ASM Sc. J., 17, 2022

https://doi.org/10.32802/asmscj.2022.1031

Mechanical Properties Evaluation for Cotton/Glass/Epoxy Hybrid Composite

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Natural fibre reinforced composites of any group are essential to satisfy the current demand and to keep the environment-friendly approach. In the present work, an attempt has been made to replace glass fibres partially by cotton fabric so as to reduce weight and cost of the resultant composite Here, cotton fabric 0.4 mm thick (125 GSM) and fibreglass woven roving 0.15 mm thick (180 GSM) were used with epoxy resin in different weight fractions to prepare hybrid composites. The composites were prepared using hand lay-up method. The Tensile strength, flexural strength, impact strength and hardness tests were performed as per ASTM standards and results are reported for each sample. The specimens were characterised using scanning electron microscope (SEM). The mechanical properties of composites with 80% glass fibre and 20% cotton fabric are found to be closer to glass/epoxy composites. Hence it is concluded that 20% glass fibres can be replaced by cotton fabric in the existing glass/epoxy products in which mechanical properties are important.

Keywords: Natural fibre reinforced composites (NFRC); Hybrid composites; Glass fibre; Cotton fibre; Composite

I. INTRODUCTION

There is always a high demand for new materials for demanding applications. A simultaneous concern is that the newly developed material should have physicomechanical properties while also being environmentally friendly (Khalid *et. al.,* 2021; Kamraj *et al.,* 2020). Natural fibre reinforced composites (NFRC) are now widely used in a variety of engineering fields. Because of its availability, low production cost, lightweight, high strength-to-weight ratio, biodegradability, good breaking strength, and comparatively better mechanical properties, NFRC is ready to compete with some heavy metals (Mutalikdesai *et. al.,* 2018; Youraj *et al.,* 2016). According to the literature, composite samples with increasing weight percentages of natural fibres with synthetic fibres such as glass fibres, carbon fibres, and so on have better mechanical properties (Sailesh *et. al.,* 2018; Giridharan *et. al.,* 2019; Kanakannavar *et al.,* 2018).

Jute/E-Glass fibre reinforced epoxy hybrid composites outperformed plain single fibre composites in terms of mechanical properties. The addition of glass fibre in jute fibre improves the mechanical properties of the composite. This improvement was attributed to fibre properties, fibre volume, and stacking sequence (Sanjay *et. al.,* 2016; Dinesh *et al.,* 2018). Hybridisation is a frequently used process for obtaining the best qualities by combining the advantages of multiple materials. It is reported that fabricated composite of coconut 30%, glass fibre 10%, and epoxy resin 60% showed the better impact strength but ultimate tensile strength gets reduced. This observation was attributed to fibres orientation and improper infusion in the composite (Prakash *et al.,* 2019). Emanoel *et al.* investigated the effect of unsaturated polyester resin on the performance of glass and cotton fibre stacking sequences. According to the mechanical characterisation of the laminates, a small amount of cotton produces similar results to glass fibre

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laminates. Glass fibre can be partially replaced by cotton fibre, and the tensile strength improves when the glass layers are on the outside (Portella *et al.,* 2016). Cotton fibre is environmentally friendly and has good physical-mechanical properties, which entices researchers to use it in automobile inner panels, roof decor, home appliances, and other applications (Reddy *et al.,* 2014). Cotton fibre reinforced composite (CFRC) is an excellent insulator that is also non-abrasive and versatile (Achukwu *et al.,* 2015). A summary of hybridised material on previous work is reported in Table 1.

Although much research has been conducted in this area, very few researchers have focused on the study of cotton fabric-coated epoxy resin. So, in the present work a composite was developed using textile-based cotton fabric and fibreglass woven roving as synthetic material in varying weight percentages with epoxy resin. This work is undertaken to investigate possibility of replacing glass fibres by cotton fabric pertaining to applications in which mechanical properties are desired. Accordingly, mechanical properties such as tensile strength, flexural strength, impact strength, and hardness were measured. The composite test specimen were characterised using scanning electron microscope to understand mode of failure.

