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Effect of Gel Coat on Moisture Absorption and Mechanical Behaviour of Jute-Epoxy Laminated Composite

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ABSTRACT : *Natural fibre composites find wide range of applications and usage in the automobile and manufacturing industries. They find lack in desired properties, which are required for present applications. In this study, the effect of gel coat on laminated natural fibre reinforced polymer composites has been studied. The experiments were carried out to evaluate moisture absorption and mechanical properties of jute fibre reinforced polymer composites. Laminated composite specimens were prepared using epoxy as the matrix material. The prepared specimens were coated with a layer of gel coat material and categorized as coated/uncoated type. The specimens were exposed to moisture and then tested for moisture uptake, tensile and flexural properties. Comparison was made between coated and uncoated specimen to evaluate the performance of gel coat on the coated specimen. The specimen preparation and the experimentations were carried out as outlined in the ASTM standards. The obtained results revealed that the process of gel coating prevented moisture uptake and improved the mechanical properties.*

Keywords - *Gel coat, laminate, moisture uptake, natural fibre, polymer composites.*

I. INTRODUCTION

In recent years natural fibers have gained increasing interest due to their eco-friendly properties and biodegradability. Natural fiber polymer composites have become increasingly popular ranging from construction, automotive, industrial, marine to aerospace applications [1],[2],[3],[4]. Natural fibers such as jute, straw, flax, hemp, wood, sugarcane, bamboo, grass, kenaf, sisal, coir, rice husks, wheat, barley, oats, kapok, mulberry, banana fiber, raphia, pineapple leaf fiber and papyrus, etc., are inexpensive, abundant and renewable. They are light weight, possess low density, high toughness, good specific strengths, modulus, economic viability, reduced tool wear, enhanced energy recovery, reduced dermal and respiratory irritation [5], [6]. The major problem with the natural fibers is that they are hydrophilic in nature due to its chemical constituent cellulose. This impend their choice in composite structures [7]. They have a tendency to absorb moisture and hence their mechanical properties get degraded over a period of time. The mechanical properties of composite materials depend on many factors, such as fiber length, shape, size, composition, orientation and distribution, as well as volume fraction. Mechanical properties of the matrix, manufacturing techniques and bonding between fibers and matrix also play an important role. Mechanical properties of polymeric composites have a strong dependence on the interface adhesion between the fiber and the polymer matrix [8]. The degradation of mechanical properties, moisture absorption and inferior fire resistance limits the potential application of these natural fiber based composites [9],[10],[11]. The degradation is due to the surrounding temperature, humidity and ultraviolet light etc., from the environment. The absorbed moisture causes plasticization of the resin at the same time causes volume expansion and generates cracking. As the moisture uptake increases the fibers get swollen separating the chemical bond between the matrix and the fiber [12],[13]. Another area of concern relates to the poor moisture resistance and dimensional stability of natural fibers, which can lead to debonding and micro-cracking in the composite. The effect of moisture absorption leads to the degradation of the fiber-matrix interface region creating poor stress transfer efficiencies resulting in reduction of mechanical and dimensional properties [14],[15]. The surface of the composite material exposed to moisture results in blisters. This problem in polymer laminated composites can be reduced by protecting the external surface with a thin film of polymeric material on the external surface. Gel coating provides high-quality finish on the visible surface of a composite material [16],[17],[18]. Gel coat also enhances fire protection and provides an additional barrier against moisture. Gel coating prevents the moisture absorption, enhances the mechanical properties, prevent the interfacial delamination and fracture [12],[19],[20]. The process of gel coating enhances the mechanical properties. Gel coats are applied to moulds in the liquid state. They are cured to form cross-linked polymers and are subsequently backed up with composite polymer matrices, fiberglass or epoxy resin with glass fibers and mixtures of polyester resin.

