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Mechanical performance studies on *Vetiveria zizanioides*/jute/glass fiber-reinforced hybrid polymeric composites

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Abstract

In this study, a new biodegradable hybrid composite material is developed with natural *Vetiveria zizanioides* (vetiver), woven jute, and commercially available E-glass as reinforcing fibers and vinyl ester as the resin. Vetiver fibers are pretreated with distilled water and alkali followed by heat treatment. Nine composite specimens are prepared by varying the proportions of natural and glass fibers in each and maintaining the resin content as a constant. The specimens are tested for tensile, compressive, flexural, and impact strengths. The results revealed that the chemical treatment to the vetiver fiber shows a substantial improvement in the mechanical properties of hybrid composite material. Also, by proper selection of fiber proportions, glass fibers can be replaced by natural fibers without losing the mechanical properties.

Keywords

Vetiver, jute, glass, mechanical properties

Introduction

The use of synthetic fibers in polymer-based composites is decreasing due to its cost, health, and environmental hazards. Biofibers like jute, sisal, vetiver, hemp, and bamboo are abundantly available at a reasonable cost. These fibers when used as reinforcements in composites provide very good mechanical properties, and they are free from environmental hazards. The research in the field of biofibers made huge changes to make it superior to commercially available synthetic fibers. During characterization of jute fiber-reinforced polypropylene composites, the mechanical properties like tensile strength, flexural strength, and impact strength are better when jute fibers are pretreated with urea than when used as raw ones.[1] Pine needles in the form of particle fibers showed better mechanical properties than used as short fibers, but it was more reactive to moisture.[2] Steam explosion technique was used to modify the structure of bamboo fibers. Tensile strength of steam-exploded bamboo fibers is superior to that of jute fibers, and its specific strength is equivalent to glass fibers. Hence bamboo fibers could act as a potential alternate to synthetic fibers.[3,4] Diameter of fibers and its surface treatment has more influence on composite properties. Investigations on different diameters of date palm fiber-reinforced epoxy laminates showed an increase in tensile strength as a result of decrease in fiber diameter during surface treatment.[5]

Experiments on Kenaf/glass hybrid composites developed by hot-impregnation technique reported that twisted kenaf fibers when used along with glass showed better mechanical properties. This kenaf/glass hybrid composite could be substituted for conventional materials in automobile bumper beams.[6] Hybridization of two fibers in a composite always gives better behavior than single-fibered composites. Mechanical properties of sisal and glass fiber-reinforced composites

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showed better characters than the sisal-fibered composites. Also, stacking sequence of the fibers plays an important role in deciding the composite properties.[7] Wooden particles act as an important natural fiber, and the composite properties are comparable with that of the medium density fiber board.[8] In another work, areca fibers are chemically treated and reinforced into an epoxy matrix. The impact strength and hardness of composite increase directly with the fiber volume fraction and postcuring time.[9] Although many research works on characterization had been done on various fibers like licuri, pine apple leaves, and hemp,[10–12] no sufficient research had been done using vetiver fibers.

Veteveria zizanioides (vetiver) is a perennial grass, and its roots are commonly known as vetiver. These roots can grow to a maximum length of 12 m and has good mechanical properties. In this investigation, chemically treated vetiver fibers and commercially available woven jute fibers are used as reinforcement with vinyl ester resin. Hybrid composite laminates are prepared with and without glass fibers. Characterization of the developed composites reveals that vetiver and jute-reinforced hybrid composite gives best performance, and hence they can be substituted for synthetic fibers.

Figure 1. Raw vetiver fibers.

Preparatory methods

The dry vetiver fiber as shown in Figure 1 is collected in bulk from commercial shops. The properties of vetiver fibers in comparison with other natural fibers are listed in Table 1. Nine hybrid composite specimens were prepared by varying the proportions of randomly oriented vetiver, woven jute, and woven glass fibers and maintaining the resin proportion constantly as 66 wt%. The composites are prepared by using hand-layup method during which the fibers' layers are bonded by manually spreading the resin in between them and maintaining a total specimen thickness of 12 mm. Of the nine specimens, the first one contains the untreated vetiver fibers and the remaining eight contains treated vetiver fibers. The vetiver fibers in first specimen are washed in water and dried in sunlight. No further chemical treatment is given to it, and hence they are called as untreated vetiver fibers. The chemical treatment to vetiver fibers is done by soaking them in 5% of sodium hydroxide solution for about 2 h, which results in the removal of unwanted soluble celluloses, pectin, lignin, etc, during which a fiber to solution ratio of 1:25 is maintained. After 2 h, the fiber is washed in distilled water to remove excess sodium hydroxide and dried by heating in furnace at 60°C for about 4 h.[13] During this preparation, methyl ethyl ketone peroxide is used as a catalyst, and cobalt octate is used as an accelerator of the process. The fiber proportions in each specimen are listed in Table 2.

Table 2. Composition of specimens.

Specimen	Vetiver (wt %)	Jute (wt %)	Glass (wt %)	Resin (wt %)
UV19G15	19 (untreated)	–	15	66
V10G24	10 (treated)	–	24	66
V19G15	19 (treated)	–	15	66
V24G10	24 (treated)	–	10	66
V17J17	17 (treated)	17	–	66
V10J24	10 (treated)	24	–	66
V24J10	24 (treated)	10	–	66
V13J13G8	13 (treated)	13	8	66
V10J10G14	10 (treated)	10	14	66

Table 1. Properties of natural fibers.

