Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2023, Volume 14, Issue 12, Page 1551-1563

http://www.jmaterenvironsci.com

Influence of Gel Coating Method and Notch Orientation on the Bending Strength of Jute-Epoxy Laminated Composites

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Received *05 Oct 2023,*
Revised *14 Dec 2023,*
Accepted *15 Dec 2023*

Citation*: Sudha G. S., Arun K. V. (2023) Influence of Gel Coating Method and Notch Orientation on the Bending Strength of Jute-Epoxy Laminated Composites J. Mater. Environ. Sci., 14(12), 1551-1563*

Abstract: The effect of notch orientation and gel coating methods on jute-epoxy laminated composites has been experimentally investigated. Uncoated and coated jute-epoxy laminated composite specimens were subjected to three-point bend test under varied flaw orientation. The flaw orientations were made across the laminate, along the laminate and compared with un-notched specimens. Results have shown that gel coating method has enhanced the load sustainability in specimens. The specimens with notch across the laminate have shown greater load sustainability than notch along the laminate. The process of gel coating has reduced the delamination when compared to uncoated specimens. Spray method has shown higher load sustainability with an uniform deposit compared to other methods.

Keywords: *Laminated Polymer composites, Natural fibre, Gel coating methods, Notch orientation, Bending Strength.*

1. Introduction

The use of natural cellulose fibres as reinforcement for fibre reinforced composite is increasing tremendously. The maximum utilization of these fibres has become a global importance which promotes a green environment and sustainability. Natural fibres such as kenaf, sisal, jute, hemp, flax etc, have been are used as reinforcement with polymer matrix to produce natural fibre reinforced composite (Sadashiva *et al.*,2023; Alsubari *et al.*, 2021; Tabaght *et al.*, 2021; Ramli *et al.*, 2018; Azzaoui *et al.*, 2015). Synthetic fibre reinforced composites possess better mechanical properties and hence are used in high-end applications. Synthetic fibres are expensive and the structure yields in high cost to weight ratio. Natural fibres can compensate the problems and hence can be replaced to produce products where high strength to weight ratio is of prime importance (Akartasse *et al.*, 2022; Bachchan *et al.*, 2020; Gamstedt 2016; Elidrissi *et al.*, 2012). Natural fibre reinforced composites find applications where energy absorption is important, such as insulation, noise absorbing panels or collapsible areas in automobiles (Alemayehu *et al*., 2021). Automobile industries are always in search of introducing alternations to the existing design. Natural fibre reinforced composites can be used to replace automotive parts which not only reduces the total weight of the vehicle but also improves the fuel efficiency and promotes a pollution free environment. Attempts have been made to use natural fibre reinforced composites in bumper of car, interior of automobile and also as packing material (Shada Bennbaia *et al*., 2023; Venkatesh Naik *et al*., 2022; Atiqah *et al*., 2014; Davoodi *et al*., 2011; Qatu 2011). These applications are susceptible to bending loads when supported between two extremities. The induced bending load may cause interlaminar delamination at the extreme edges. Moisture absorption is a major culprit associated with natural fibre composites when exposed to open environment. Moisture absorption reduces the interfacial properties of the composite due to swelling of the fibre. The strength of the composite decreases due to degradation of the properties (Zhou *et al*., 2016; Prasanna Venkatesh *et al*., 2016). Moisture absorption property of natural fibres can be reduced by chemical modification methods. The process of chemical treatment increases the surface roughness and enhances the interfacial adhesion between fibre and matrix.

Fibre treatment improves the interfacial bonding strength and thereby improves the mechanical properties (Chandrasekar *et al*., 2017; Sepe *et al*., 2018). The degradation of mechanical properties by moisture absorption can also be prevented by coating the laminated composite with a thin polymeric material on the external surface. The process is identified as gel coating. Several methods of gel coating are available in order to overcome the aforementioned problem. Gel coating process improves the aesthetic, performance characteristics and helps to retain the physical properties of the natural fibre reinforced composite (Preet Singh *et al*., 2017; Yuhazri *et al*., 2016; Yuhazri *et al*., 2018; Sudha *et al*., 2020; Sudha *et al*., 2023). Even though much work on gel coating of the composites has been carried out, research on the bending strength with different coating methods and the notch orientation is scanty.

In this experimental investigation a work has been carried out on the bending strength with a particular emphasis on the aforementioned parameters.

2. Methodology

The experimentations were carried out on natural fiber reinforced polymer laminate composites. The effect of gel coating on bending strength of uncoated and coated composites is evaluated by subjecting to varied flaw condition and coating methods. The details of which have been discussed in this section.

2.1 Materials

Experimentations were carried out on jute-epoxy composite laminate specimens. The composite specimens were coated with gel coat and compared with uncoated ones. The details of which have been discussed below.

2.2 Matrix

The matrix material used is Lapox L-12, 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 fibre reinforced composites. The choice of hardener depends on the processing method to be used and on the properties required for cured composite. Hardener K-6 is a low viscosity room temperature curing liquid. It is commonly employed for hand lay-up applications. Being rather reactive, it gives a short pot life and rapid cure at normal ambient temperatures.

2.3 Reinforcement

A reinforcement material is the one which strengthens or increases the mechanical properties of the composite. It provides strength and stiffness to the matrix. Jute is one of the cheapest natural fibre which has high tensile strength and low extensibility. It is biodegradable, environment friendly, durable and rough fabric due to which it is primarily used for carpets, twined ropes and gunny bags. It also finds applications in geo textiles, pulp and paper along with a wide variety of house hold products. Jute is available in non-woven and woven form. Woven jute of 27 GSM is used as reinforcement material.

2.4 Gel Coat

The gel coat used is Epoxy (Lapox L-12) a liquid, unmodified epoxy resin of medium viscosity which can be used with various hardeners for making fibre reinforced composites. Epoxy (Lapox L-12) with Hardener K-6 is mixed in the ratio of 10:1 thoroughly to form a gel. The obtained mixture of gel has a pot life of 30-40 minutes at 25°C. The gel coat mixture is applied by suitable methods on the composite and allowed to cure.