II. MATERIALS AND EXPERIMENTATION

The experimentations were carried out on natural fiber reinforced polymer laminate composites. The effect of moisture absorption on the mechanical properties and the performance of gel coat on coated and uncoated composite specimen are evaluated. The details of which have been discussed in this section.

1.1 Materials

2.1.1 Matrix: The matrix material used is Lapox L12, the trade name of epoxy resin. It is a low temperature curing unmodified general purpose epoxy resin. It has medium viscosity which can be used with various hardeners for making fiber reinforced composites. The choice of hardener depends on the processing method to be used and on the properties required for cured composite. Hardener K6 is a low viscosity room temperature curing liquid. It is commonly employed for hand layup applications. Being rather reactive, it gives a short pot life and rapid cure at normal ambient temperatures.

2.1.2 Reinforcement: The function of reinforcement material is to improve the strength of the composite. One such reinforcement material used here is jute fiber. Jute is a versatile fiber. It is long, soft and shiny, with a length of 1m to 4 m and a diameter of 17 to 20 microns. Jute is one of the most affordable natural fibers, which is primarily composed of the plant materials like, cellulose and lignin. Jute fiber has some unique physical properties like high tenacity, bulkiness, sound &heat insulation property, low thermal conductivity, antistatic property moderate moisture retention etc. It is 100% bio-degradable and thus environment-friendly.

2.1.3 Gel-coat: Gel coat used is an epoxy base resin which is red in color having thixotropic consistency. It is supplied by Shahani (India) Company Ltd, Bangalore. It is used in combination with room temperature curing hardener 758. Epoxy gel coat (red) with hardener 758 is a fast curing system with hard cured mass. The hard cured material shows good mechanical, electrical, chemical property and humidity resistant. Hardener 758 is pale yellow color with viscosity of 15-35 MPa at 250C. Epoxy gel coat (red) has hardly any effect on skin and mucous membrane. Hardener 758 has vapors that result in irritation to mucous membrane and eyes. Its direct contact with the skin cause dermatitis associated with slight swelling and itching or irritation. Direct contact with hardener as well as resin-hardener mix should be avoided by using necessary hand gloves. Any area of skin affected should be scrubbed with 5% of acetic acid and washed well with plenty of water.

1.2 Specimen Preparation

Laminated composite were prepared by hand lay-up technique. The laminate is prepared for the volume fraction of 60% of epoxy and 40% of reinforcement material. Experimentations were carried on specimen in accordance with ASTM D5229, ASTM D5766, ASTM D7264 standards. For the chosen volume fraction the quantity of matrix, reinforcement and jute fabric layers are calculated and the laminate is fabricated. The laminate is allowed to cure under room temperature for 18 to 24 hours. Fig. 1 shows the fabricated composite laminate.

Fig.1 Fabricated composite laminate

The cured laminate is then cut to the required dimensions for different tests. Epoxy gel coat (red) with hardener 758 is mixed in a ratio of 100:10 according to the standard and then coated to the specimen by brush method.

2.2.1 Moisture absorption test: Moisture absorption test is conducted for coated and uncoated specimens with ASTM D5229 standard. Fig. 2 shows the moisture absorption test specimen and its schematic diagram.

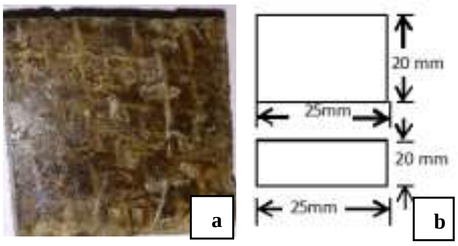


Fig. 2 Moisture absorption specimen
a) Pictorial View b) Schematic diagram of specimen

2.2.2 Tensile test: Tensile test is important to determine the mechanical behavior of the laminated composite materials. Tensile test specimens were fabricated according to the ASTM D5766 standard. The specimens were tested using Universal Testing Machine. The test is conducted for coated and uncoated specimen with hole diameters of 6mm, 8mm and 10mm individually at the center of the specimen. Some of the specimens were coated with gel coat material and cured at room temperature and some left uncoated. The specimens were exposed to moisture for 12 hour duration and tested for tensile strength. Fig. 3 shows the tensile test specimen and its schematic diagram.