Table 1. Summary of different mechanical properties of hybridised materials

Hybridisation of synthetic fibre with natural fibre	Hybrid ratio synthetic-natural fibre	Chemically treated	Tensile strength (MPa)	Flexural strength (MPa)	Impact Strength	Hardness	References
Glass/Cotton	20/80	Yes	113.67	89	0.95J/mm	-	(Sharma *et al.,* 2017)
Glass/Cotton	20/80	No	50	80	52 (KJ/m^2)	-	(Portella *et al.,* 2016)
Glass/Cotton	40/60	No	90	100	80 (KJ/m^2)	-	(Portella *et al.,* 2016)
Glass/Cotton	60/40	No	99	110	99 (KJ/m^2)	-	(Portella *et al.,* 2016)
Glass/Cotton	80/20	No	85	68	142(J/m^2)	-	Giridharan *et al.,* 2019)
Glass/Cotton	70/30	No	87	72	180 (J/m^2)	-	Giridharan *et al.,* 2019)
Glass/Jute	50/50	No	123.01	258.76	4.35 J	-	Sanjay *et al.,* 2016

II. MATERIALS AND METHODS

Fibreglass woven roving and cotton fabric are used as reinforcements in the present study. K.S. Industries in Pune, India, provided us fibreglass woven roving 0.15 mm thick with 180 GSM weight. Cotton fabric 0.40 mm thick with 125 GSM was procured from Gramin Khaddi Udyog in Mumbai, India. The Epoxy resin and the hardener were purchased from Grasim Industries Ltd, Gujarat, India and Electro coating and Insulation Technologies Pvt. Ltd., respectively.

A. Preparation of Samples

To prepare specimen for mechanical properties measurement, sheets of size 30 cm x 30 cm x 0.3 cm are fabricated using glass/cotton/epoxy by hand lay-up method in different stages as per ASTM standard. The materials are combined with epoxy resin and hardener. Initially, the epoxy resin and hardener were mixed in a proportion of 10 gm:1gm with the objective of using less hardener and give the hardening process more time. Then the mixture is stirred for 3 to 5 minutes with a rod thoroughly till it becomes a homogeneous mixture. The plane wooden surface is used to prepare the mould and the release gel is applied to it to prevent the sticking of epoxy to the mould. Then to get an even uniform surface, thin plastic sheets are used on the wooden surface. The fibreglass woven roving and cotton fabric are cut to 30 cm x 30 cm so as to match the mould size (Figures 1(a) and 1(b)).