2.5 Specimen Preparation

Jute-epoxy composite laminates were fabricated for a volume fraction of 60% of epoxy and 40% of jute by hand lay-up technique. The specimens were fabricated according to ASTM D790. Based on the volume fraction the quantity of matrix and reinforcement are calculated and the laminate is fabricated. The laminate is allowed to cure under room temperature for 18 to 24 hours. The fabricated composite laminate is then cut as per the required dimensions. During the course of fabrication, ample precautions were taken to avoid the entrapment of air between the laminae leading to void. **Figure 1** shows the specimens as per ASTM standards with varied notch orientation. The specimens were made with V-notch at the centre of the specimen keeping the notch orientation across the laminate and along the laminate to a depth of 3 mm.

Figure 1 Three point bending specimen as per ASTM with different notch orientation

2.6 Experimentation

Three point bending test is conducted on uncoated and coated jute-epoxy composite laminate specimens with the help of universal testing machine (UTM). The specimens were made with V-notch across and along the laminate exactly at the centre to a depth of 3 mm. The specimens were then compared with un-notched specimens. The prepared specimens were then coated with gel coat material by brush method, dip method, roller method and spray method and allowed to cure at room temperature. Based on the data available the behaviour of uncoated specimens is compared with coated ones. Load/Displacement data and other salient points were recorded for all the specimens.

3. Results and Discussion

Three point bending test is conducted on uncoated and coated jute-epoxy composite laminate specimens to examine the behaviour under three point bending. The discussions were made with particular emphasis on notch orientation and method of coating.

3.1 Characterising parameters of jute-epoxy laminated composite under bending loads.

Un-notched jute-epoxy composite laminate specimens were subjected to examine the delamination strength, yield strength, ultimate strength and breaking strength for varied gel coating methods. **Figure 2** shows the salient features of un-notched jute-epoxy composite laminate specimens with different gel coating methods. It can be inferred from figure that, the spray method of coating has yielded in a substantial improvement in delamination strength. When jute-epoxy composite laminate specimen is subjected to bending load, the interfacial bond between the matrix and fibre will try to sustain the load. Since the forces are acting in a direction opposite to the direction of load application at the roller supports the specimen failure is observed by delamination at the edges.

Delamination is always initiated at a weak fibre-matrix interface and later a number of such delamination points arise in the specimen. Delamination is cautioned by sharp sound and is clearly observed by debonding between fibre-matrix. The process of delamination is delayed in spray and brush process since the gel coat seeps between each lamina, covers the surface pores and voids, whereas rapid delamination occurs in roller method of gel coating. This is due to open pores and exposed voids at surface and edges. These voids act as delamination triggering points and the specimen fails at fewer loads. In dip method of gel coating less pores and voids are formed due to which there is significant increase in delamination strength when compared with roller method of gel coated specimens.

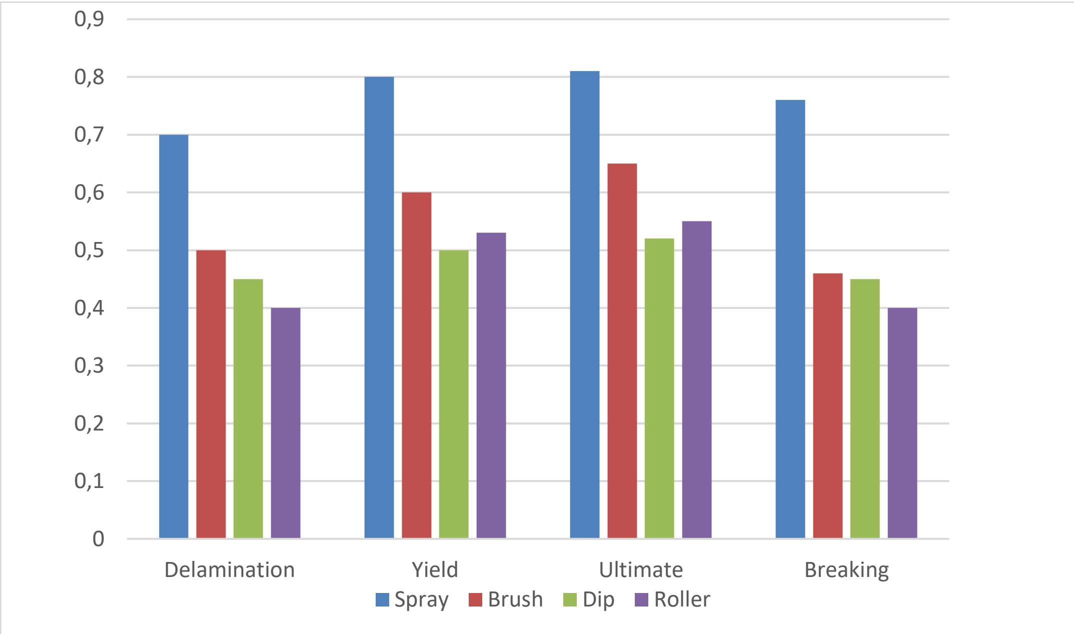

Figure 2. Salient features of un-notched jute-epoxy composite laminate specimens with different gel coating methods

Yield strength of a specimen is a machine indicated parameter. **Figure 2** shows that the yield strength of spray coated specimen is higher than other specimens coated by brush, dip and roller method. Yield strength depends on the plastic deformation of the matrix and is the maximum load the specimen can sustain. Since the process of spray method of gel coating yields in complete covering of the surface voids and pores, the strength of the composite is enhanced. Also the gel coat has shown good adherence with the substrate, under the applied load. The absence of void and pores will improve the load bearing capacity at the interface of gel coat and substrate resulting in increase in yield stress and yield strength. Since the failure of the specimen initiates at the open pores and voids and the delamination reduces the interfacial strength of the composite due to which the yield strength is found to be comparatively lesser in brush coated specimens. As it is well known that in roller and dip method of gel coating the delamination growth rate is higher, eventually the yield strength is also lesser in these specimens.

