Water uptake of short fibre composites is shown in Figure 2 and different lengths of fibre were taken. Normal water absorption shows sudden rise in water gain at the initial stage for 4 mm and 21 mm length of fibres and after that they gradually increased in weight percentage and they were saturated in about 10 root hours. 50 mm length of fibre showed the gradual increase in weight and it was saturated in about 10 root hours. 10 mm length of fibre reached saturation limit earlier than the other length of fibres. In sea water condition, there was uniform water uptake as shown in Figure 2. 10 mm length of fibre showed better performance than the other fibre length and it was saturated at about 7 root hours.

Effect of surface modification of basalt fibre on water absorption was studied. It was observed that the composites with short fibre in sea water condition and woven fabric in

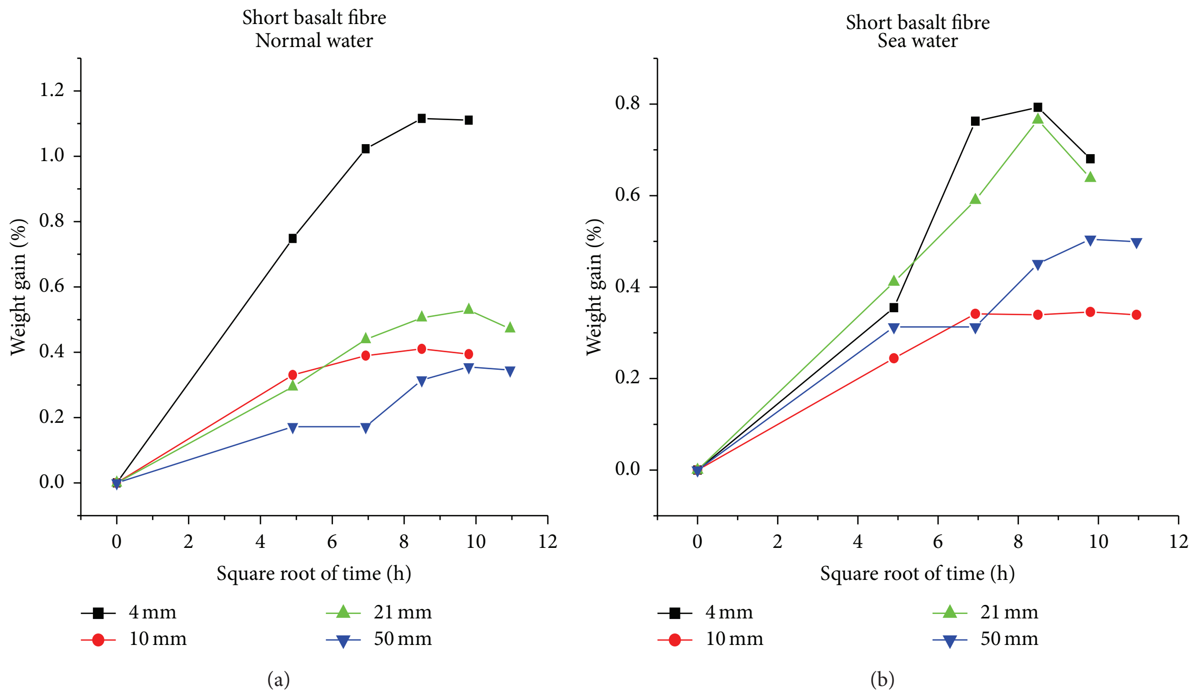

FIGURE 2: Short basalt fibre in normal and sea water immersion.