Property	Vetiver	Jute	Coir	Sisal	Flax
Density (g/cm^3)	1.5	1.3–1.4	1.1	1.4	1.5
Diameter (μm)	100–220	25–200	100–450	50–200	–
Tensile strength (MPa)	247–723	393–773	131–175	468–640	345–1100
Young's modulus (GPa)	12.0–49.8	13.0–26.5	4.0–6.0	9.4–22.0	27.6
Elongation at break (%)	1.6–2.4	1.1–1.5	15.0–40.0	3.0–7.0	2.7–3.2

Mechanical testing

Mechanical tests like tensile, flexural, compressive, and impact are done, and the results are analyzed. Three samples for each test are cut manually using saw as per ASTM standard shape and dimensions at different locations on the specimen forming 12 samples for each specimen. During tensile testing, the specimen is cut in the shape of a dumb bell with a gauge length of 50 mm. Tensile and compressive testing were carried out using INSTRON 3369 Universal Testing Machine according to ASTM D 638. During three-point horizontal flexural testing, the specimen is cut into a rectangular bar with a span length of 192 mm and a depth of 12 mm (span to depth ratio 16:1) according to ASTM D790. The loading and supporting nose radii are maintained at 4 and 1.6 times the specimen thickness, respectively. Charpy impact test on specimen was carried out using a pendulum impact testing machine with a notch angle of 45° according to ASTM D256.

Results and discussion

Influence of chemical treatment on mechanical properties

From Table 3, it was observed that tensile, flexural, compressive, and impact strengths of specimen UV19G15 are lesser than the remaining specimens. This shows that the chemical treatment to the vetiver fibers improved the mechanical properties of the composite. Chemical treatment has improved the surface properties of natural fibers and enhanced the adhesive-bonding ability of the fibers with the matrix.[14–16] Due to chemical treatment, the average increase in

Table 3. Strengths of all specimens.

	Tensile strength (MPa)		Flexural strength (MPa)		Compressive strength (MPa)		Impact energy (J)	
Specimen no	Test 1, 2, 3	Average	Test 1, 2, 3	Average	Test 1, 2, 3	Average	Test 1, 2, 3	Average
UV19G15	52.61	53.21	96.22	97.27	92.19	91.84	8	8.67
	52.95		98.56		90.45		9	
	54.07		97.03		92.88		9	
V10G24	63.44	64.42	118.56	120.06	119.42	119.45	17	16.67
	64.78		120.5		120.5		16	
	65.05		121.11		118.44		17	
V19G15	70.32	69.76	131.25	131.92	118.61	117.92	14	14.33
	69.16		130.61		115.6		13	
	69.79		133.9		119.56		16	
V24G10	60.78	60.89	125.54	124.27	108.35	108.33	12	12.67
	61.22		121.06		110.22		13	
	60.67		126.22		106.42		13	
V17J17	71.08	71.73	132.11	133.11	121.67	122.21	11	11
	73.21		135.81		118.45		10	
	70.91		131.4		126.5		12	
V10J24	62.15	63.3	115.91	114.79	116.23	115.65	10	10.33
	63.7		110.6		114.76		11	
	64.06		117.87		115.97		10	
V24J10	65.12	64.53	120.38	121.31	110.29	111.57	11	11.67
	63.92		118.44		115.53		12	
	64.55		125.1		108.89		12	
V13J13G8	73.42	74.14	131.34	131.9	121.34	121.81	16	15.33
	72.06		134.91		120.3		15	
	76.95		129.45		123.78		15	
V10J10G14	70.21	70.96	136.71	137.6	128.12	128.23	18	18.33
	68.92		137.87		125.94		19	
	73.76		138.21		130.62		18	

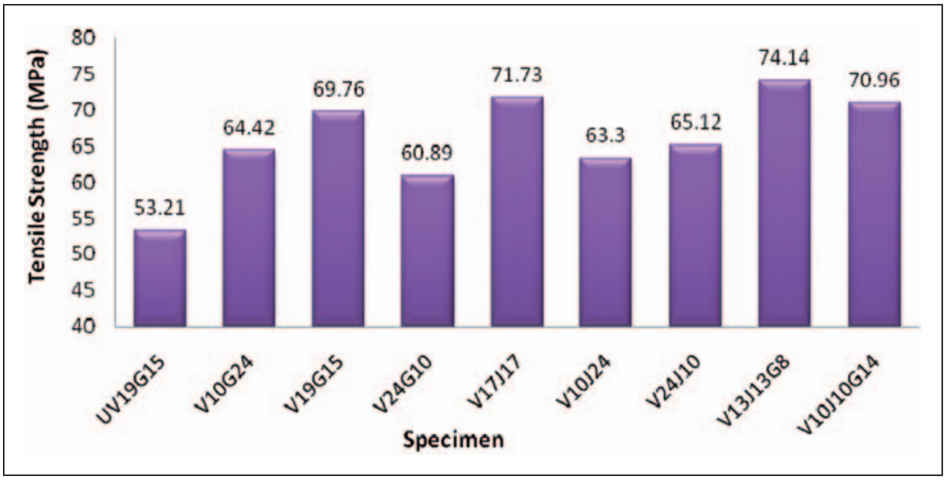

Figure 2. Tensile strength plot.

mechanical properties is 26.8% for tensile strength, 28.65% for compressive strength, 30.44% for flexural strength, and 59.1% for impact strength.

