

Impact of Fiber Length and Chemical Alteration on the Mechanical Properties of Blended Composites



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Abstract The effort of instigator in this recent work was to investigate the effect and impact of fiber length and surface treatment on the mechanical properties of biofibers fortified composites. Biofibers are hydrophilic and resin is aquaphobic, which does the fibers and resin contrary and effects in deprived interfacial binding among the resin blend and fibers. Fundamental inspiration driving this chemical action was to shrink their wetness retention property of the fibers and, further more, to expand the compatibility with matrix blend. In the current research work, hybrid biofibers composites were fabricated by blending 10% vinyl ester matrix with 90% epoxy with the reinforcement of Bagasse–Luffa fibers into the resins blend. The superiority and optimal values of tensile, compressive, and flexural properties were observed for 2-cm fiber length, benzene diazonium chloride-processed composites than the unprocessed fiber composites, 5% NaOH-treated, 10% NaOH-treated hybrid biofibers composites, and other chemically customized composites.

Keywords Bagasse–luffa fibers · Surface treatment · Chemical resistance test and mechanical tests

1 Introduction

Unreal strands namely carbon, Kevlar, glass, and aramid have been most broadly utilized in polymer matrix composites because they are highly sturdy and stiff. Aside from the many advantages acquired by synthetic fibers in diverse directions and applications, these synthetic fibers have many limitations in terms of their biodegradability, initial processing costs, recyclability, energy utilization, machine abrasion, wear, and health hazards, etc. In order to overcome this crisis, more demand was raised toward the fabrication of natural/renewable fiber-based composites to make the world ‘green fibers’ [1, 2]. Biofibers have been utilized as a substitute fiber to synthetic fibers as well as fortification for polymer matrix composites. Natural fibers generally contain

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cellulose, hemicelluloses, pectin, lignin, and waxes [3–5]. The water absorption character possessed by the natural fibers controls the utilization of fibers in the fabrication of composites. Because of the aquaphobic property of polymer matrix may cause resin and fiber contrary and effects in frail bonding between the resin and fiber. The reason for this chemical action was to curtail the water retention quality of the biofibers which enhances the rapport with resin.

The matrix blend comprise various advantages in terms of the product end use applications and enhancing resin's utilization, performance, and properties [4, 6, 7]. Epoxy is a multipurpose and widely used matrix material for various applications such as advanced composites due to good pairing abilities. Thermoset resin applications were limited due to loxer toughness. Further blending strategy can be utilized productively to overcome the poorer properties of both the polymers. Miscible polymer blends produce a recently improved material from less predominant separate materials [8]. Vinyl ester is a toughening material which can be used together with epoxy materials. Vinyl ester was the extra resulting product of epoxy. The blending of epoxy with flexible polymers and elastomers improved the hardness [2, 4]. Subsequently, an appropriate polymer was required for the enhancement of stiffness and resistance against impact load. Vinyl ester was largely utilized for thermosetting material due to its low price and immense mix of qualities like resistance against chemicals. The extremity of vinyl ester was boosted by hydroxyl groups and make easy the adhesion and pigment soaking properties, promote grip, and color wetting properties, which gave the route to the damping of the fibers in matrix. For this reason a framework mix of matrix mix of vinyl ester/epoxy (90/10% w/w) resins was developed. Composite specimens with the 1, 2 and 3 cm length of unrefined, NaOH- and benzene diazonium chloride-processed Bagasse–Luffa fibers with a blend of epoxy/vinyl ester were fabricated.

2 Experimentation

2.1 Resins and Fibers

Two resins, namely: 1. Epoxy Araldite LY 556 as resin, hardener HY 951, 2. Vinyl ester.

Two Fibers, namely: 1. Luffa fiber, 2. Bagasse fiber were utilized to fabricate the composites (Fig. 1).