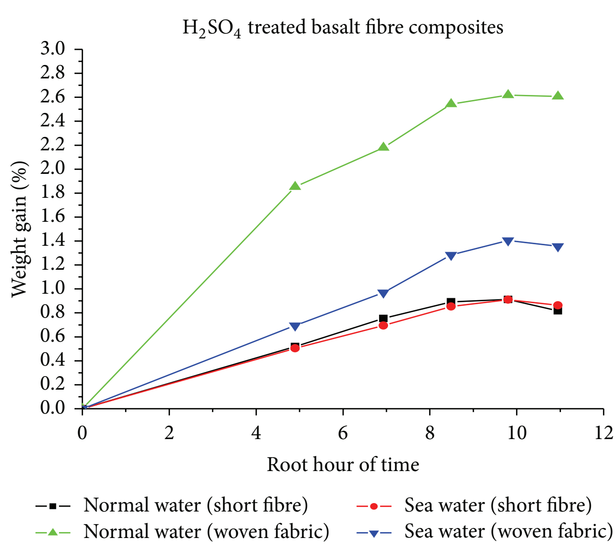

FIGURE 3: Acid treated basalt fibre in normal and sea water immersion.

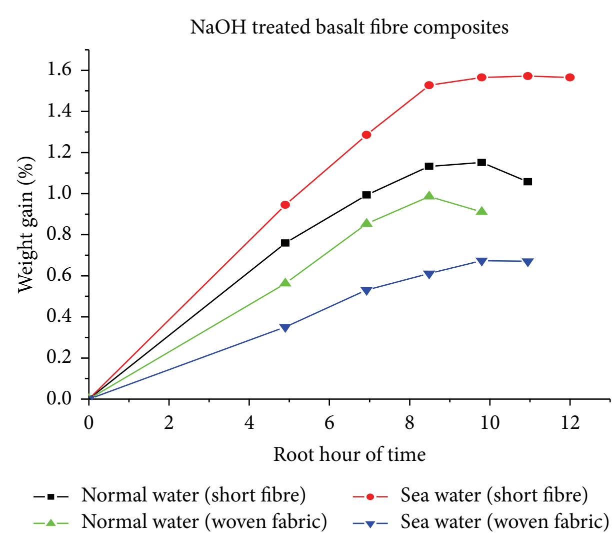

FIGURE 4: Base treated basalt fibre in normal and sea water immersion.

normal water condition had higher mass gain than that of the other composites. The higher weight gain exposure was absorbed in water than in sea water condition. For the short fibre there was no significant variance in the water and sea water treatments.

The NaOH treated (Figure 4) basalt fibre composites were immersed in both normal and sea water. The moisture uptake in normal water reached the saturation limit in 9 root hours for both woven and short fibre composites and then they started to lose their weight of composites. In sea water condition, both short and woven basalt fibre composites reached the saturation limit in about 10 root hours and it maintained that weight. Sea water immersion of composites produced less amount of water absorption due to its density and salinity. In some cases it was observed that there was decrease in weight gain because of the degradation of fibre. Polymers are hydrophobic in nature: it can absorb a small amount water [4].

4. Effect of Moisture Absorption on Mechanical Properties of Basalt Fibre Composites

The effect of water absorption on basalt fibre reinforced unsaturated polyester composites was investigated. Water uptake process for all the specimens was linear in the beginning and approached the saturation after prolonged time. Most of the specimens reached their saturation state with the maximum moisture absorption content in about 96 to 120 hrs. There was no significance mass loss observed**.**

4.1. Effect of Water Absorption on Tensile Strength. Figures 5 and 6 show the tensile strength of the woven and short basalt fibre composites. It was observed that tensile strength was higher for dry specimens unlike the immersed specimens where the tensile strength was found to decrease. Tensile strength of composites after moisture absorption for different time periods was analyzed. Woven basalt fibre without moisture specimen had tensile strength of 152 MPa and the normal water and sea water immersed specimen had decreased in strength. In case of all the samples, tensile strength decreased compared to without moisture specimen in sea water absorbed sample for woven basalt fibre composites. Similarly, surface treatment of woven basalt fibre composites had decreased in strength compared to dry specimen due to water uptake. Short fibre composites also had decreased in tensile strength nearly by 50–60%. This is due to discontinuous fibre in the composites. The large decreases in tensile strength of composites were due to swelling of polyester matrix in sea water. Since swelling of basalt fibre is comparatively low, the absorption of water leads to reduction in the fibre matrix interface and a decrease in tensile strength. All inorganic polymeric materials will absorb moisture to some extent resulting in swelling and dissolving which can result in loss of mechanical properties [1]. Fibre can absorb more water than matrix, and in improper interfacial bonding between fibre and matrix water can easily enter and wet the fibre completely through that interfacial bonding and the strength is decreased. During tensile testing, surface modified woven basalt fibre was not much affected by immersion than the untreated basalt fibre composites. This shows that the interfaces of the composites are more vulnerable to water absorption, as water molecules get diffused only into the surface of the composites and the woven fabric blocks the diffusion [17].