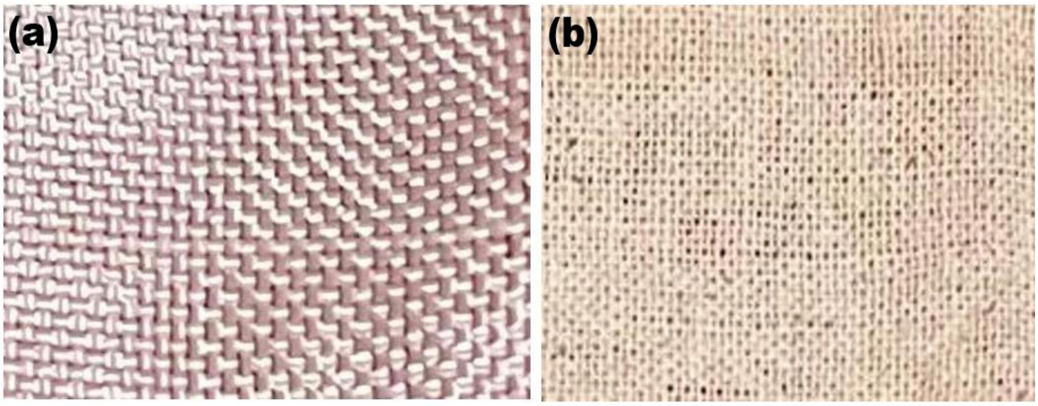

Figure 1. (a) Fibreglass woven roving, and (b) Cotton fabric mat

The homogeneous liquid mixture of epoxy and hardener is poured and uniformly spread on the mat surface with the help of the brush. Layers of fibreglass woven roving and cotton fabric are stacked in a particular sequence. The second layer is placed and to get proper strength, a roller is moved on the surface of the mat with suitable pressure. This is done to make fibreglass woven roving /cotton fabric straight, to prevent the formation of air bubbles and to wipe out excess resin as shown in Figure 2(a). Layer sequence and designation are as shown in Table 2. After stacking all layers to the requisite thickness of composite, the top and bottom fibreglass woven roving surface is covered with a plastic sheet with a release gel. To maintain pressure on the composite wooden plates are clamped at top and bottom using clamping screws at minimal distances as shown in Figure 2(b). This arrangement was kept for 10-12 hours at a temperature in the range of 300C- 400C. The resultant composite is as shown in Figure 2(c).

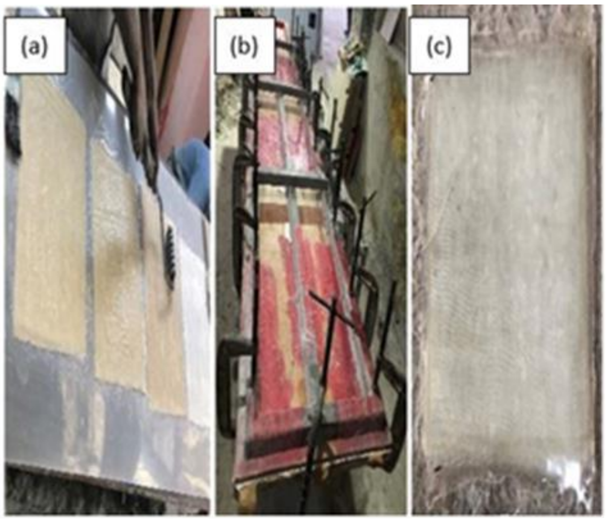

Figure 2. (a) Layer stacking process by hand lay-up method, (b) Pressure applied with clamping screw, and (c) Composite plate produced.

Table 2. Material Description

Type of Fibres	Fibre Designation	Layer Sequence	Laminate Designation	Hybrid
E-Glass fibre	G	G-G-G-G-G-G-G-G-G-G-G-G-G-G-G	[G]-100%	No
Cotton fibre	C	G-G-G-G-G-C-G-G-C-G-G-G-G-G	[G,C]-70%,30%	Yes
		G-G-G-G-C-G-G-C-G-G-G-G	[G,C]- 60%,40%	
		G-G-G-G-G-G-C-G-G-G-G-G-G-G	[G,C]-80%,20%	
		C-C-C-C-C-C	[C]-100%	

The specimen required for evaluation of mechanical properties were cut out of composite sheet using abrasive jet machine as shown in Figures 3(a) and 3(b). Physicomechanical properties of cotton fabric and the laminate final dimension sans epoxy resin are reported in Tables 3 and 4. The properties of epoxy resin and hardener shown in Table 5.

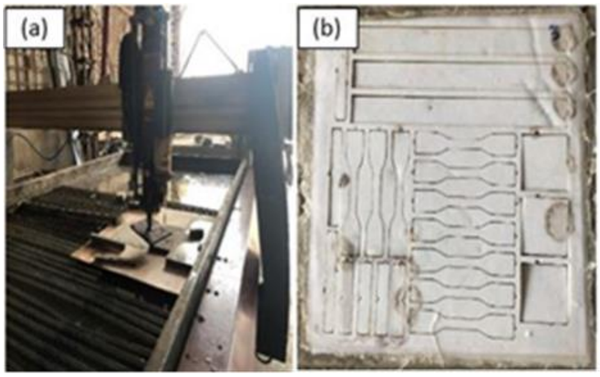

Figure 3. (a) Abrasive jet machine, and (b) Test specimen cut from composite sheet as per ASTM standard.