Tensile behavior

The tensile behavior of the specimens is shown in Figure 2. The tensile strength reaches a maximum value of 74.14 MPa for specimen V13J13G8 followed by 71.73 MPa for V17J17 and 70.96 MPa for V10J10G14. Among the bifibered hybrid composites, it was observed that as glass fiber content increases, the tensile strength also increases until 15% and drops with further increase. This shows that too much inclusion of glass fibers is not suitable to achieve higher tensile strength. Comparison of specimens V13J13G8 and V10J10G14 also infers the same trend. Among the bifibered hybrid composites, it was observed that a 5% increase in glass fiber content increases the tensile strength by 14.57%, and the specimen without glass namely V17J17 provides the maximum strength. So, a maximum of 15% of glass fibers could be completely replaced by natural fibers without losing the tensile property.

When vetiver fiber is used along with glass, a 9% increase in vetiver content increases the strength by 8.3%, but further increase in vetiver decreases the strength. When vetiver fiber is used along with jute, a similar trend was obtained, and the optimum proportion of vetiver is found to be 17%. Among the trifibered composites, 6% increase of glass fiber decreases the tensile strength by 4.5%, and a mixture of 13% of vetiver fibers, 13% of jute fibers, and 8% of glass fibers would be the best proportion to obtain a maximum tensile strength of 74.14 MPa. Hence, by appropriate fiber proportions, hybridization of multiple fibers into the matrix substantially improved the tensile property.[17]

The tensile stress–strain plot of all the specimens is shown in Figure 3. The plots may be divided into two stages namely, low-strain levels and high-strain levels. At low-strain levels, the stress increases linearly, and above this, the specimens show a plastic behavior. This plastic behavior is due to the plastic deformation of the resin and formation of micro cracks in the resin. These cracks propagate due to the presence of random fibers and the bonding between fibers and resin breaks; as a result, there would be an abrupt decrease in strength.[18] The specimens namely UV19G15, V19G15, and V10J10G14 almost behave like brittle material, which would be due to the presence of more glass fibers. Specimen V10G24 behaves like a pure glass due to the presence of 24% of glass fibers. Stress–strain curves of remaining specimen increase linearly during first stage and then increase nonlinearly with a slight deflection in their slope until maximum stress limit during second stage followed by sudden drop before complete breakage.

The tensile modulus and strain at break for the tested specimens are summarized in Table 4. It was observed that modulus varies inversely as the strain at break. The tensile modulus reaches a maximum for specimen V10G24 followed by V10J10G14 and V13J13G8. For trifibered hybrid composites, a 6% increase in glass fibers increased the modulus by 10.11%. Also, examinations on specimens V10G24, V19G15, and V24G10 revealed that 5% increase in glass content increased the modulus by 13.5, and 14% increase in glass fibers increased the modulus by 32.5%. For both bifibered and trifibered hybrid composites, increase in glass content increases the modulus as reported in an earlier research.[19] A maximum strain at break of 9.5% was observed for specimen V17J17 followed by three specimens namely V10J24, V24J10, and V24G10. It is evident from the table that strain at break varies inversely

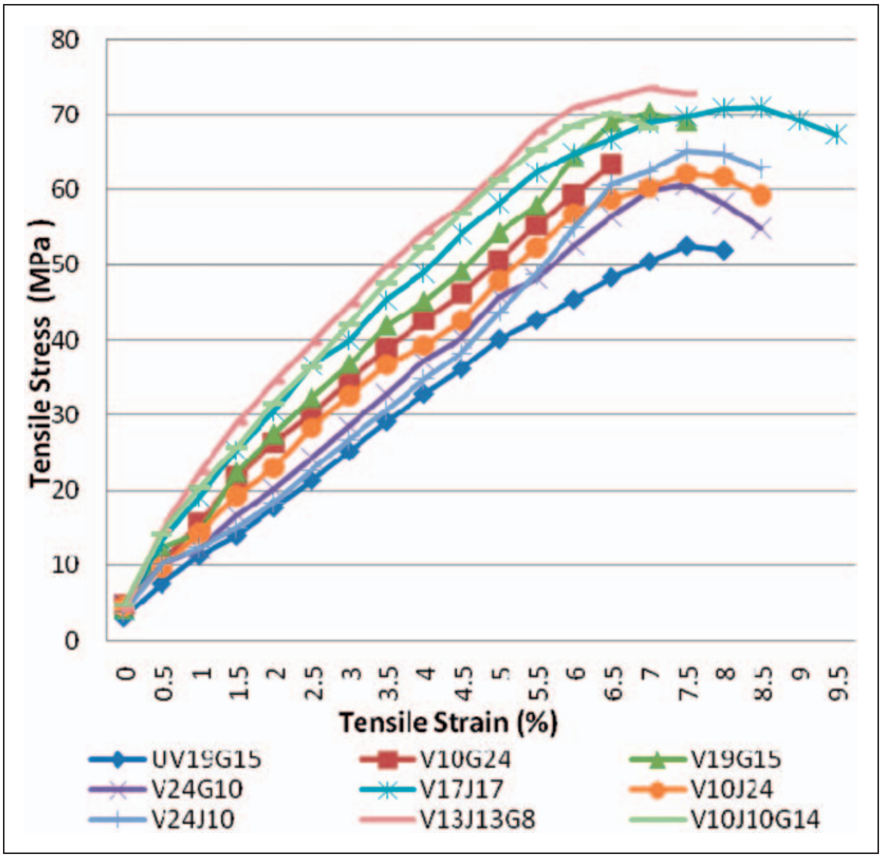

Figure 3. Tensile stress–strain plot.

at the presence of glass content. Failure of glass fibers transfers high stress to the natural fibers leading to the failure of the composite. Hence glass fibers are more responsible in determining the breakage of the hybrid composite.