4.2. Effect of Water Absorption in Flexural Strength. In woven basalt fibre, after it reached saturation state the composites were tested. Flexural strength for water immersed samples had decreased dramatically compared to the dry samples. Flexural strength of without moisture basalt fibre composites was 44% greater than the normal water immersed specimen and 48% greater than the sea water immersed specimens (Figures 7 and 8). Acid treated dry basalt fibre composites were 8% greater than the normal water immersed specimens and 29% greater than the sea water immersed specimens. Similarly, NaOH treated water immersed specimens had significant decreases in the flexural strength than without moisture specimens. During water uptake of basalt fibre composites, flexural strength decreased. But acid treated specimen greatly withstood the water immersion during bending load. Flexural strength decreases due to water uptake which weakened the interfacial bonding strength.

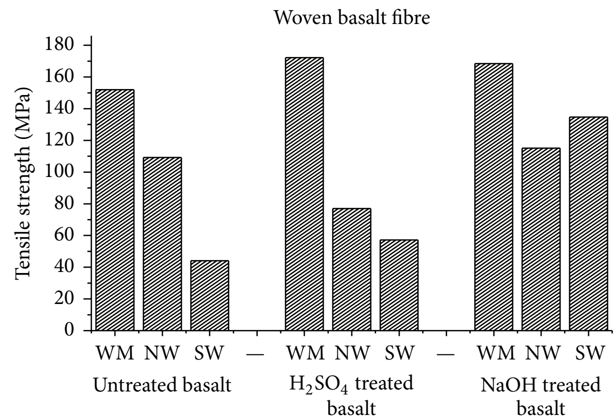

Figure 5: Tensile strength of woven basalt fibre composites.

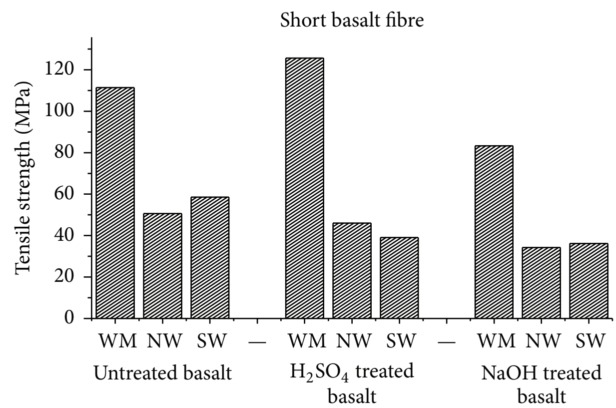

Figure 6: Tensile strength of short basalt fibre composites.