Table 3. Mechanical Properties of Cotton fibre

Physical Properties		**Mechanical Properties**	
Cellulose (%)	82 -96	Tensile strength (MPa)	287-597
Hemicellulose (%)	2-6.4	Young's modulus (GPa)	5.5-12.6
Lignin (%)	0-5	Elongation (%)	7.0-8.0
Weave Pattern	Plain		

Table 4. Laminates (without epoxy resin) details after cutting

Laminates Designation	**[G]-100%**	**[G,C]-70%,30%**	**[G,C]-60%,40%**	**[G,C]-80%,20%**	**[C]-100%**
Thickness(mm)	2.40	2.60	2.70	2.35	2.40
Size (cmxcm)	30x30				

Table 5. Properties of epoxy resin and hardener

Properties	**Epoxy Resin –YDL 680**	**Hardener**
Appearance	Clear liquid	Clear yellow to haze
Viscosity @ 25 °C	10,000 - 15,000 cPs	10-20 cPs
Density	1.20 g/cc	0.95-1.05 g/cc

B. Mechanical Properties Evaluation

1. Tensile Testing

The specimen required for tensile testing measurement were cut as per ASTM D-638 standard. The dimensions of the specimen are 165mm x 19mm x 3mm. The tensile test was carried out on Universal Testing Machine (UTM), model no. STS 248 with a maximum load rating of 100 KN. Five samples of each composite with varying % wt. of glass and cotton reinforcement were considered for tensile testing and average value was noted. The brake load and ultimate tensile strength readings were recorded.

2. Flexural Testing

The Flexural test is carried out on a three-point flexural setup of the sample prepared as per ASTM D-790 standard with 90 mm x 10mm x 3mm specimen size. A universal testing machine is used for the same. The bending in the specimen occurred at the centre because of load applied over there. The magnitude of braking load was recorded. The reported value is an average of five samples for each composite.

3. Impact Testing

To measure the impact strength of composite Izod Impact Tester was used. The test is performed on the sample as per ASTM D-256 standard with sample dimensions of 64mm x 12.7mm x 3.2mm. The notch is made on each sample for impact testing. The samples are held in an impact tester and a heavy pendulum is allowed to strike the sample. The energy required to break or fracture the sample is noted. The reported value is an average of five samples for each composite.

4. Hardness Testing

The Rockwell Hardness Tester (Model RAS 250) is used to determine the hardness of composite samples of size 50 mm x 50 mm. The sample is tested in accordance with the ASTM E-384 standard. Scale-P, 1/4" Diameter ball indenter, and 150 Kg load are used.

5. Microstructure Characterisation

The fabricated composite samples before mechanical testing and samples after testing were characterised using under FE-SEM (ZEISS- Gemini, Cambridge CB 1 3JS, United Kingdom) for microstructural characterisation at MMMF lab, IIT Bombay.

III. RESULTS AND DISCUSSION

Photographs of prepared hybrid composite samples for different mechanical testings are shown in Figure 4.