2.2 Chemical (Alkali) Treatment

The biofiber's hydrophilic feature, damage the successful bonding of fibers with a matrix blend. Furthermore, unwanted materials like pectin, grease, oil, and waxy

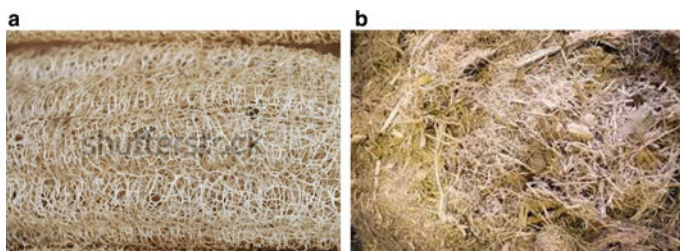


Fig. 1 a Luffa fiber. b Bagasse fiber

substances cover the reactive functional groups of the fiber and act as an obstruction for the interlock of fibers with the matrix. For the progress of the interfacial adhesion/bonding, surface of the fibers should be tailored with different chemical treatments. Chemical treatments provide more reactive bunches on the biofibers and this improves proficient coupling with the matrix blend. Surface of the fibers required to be modified by alkali action using different concentrations of NaOH: 5 and 10 wt% was conducted out in this work. After the alkali treatment, the reinforcing materials were immersed in the refined solution for 24 h to eliminate the remaining alkali. Further cleaning would be finished using the refined solution having a less quantity of acetic acid. In an oven, moist fibers were get cured for 3 h at 70 °C.

2.3 *Development of Benzene Diazonium Chloride*

Concentrated hydrochloric acid of 8 cm³ was poured to a bubbling tube having phenylamine (aniline) of 3 and 10 cm³ of H₂O, then the blend was shaken for amine liquefaction. Afterward, the solvent was chilled to 5 °C by using a frost bath. In the wake of cooling, a solvent of sodium was added to the pre-cooled merge. The temperature of the blend was kept underneath 10 °C, while purifying sodium nitrite [9].

2.4 *Benzene Diazonium Treatment of Bagasse–Luffa Fibers*

Bagasse–luffa fibrils were sliced to 10 mm length, then were cleaned using a refined solution. Afterward, this got cured by heating in the oven for 24 h at 70 °C. The fibers were cured and then immersed in the solution having 6% NaOH by curing the glass beaker at about 5 °C for 10 min. Recently prepared diazo solution was poured gradually to the blend by steady vibrating. After that, the fibrils were taken outside, cleaned with soap solution pursued by refined solution, and ultimately cured outside for 48 h [10].

2.5 *Development of Blended Hybrid Biocomposites*

The mold cavity was coated with a thin layer of hard wax for trouble-free discharge and pulled back of manufactured composite specimens. After the wax was cured, a lean layer of the aqueous solution of polyvinyl alcohol (PVA) was applied. Then the hybrid biofibers of the untreated and processed Bagasse–Luffa fibers were fortified to the matrix merge to get the required biocomposite specimens for the exploration of performance and mechanical properties. Then air bubbles were removed from cautiously by using the roller with delicate rolling. With the goal of a complete cure, composite samples were post-cured at a temperature of 80 °C for 2 h by keeping the specimens in a hot oven. After the complete curing, unprocessed and treated samples of biocomposite specimens were examined.

3 Results and Discussion

3.1 *Tensile Strength Properties*

Composite samples for the tensile strength test, prepared with 150 mm × 15 mm × 3 mm, were assessed as per ASTM standards and were investigated utilizing Universal testing machine with a cross-head speed of 50 mm/min. Due to the hydrophilic nature of natural fibers, inconsistency was noticed between natural fibers and matrix, which prompted an improper and lacking wetting of fibers in the matrix blend, which resulted in low-grade properties for the untreated composites. The impact of alteration of fiber's surface by the chemical treatment, alkali treatment, and quantity of reinforcement on the tensile property of bioconglomerates is presented in Fig. 2. In untreated biofiber composites, the repellency between hydrophobic matrix and hydrophilic natural fibrils would antagonistically influence the interfacial bonding between fiber's surface and matrix blend, and bring about decline of the load-bearing capability of the fibers due to the inadequate stress convey from the resin to fibers. Among a variety of surface variations performed, 2-cm-length benzene diazonium chloride-treated Bagasse–Luffa fibers blended composite displayed superior and optimum value for tensile strength than 1-cm and 3-cm fiber length 5% NaOH-treated, 10% NaOH-treated composite, and 1-cm, 2-cm, and 3-cm fiber length unprocessed biocomposites [7, 9]. However, a substantial tensile strength was noticed in NaOH-treated Bagasse–Luffa fibers composites, while noteworthy increase in the tensile property of benzene diazonium chloride-processed composites was noted. Benzene diazonium chloride-treated composite demonstrates more drop of the aquaphilic character of Bagasse–Luffa fibers due to the mixing of the hydroxyl bunches of fiber with benzene diazonium chloride and surface of the reinforcement turns out to be progressively uniform and coarse because of the annihilation of smaller scale gaps and thus the load conveys capability amid the cells increments [5, 11, 12]. Most significant tensile strength was seen for 2-cm length