Flexural behavior

Flexural behavior was analyzed by using three-point bending test. During this test, the top layer of the specimen is subjected to compression, and the bottom layer is subjected to tension. The mid-layer is subjected to shear, and hence, the failure of composite is due to a combination of bending and shear. The variation in flexural strength of tested specimens is shown in Figure 4. The flexural strength reaches a maximum value of 137.6 MPa for specimen V10J10G14 followed by 133.11 MPa for V17J17 and 131.92 MPa for V19G15. Observations on specimens V10G24, V19G15, and V24G10 show that increase in glass fiber content increases the flexural strength only until 15%; thereafter, there is a sudden decline to a value lesser than obtained by 10% of glass fibers. Among the bifiber-reinforced hybrid composites, a 5% increase in glass content increases the flexural strength by 6.16% and but 14% increase in glass content decreases the strength by 3.5%. Maximum flexural strength was shown by V17J17, and so a fiber proportion of 17% of vetiver and 17% of jute would be the best combination. Also, comparing V19G15 and V17J17, it was observed that 15% of glass fibers could be completely replaced by natural fibers without losing the flexural strength.

Analysis of vetiver/glass composites shows that 9% increase in vetiver content increases the strength by 10% and further increase decreases the strength. Observations on vetiver/jute composites also show a similar trend with optimum vetiver content of 17%. Among trifibered hybrid composites, 6% increase in glass content increases the strength by 4.32%, and a combination of 10% of vetiver, 10% of jute, and 14% of glass provides the maximum flexural strength. Hybridization of glass fibers into the matrix provides a positive effect on the composites as reported by Patel and Parsania.[20] The flexural stress–strain plot is shown in Figure 5. Flexural strength is a measure stiffness of the composite and is calculated from the slope obtained from the load–displacement curve.[4] From the stress–strain plot, it is evident that specimen V10J10G14 gives the highest stiffness followed by V17J17 and

Table 4. Modulus and strain at break.

	Tensile modulus (MPa)		Tensile strain at break (%)		Flexural modulus (MPa)		Flexural strain at break (%)	
Specimen no	Test 1, 2, 3	Average	Test 1, 2, 3	Average	Test 1, 2, 3	Average	Test 1, 2, 3	Average
UV19G15	1012	1014	8	8	2017	2048	6	6.33
	1008		8		2132		6.5	
	1021		8.5		1994		6.5	
V10G24	2439	2451	6.5	6.5	3204	3223	6.5	6.67
	6.5		6.5		3108		7	
	6.5		6.5		3356		6.5	
V19G15	2100	2100	7.5	7.5	3156	3149	6.5	6.67
	2089		7.5		3104		6.5	
	2112		7.5		3186		7	
V24G10	1821	1850	8.5	8.5	3678	3667	6	6.17
	1796		8		3721		6	
	1933		9		3601		6.5	
V17J17	1710	1736	9.5	9.5	2896	2894	7	7
	1787		9.5		2821		7	
	1711		9.5		2965		7	
V10J24	1656	1650	8.5	8.5	3594	3610	6	6.17
	1589		9		3781		6	
	1705		8		3456		6.5	
V24J10	1852	1865	8.5	8.5	3024	3050	6.5	6.5
	1883		8.5		3121		6.5	
	1861		8.5		3006		6.5	
V13J13G8	2108	2105	7.5	7.5	3317	3358	6.5	6.67
	2097		8		3291		6.5	
	2111		7		3466		7	
V10J10G14	2316	2318	7	7.5	2946	2950	7	7
	2229		7.5		2995		7	
	2408		6.5		2910		7	

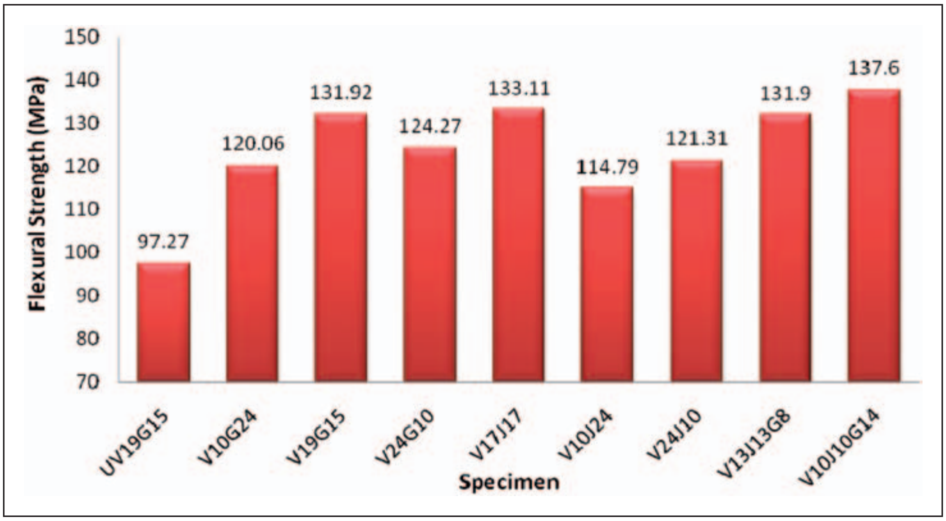

Figure 4. Flexural strength plot.