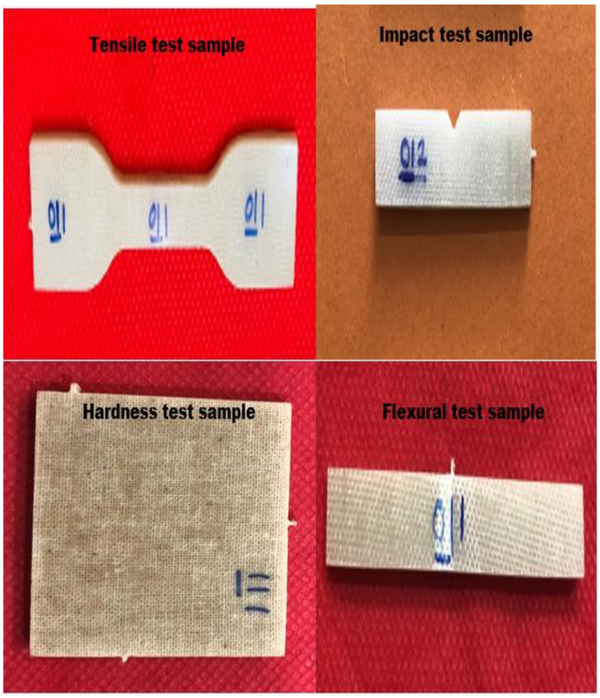

Figure 4. Hybrid composite samples for different mechanical testing

A. Experimental Tensile Testing

Instruments were calibrated before the testing as per the standard process in order to reduce the experimental error. Measurement uncertainty @ 95% confidence level was observed to be ± 0.001 MPa. Figure 5 presents the bar chart for tensile strength of non-hybrid composite verses glass/cotton hybrid composites. A considerable change was observed due to the presence of natural fibre. The maximum tensile strength for [G]-100% is 230.3 MPa. as it is pure non hybrid composite of glass fibre reinforced laminate. The tensile strength 218.4 MPa observed for [G,C]- 80%,20% which is glass/ cotton hybrid composite. As per weight percentage, only one layer of cotton was used in [G,C]-80%,20% composite located at mid plain and surrounded with glass fibre. A single layer provides good bonding with other glass fibre laminates without significant loss of tensile strength. Partially it is possible to replace the glass fibre with cotton fibre. Subsequently the tensile strength was found to be reduced for [G,C]- 70%,30% and [G,C]-60%,40% with approximately 8% and 11% respectively compared with pure tensile strength for [G]-100%. This decrease in tensile strength may be attributed to more number of cotton fabric layers in the matrix and also due to lesser interfacial strength with the matrix. The lowest tensile strength was observed for [C]-100% due to higher content of cotton fibre laminates and poor adhesion between the consecutive layers.

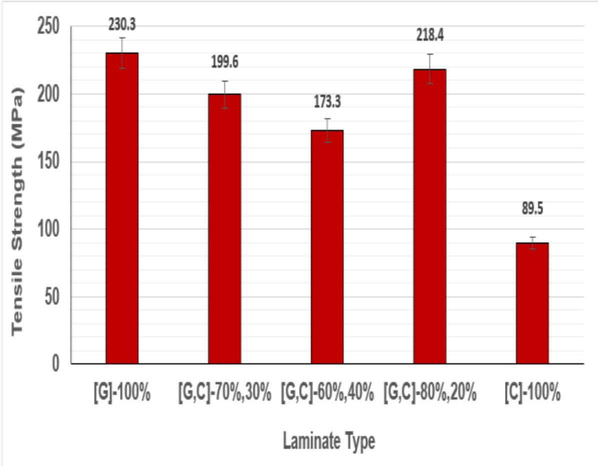

Figure 5. Tensile strength of non-hybrid composite verses glass/cotton hybrid composites

B. Experimental Flexural Testing

Figure 6 depicts a bar chart comparing the flexural strength of non-hybrid composites to Glass/Cotton hybrid composites. The flexural strength of the [G]-100 percent hybrid composite was 208.12 Mpa. Three point bending test comprised of tensile, compressive and shear components and they all benefit from the presence of glass fibres thus composite with only glass fibre showed much higher flexural strength than pure cotton composites. The flexural strength of hybrid composites was found to be between the flexural strength of pure glass and pure cotton composites.

