Study of effects of weathering on natural fiber composites

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Abstract. Composite materials are known to have many advantages and they can be used in the manufacture of a wide variety of products which make them commercially valuable. However, they may come into contact with various conditions that might lead to weathering. Weathering might lead to discoloration, decrease in durability, decline in mechanical properties and decrease in mass in composites. Hence, it is paramount to study the effects of weathering on composites before they are used in service. For this study, wood polyester composite (WPC), jute polyester composite (JPC) and coir polyester composite (CPC) were fabricated and subjected to four weathering tests - water ageing test at room temperature, water immersion test at 100°C, exposure to external environment and exposure to UV rays. It was seen that CPC samples subjected to water ageing at room temperature and immersion at 100°C showed comparatively higher water absorption rate than the WPC and JPC samples as coir fibres in CPC are hollow at the centremost region. JPC and CPC also turned whitish after 24 hours of water ageing. However, exposing the samples to the environment for a period of 144 hours did not show any significant change in the sample. It was also found that the tensile strength of all the composites decreased after being exposed to UV rays in a QUV spray weathering tester. Additionally, the mechanical properties of the composites were also modelled with analytical techniques (Halphin Tsai method) and FEM analysis and the results were found to be analogous.

Keywords – natural fibre, composites, polyester resin, weathering, mechanical properties.

1. Introduction
Composite materials are combination of two materials which can be custom tailored as per requirement. They have high fatigue life, high strength to weight ratio, high specific strength and stiffness, durability, [1-2] etc. Hence, they are widely used in the manufacture of many modern products making them commercially valuable.

However, composite materials on coming in contact with certain conditions like harsh climatic condition, exposure to ultraviolet radiation [3-4], absorption of large quantity of water, exposure to chemicals such as acids, bases [4-7], etc may experience weathering. Due to weathering, various harmful effects are seen in composites such as decrease in durability and life span, discolouration [8-9], decrease in tensile strength, flexural strength, hardness, interlaminar shear strength of composites [3,9-11], loss of mass [12-13], etc. Furthermore weathering tends to cause more harm in natural fiber based composites than artificial fiber based composites.

Natural fibers such as coir, jute etc are some of the most affordable fibers and are abundantly available in most parts of India. They are composed primarily of cellulose and lignin. They are usually used in the manufacture of cloth, carpets, bags, ropes, wrapping clothes, mats, vehicle seats, etc.

Numerous researchers have investigated and contributed their valuable findings on the ill effects of weathering on composite materials. Butylina et al. [8] studied the effects of external weathering on wood-polypropylene composites. The surface changes of the composites, colour fading, higher moisture absorption and decrease in charpy impact strength were the various effects that were observed in the study. Seki et al. [14] observed that the water aging test decreases the inter-laminar shear strength on jute polyester composite. Dash et al. [15] found that the flexural strength, tensile strength and inter-laminar shear strength of the composites lowered extensively upon their exposure to external weathering and water. Yan, L. et al. [11] found that accelerated weathering of flax-FRP composites decreases the tensile modulus and strength of the weathered composites by 34.9% and 29.9%, respectively. Amaro et al. [6] studied the effects of alkaline and acid solutions like sodium
hydroxide (NaOH) and hydrochloric acid (HCl) on glass/epoxy composites and found that they decreased the flexural strength and modulus of the composite with the exposure time. Peng et al. [16] showed that the surface properties of polypropylene composites reinforced with cellulose, lignin and wood flour on being exposed to UV weathering, accelerated the discoloration of composites due to presence of lignin and decreased the flexural properties. Vates, U. K et al. [17] performed a study which involved composites of aluminium alloy metal matrix composites reinforced with reinforced with nitinol particulates (NiTi) ranging from 0%, 4%, 8%, and 12%. The results showed that the surface roughness and hardness of the AAMMC increased with an increase in the percentage of NiTi. This was attributed due to the superior matrix-reinforcement interfacial bonding. Devi et al. [19] in their study which included ageing of pineapple leaf fiber–reinforced polyester composites, reported that the absorption of water in fiber reinforced composite is due to the capillary phenomenon. Furthermore it was also reported that there was decrease in tensile strength of the composite.