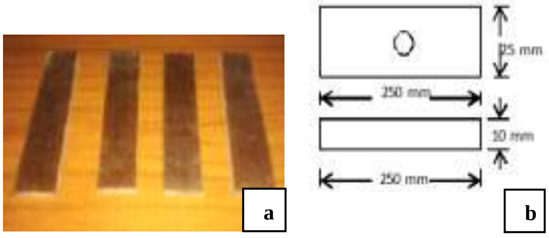


Fig. 3 Standard tensile Test Specimens
a) Pictorial View b) Schematic diagram of specimen

2.2.3 Three-point bending test: Three point bending test is conducted on coated and uncoated specimens with the help of universal testing machine (UTM). The specimens were fabricated according to ASTM D7264 standard. The specimens were made with V-notch exactly at the centre on the width side and edge side to a depth of 3mm. The prepared specimens were then coated with gel coat material and allowed to cure at room temperature. The specimens were exposed to moisture for 4 hour and 12 hour duration and tested for flexural strength. Fig.4 shows the three-point bending test specimen and its schematic diagram.

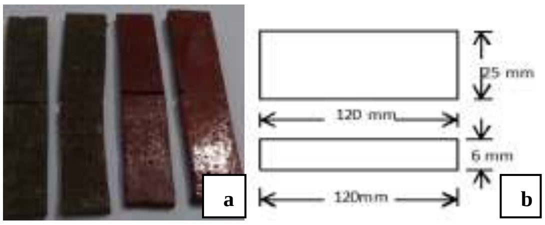


Fig. 4 Standard bending Test Specimens
a) Pictorial View b) Schematic diagram of specimen

III. EXPERIMENTATION

3.1 Moisture absorption test: Moisture absorption test aims to determine the percentage of moisture uptake when exposed to humid environment. The test is conducted on coated and uncoated specimen. The initial weight of the specimen is recorded before exposing to moist environment. The specimens exposed to moisture were tested for every 2 hours. The specimens were taken out from the beaker and gently wiped with soft cloth in order to make the surfaces dry. The final weight is recorded and the percentage weight gain is determined by using the formula,

$$\% W = (W_f - W_i) / W_i$$

Where, W_i = initial weight of the specimen
W_f = final weight of the specimen
%W= percentage weight gain

3.2 Tensile test: The tensile test is conducted on coated and uncoated specimen using Universal testing machine (UTM). The specimens were exposed to moisture for 12 hour duration. The specimens were fixed in the UTM with the help of fixtures. Fig. 5 shows the arrangement for tensile test. Load/Displacement data were recorded for all the specimens.


Fig. 5 Experimental set-up for tensile test

3.3 Three-point bending test: Three point bending test is conducted on coated and uncoated specimens with the help of universal testing machine (UTM). The test is conducted on coated and uncoated specimens with edge notch and width notch on Universal testing machine. The specimens were exposed to moisture for 4 hour and 12 hour duration. Fig. 6 shows the arrangement for flexural test. Load/Displacement data was recorded for all the specimens.