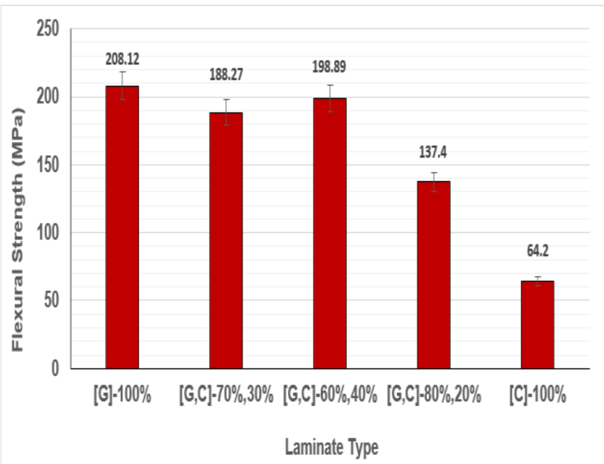

Figure 6. flexural strength of non-hybrid composite versus Glass/Cotton hybrid composites

C. Experimental Impact Testing

Figure 7 shows a bar chart comparing the impact strength of non-hybrid composites to Glass/Cotton hybrid composites. Impact strength of [G,C]- 80%,20% hybrid composite is closer to [G]-100% non-hybrid composite. Also hybrid composites [G,C]-70%,30%, [G,C]-60%,40% yielded appropriate results of 8.1 KJ/m² and 7.6 KJ/m², respectively. In comparison, [G,C]-70%,30% impact strength is 91% of pure glass fibre and [G,C]-60%,40% impact strength is 85% of pure glass fibre. However, when compared to other hybrid composites, [G,C]-80%,20% produced better results. This could be due to low voids, good fibre-epoxy adhesion, and proper infusion in the composite samples (Gopinath *et. al.,* 2014; Kim *et al.,* 2008). The minimum voids in the [G,C] -80%,20% hybrid composite evident from the SEM.

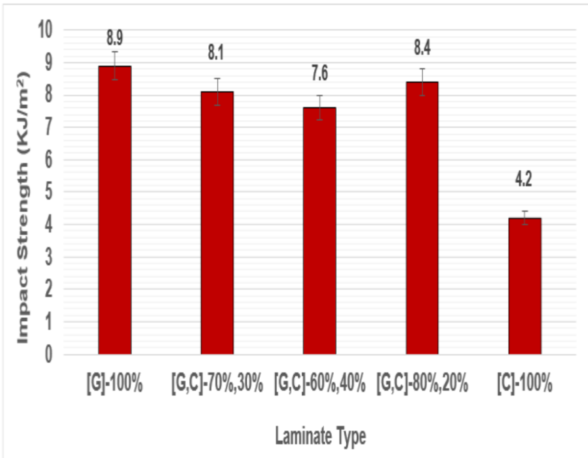

Figure 7. Impact strength of non-hybrid composite versus Glass/Cotton Hybrid Composites

The impact strength of hybrid composite decreased with increased weight % of cotton fibres as shown in the figure. But, the difference between the impact strength of pure glass [G]-100% and [G.C]-80%,20% is a marginal difference. However, considering the cost-effectiveness and biodegradability point of view the use of [G.C]-80%,20% hybrid composite is suggested as an alternative to the pure synthetic composite structure.

D. Experimental Hardness Testing

Figure 8 presents the bar chart for the hardness of non-hybrid composite versus Glass/Cotton hybrid composites. Non-Hybrid composite [G]-100% provided an 82 hardness number. Also [G, C]-80%, 20% gives nearer result to hybrid composite [G]-100%. Even though non-hybrid composite [C]-100% gives results in the percentage of 70% compared to pure synthetic composite. This could be due to improper infusion of synthetic epoxy with natural fibres. The overall mechanical testing results for Glass/Cotton hybrid composites are reported in Table 6.