The ultimate strength of jute-epoxy composite laminate specimens greatly depends on the properties of matrix and reinforcement material as well. The interfacial strength between the matrix and reinforcement is affected by the fabrication procedure of the laminate. **Figure 2** shows that since the specimen is coated by spray method a consistent and thin film of gel coat is deposited under the compressed air due to which the strength of the gel coated specimen in enhanced leading to an increase in ultimate strength of the composite. The ultimate strength of any composite depends on the loading conditions, surface voids, open pores and unfilled areas on the surface. The lesser the surface defect more will be its load bearing capacity and higher ultimate strength. The absence of voids and pores in brush method of gel coating has led to an improved ultimate strength, whereas the pores are uncovered in dip method of gel coating and has yielded in reduction of ultimate strength. The width of the roller is larger than the width of the specimens due to which the gel coat blocks the pores and voids present on the surface and hence specimens coated by roller method of gel coating has exhibited a significant improvement in ultimate strength than dip method.

Breaking strength indicates the final failure in the specimen in its plastic state. Polymer laminated composites are brittle in nature due to which the delamination growth is ascertained by sharp sound. This delamination weakens the interfacial properties of the laminate and the specimen deflection increases with load. A point is reached wherein the specimen sustains the maximum peak load and further increase in load leads to failure of the specimen. The corresponding stress is identified as breaking stress or breaking strength of the composite. In the figure it is clearly observable that the minimized defective regions enhance the physical properties yielding in greater breaking strength in specimens coated by spray method of gel coating. A significant drop in breaking strength is found in brush coated, dip coated and roller coated specimens. The brittle gel coat layer formed on the surface easily chips off under the load at the weakest region and later the cracks propagate in the gel coat layer leading to reduction in strength of the composite and early failure indicating lesser breaking strength.

3.2 Effect of flaw orientation on bending characteristics of uncoated jute-epoxy laminated composite

Figure 3 shows the Load/Deflection graph for uncoated jute-epoxy composite laminate specimens examined with varied flaw orientation. It can be clearly seen from the nature of graph that the load sustainability in specimens with notch across the laminate is comparatively greater than notch along and un-notched specimen. This is because when the pre-notched specimen is subjected to three-point bending, the specimen will try to deflect in the direction of the applied load due to compressive loading conditions. The fibre-matrix interface region resists the growth of crack by sustaining the applied load. The sharp notch root has many minute cracks which undergo branching under the applied load and disperse into the laminate. Since the notch is made across the laminate the specimen failure is initiated at the sharp notch root which disseminates through the lamina alongside the width. The progressive crack growth at the sharp notch root across the laminate is shown in **Figure 4a-d.** The applied load causes matrix crushing and drastic deflection at the extreme edges ascertained by sharp sound as observed in **Figure 4a**. In these specimens the crack growth rate is high and the crack propagation is clearly visible in **Figure 4b**. The specimen failure is observed by matrix cracking and fibre pull-out as in **Figure 4c**. The compressive forces cause the specimens to bend and break as observed in **Figure 4d.**

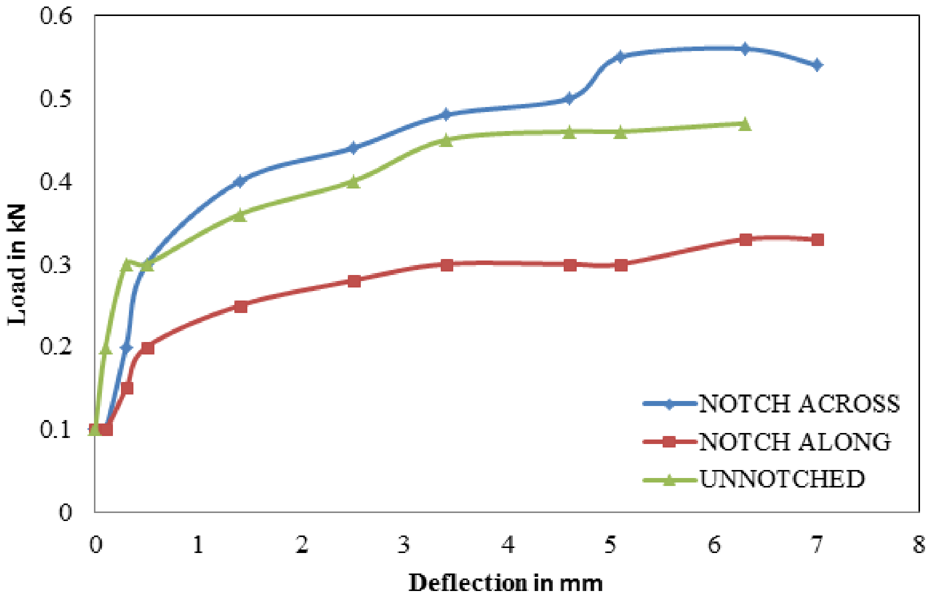

Figure 3. Load/Deflection for uncoated jute-epoxy composite laminate specimens with varied flaw orientation