In this study, three different types of composites, viz. wood polyester composite (WPC), jute polyester composite (JPC) and coir polyester composite (CPC) were fabricated to study their mechanical properties. Thereafter, the ill effects of weathering on the fabricated composites was studied using different techniques. Additionally, analytical and FEM models were developed to model the mechanical properties of the natural fiber composites.

2. Materials and Methodology

2.1. Materials

Three types of composite viz. wood polyester composite, jute polyester composite and coir polyester composites were prepared for this research. Polyester resin was used as the matrix material. Polyester resin was procured from Carbonblack Composites, Mumbai. Methyl ethyl ketone peroxide (MEKP) was used as hardener and cobalt accelerator was used as a catalyst during fabrication. Reinforcements such as wood dust, jute and coir fiber were procured locally. The reinforcements were cleaned and dried under sunlight for 4 days. The fibers (jute, coir) were chopped into smaller fragments of 14 mm each. The wood dust was ground and sieved to obtain finer quality wood dust. A MS mold used for fabrication process was prepared having dimensions of 140 mm x 140 mm x 5 mm and samples were cut from the bigger composite plate. Composites were fabricated by hand-layup technique and a weight of 150 kg was used over the mold during the curing process. Images of fabricated composites are shown in figure 1. For fabricating the composites, 15% wt. fraction of reinforced materials (jute, coir, wood dust) was used.

![Figure 1. Composite panels of WPC, JPC and CPC.](image)

2.2. Mechanical measurements

Composites were subjected to tensile testing by Universal Testing Machine UTM (model: Hounfield H100K-S) of capacity 100 kN. The dimensions of the specimen were taken as 115 mm x 10 mm x 5 mm as per ISO 527 standards. Tensile testing was done both before and after exposing the samples to QUV weathering. The strain rate used was 2 mm/min.

2.3. Weathering tests

2.3.1. Water ageing in normal distilled water. For this study the fabricated composite samples were initially dried under sunlight for a period of 96 hours or 4 days. The samples from each type of composites were then immersed in three different containers containing distilled water for a period of
336 hours or 14 days. The initial weight of each sample was noted. The change in weight and change in surface of the samples was monitored every 24 hours. Photographs of the samples were also taken every 24 hours to monitor the surface and colour changes. Percentage of water content (W.C.) is calculated using Eq. (1):

$$W.C = \frac{W_w - W_d}{W_d} \times 100\%$$

(1)

$W_w$ = Weight of the wet specimen (gm)
$W_d$ = Weight of the dry specimen (gm)

2.3.2. Water ageing at boiling temperature and gradual cooling. For this study the fabricated composite samples were initially dried under sunlight for a period of 96 hours or 4 days. Samples were taken and initial weight was measured. The samples were then submerged in a container with distilled water at 100°C. After 9 hours, samples were taken out, wiped with a clean cloth and weight was measured again. Percentage of water content (W.C) is calculated using Eq. (2):

$$W.C = \frac{W_w - W_d}{W_d} \times 100\%$$

(2)

$W_w$ = Weight of the wet specimen (gm)
$W_d$ = Weight of the dry specimen (gm)

2.3.3. Exposure to external environment. The fabricated composite samples were placed outdoors in a region where they could easily come into contact with different environmental conditions like rainfall, sunlight, dew, moisture, etc. The weight of these samples were recorded every 24 hours on a weighing scale. Photographs of the samples were also taken every 24 hours to monitor the surface and colour changes.

2.3.4. Exposure of samples to QUV spray weathering tester. The composite samples were exposed to QUV spray weathering tester. The test was performed under ASTM G154 standards wherein the samples were exposed to 8 hours of UV radiation at 70° ± 3°C black panel temperature followed by condensation for a period of 4 hours at 50° ± 3°C black panel temperature in a cyclic pattern. The fabricated samples were exposed in the QUV weathering tester for a total period of 500 hours (21 days). QUV spray weathering tester simulates the outdoor weathering by exposing the samples of composite materials to alternating UV light and moisture at controlled temperature. UV light simulates effects of sunlight and rainfall and dew is simulated by means of condensing humidity or spray of water.