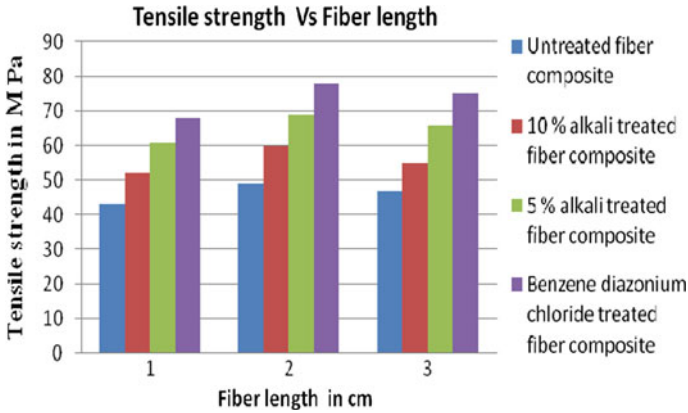


Fig. 2 Shows the tensile strength of untreated, alkali treatment, enzene diazonium chloride-treated biocomposites

benzene diazonium chloride-treated composite, because which improved the aspect ratio and surface roughness gave the channel to upgraded reinforcement distribution in resin and prompted increment in the interfacial adhesive coupling amid the resin and Bagasse–Luffa fibers and also affected in the upgraded morphological qualities [1, 2, 4]. The investigation clearly indicates that a sturdy interface with reinforcement cell boundaries and Coupling reaction will take place among cellulose of reinforcement and benzene diazonium chloride and results in the development of a diazo cellulose compound, represents the enormous increment in tensile strength values [3, 5]. The fibers surface treatment by means of both benzene diazonium chloride, NaOH, gives the route for the evacuation of undesirable materials like waxes, oils, impurities, hemicellulose and lignin from the natural fibers in addition to the diminution of moisture retention, yields the higher level of (alpha) cellulose in natural fibers and, furthermore, cleans the fiber surface [2, 13]. Be that as it may, where as at 3-cm fiber length treated composite, even benzene diazonium chloride-treated composite, 5% NaOH-treated, 10% NaOH-treated, untreated biofiber composite presented inferior values [7, 14, 15] on account of more fiber length.

3.2 Flexural Properties

The specimens with dimensions 150 mm × 15 mm × 3 mm were fabricated and investigated for flexural properties as per the ASTM D 5943-96 standards. The deviation of flexural strength as a function of reinforcement length, with and without chemical action was noted and shown in Fig. 3. From the test it was noticed that the flexural property of the 2-cm length benzene diazonium chloride-treated Bagasse–Luffa fibers blended composite demonstrated elevated and optimum value than the 1-cm

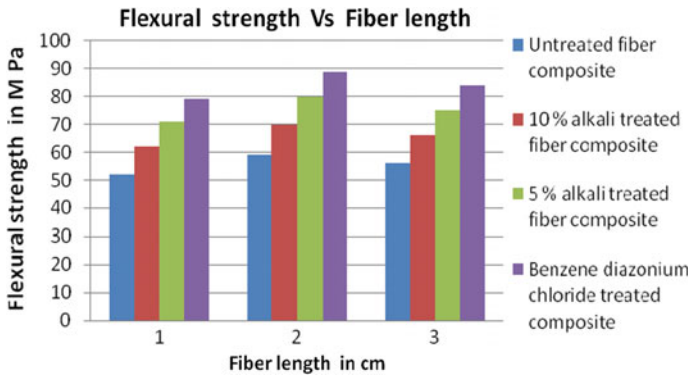


Fig. 3 Reveals the effect of alkali treatment, benzene diazonium chloride treatment and length of the fiber on the flexural property of biocomposites

and 3-cm length fiber, untreated, 5% NaOH-treated, 10% NaOH-treated composites [3, 9, 15, 16]. Due to the further alkali concentration at (10% NaOH), excess delignification of the fiber occurs, which brought about debilitating or harming of the fiber surface and effected in diminished flexural strength, than the (5% NaOH) treated composites and is indicated in the Fig. 3 [2, 17, 18]. Better fiber-matrix interaction and interfacial bonding was observed for 5% NaOH-treated composite compared with 10% NaOH-treated biocomposites [4, 11, 13, 18]. Alkali treatment mostly drive out the undesirable and debased materials like waxes, oil, hemicellulose and lignin, which yields a higher level for (alpha) cellulose in natural fibers and also cleanse the fiber's surface [5, 13, 16, 19]. But superior and noteworthy improvement of aspect ratio, fiber distribution in matrix blend, and stress convey capacity was viewed in benzene diazonium chloride-treated composites than in alkali-treated biofibers composites and untreated composites.