Flexural strength for water immersed samples was not much affected by water uptake. The flexural strength of untreated with moisture short basalt fibre was 461 MPa and normal and sea water immersed samples had 454 MPa and 447 MPa, respectively. Acid treated basalt fibre composites had flexural strength of 513 MPa which was 30.9% greater than the normal water absorbed samples and 28% greater than the sea water absorbed samples. Base treated basalt fibre composites had flexural strength of 564 MPa and water immersed samples were greatly affected by the property of composites. Decreases in flexural strength due to water uptake of the composites and leading the material to moisture induced interface were results of degradation in the fibre-matrix interface region. The bending load easily breaks the matrix and fibre bonding strength. But the untreated basalt fibre composite was not much affected by water uptake of composite, and it gave equivalent strength to untreated basalt fibre composites. Void content in the composites plays an

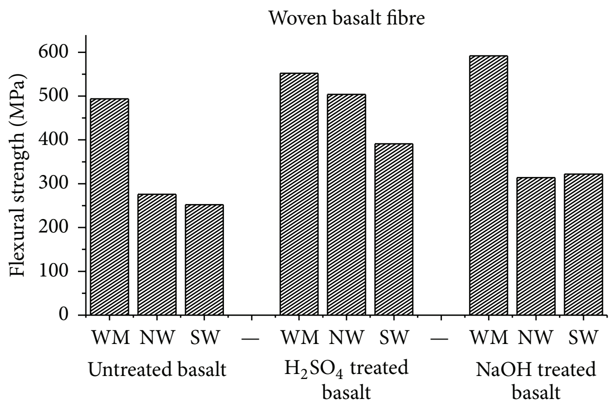

Figure 7: Flexural strength of woven basalt fibre composites.

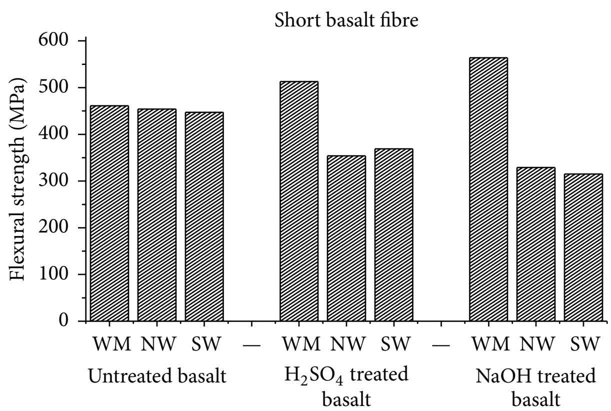

Figure 8: Flexural strength of short basalt fibre composites.

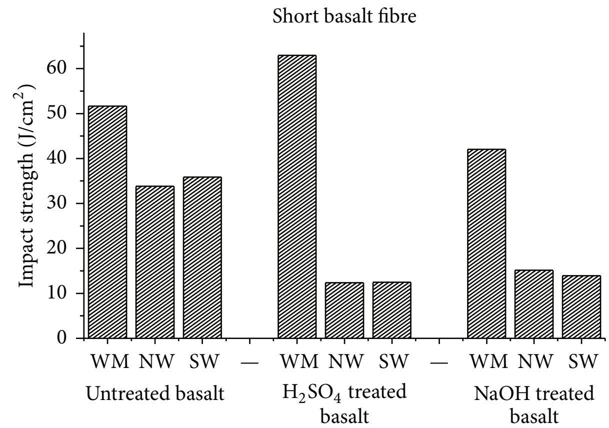

Figure 9: Impact strength of short basalt fibre composites.

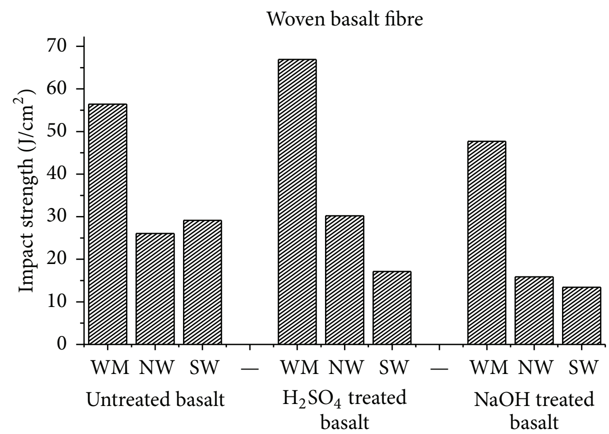

Figure 10: Impact strength of woven basalt fibre composites.