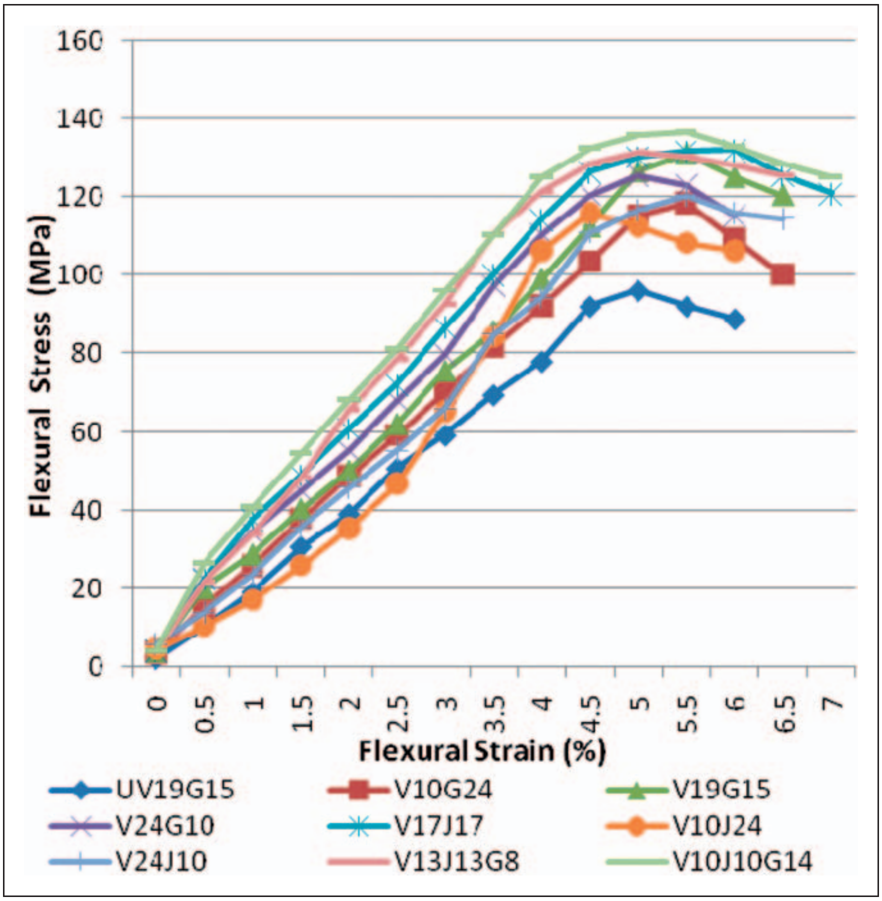

Figure 5. Flexural stress–strain plot.

V13J13G18. The slope of all curves at the beginning remains constant followed by an increase and drop before the fracture of the composite. Unlike tensile stress–strain plot, there is no sudden damage of specimens containing high-glass content.

From Table 4 for flexural modulus and strain, no evident relationship between flexural modulus and flexural strain was obtained. The maximum modulus was obtained for specimen V10G24. Among the bifibered composites, increase in glass content increases the flexural modulus, which is not observed for trifibered hybrid composites. Among the vetiver/jute fiber hybrid composites, there is no clear trend for the influence of vetiver and jute on flexural modulus, but the optimum proportions were found to be 10% of vetiver and 24% of jute. A maximum strain during break was obtained for specimens V17J17 and V10J10G24. Also, presence of glass fibers has no influence on flexural strain during break.

Compressive behavior

The compressive strength plot of all composite specimens is shown in Figure 6. Investigations on compressive strength show a maximum value of 128.23 MPa for V10J10G14 followed by 122.21 MPa for V17J17 and 121.81 MPa for V13J13G8. Comparing specimens V10G24, V19G15, and V24G10, it was observed that increase in glass fiber content increases the compressive strength, and comparing specimens V10G24 and V17J17, it may be concluded that 24% of glass fibers may be completely replaced by natural fibers without losing the compressive property. Analysis of vetiver/glass composites shows that 14% increase in vetiver content decreases the strength by 10.26%. A similar trend was obtained during analysis of vetiver/jute composites. Hence among bifibered composites, optimum proportion for vetiver and jute were found to be 10% and 17%, respectively. Among the trifibered composites, increase in glass fiber content increases the compressive strength, which was similar to the flexural behavior.

Impact behavior

Impact strength is the measure of resistance offered by composite against fracture during application of high-speed stress. In other words, it is a measure of