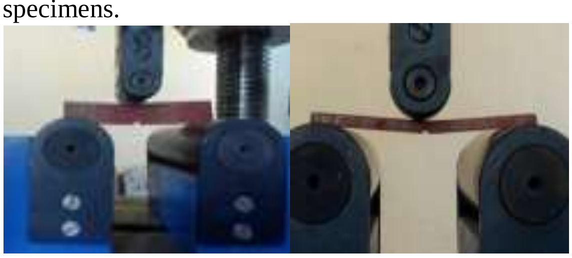

a b

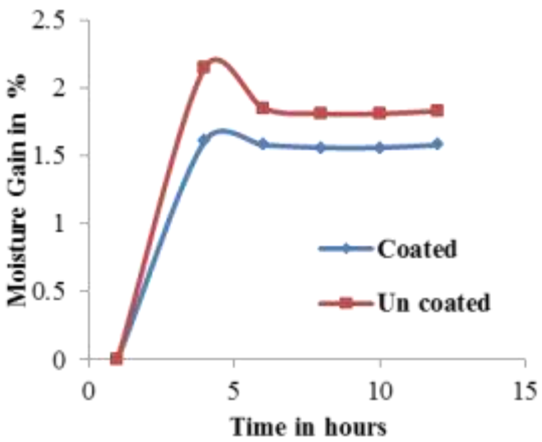
Fig. 6 Experimental set-up for flexural test
a) Edge notch b) Width notch

IV. RESULTS AND DISCUSSION

In order to identify the effect of gel coat on the performance of polymeric laminated composite specimen, moisture absorption test, tensile test and flexural test were conducted. Experiments were conducted on coated and uncoated jute fiber reinforced laminated polymer composites. The specimens were exposed to moisture before conducting the test.

4.1 Effect Of Coating On Moisture Absorption
Moisture uptake tests were carried out under an extreme condition, where in the complete exterior

surface of the specimen is exposed to moisture. Fig. 7 shows the moisture gain/Time in coated and uncoated specimens for a total duration of 12 hours. It can be seen from the graph that both the specimen gain weight gradually for the first one hour. The uncoated specimen show more moisture uptake than the coated specimens for the next one hour duration. The graph reveals that both the specimen gets saturated for further exposure to moisture. The moisture uptake in uncoated specimen is comparatively high due to the presence of voids, craters and micro-cracks on the surface [21]. These voids initially absorb more moisture and later get saturated. The saturated voids are unable to uptake the moisture later. This is because moisture uptake depends on the property of unsaturated jute fabric material and wetting of polymer. After the saturation level the percentage of voids on the specimen become less. Moisture absorption reduces interfacial adhesion of fiber with matrix. This causes swelling of the fiber and eventually lead to debonding between fiber and matrix. The application of gel coat heals the surface voids, craters and micro-cracks and prevents the moisture up take and hence prevents the delamination of the specimen, fiber degradation and polymer wetting. The process of providing gel coating on



the surface reduces the swelling stresses [22].

Fig. 7 Moisture gain/Time curve for moisture absorption test

Even though the nature of graph is similar, but the process of gel coating acts as barrier in coated specimen and prevents the moisture uptake to some extent. The uncoated specimens gain weight of 2.84 percent for time duration of 8 hours, whereas the coated specimens show weight gain of 1.85 percent. Suppose if the specimens are further exposed to moisture, there is proportionate increase in moisture uptake for both specimens. Moisture uptake is a time dependent parameter.

4.2 Effect Of Coating On Tensile Characteristics

The tensile test is conducted to study the tensile strength on both coated and uncoated laminated composite specimens when exposed to moist environment for total time duration of 12 hour. Fig. 8 shows the comparison of Load/Deflection curves for coated specimen with various drilled hole diameters. It can be seen from the graph at 0.5mm deflection the coated specimen with 6mm sustains less load than 8mm and 10mm diameter hole. Further for 1mm deflection the 10mm diameter hole specimen bears more load than 8mm and 6mm hole specimen. The failure positions of most specimens were near the hole center. This is due to formation of cracks during the drilling process. The volume of cracks in the 6mm drilled hole specimen has initiated the moisture uptake through the cracks and hence the load bearing capacity is less in the initial stage. But 8mm and 10mm drilled hole specimen bear more load due to less number of cracks and reduced stress concentration. Further at 1.5mm deflection 8mm hole specimen sustains more load than 10mm revealing that the pre notched hole has less impact than 10mm hole. The nature of graph further continues with 8mm hole bearing more load of 5.3 KN and further declines, whereas the 6mm hole specimen bears 5.8 KN indicating more load sustainability than the other two. More over the process of gel coating has prevented the moisture uptake in 6mm hole specimen and hence the ultimate load bearing capacity is high.