important role in absorbing high amount water (Figure 11). If void content is higher, the composite absorbs higher amount of water. If void is less, the composite absorb less amount of water. Higher void content in the composites causes degradation of composites due to higher absorption and also creates poor interfacial bonding. Generally tensile and flexural strength of the composites are fibre sensitive and the fibre attack by water would degrade the tensile and flexural strength [18]. The degradation of composites either the fiber or the matrix constituent will also degrade the interface between the constituents and there will be losses in interface strength that will degrade all the mechanical properties of the composite [19]. Water absorption of synthetic fibre is less than that of natural fibre. Water molecules entering into network of matrix accelerate the matrix cracking which leads to decreases in tensile and flexural strength [17]. NaOH treatment of basalt fibre shows better results than H_2SO_4 treatment due to reduction of capillary water uptake by improving the adhesion [20].

4.3. Effect of Water Absorption on Impact Strength. The water uptake of basalt fibre composites at different periods of immersion are shown in Figures 1, 2, 3, and 4. Impact strength of composites is reported in Figures 9 and 10. The results obtained show that impact property of the composites changed significantly at saturation state, independent of the type of fibre reduction in impact strength. Woven basalt fibre without moisture specimen showed 53% greater impact strength than the normal water absorbed specimens and 48% greater than the sea water immersed specimens. Acid treated woven basalt fibre composites were affected by uptake of water; approximately, 50% of the impact strength decreased compared to dry specimens.

Short basalt fibre composites had impact strength of 51.635 J/cm^2 and water immersed specimens were considerably decreased in strength. A dry specimen was 34.45% and 30% greater than the normal water and sea water absorbed specimens, respectively. Impact strength of the surface modified basalt fibre composites was highly affected by water uptake and higher reduction in strength compared with dry specimens (Figures 9 and 10). Failure of the short basalt fibre composites may be due to discontinuity of short fibre composites resulting in decrease in material homogeneity and possible interfacial defects leading to poor stress transfer between fibre and polymer matrix [3]. Under environmental aging, the polymer matrix composites may plasticize [1]. Due to the damages of the fibre under immersion, the interface of the composites was also damaged. During the water

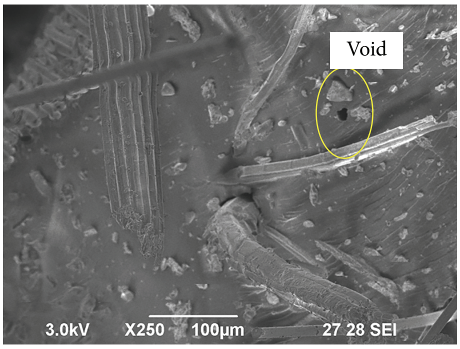

Figure 11: Void in the composites.

immersion tests of the composites, either the interface alone or both the interface and fibre were damaged and caused degradation of composite properties and decreased the mechanical properties of the composites. The thickness swelling of the short fibre composites was higher than that of woven basalt fibre composites. This was attributed to weak interfacial adhesion between the fibre and matrix. Impact strength of the composites is increasing with increasing of water absorption. It is because water molecule also resists the impact energy to produce the higher impact values.

5. Conclusion

Composites specimens are immersed for different time period till it reached its saturation state and then the specimen subjected to mechanical testing the following results were drawn.

The results indicate that the interfacial region in basalt composites may be more vulnerable to damage due to hydrolysis. Tensile strength of water immersed woven basalt fibre composites were not much significantly affected by immersion. But tensile strength of H_2SO_4 treated basalt fibre was significantly affected by untreated fibre in sea water immersion. Water immersed short basalt fibre composites were much affected by tensile strength.

Flexural strength of the water uptake composites was significantly affected. But H_2SO_4 and NaOH treated basalt fibre composites were not much affected by water absorption. Impact strength of the water uptake specimens was much affected by moisture absorption.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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