2.4. Analytical analysis

Analytical analysis was carried for JPC and CPC samples. Table 1 shows the elastic properties of the natural fibers and polyester resin that were used for the purpose of fabrication. Analytical analysis was carried out by a semi empirical method called Halpin-Tsai method [2]. The longitudinal Young’s modulus, $E_1$, is calculated as per rule of mixture given by the Eq. (3):

$$E_1 = \frac{E_{m}V_f + E_{f}V_m}{V_f}$$

(3)

In Eq.(3), $E_m$ and $E_{f}$ are the modulus of elasticity of matrix and fiber respectively and $V_m$ and $V_f$ are volume fraction of matrix and fiber respectively. The transverse Young’s modulus, $E_2$ and $E_3$ is calculated from the Eq.(4):
Where, \( \eta = \frac{\gamma - 1}{\gamma + 2}, \quad \gamma = \frac{E_{or}E_y}{E_w}, \)

\[
\eta = \frac{1 + \xi V_f}{1 - \eta V_f}
\] (4)

In Eq.(4), \( \xi \) is known as the reinforcing factor and depend on packing geometry, fiber geometry, loading conditions. In transverse direction, for circular or rectangular fiber, \( \xi \) is given as:

\[
\xi = 2 \times (\text{wt}) + 40 \times (V_f)^{0.10}.
\]

### Table 1. Elastic properties of jute, coir and polyester resin.

| Property                        | Jute [18] | Coir [18] | Polyester resin |
|--------------------------------|-----------|-----------|----------------|
| Longitudinal Young’s Modulus, \( E_1 \) (MPa) | 39618     | 4600      | 3300           |
| Transverse Young’s Modulus, \( E_2, E_3 \) (MPa) | 5500      | 4700      | 3300           |
| Axial Shear Modulus, \( G_{12}, G_{13} \) (MPa) | 7124.1    | 1760      | 1253           |
| Transverse Shear Modulus, \( G_{23} \) (MPa) | 2137      | 1760      | 1253           |
| Major Poisson’s Ratio, \( \nu_{12}, \nu_{13} \) | 0.11      | 0.30      | 0.316          |
| Minor Poisson’s Ratio, \( \nu_{23} \) | 0.35      | 0.30      | 0.316          |

2.5. FEM Analysis

A 3D FEM modelling of the fiber composite was done in ANSYS APDL 18.8 noded SOLID 185 was chosen as the element type for modelling of the fabricated fiber reinforced composites.

The element SOLID 185 is defined by eight nodes and has 3 degrees of freedom at each of the nodes, translations in the nodal x, y and z direction. The model is considered to be orthotropic in nature. The length, width and thickness of the specimen are 115 mm, 10 mm and 5 mm respectively.

Two number of ply with thickness 2.5 mm each are taken with orientation of \((0^\circ/0^\circ)\). One end of the sample is fixed in all direction; the other end of the sample is also fixed in all direction except in longitudinal direction where loading is applied. The applied boundary condition on the composite is shown in figure 2(a), and the meshing is shown in figure 2(b).

![Figure 2](image)

(a) Boundary condition for tensile test; (b) Meshing on composite material.

3. Results and Discussion

3.1. Weathering tests

Four different types of weathering tests were conducted to investigate the effects of various environments on the three different types of composites. It was observed that weathering adversely affected the mechanical properties of the composites in addition to causing visible physical changes in the composites.

3.1.1. Water ageing at room temperature. Containers were filled with distilled water at room temperature and the fabricated composite samples were submerged in them for a period of 336 hours
or 14 days. The water absorption rate was calculated every 24 hours. Table 2 and Figure 3 shows the rate of water absorption of the fabricated. It was observed that change in rate of water absorption is highest for the initial twenty four hours and then the rate steadily increases to a point of saturation. CPC samples shows the highest water absorption rate followed by JPC and WPC respectively. The reason for higher water absorption in CPC and JPC can be explained by the fact that coir and jute fibers are hydrophilic in nature i.e. they have a tendency to absorb water. Furthermore, coir and jute fibers are cellulose based fibers with hollow central regions which can hold water. Thus, rate of water absorption for CPC and JPC was higher. Slight damage to the surface of the composite was seen for the fiber reinforced composite but the same was not the case for WPC. Deposition of slight whitish material was seen for CPC and JPC samples however, no noticeable change in dimension of the samples was observed. Devi et al. reported the absorption of water in fiber reinforced composite is due to the capillary phenomenon [19]. These fibers were reported to swell with absorption of water (increasing the weight with increasing fiber loading) which resulted in leading to delamination and debonding.