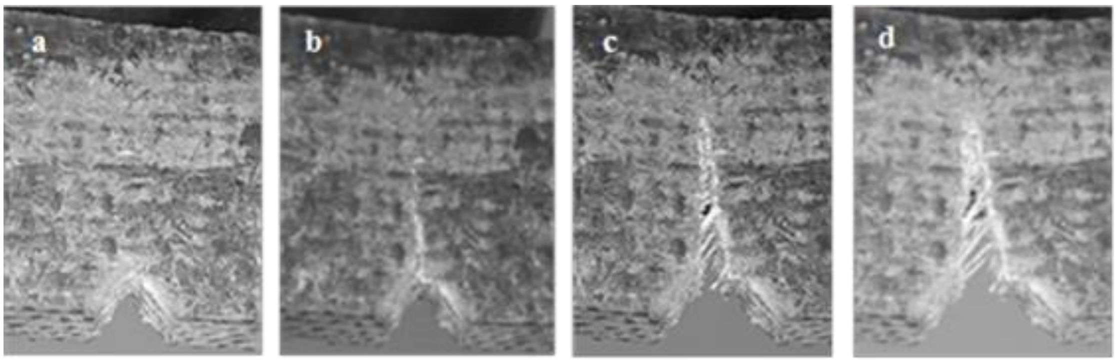

Figure 4. Crack growth at notch root across the laminate

Figure 5 shows the failure in jute-epoxy composite laminate specimens with notch along the laminate. The load exerted by the roller supports will try to converge at the centre during which the inner layer of the laminate is subjected to compressive load and the outer layer of the laminate is subjected to tensile load as observed in **Figure 5a**. The failure is initiated at the notch root and since the notch is exactly opposite to the application of the load, the specimen failure occurs by matrix crushing just below the roller, fibre pull-out and delamination at the extreme edges as in **Figure 5b**. As the applied load increases, the width of the notch increases with fibre pull-out as in **Figure 5c**. In these specimens the delamination growth rate is low comparatively. This leads to failure at fewer loads and deflection. The elliptical region indicates the delamination at the edges and fibre pull-out is observable at the notched region as shown in **Figure 5d.** The trend of the graph for un-notched specimen clearly shows that the load sustainability is higher than that of the specimens with notch along the laminate. This is because the load is applied in the direction parallel to the lay-up of the lamina. Also, the absence of flaw in the specimen improves its load sustainability and the specimen failure occurs by delamination at the extreme edges, matrix crushing and fibre pull-out. **Figure 6** shows the failure of un-notched specimen subjected to three-point bending. **Figure 6a** shows the point load acting on the un-notched specimen when supported between support rollers. **Figure 6b** shows that the application of load has initiated specimen failure at the centre. The crack propagates into the thickness of the laminate with increase in applied load as seen in **Figure 6c.** The un-notched specimen under the load deflects such that the specimen will fail at maximum deflection and load as in **Figure 6d**. The progressive failure in the specimen is shown in **Figure 6a-d.** The specimen failure occurs below the roller.

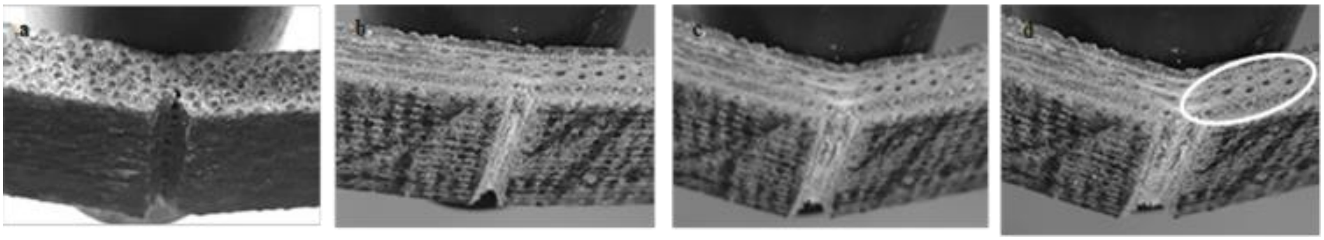

Figure 5. Specimen failure with notch along the laminate

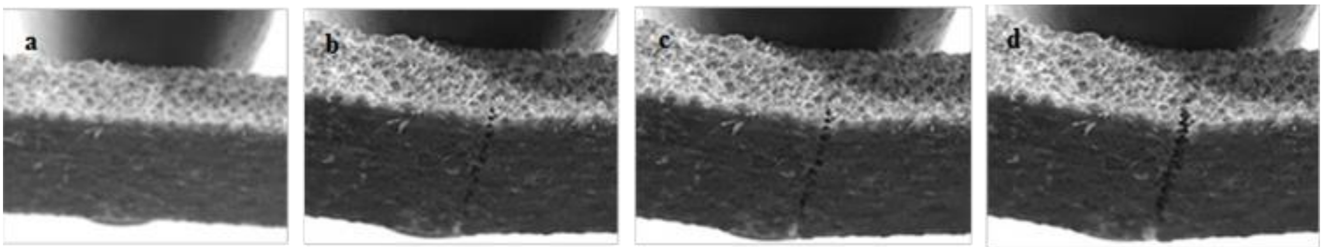

Figure 6. Specimen failure in un-notched specimen

3.3 Effect of coating method on bending characteristics of jute-epoxy composite laminate with varied flaw orientation

Figure 7 shows the Load/Deflection curve for jute-epoxy composite laminate specimens with notch across the laminate coated by different gel coating methods. The trend of the curves signifies that the load sustainability is significantly improved in specimens coated by spray method when compared with other methods of coating. This is mainly due to the orientation of the notch and application of gel coat layer on the surface. The process of notch creation in the specimen induces micro cracks and minor surface damages to the specimen. The process of gel coating by spray method will cause the micro pores, micro cracks and surface voids to seal. The impingement of gel coat under the compressed air will cause the gel coat to adhere with the substrate producing a thin film on all the extremities. When the specimen is subjected to compressive load perpendicular to the laminate the gel coat layer will sustain the load to some extent. Later the gel coat layer due to its brittle nature tries to debond with substrate by chipping off. The failure is initiated at the sharp notch root which later propagates through the lamina. Further the load is sustained by the adjoining matrix and reinforcement until complete failure occurs in the matrix by crushing and fibre pull-out in the reinforcement material.

As can be seen the trend of the curve for brush method has shown an improvement in load sustainability than roller and dip coated specimens. This is because in brush method of gel coating the strokes of the brush causes the surfaces irregularities and the cracks formed at the notched region to be completely smeared by the gel coat. In roller method of gel coating the width of the roller is comparatively larger than the width of the specimen and also the movement of the roller is unable to seal the micro cracks and pores at the notched region. The application of load leads to premature failure at the notched region, propagating through the gel coat and laminate.