3.3 Compressive Strength

Specimens were manufactured and examined for Compressive strength properties as per ASTM D specifications. It was also seen that Benzene diazonium chloride-treated biocomposites disclosed predominant and ideal character for compressive strength than the alkali-treated and untreated biocomposites [3, 15]. The most favorable condition was an instantaneous outcome of factors like perfect fiber length, and chemical treatment, which was a direct result of variables like ideal fiber length, the better exterior coupling among resin and fibers resulted in ample stress transfer and performance [2, 14, 15]. Past works uncovers that fiber exterior modification by chemical treatment increases surface coarseness with the and lessening in dampness [12, 19, 20]. However, inferior compressive strength for the composite was detected at a reinforcement length of 3-cm treated composite. For reinforcement length of 3 cm,

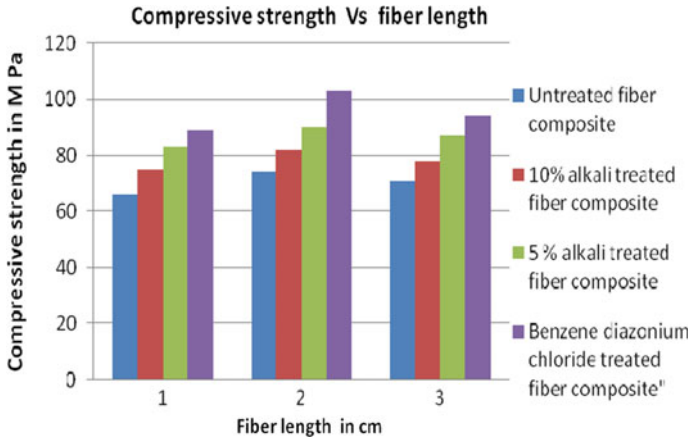


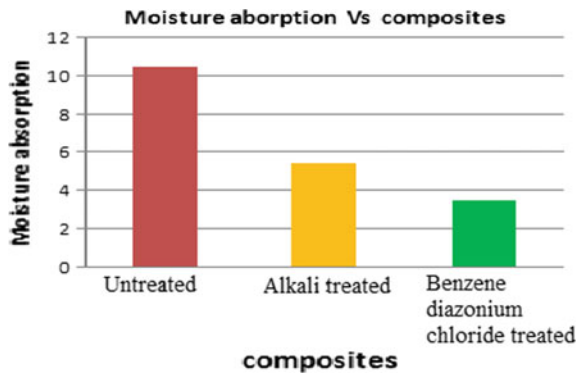
Fig. 4 Represents the compressive strength of untreated, alkali treatment, benzene diazonium chloride treated biocomposites

untreated and treated composites, there was a decline in the compressive property because of inadequate fiber–matrix interfacial bonding and micro-crack formation at the interface prompted deficient stress transfer. But benzene diazonium chloride treatment occupies the gaps of fiber with further aligning irregular fiber, more and better Compressive strength values as compared to alkali-treated composites [4, 16, 19] (Fig. 4).

3.4 Moisture Content Test

Figure 5 shows the incorporation rate of wetness amount by unprocessed reinforced composite, NaOH-processed and Benzene diazonium chloride-processed composites. The natural fibers composites show evidence of hydrophilic properties [2, 10].

Fig. 5 Moisture content absorption of unprocessed, NaOH-processed and benzene diazonium chloride-processed composites



Hydrophilic hydroxyl bunches present in the natural fibers were diminished by the alkali and Benzene diazonium chloride treatment, henceforth exterior of the fiber was tailored and increases the fibers wetness obstruction property, however which was more in Benzene diazonium chloride treatment [3, 5, 14]. The assimilation rate of dampness quantity by unprocessed fiber composite, was more when contrasted to alkali-treated and Benzene diazonium chloride-treated composites [4, 21].