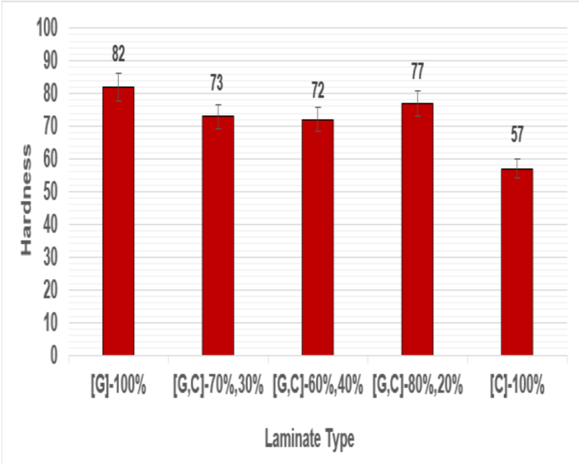

Figure 8. Hardness of non-hybrid composite versus Glass/Cotton hybrid composites

Table 6. Mechanical testing result for Glass/Cotton hybrid composites

Laminate Type	**Tensile Strength (MPa)**	**Flexural Strength (MPa)**	**Impact Strength (KJ/m²)**	**Hardness no.**
[G]-100%	230.3±8	208.12±5	8.9±2	82±4
[G,C]-70%,30%	199.6±7	188.27±4	8.1±3	73±5
[G,C]-60%,40%	173.3±7	198.89±4	7.6±2	72±4
[G,C]-80%,20%	218.4±5	137.4±6	8.4±3	77±5
[C]-100%	89.5±6	64.2±5	4.2±2	57±4

E. Microscopic Interpretation of a Hybrid Composite Structure

Microscopic examinations of glass, cotton and a glass/cotton hybrid composite were performed to investigate the mode of failure. The SEM images 9 (a,b,c,d,e) depicts the fibre dispersion in various hybrid composites.

[G]-100 % demonstrated good bonding behaviour with epoxy, implying that they serve as load-carrying constituents in the hybrid composite. The microstructure behaviour of the [G]-100 % composite sample is similar to that reported in the literature. (Arthanarieswaran *et. al.*, 2014; Shin *et al.*, 2015). Whereas Figure 9(b) of [G,C]-70%,30% especially shows fibre pullout which is the main reason for the reduction in strength of glass/cotton hybrid composite. The decreased weight % of glass fibres in the composite results in decreased mechanical properties of hybrid composite. This could be due to the superior properties of glass fibres as compared to cotton fibres. The main cause of laminate failure is fibre pullout and bending, which is predominately observed at [G,C]-60%,40% hybrid composite structures. Figure 9(d) of [G,C]-80%,20% - shows good adhesion between cotton fibre and epoxy results in the formation of fewer voids and cracks evident from SEM. Improper fibre adhesion, void formation, and crack formation are also causes of mechanical property reduction in the [C]-100% composite matrix, as shown by SEM in Figure 9(e).