Table 2. Change in weight of fabricated samples due to water ageing.

| Material            | Sample | Initial Weight (gms) | Final Weight (gms) | % Water Content |
|---------------------|--------|----------------------|--------------------|-----------------|
| Jute Polyester Composite | JPC 1  | 7.01                 | -                  | -               |
|                     | JPC 2  | 6.87                 | 7.36               | 7.13            |
|                     | JPC 3  | 7.1                  | 7.43               | 4.64            |
| Wood Polyester Composite | WPC 1  | 7.26                 | -                  | -               |
|                     | WPC 2  | 6.88                 | 7.11               | 3.63            |
|                     | WPC 3  | 7.19                 | 7.42               | 3.47            |
| Coir Polyester Composite | CPC 1  | 8.27                 | -                  | -               |
|                     | CPC 2  | 7.69                 | 8.46               | 10.01           |
|                     | CPC 3  | 7.3                  | 8.06               | 10.41           |

Figure 3. Water absorption rate of fabricated samples due to water ageing.
Figure 4. Before water ageing and after water ageing for 14 days images of (a-b) WPC, (c-d) JPC, (e-f) CPC samples.

Figure 4(a) and 4(b) shows the WPC samples before and after water ageing in distilled water for 14 days. It is clearly seen that there was no visible and dimensional changes after water ageing. In case of JPC samples (figures 4(c) and 4(d)), it was observed that there was a slight whitish deposition on the composite upon water ageing. However, in case of CPC samples (figures 4(e) and 4(f)), a high deposition of a whitish material takes place. The fibers are also seen to come out of the laminate in certain areas along with some swelling in certain areas.

3.1.2. Water ageing at boiling temperature and gradual cooling. To study the effects of hot and moist environmental conditions on the composite samples, boiling water ageing tests of the composite samples was conducted. This test was carried on for a period of 9 hours in distilled water at 100°C and the samples were allowed to gradually cool down.

Figure 5. Before boiling water ageing and after boiling water ageing images of (a-b) WPC, (c-d) JPC, (e-f) CPC samples.

Figures 5(a) and 5(b) shows WPC samples before and after being exposed to water ageing at boiling temperature. It was observed that the samples after the end of the test showed surface damage. Swelling of the wood polyester composite sample was also seen. Figures 5(c), 5(d), 5(e) and 5(f) shows JPC and CPC samples respectively before and after being exposed to water ageing at boiling temperature for a period of 9 hours. It is seen that the samples after the end of exposure period showed surface damage along with swelling and white powdery deposition on the surface.
Table 3. Change in weight of fabricated samples subjected to distilled water at 100°C.

| Composite                      | Weight (gms) | % Water Absorption |
|--------------------------------|--------------|--------------------|
|                                | 0 hours      | 9 hours            |
| Wood Polyester Composite       | 7.83         | 7.91               | 1.02               |
| Jute Polyester Composite       | 6.98         | 7.12               | 2.005              |
| Coir Polyester Composite       | 7.68         | 8.11               | 5.59               |

Table 3 shows the water absorption rate of the samples of composites on being immersed in boiling water. It is seen that in this case too, rate of water absorption was highest for coir polyester composite followed by jute polyester composite and wood polyester composite but unlike in normal water the rate of water absorption of samples immersed in boiling water was comparatively higher.

3.1.3. Environmental weathering. To study the effects of environmental weathering on the fabricated composite materials, the samples are placed outside in a region where it can get proper exposure to sunlight, rainfall, moisture, dew etc. No significant changes were observed in the composite samples after environmental weathering of 144 hours. This is probably because a longer amount of time will be required to properly note the effects of environment on the samples.