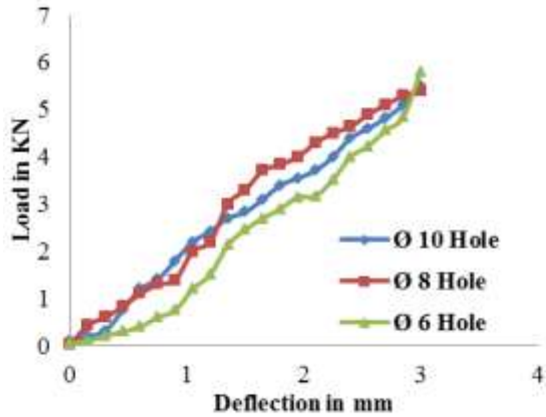


Fig. 8 Load/Deflection curves of coated specimens exposed to moisture

The process of gel coating acts as healing agent and covers the voids and surface craters. The 6mm drilled hole specimen sustains more load due to less change in cross sectional area. The process of drilling hole in the specimen produces micro cracks and these cracks are the origin of high stress concentration. Stress concentration is less in 6mm diameter hole as compared to 8mm and 10mm diameter holes. Due to increased stress concentration the 10mm drilled hole specimen fails by fiber pulling. The ultimate strength values varies greatly with the hole size, and the laminate strength decreases as the hole size increases.

Fig. 9 shows the Load/ Deflection curve for uncoated specimen with various drilled hole diameters. It can be seen from the graph that for a load of 1KN at 0.5mm deflection the 6mm drilled hole specimen show less load sustainability than 8mm and 10mm. Further load bearing continues for 8mm and 10mm up to 1.2mm deflection for 2.1 KN load whereas graph for 6mm hole declines with less load bearing capacity. This is due to improper fabrication of the specimen or incorrect drilling procedures. As seen from the graph the 8mm diameter hole continues its load bearing capacity and further fails at 4.95KN. The 6mm hole specimen further show high load bearing capacity due to reduced stress concentration. The graph further continues and the specimen fails at 5.1 KN.

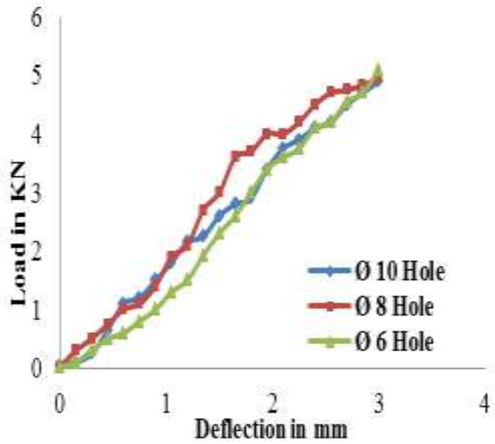


Fig. 9 Load/Deflection curves of uncoated specimens exposed to moisture

The volume of micro cracks are more near the vicinity of the hole and hence moisture uptake is more in larger diameter hole specimen and hence the load sustainability is less. As the moisture uptake increases with increase in surface voids the specimen fails by fiber damage and pulling out of fibers. The absorbed moisture causes plasticization of the resin at the same time causes volume expansion and generates cracking. As the moisture uptake increases the fibers get swollen separating the chemical bond between the matrix and the fiber.