3.5 Chemical Resistance Test

To gain knowledge of the chemical resistance of the composites in each case, the composite samples of $(5 \times 5 \times 3) \text{ mm}^3$ were inspected according to the ASTM D 543-87 [5, 22]. The chemical resistance test was conducted to know the impact of underneath referenced chemicals on unprocessed and treated fibers fortified composites. Then % weight loss or % weight gain values for unprocessed and processed biocomposites submersed in the mentioned chemicals was shown in Table 1. Put on in weight was observed for almost all the chemicals with the exception of toluene and carbon tetrachloride and which was indicated by in the table. The table obviously point out that processed biocomposites also have a weight drop in carbon tetrachloride [4, 9, 13]. The explanation for the weight reduction was a direct outcome of the assault of chlorinated hydrocarbons on the cross-connected vinyl ester-epoxy matrix blend system. The weight gain after the test demonstrated that the composites were

Table 1 shows the effect of chemicals on the weight of unprocessed and surface modified Biocomposites

Sl. no.	Chemicals used for the test	Weight loss (–) or gain (+) in %	
		Untreated composites	Treated composites
1	8% Acetic acid	11.85	12.31
2	40% Nitric acid	12.01	12.86
3	10% Hydrochloric acid	13.03	13.89
4	10% Sodium hydroxide	12.14	12.87
5	10% Sodium carbonate	10.07	10.68
6	10% Ammonium hydroxide	9.7	10.56
7	Benzene	2.03	2.73
8	Toluene	–1.74	–0.89
9	Carbon tetrachloride	–0.97	–0.78
10	Water	2.48	2.75

swelled with the gel creation rather than dissolving in chemical reagents [2, 5–7]. It was seen after the test that composites were also opaque to water, unaffected by almost all the chemicals excluding toluene and carbon tetrachloride.

3.6 Dielectric Strength

The investigation of dielectric strength of raw, NaOH-processed, and benzene diazonium chloride-processed composites, directed according to ASTM D-149 standards. The composite specimens with measurements of 120 mm × 120 mm × 3 mm were formed. The voltage was perceived for five points to all specimens, then the normal value was noted during the exploration. The test was directed at 50 Hz frequency and room temperature. Digital micrometer of 0.001 mm least count was employed to discover the thickness of the composites at the breakdown point. It was substantial that the dielectric strength of hybrid biofiber composites increments with an increase in the length of fiber from 1 cm to 2 cm but reduced at 3-cm length fiber treated and untreated composite [2, 4, 7, 15, 19]. At 3-cm length fiber composite, a decline in dielectric strength was noticed because of inappropriate fiber circulation in the matrix blend and meager interfacial bonding amid the fibers and matrix blend [5, 9] (Fig. 6).

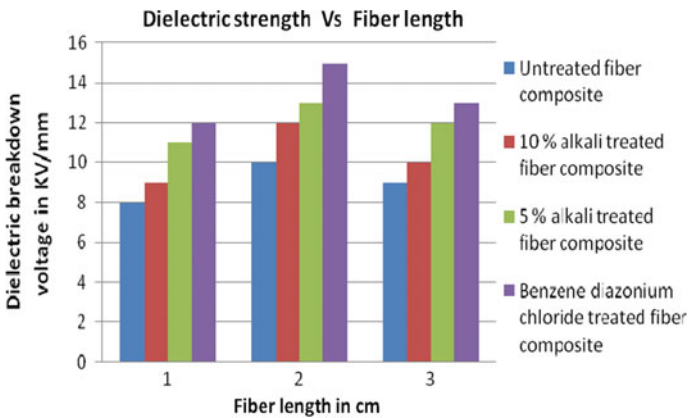


Fig. 6 Shows the dielectric strength of unprocessed, NaOH-processed and benzene diazonium chloride-processed composites

4 Conclusion

Chemical treatment carried out in the current work illustrates that, which extensively improves the fiber–matrix adhesion, enlarged the strength, and thus the performance of the natural fiber composites. The assimilation rate of dampness amount by unrefined fiber composite was more when contrasted with the alkali-treated and benzene diazonium chloride -treated composites. The tensile, compressive, and flexural strength esteems were improved for both alkali- and benzene diazonium chloride processed composites. But the benzene diazonium chloride treatment consumes the void gaps of fiber and adjusts uneven fibers looked superior strength values as compared to alkali-treated composites. The results show that the tensile, compressive and flexural strength of 2-cm length benzene diazonium chloride-treated fiber composites have exhibited have displayed prevalent and ideal values but 3-cm length fiber untreated and treated composite illustrated a substandard tensile, compressive and flexural strength, because of the improper fiber allocation in the matrix blend and deficient interfacial bonding between the fibers and matrix blend which additionally prompted diminished stress transferability. But after the chemical treatment or surface modification of fibers, it was exposed that improvement in the properties of the composites because of removal of impurities, hemicellulose, oils, waxes, pectin grease, and lignin from the surfaces of the fibers, and yields rough surface topography, which improves the aspect ratio of fibers and expands the strengthening output of the fiber with the improvement of stress convey from the matrix to load-bearing fibers.