Table 4. Change in weight of fabricated samples subjected to environmental weathering.

| Material                      | Weight (gm) |
|-------------------------------|-------------|
|                               | 0 hours     | 24 hours | 48 hours | 72 hours | 96 hours | 120 hours | 144 hours |
| Jute Polyester Composite      | 7.03        | 7.03     | 7.04     | 7.02     | 7        | 7.03      | 7.02      |
| Wood Polyester Composite      | 8.11        | 8.12     | 8.12     | 8.1      | 8.11     | 8.13      | 8.11      |
| Coir Polyester Composite      | 7.63        | 7.58     | 7.57     | 7.56     | 7.56     | 7.57      | 7.57      |

3.1.4. Tensile strength before QUV weathering. The fabricated samples of JPC, CPC and WPC were subjected to tensile test to investigate their mechanical properties. Table 5 shows the results of the tensile testing. It was seen that the tensile strength is maximum for JPC, followed by CPC and WPC respectively. JPC and CPC are both fiber reinforced composites with stronger tougher which are able to withstand maximum loading in the direction of their fibres, thereby improving the property of the composite. However, the same is not the case for WPC as it is a particulate reinforced composite and depends mostly on the interfacial adhesion at the particulate-matrix boundary. Therefore, it was observed to have a lower tensile strength than JPC and CPC respectively.

Table 5. Tensile strength of the composites before weathering.

| SI No. | Tests Method | Units            | WPC | JPC | CPC |
|--------|--------------|------------------|-----|-----|-----|
| 1      | Tensile      | N/mm²            | 22.46 | 81.7 | 15.66 |
|        | Strength     | (before        | 12.29 | 72.9 | 18.07 |
|        |              | weathering)     | 10.46 | 71.8 | 16.86 |

3.1.5. Tensile test after exposure to QUV Weathering. After performing the QUV weathering test, JPC, CPC and WPC samples were again subjected to tensile test to investigate the effects of weathering on the mechanical properties (refer table 6). It was revealed that after 500 hours (21 days) of continuous exposure to ultraviolet/condensation cycle in the QUV spray weathering testing machine, the tensile strength of all the samples decreased. The decrease in tensile strength was seen to be maximum for JPC followed by CPC and WPC respectively. The decrease in tensile strength after
performing QUV weathering test may be due to the degradation of the fibres as well as damage in the polyester matrix of the composite. Furthermore, due to this exposure, the bonding between the matrix and reinforcements also weakened. Thus the load carrying capacity of the composites decreased which in turn led to reduction in tensile strength (mechanical properties).

3.2. Analytical results.

The elastic constants of the fabricated 2 ply single fiber composite samples viz. JPC and CPC have been calculated by means of the semi empirical Halph-Tsai method. The details of the results obtained have been discussed below.

3.2.1. Effect of fiber loading on composite materials. The elastic constants of the JPC and CPC samples viz. Longitudinal Young’s Modulus ($E_1$), Transverse Young’s Modulus ($E_2, E_3$), Axial Shear Modulus ($G_{12}, G_{13}$), Transverse Shear Modulus ($G_{23}$) and major Poisson’s Ratio ($\nu_{12}, \nu_{13}$) were calculated by Halphin-Tsai method. Fiber weight fraction was varied from 15% to 50% and the change in elastic constants was observed. The results were plotted graphically from Figures 6 (a-e).

Table 6. Tensile strength of the composites after 500 hours of QUV weathering.

| SI No. | Tests Method | Units | Results Obtained |
|--------|--------------|-------|------------------|
|        |              |       | WPC | JPC | CPC |
| 1      | Tensile Strength (After 500 hours UV Exposure) (at 2mm/min) | N/mm² | 15.81 | 59.8 | 9.6 |
|        |              |       | 13.36 | 65.7 | 9.83 |
|        |              |       | 15.05 | 75.5 | 12.46 |
|        |              | AVG: | 14.74 | AVG: 67.0 | AVG: 10.63 |

The value of longitudinal young’s modulus, $E_1$ has been calculated by application of rule of mixture method while the other elastic constants were calculated through Halphin Tsai method. It is seen that for the fabricated 2 ply fiber reinforced composites, the elastic properties ($E_1, E_2, E_3, G_{12}, G_{13}, G_{23}$) increases with the increase in fiber loading for both JPC and CPC. Furthermore, it is also seen that the elastic constants other than major poisson’s ratio, for jute polyester composite are better than coir polyester composites. This is due to the fact that jute fibers have inherently better elastic properties than coir fibers. Thus using jute fiber instead of coir fiber as reinforcement material for fabrication of composite will give better elastic properties to the composite. The major Poisson’s ratio was however found to decreases with increases in fiber weight fraction for both JPC and CPC.