By comparing the above two graphs we can conclude that the load bearing capacity of coated specimens for varied hole diameter is higher than the uncoated specimens. This is because the gel coat used is highly resistant to humidity. The gel coat layer prevents the moisture uptake and hence prevents the delamination of the specimen, fiber degradation and polymer wetting. Gel coating prevents the external surface of the specimen from immediate exposure to moisture and thereby increases the tensile strength. The reinforcement material jute consist lignin as the main constituent. Lignin has a tendency to absorb moisture. As the moisture uptake increases the fiber undergoes swelling leading to weakening the interface of matrix and reinforcement and ultimately decreasing the strength of the specimen. Moisture diffusion in composites degrades mechanical properties by three different mechanisms [6],[10]. The first mechanism involves the diffusion of water molecules inside the micro gaps between polymer chains. The second mechanism involves capillary transport into the gaps and flaws at interfaces between fiber and matrix. The third mechanism involves swelling effects which propagates micro cracks in the matrix. In a moist environment, water molecules penetrate in natural fiber reinforced composites through micro-cracks and reduce interfacial adhesion of fiber with matrix. This causes swelling of the fiber and eventually lead to debonding between fiber and matrix [21]. The specimen fails by fiber damage, delamination and pulling-out of fibers that take place in the vicinity of the hole.

4.3 Effect Of Coating On Bending Characteristics With Edge Notch

The Load/Deflection curves for coated and uncoated specimen with edge notch exposed to moisture for time duration of 4 hour is shown in Fig. 10. The specimen failure takes place at the pre-notched region. At 0.05 mm deflection the specimen show comparatively high load bearing capacity than the uncoated one. It is due to the specimen being failed at its notched edge to the initial load applied. Further as the load is increased the load bearing capacity of the coated specimen is found to be high even though exposed to moisture for duration of 4 hour. The area above the notch is subjected to cracking and the specimen fails by shearing. It can be seen from the graph that the uncoated specimen fails at a deflection of 0.19mm for a load of 0.15 KN than the coated specimen at 0.2 KN.

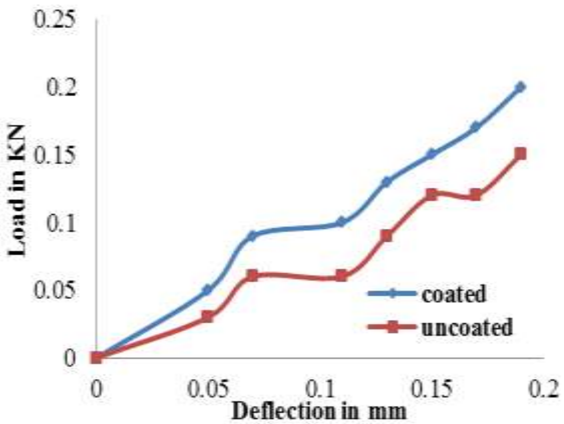


Fig. 10 Load/Deflection curves of coated and uncoated specimens with edge notch exposed to moisture for 4 hour duration

The uncoated specimen show comparatively less load bearing capacity due to presence of surface voids. The moisture penetrates readily through surface voids, micro cracks and craters. The leads to swelling of the reinforcement and weakening between the interface layer leading to brittleness of matrix material. When transverse load is applied the specimen fails by fiber pull-out and brittle failure of the fiber-matrix interface. In coated specimen the gel coat material used is highly resistant to humidity. It acts as healing agent to fill the voids, craters, micro-cracks and prevent moisture uptake.

The Load/Deflection curves for coated and uncoated specimen with edge notch exposed to moisture for time duration of 12 hour is shown in Fig. 11. In uncoated specimen as the time of immersion increases, brittleness of the matrix increases with decrease in load bearing capacity. It can be seen that at 0.05mm deflection the uncoated specimen sustains 0.01KN than the coated specimen with 0.03KN. This is due to prolonged exposure of uncoated specimen to moisture. The moisture uptake is more in uncoated specimen due to surface cracks and voids. The pre-notched region comprises of small cracks through which the moisture penetrates easily and makes the specimen weak. As the load is applied the uncoated specimen fails soon than coated specimen at the notched region.