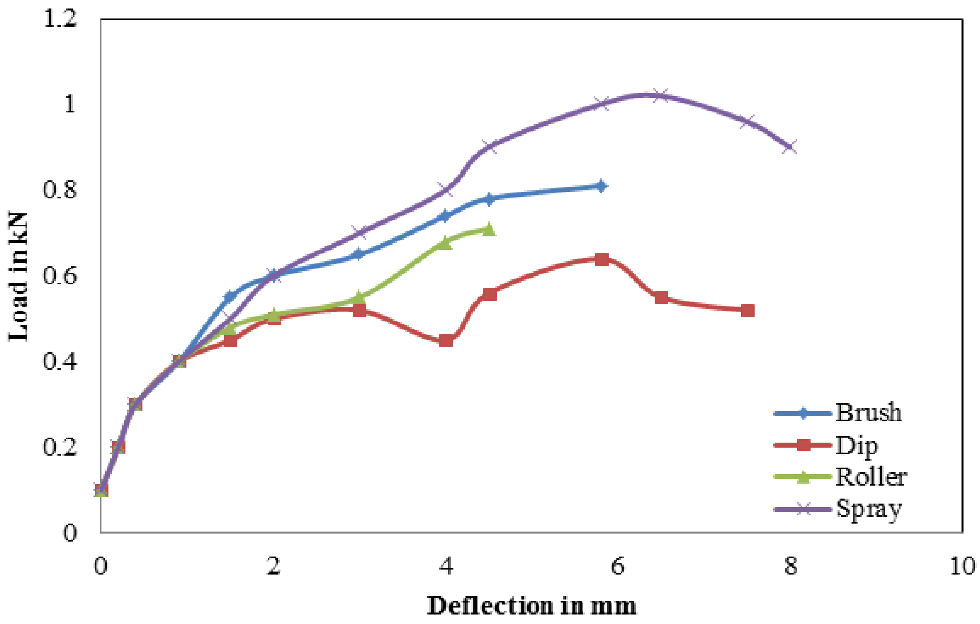

Figure 7. Load/Deflection for coated jute-epoxy composite laminate specimen with notch across the laminate

The slope of the curve for dip method of coating is comparatively lesser than other method of coating which indicates that the load sustainability is lesser. This is because under the process of dip method a dense deposition of gel coat is formed at the notched region as well as at the surfaces. The formation of thick and brittle gel coat leads to fewer load sustainability with increase in displacement. The failure in coated specimen with notch across the laminate is as shown in **Figure 8**. The initiation of crack at the notch root causes gel coat debonding with the substrate as in **Figure 8a.** The application of point load opposite to the notch leads to further crack growth leading to gel coat cracking as seen in **Figure 8b.**

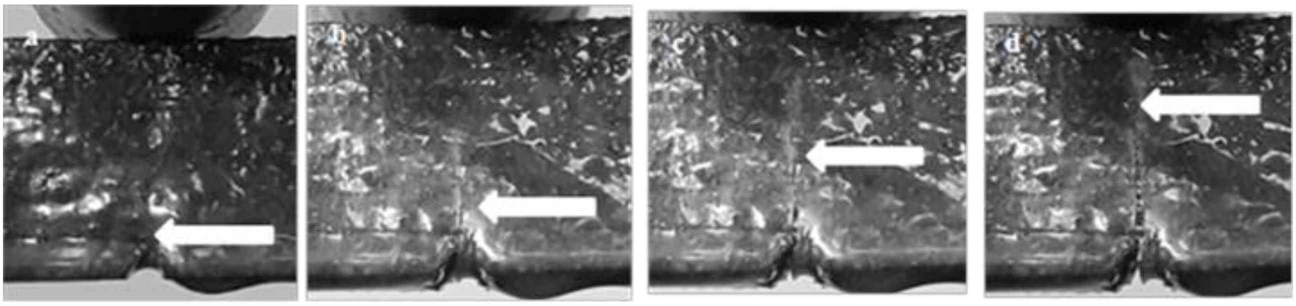

Figure 8. Failure in coated specimen with notch across the laminate

The increase in load sustainability can be observed by gel coat chipping at the notch and crack dissemination through the laminate as shown by horizontal blocked arrow in **Figure 8c**. **Figure 8d** shows the crack growth alongside the width indicating specimen failure at maximum bending load. **Figure 9** shows the Load/Displacement curve for jute-epoxy composite laminate specimens with notch along the laminate coated by different gel coating methods. The area below the curve signifies the load sustainability of the specimens coated by different methods. The peak load sustained by specimens coated by spray method is found to be significantly higher than the specimens coated by other methods. The jet of compressed air causes the gel coat to form a mist during the process of coating. This leads to increase in bonding strength of the gel coat with the substrate, closure of surface irregularities and gel coat deposition at the extreme edges.