3.3. FEM modelling

3D solid models of the JPC and CPC samples were prepared in ANSYS APDL 18.1. The dimension of the specimen was taken as per the size of the samples. The FEM models of tensile testing for JPC and CPC samples are shown in Figure 7 (a-b). The experimental results of the tensile test (refer table 6) for the composites and the FEM analysis in ANSYS were found to be approximately similar. However a slight variation in the results can be seen. The variation is shown in Table 7.

Table 7. Comparison of the values of tensile test experimentally and via FEM.

| Material | Experimental (N/mm²) | FEM (N/mm²) |
|----------|----------------------|-------------|
| JPC      | 75.47                | 76.39       |
| CPC      | 16.86                | 17.39       |

4. Conclusion

Composite materials are constituted of two or more materials and they have better physical and chemical properties than either of their constituent materials. As such, they have many advantages and thus they find their application in a wide range of field. Due to excessive use in different conditions, these materials may come into contact with various natural as well as artificial agents that may lead to
weathering in composites which in turn might lead to their degradation, discoloration and further
deterioration in elastic and mechanical properties.

Figure 6. Graphical representation of the elastic constants of JPC and CPC (a) longitudinal Young's Modulus ($E_1$), (b) Transverse Young's Modulus ($E_2, E_3$), (c) Axial Shear Modulus ($G_{12}, G_{13}$), (d) Transverse Shear Modulus ($G_{23}$) and (e) major Poisson’s Ratio($\nu_{12}, \nu_{13}$) calculated by Halpin Tsai method.

In this study, three different composites viz. WPC, JPC and CPC were fabricated and exposed to various weathering tests like water ageing, immersion and subsequent cooling of samples in boiling
water, QUV accelerated weathering, etc. to test their durability, longevity, change in mechanical properties and to understand their behavior under different weathering conditions.

![FEM model of tensile testing](image)

**Figure 7.** FEM model of tensile testing (a) JPC and (b) CPC.

It was observed that the properties of the composites degraded upon weathering. Due to weathering ill effects like swelling, increased water absorption rate, whitish surface deposition was seen in the composites samples. Water ageing test at room temperature revealed that rate of water absorption was highest in CPC which was followed by JPC and WPC. Furthermore the samples exposed to accelerated weathering showed a significant drop in tensile strength, this can be due to degradation of the fibres as well as damage in the polyester matrix of the composite as a result of exposure to accelerated weathering. The bonding between the matrix and reinforcements also weakened and therefore the load carrying capacity of the composites decreased which in turn led to reduction in tensile strength (mechanical properties).

Composite materials have lots of advantages and thus they find their application in manufacture of a large number of products but they have certain limitations. Composites on being exposed to certain conditions like water ageing, prolonged exposure to UV radiation, hot and humid environmental conditions etc. may eventually experience deterioration in mechanical properties and physical damage in the surface of the composite thereby decreasing longivity and durability. Analysis of the different elastic constants of the composites have shown that with the increase in fiber loading of the composites, the elastic constant of the fiber composites also improve.

This can be ascertained due to the fact that fibers impart further strength to the matrix materials after being fabricated as a composite. The elastic properties of jute being better than coir, results in better elastic properties of the jute polyester composite than coir polyester composite.

A 3D FEM model of the fabricated sample was done in ANSYS 18.1. 8 noded SOLID 185 defined by eight nodes and has 3 degrees of freedom at each of the nodes, translations in the nodal x, y and z direction was chosen as the element type. The model is considered to be orthotropotropic in nature and the dimensions were taken as per specimen. One end of the sample is fixed in all direction; the other end of the sample is also fixed in all direction except in longitudinal direction where loading is applied. FEM modeling showed that the model satisfactorily predicts with the experimental results.

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