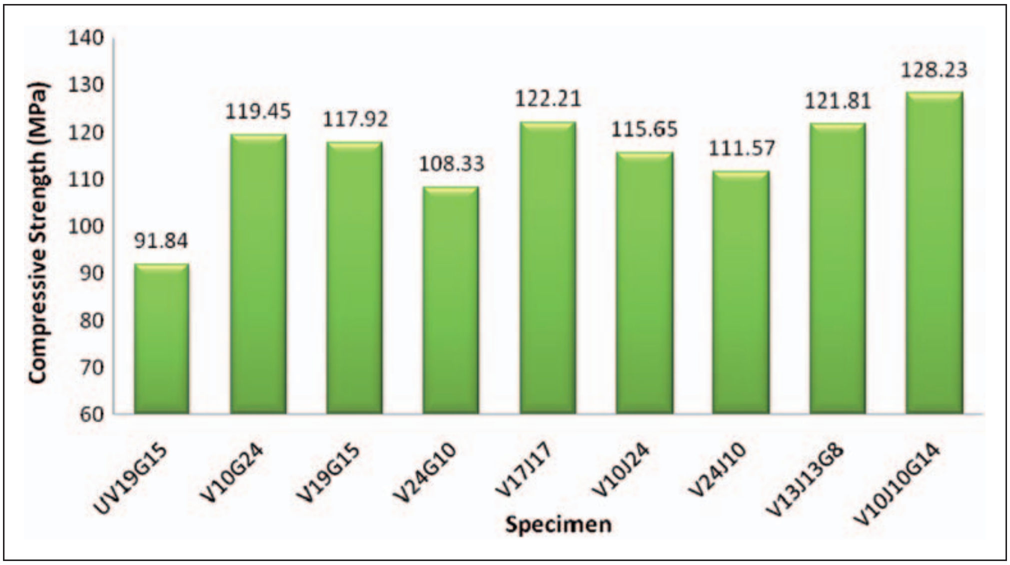

Figure 6. Compressive strength plot.

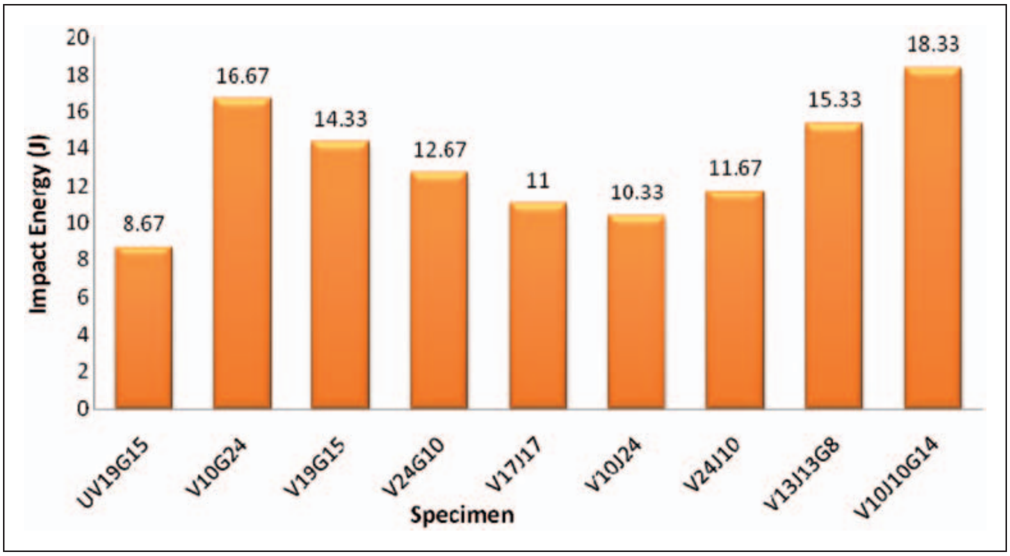

Figure 7. Impact strength plot.

toughness of the composite. Impact strength depends upon the fiber pullout during fracture. Inclusion of more fibers increases the pull-out force, and hence there is an increase in impact strength.[1] The energy absorbed during Charpy impact test was measured and plotted in Figure 7. A maximum impact energy of 18.33 J was observed for specimen V10J10G14 followed by V10G24. Investigation on specimens V10G24, V19G15, and V24G10 shows that increase in glass fiber content increases the impact strength.

Among the vetiver/glass hybrid composites, a 5% increase in glass content increases the impact energy by 13.1%, and a 14% increase of glass content increases the energy by 31.6%. Among bifibered hybrid specimens, a combination of 10% of vetiver and 24% of glass is the best proportion for achieving maximum impact strength. The same behavior is observed while comparing specimens V13J13G8 and V10J10G14. Similar results have been reported by Reddy et al.[21] Among trifibered hybrid composites, a 6% increase in glass content increases the energy by 19.57%. Specimens V17J17, V10J24, and V24J10 show almost equal and low-impact energy. This is due to the fact that glass fibers have the ability to absorb high energy during impact than the natural fibers. So, glass fibers are responsible for obtaining good impact properties in a composite. Hence it may be concluded that a minimum glass content of 14 % must be maintained to get ideal impact properties.

Surface morphology study

The surface morphology shows the bonding of fibers with matrix, adhesive property of matrix, matrix cracking, cavities, micro holes, pullouts, etc. while visualizing a fractured surface. The SEM micrograph of tensile-fractured specimens and prepared specimens are shown in Figures 8 and 9, respectively. Micrograph of specimen UV19G15 shows improper adhesion between the vetiver fibers and resin in both fractured and prepared specimens. This resulted in the formation of cavities and poor interfacial strength due to which the stress-transfer mechanism fails. Also, the fiber pullouts are more when compared to the remaining specimens. These reasons make the composite to break earlier than the remaining ones. Comparing the morphology of specimen UV19G15 with others, it could be concluded that chemical pretreatment to natural fibers improved the mechanical properties.[22–24] Micrograph of specimen V10G24 shows denser distribution of vetiver fibers in between the glass layers and there found to be a proper bond between the vetiver and glass fiber layers, and fiber pullout is not visible in the prepared specimen. Specimen V19G15 shows uniform distribution of glass and vetiver fibers, and there is no evidence for debonding of fibers from the matrix. Both specimens V19G15 and V24G10 show micro holes and sudden breaking of vetiver fibers. Formation of micro holes may be due to improper coverage of resin over the fibers during hand-layup process. An abrupt breakage of vetiver fibers happens where there is a strong bond between the matrix and fiber, and pullouts take place where there is a weak bond between the matrix and fiber.