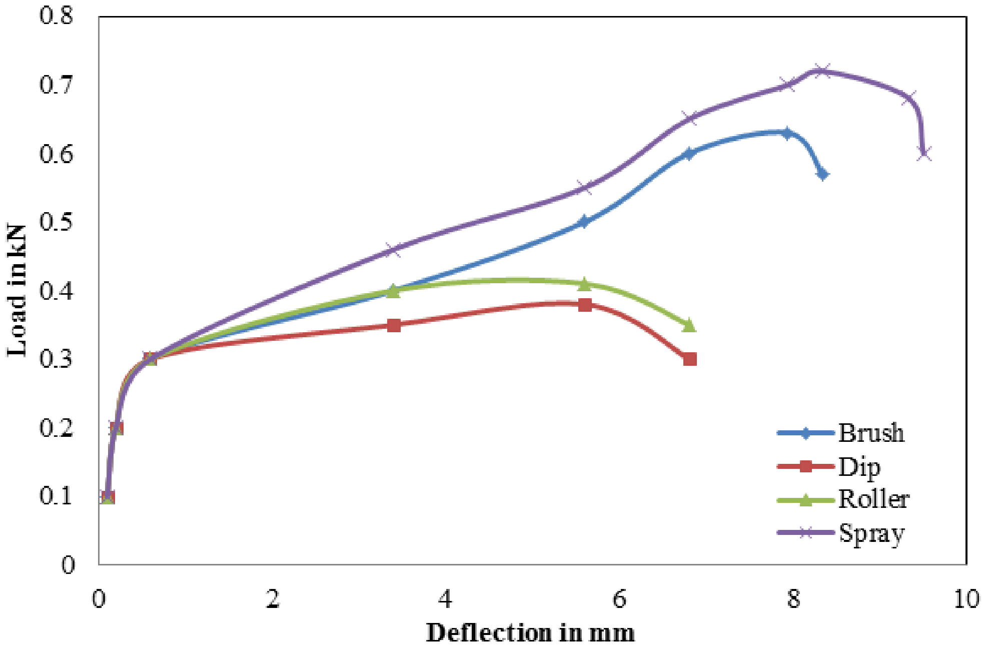

Figure 9. **Load/Deflection for coated jute-epoxy composite laminate specimen with notch along the laminate**

The specimens when subjected to point load will induce compressive loads on the extreme edges between the specimen and the rollers. This causes the compressive forces to originate from the extreme edges and converge at the notched region leading to catastrophic failure. Since the notch is along the laminate the load sustainability is comparatively less and the specimen failure is observed by chip-off of gel coat, gel coat crushing, matrix tearing and fibre pull out.

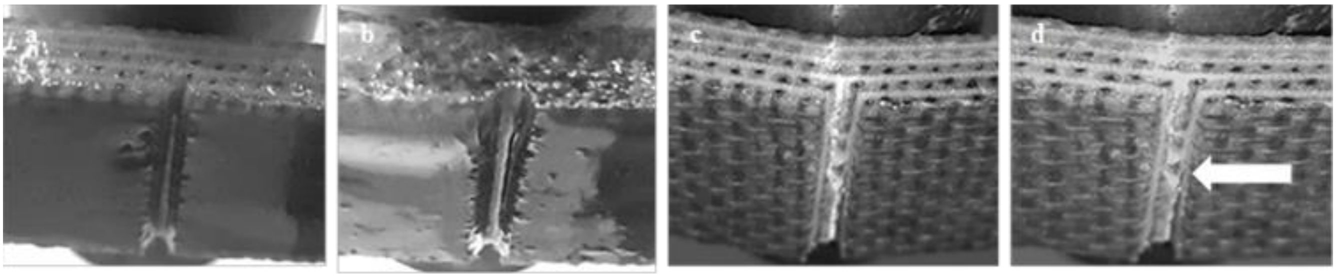

Figure 10. Failure in coated specimen with notch along the laminate

Figure 10 shows the failure in coated specimen with notch along the laminate. **Figure 10a** shows the specimen supported on rollers and subjected to point loading at the centre of the specimen. The specimen is so placed that the notch is exactly opposite to the direction of loading. As the magnitude of the applied load increases gradually, the width of the notch also increases as can be seen in **Figure 10b.** This is because the compressive forces on the specimen induce tensile forces on the opposite surface leading to widening of the notched region. **Figure 10c** shows that the crack growth at the notch root has led to gel coat cracking which further propagates through the laminate. **Figure 10d** shows that ultimate failure in the specimen is due to crack propagation through the true depth of the notch under fewer loads. The effect of delamination is reduced due to the process of gel coating and failure is ascertained with chip-off of gel coat at the notch and gel coat crushing below the roller, matrix tearing and fibre pull out. Similar nature of failure is observed in specimens coated by other methods but the load sustainability greatly depends on coating method, surface flaws and loading conditions. Brush method of gel coating results in blocking of surface pores, cracks and voids and hence the load sustainability is found to be improved than roller method of gel coating. The trend of the graph for roller method depicts that the insufficient deposition of gel coat at the notch has led to open pores and cracks and early crack initiation leading to fewer load sustainability. Since dip method results in thick gel coat in the direction opposite to its lifting leads to brittle failure of gel coat under the applied load. Due to this the load sustainability is significantly less than brush and roller coated specimens.

Figure 11 shows the Load/Deflection curve for coated un-notched jute-epoxy composite laminate specimens. Visual observation on the nature of graphs shows that spray method of coating has yielded in considerable increase in the load sustainability than the specimens coated by other methods. Since the high velocity gel coat seeps into the laminate voids and edges the action of compressive load prevents the deflection and improves the load sustainability. The application of load on the laminated specimens induces compressive force on the concave surface and tensile forces on the convex surface. The gel coat is subjected to crushing at the point of load application. This results in maximum deflection at the centre with slipping at the edges. The gel coat prevents the delamination at the edges and ultimately specimen failure is observed at the centre by gel coat chipping, matrix tearing and fibre pull-out.