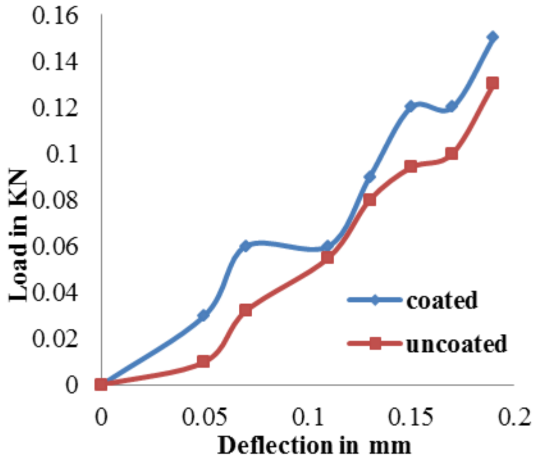


Fig. 11 Load/Deflection curves of coated and uncoated specimens with edge notch exposed to moisture for 12 hour duration

The un-notched region allows bearing the load further in both the specimen. The graph reveals that the coated specimen shows good response to flexural load at 0.15mm deflection for 0.12 KN whereas the uncoated specimen bears 0.094 KN for the same deflection. This indicates that the moisture in the specimen has initiated the shearing of the brittle fiber-matrix interface in uncoated specimen. Gel coat in coated specimen has prevented moisture uptake to some extent and has shown improved flexural property. Both coated and uncoated specimens fail at 0.19mm deflection for 0.15 KN and 0.13 KN respectively. When water uptake reaches saturation level, the bound water and the free water remains in the composite as a reservoir. This leads to softening of the fibers and weakening of fiber matrix adhesion resulting in reduced flexural properties.

By referring to Fig. 10 and Fig. 11 it can be concluded that the load bearing capacity for coated specimen is more than the uncoated specimen. This is because the percentage of moisture uptake in uncoated specimen increases with increase in time and later get saturated after 10 hour. The reinforcement material jute contains a material called lignin. This lignin readily absorbs moisture, undergoes swelling and weakens the interlaminar strength of the specimen [23]. Initially the moisture uptake is high due to more number of open voids on the surface and as the exposure time increases the number of voids reduces leading to swelling of reinforcement material and saturation of the specimen. If further the time of immersion is increased then the moisture uptake increases tremendously leading into weakening of the specimen. Whereas the coated specimen show increased load bearing capacity as the gel coat material used is highly resistant to humidity. The process of gel coating heals the surface voids and prevents immediate exposure to moisture and thereby increases the load sustainability.

4.4 Effect Of Coating On Bending Characteristics With Width Notch

The Load/Deflection curves for coated and uncoated specimen with width notch exposed to moisture for time duration of 4 hour is shown in Fig. 12. The graph reveals that uncoated specimen show less load bearing capacity than the coated specimen. For a deflection of 0.05mm both coated and uncoated specimen show 1.3KN and 1.5KN load respectively. It is due to load being transferred to the coating material and then later to the composite laminate in coated specimen. The absorbed moisture weakens the surface in uncoated specimen hence the difference in load bearing can be observed in the Fig. up to 0.11mm deflection. The coated specimen shows that gel coating process has prevented moisture uptake and hence increased load sustainability.

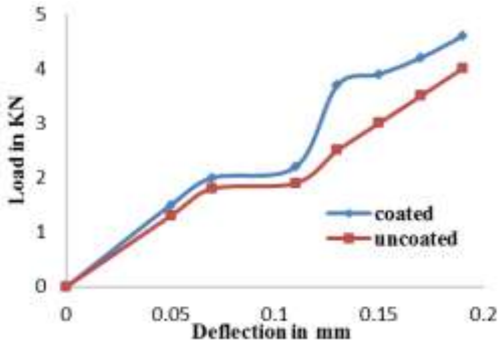


Fig. 12 Load/Deflection curves of coated and uncoated specimens with width notch exposed to moisture for 4 hour duration

Further there is no considerable increase in load bearing capacity in both the specimen. It is because of the initial failure of the specimen at pre-notched region. The pre-notched region of the specimen is under tension and fractures by delamination of matrix and fiber. Further as the load increases the deflection increases considerably and ultimately the coated specimen fails at 4.6KN than the uncoated failing at 4.0 KN. This is due to shearing of the brittle fiber-matrix interface. The failed specimen reveals fiber pulling and weak interlaminar strength [24],[25].