The micrographs of specimen V17J17 and V10J24 show uniform distribution of fibers in their respective layers, and there is no evidence for the formation of cavities and micro holes. Formation of these cavities and micro holes is responsible for reduction in tensile, flexural, and compressive strengths of the composites. Also, pullout of jute fibers is more than vetiver in specimen V10J24. Micrograph of specimens V24J10 and V13J13G8 also shows more jute fiber pullouts than vetiver and glass fibers. In specimen V13J13G8, jute and glass were used as the top and bottom skin layers. The surface morphology indicates that the damage is initiated from the area where vetiver is present and then it moves to the area where jute and glass fibers are present. Hence vetiver behaves as a brittle material in combination with the vinyl ester. Here, it was evident that the skin layers namely jute and glass are responsible for increasing the tensile properties of the composite. The micrograph of specimen V10J10G14 also shows uniform distribution of fibers in respective layers, but there is less evidence for damage to initiate from the vetiver layer as like specimen V13J13G8. In both fractured and prepared specimens, bonding between jute and the resin is qualitatively better than between vetiver and resin. This is due to random distribution of vetiver fibers over the resin.

Conclusion

In this research work, new composite materials have been prepared with vetiver, jute, and glass as fibers and vinyl ester as the resin. The composite specimens have been tested for tensile, flexural, compressive, and impact properties. The fractured surface morphology of tensile tested specimens is studied, and the conclusions are given as follows:

1. Chemical pretreatments to natural fiber have increased the mechanical properties of the composites. On an average, the tensile strength increased by 26.8%, flexural strength increased by 30.44%, compressive strength increased by 28.65%, and impact strength increased by 59.1%.
2. Increase in glass content increases the tensile strength until 15%, but too much inclusion of glass fibers is not suitable for achieving ideal tensile properties. Among bifibered hybrid composites, specimen V17J17 showed the maximum strength, and 15% of glass fibers could be replaced by natural fibers without losing the composite properties.
3. Investigations on flexural behaviour revealed that 15% of glass fibers could be replaced by natural fibers without losing the composite properties. Among bifibered composites, maximum flexural strength was shown by V17J17, and among trifibered composites specimen, V10J10G14 showed the maximum strength.
4. Analysis of compressive behaviour showed an increase in glass content that increases the compressive strength, and a maximum of 24% of glass fibers could be completely replaced by natural fibers without losing the compressive property.
5. Impact behaviour study revealed that the presence of glass fibers is vital, and a minimum glass content of 14% must be maintained to get ideal impact properties.
6. In both bifibered and trifibered composites, hybridization shows a positive effect on mechanical properties.
7. The SEM micrographs showed a clear evidence of various defects in the untreated specimen and