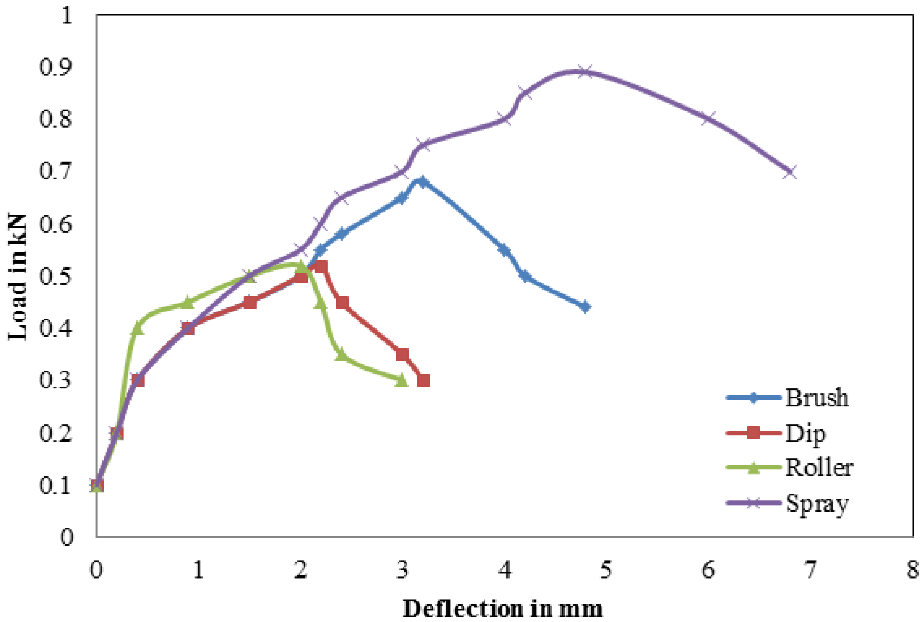

Figure 11. Load/Deflection for coated un-notched jute-epoxy composite laminate specimen

The load sustainability is deprived in specimens coated by brush, roller and dip method due to poor bonding between gel coat and substrate, improper sealing of surface voids and cracks and thick and brittle gel coat layer. Though the ultimate strength depends on the coating method few of the other parameters such as viscosity of the gel coat, number of strokes and curing temperature affect the strength of the composite. **Figure 12** shows the failure region in un-notched coated jute-epoxy composite laminate specimens subjected to three-point bending. As can be seen **Figure 12a** shows the specimen supported between rollers and point load acting at the centre. A small increase in load leads to specimen deflection, which is ascertained by cracking sound in the brittle gel coat layer in **Figure 12 b**.

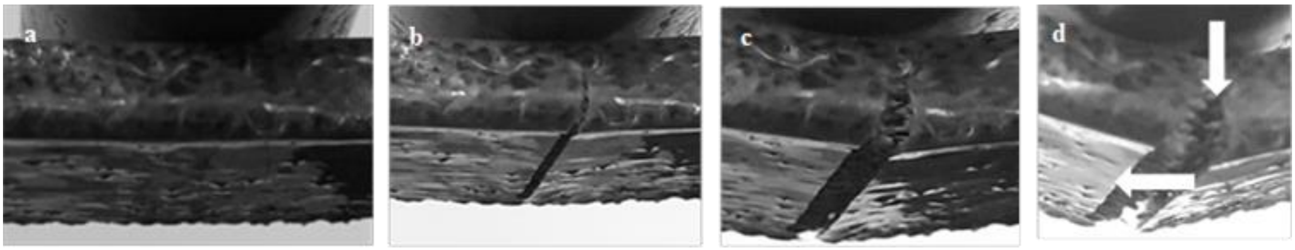

Figure 12. Failure in un-notched coated specimen

Figure 12c shows that the width of the cracks increases with further increase in the load acting at the centre of the specimen. **Figure 12d** shows that the increase in the stress eventually lead to crack growth through the thickness leading to further failure of brittle gel coat by chipping with matrix tearing and fibre pull-out.

Conclusion

The following conclusions were drawn from the experimental results on coated and uncoated jute-epoxy composite laminate specimens,

- Delamination is more profound in uncoated specimens. The process of gel coating reduces delamination. In spray coated specimen delamination is reduced due to covering of pores and voids by gel coat. Yield strength, ultimate strength and breaking strength of spray coated specimen are improved to greater extent. The dense deposition of gel coat in roller and dip method has a significant effect in reducing the yield, ultimate and breaking strength than brush coated specimens.
- Uncoated jute-epoxy composite laminate specimens with varied notch orientations were examined under three point loading. The specimens with notch across show greater load sustainability than notch along the laminate. The load sustainability in un-notched specimen is comparatively greater than notch along the laminate. The failure in the specimens is by matrix cracking, fibre pull-out and delamination at the edges.
- Coated specimens have shown an increase in load sustainability. Gel coated specimens with notch across show greater load sustainability than notch along the laminate. The cracks formed at the notched region are covered by the gel coat due to which the failure in the specimen is prolonged. The failure in the specimens is by gel coat cracking, brittle failure in matrix and fibre pull-out.
- Spray method of coating has uniform deposition of gel coat on the substrate surface and edges. The load sustainability in specimens coated by brush, roller and dip method is lesser due to poor bonding between gel coat and substrate, improper sealing of surface voids and cracks and thick gel coat layer.

Acknowledgement, The authors are highly grateful to the Vision Group of Science and Technology (VGST), Karnataka for the financial grant to procure Computerized Universal Testing Machine and related accessories.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

References

Akartasse N., Azzaoui K., Mejdoubi E., Elansari L. L., Hammouti B., Siaj M., Jodeh S., Hanbali G., Hamed R., Rhazi L. (2022) Chitosan-Hydroxyapatite Bio-Based Composite in film form: synthesis and application in Wastewater, *Polymers*, 14(20), 4265, https://doi.org/10.3390/polym14204265

Alemayehu Z., Nallamothu R. B., Liben M., Nallamothu S. K., Nallamothu A. K. (2021) Experimental investigation on characteristics of sisal fiber as composite material for light vehicle body applications, *Materials Today: Proceedings*, 38(5), 2439-2444, doi.org/10.1016/j.matpr.2020.07.386

Alsubari S., M. Y. M. Zuhri., S. M. Sapuan., M. R. Ishak., R. A. Ilyas., M. R. M. Asyraf., (2021) Potential of natural fiber reinforced polymer composites in sandwich structures: A review on its mechanical properties, *J. Polymers (Basel).*, 13(3), 1–20. https://doi.org/10.3390/polym13030423

Atiqah M.A. Maleque M., Jawaid M. Iqbal., (2014) Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications, *J Comp. Part B Engg*, 56, 68–73. http://dx.doi.org/10.1016/j.compositesb.2013.08.019