The Load/Deflection curves for coated and uncoated specimen with width notch exposed to moisture for time duration of 12 hour is shown in Fig. 13. The graph shows that the nature of curve for both coated and uncoated specimen is same up to 0.1KN. At an initial deflection of 0.05mm deflection the coated specimen shows slight increase in load bearing capacity as compared to uncoated specimen. This is because the coated specimen has a gel coat layer on its external surface. The gel coat layer has prevented the moisture uptake and has enhanced its load bearing property, whereas the uncoated specimen withstands fewer loads due to moisture uptake.

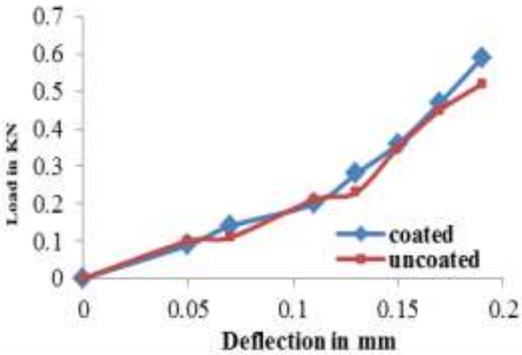


Fig. 13 Load/Deflection curves of coated and uncoated specimens with width notch exposed to moisture for 12 hour duration

Further the graph shows that the as the load increases the deflection increases at 0.21 KN. The coated specimen again show more load sustainability further from 0.28 KN to 0.59 KN as compared to uncoated from 0.13KN to 0.52KN. The moisture uptake in uncoated specimen has weakened the fiber-matrix interface causing it to delaminate under the applied load at the notched region. However the gel coat layer has prevented the moisture uptake in coated specimen and has increased the load bearing capacity to some extent.

By referring to Fig. 12 and Fig. 13 it can be concluded that continued exposure of the specimen to moisture has led to more moisture uptake in uncoated specimen weakening the inter laminar shear strength. This is due to the compounds present in reinforcement material. Lignin present in reinforcement has a tendency to readily uptake moisture. The process of gel coating has prevented the moisture uptake and has considerably increased the flexural strength of the specimen. It can also be seen that the load sustainability decreases with increased exposure to moisture in both coated and uncoated specimen.

V. CONCLUSIONS

Based on the results obtained and the discussions made on coated and uncoated laminated polymer composite materials the following conclusions were drawn,

- The moisture absorption capacity of uncoated specimens is found to be more than the coated specimen. The coated specimen also have the moisture uptake upto a time duration of 4 hours, later it is reaches to saturation level, because the gel coat prevents moisture uptake.
- The process of gel coating reduces delamination, fiber degradation, polymer wetting.
- In tensile test the coated specimens with minimum hole diameter showed high load bearing capacity than the maximum hole diameter of coated specimens.
- In bending test the coated specimens of width notch showed more load sustainability than coated edge notch specimens.
- Exposure of natural fiber reinforced composites to moisture results in significant drop in mechanical properties due to degradation of the fiber-matrix interface. As the time of immersion increases brittleness of the matrix increases with decrease in load bearing capacity. When water uptake reaches saturation level, the bound water and the free water remains in the composite as a reservoir. This leads to softening of the fibers and weakening of fiber matrix adhesion resulting in reduced mechanical properties. The process

of gel coating prevents moisture uptake and improves the mechanical properties.

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