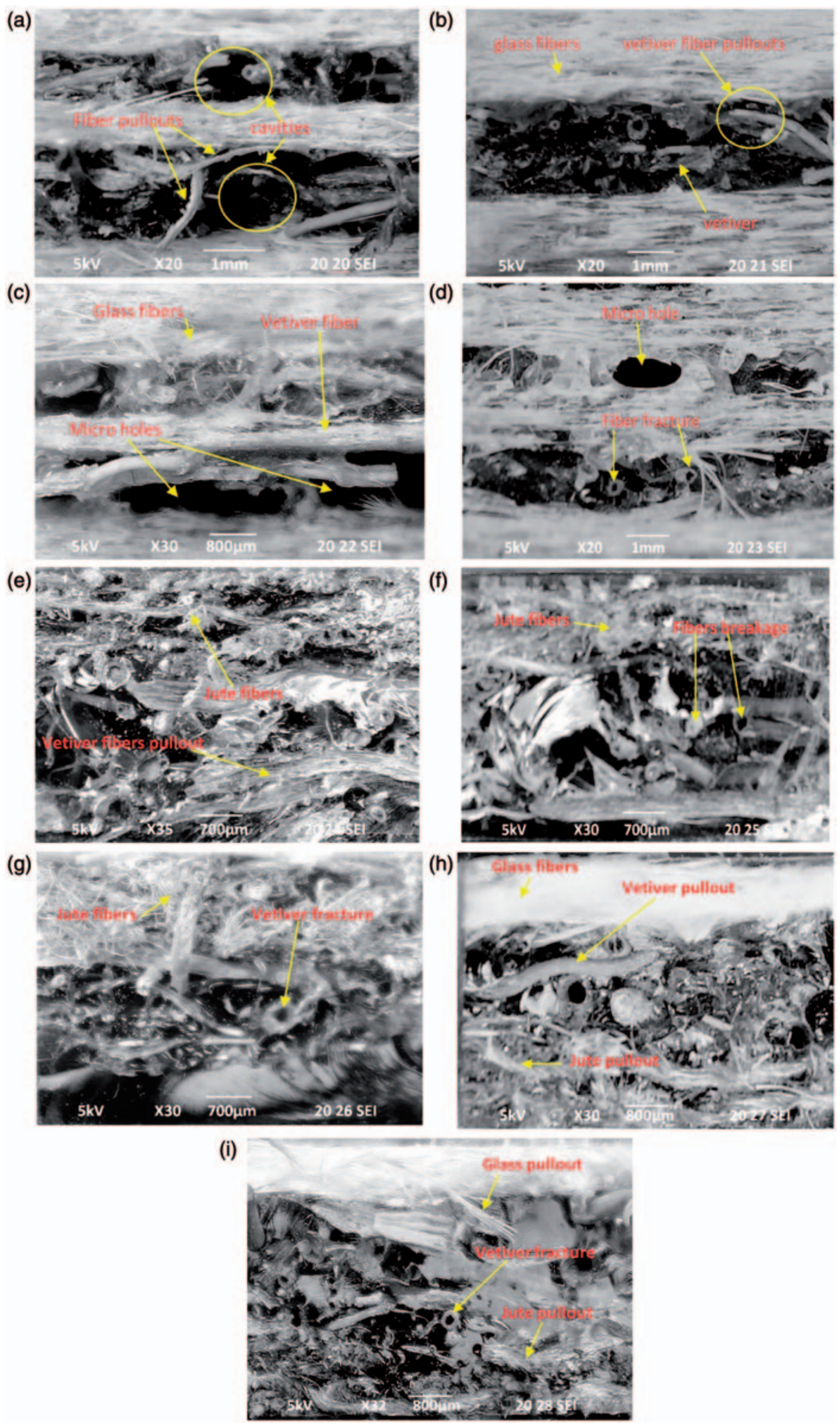

Figure 8. SEM micrographs of tensile fractured specimens: (a) UV19G15; (b) V10G24; (c) V19G15; (d) V24G10; (e) V17J17; (f) V10J24; (g) V24J10; (h) V13J13G8; (i) V10J10G14.

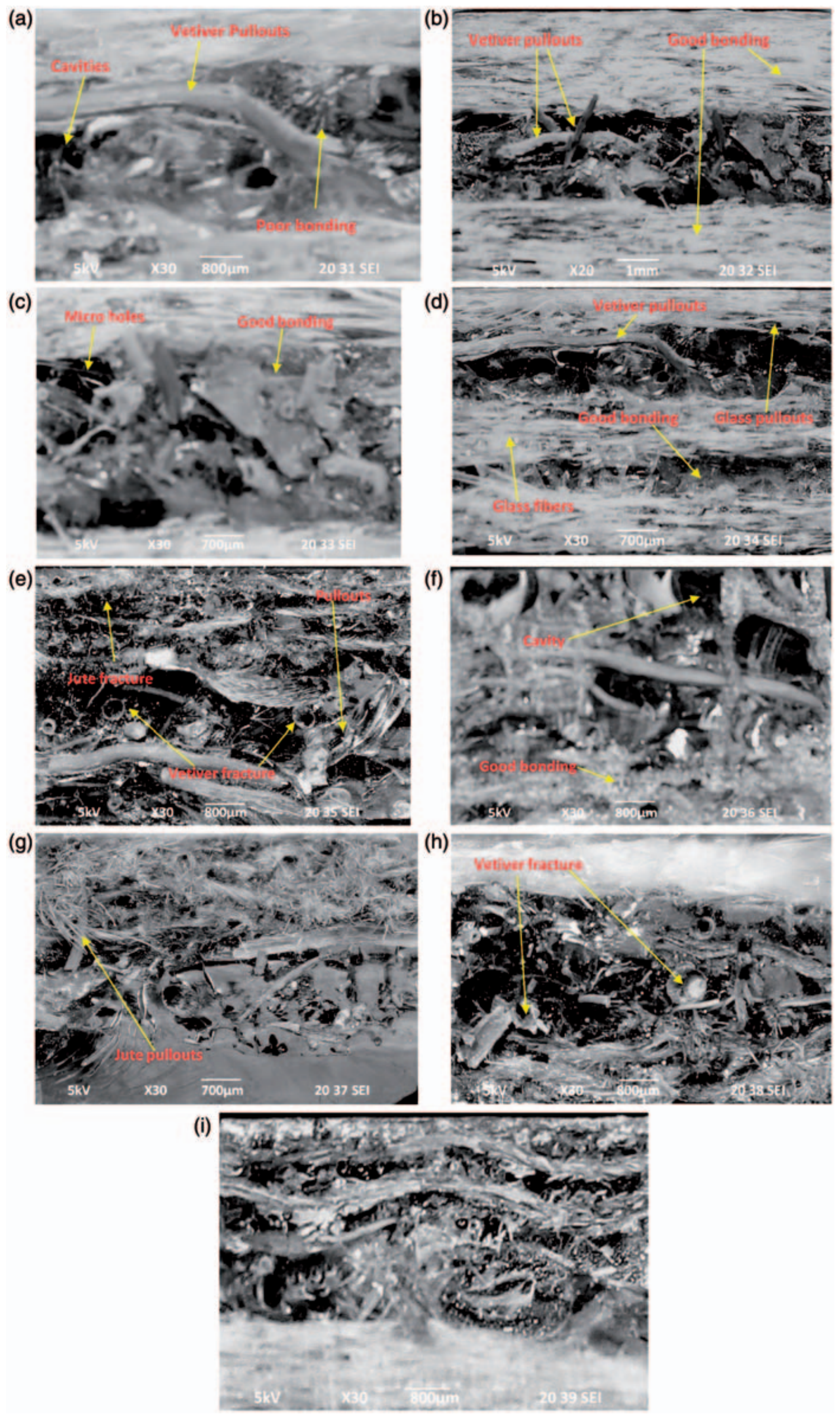

Figure 9. SEM micrographs of prepared specimens: (a) UV19G15; (b) V10G24; (c) V19G15; (d) V24G10; (e) V17J17; (f) V10J24; (g) V24J10; (h) V13J13G8; (i) V10J10G14.

qualitative enhancement of those defects in treated specimens.

8. Hence by careful selection of natural fiber proportions and by proper chemical treatments to the natural fibers, it is possible to use vetiver and jute fibers as substitute for glass fibers.

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