Azzaoui K., Mejdoubi E., Lamhamdi A., Zaoui S., Berrabah M., Elidrissi A., Hammouti B. , Fouda M.M.G., Al-Deyab S.S., (2015) Structure and properties of hydroxyapatite/Hydroxyethyl cellulose acetate composite films, *Carbohydrate Polymers* 115, 170–176, doi.org/10.1016/j.carbpol.2014.08.089

Bachchan A.., P. P. Das., V. Chaudhary., (2020) Effect of moisture absorption on the properties of natural fiber reinforced polymer composites: A review, *J. Mater Today Proc*, 49, 3403–3408. https://doi.org/10.1016/j.matpr.2021.02.812

Chandrasekar M., Ishak M. R., Sapuan S. M., Leman Z. Jawaid M., (2017),A review on the characterisation of natural fibres and their composites after alkali treatment and water absorption, *J Plastics, Rubber and Composites*, 46(3). http://dx.doi.org/10.1080/14658011.2017.1298550

Davoodi M.M., Sapuan S. M., Ahmad D., Aidy A., Khalina A., Jonoobi M., (2011),Concept selection of car bumper beam with developed hybrid bio-composite material, *J Matls Design*, 32(10). 4857–4865. http://dx.doi.org/10.1016/j.matdes.2011.06.011

Elidrissi A., El barkany S., Amhamdi, H., Maaroufi A., Hammouti B., (2012) New approach to predict the solubility of polymers Application: Cellulose Acetate at various DS, prepared from Alfa "Stipa - tenassicima" of Eastern Morocco, *J. Mater. Environ. Sci.* 3 (2), 270-285. https://www.researchgate.net/publication/236686641

Gamstedt E. K., (2016) Moisture induced softening and swelling of natural cellulose fibres in composite applications, IOP Conference Series, *J Matl Sci and Engg*, 139 012003. doi:10.1088/1757-899X/139/1/012003

Prasanna Venkatesh R., Ramanathan K., Srinivasa Raman V., (2016) Tensile, flexural, impact and water absorption properties of natural fibre reinforced polyester hybrid composites, *J Fibres and Textiles, Eastern. Europe*, 24(3). http://dx.doi.org/10.5604/12303666.1196617

Preet Singh J. I., Dhawan V., Singh S., Jangid K., (2017) Study of Effect of Surface Treatment on Mechanical Properties of Natural Fiber Reinforced Composites, *J Matls Today Proc*, 4(2), 2793–2799. http://dx.doi.org/10.1016/j.matpr.2017.02.158

Qatu M. S., (2011) Application of kenaf-based natural fiber composites in the automotive industry, *J SAE Int*, 1–5. http://dx.doi.org/10.4271/2011-01-0215

Ramli N., Mazlan N., Ando Y., Leman Z., Abdan K., Aziz A A., Sairy N A., (2018) Natural fiber for green technology in automotive industry: A brief review, IOP Conference Series, *J. Matl. Sci. and Eng.g*, 368(1), 012012. http://dx.doi.org/10.1088/1757-899X/368/1/012012

Sadashiva K., Purushothama K. M., (2023) Physical and Mechanical Properties of Bio Based Natural Hybrid Composites *J. Mater. Environ. Sci*, 2023, 14(1), Page 131-140.

Sepe R., Bollino F., Boccarusso L., Caputo F., (2018) Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites, *J Comp, Part B Engg*, 133, 210-217. https://doi.org/10.1016/j.compositesb.2017.09.030

Shada Bennbaia., Elsadig Mahdi., Galal Abdella., Aamir Dean., (2023) Composite Plastic Hybrid for Automotive Front Bumper Beam, *J Compos Sci*, *7*(4), 162. https://doi.org/10.3390/jcs7040162

Sudha G.S., Arun K.V., (2020) Methods and process parameters of gel coating on laminated composites - A review, *J of AIP Conf Proc*, 2236 040004. https://doi.org/10.1063/5.0007094

Sudha G. S. and Arun K. V. (2023) Behaviour of Damage in Gel Coated Natural Composite under Chemical Environment and Eccentric Loads, *AIP Conf. Proc.* 2399, 020006, https://doi.org/10.1063/5.0131882

Tabaght F. E., Azzaoui K., Elidrissi A., Hamed O., Mejdoubi E., Jodeh S., Akartasse N., Lakrat M. & Lamhamdi A. (2021) New nanostructure based on hydroxyapatite modified cellulose for bone substitute, synthesis, and characterization, *International Journal of Polymeric Materials and Polymeric Biomaterials*, 70(6), 437-448, DOI: 10.1080/00914037.2020.1725758

Venkatesh Naik., Mohan Kumar., Vijayananda Kaup., (2022) A Review on Natural Fiber Composite Material in Automotive Applications, *J Engineered Science*, 18, 1–10. https://dx.doi.org/10.30919/es8d589

Yuhazri M. Y., Amirhafizan M. H., Nilson G. C. H., Sihombing H., Kamarul A. M., Nirmal U., (2018), Effects of gelcoat thickness on mechanical properties of woven glass/polyester laminated composite, *J of Mech Engg Sci*, 12(1), 3370–3386. https://doi.org/10.15282/jmes.12.1.2018.7.0301

Yuhazri M. Y., Nilson G. C. H., Sihombing H., Abd Manaf M. E., (2016) Mechanical properties and failure analysis of laminated glass reinforced composite with various gelcoat thickness, *J. Key Engg. Matls*, 694, 8–12. http://dx.doi.org/10.4028/www.scientific.net/KEM.694.8

Zhou Y., Fan M., Chen L., (2016) Interface and bonding mechanisms of plant fibre composites: An overview, *J Comp, Part B: Engg*, 101. https://doi.org/10.1016/j.compositesb.2016.06.055

(2023) ; http://www.jmaterenvironsci.com