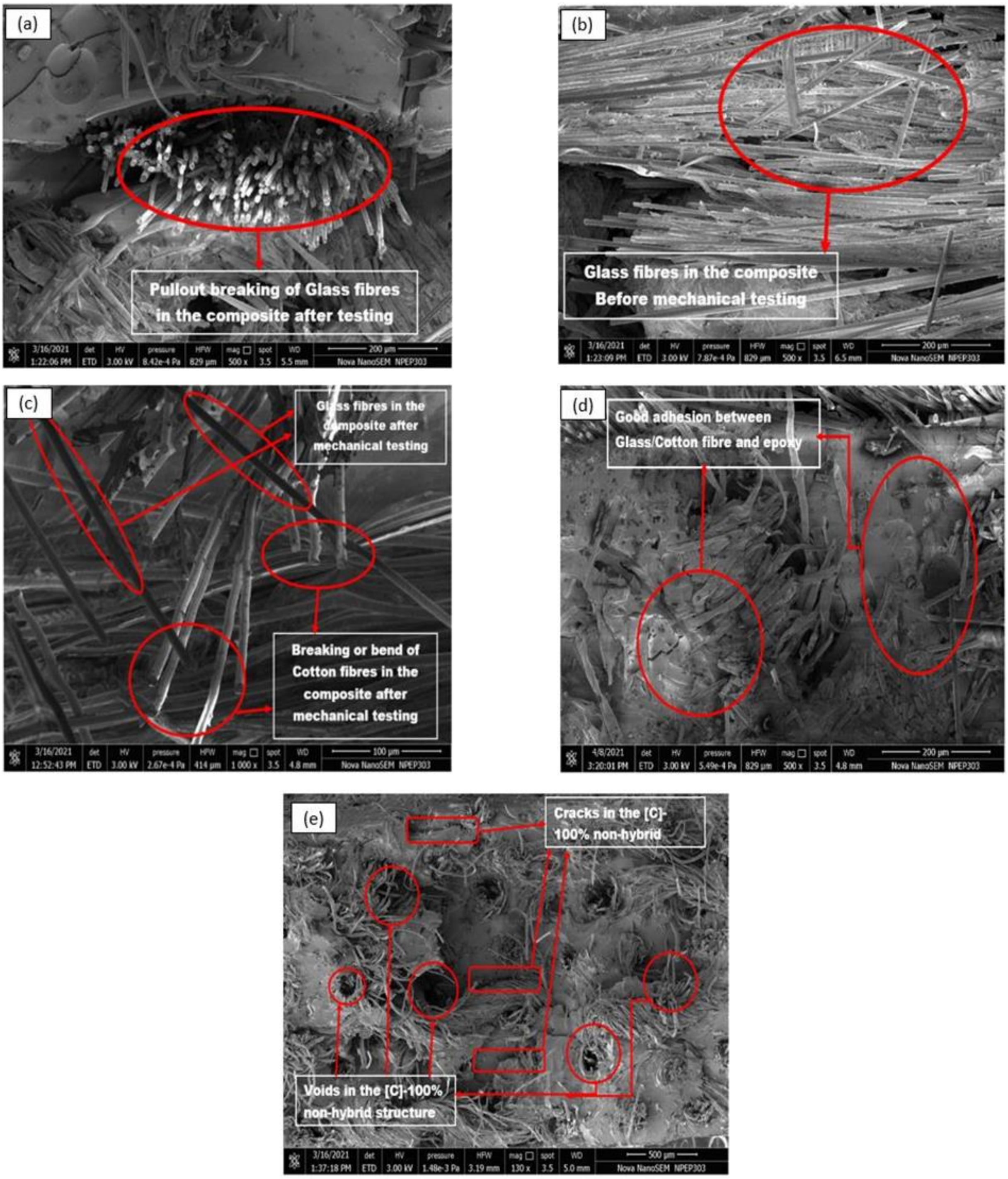

Figure 9. SEM micrographs of Glass fibre-Cotton fibre composites: (a) [G]-100% pullout fibres after tensile testing, (b) [G]-100% pullout fibres before testing, (c) [G,C]-70%,30%, (d) [G,C]-80%,20%, and (e) [C]-100%.

IV. CONCLUSION

The hand lay-up method was used to fabricate the hybrid composite of cotton and glass fibre reinforced epoxy composite in this study. The specimen used for various tests were as per ASTM standards. The mechanical properties of [G]-100% were found to be higher than other hybrid composites. The composite made with [G,C]-80%,20% using a single layer of cotton fabric exhibits mechanical properties closer to non-hybrid composite with [G]-100%. It indicates that E-glass can be partially replaced by cotton fabric and therefore, hybrid composite [G,C]-80%,20% can be considered for existing applications of glass/epoxy composites in which mechanical properties are important.

Also, based on the findings, it is possible to conclude that the stacking sequence and epoxy matrix interaction between glass and cotton are critical in determining the mechanical properties of the composite. As per SEM, more than 30% adhesion of an alternative layer of cotton fibre significantly affects the mechanical properties. The different arrangement of plies give rise to micro- voids between fibre layers thus lowering the tensile strength.

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