References

1. Kaith BS, Singha AS, Sanjeev K, Susheel K (2008) Mercerization of flax fibre improves the mechanical properties of fibre-reinforced composites. *Int J Polym Mater* 57(1): 54–72
2. Prasanna GV, Rohit K (2019) Surface modification, characterization and optimization of hybrid bio composites. Springer (2019)
3. Edeerozey AM, Akil HM, Azhar AB, Ariffin MZ (2007) Chemical modification of kenaf fibres. *Mater Lett* 61: 2023–2025
4. Zhiwei X, Yudong H, Yuanjun S, Chunhua Z, Li L (2007) Surface characteristics of rare earth treated CFs and interfacial properties of composites. *J Rare Earths* 25: 462–468
5. Prasanna GV (2018) Modification, optimization of mechanical properties of bio fibers blended composites. *Int J Eng Technol* 7(2.33): 799–801
6. Prasanna GV, Subbaiah KV, Rajulu AV (2012) Chemical resistance, impact, flexural, compressive properties and optimization of fibers of natural fibers reinforced blend composites. *Scholarly J Eng Res* 1(6): 85–89
7. Prasanna GV, Jayadeep GT, Poornabhodha N (2019) Chemical treatment, influence of fiber content and optimization of hybrid natural fibers reinforced composites. Springer, The Smart Innovation, Systems & Technologies (SIST)
8. Raghavendra Rao H, Ashok Kumar M, Ramachandra Reddy G (2011) Hybrid composites: effect of fibers on mechanical properties. *Int J Macromol Sci* 1(1): 9–14
9. Alamgi MK, Monimul MH, Islam RM, Bledzki AK (2010). *BioResources* 5: 1618–1625

10. Akin DE, Gamble GR, Morrison WH, Rigsby L (1996) Chemical and structure analysis of fibre and core tissues from flax. *J Sci Food Agric* 72: 155–165
11. Kalia S, Kaith BS, Kaur I (2009) Pretreatments of natural fibres and their application as reinforcing material in polymer composites. *Rev Polym Eng Sci* 49: 1253–1272
12. Mohanty AK, Misra M, Drzal LT (2001) Surface modifications of natural fibres and performance of resulting bio-composites. *Compos Interfaces* 8(5): 313–343
13. Yu T, Ren J, Li S, Yuan H, Li Y (2010) Effect of fibre surface-treatments on the properties of poly (lactic acid)/ramie compo-sites. *Compos Part A Appl Sci Manuf* 41: 499–505
14. Bessadok A, Marais S, Roudesli S, Lixon C, Metayor M (2008) Influence of chemical modifications on water sorption and mechanical properties of Agave fibre. *Composites Part A* 39: 29–45
15. Myrtha K, Holia O, Anung S (2007) Physical and mechanical properties of natural fibers filled polypropylene composites and its recycle. *J Biol Sci* 7: 393–396
16. Prasanna GV, Subbaiah KV (2013) Hardness, tensile properties and morphology of blend hybrid biocomposites. *Scholar J Eng Res* 2(1): 21–29
17. Seena J, Koshy P, Thomas S (2005) The role of interfacial interactions on the mechanical properties of banana fibre reinforced phenol formaldehyde composites. *Compos Interfaces* 12: 581–600
18. Prasanna VG, Subbaiah KV (2013) Modification of Tensile, Compressive properties & Chemical Resistance of hybrid biocomposites. *Int J Nanomater Biostruct* 3(1): 9–12
19. Rajulu AV, Devi G, Rao GB (2003) Miscibility studies of epoxy/unsaturated polyester resin blend in chloroform by viscosity, ultrasonic velocity and refractive index methods. *J App Polym Sci* 89: 2970–2972
20. Zhang XR, Zhao P, Pei XQ, Wang QH, Jia Q (2007) Flexural strength and tribological properties of rare earth treated short CFs/polyimide composites. *Ex Poly Lett* 1(10): 667–672
21. Sreekal MS, Thomas S (2003) Effect of fibre surface modification on water-sorption characteristics of oil palm fibres. *Compos Sci Technol* 63: 861–869
22. Qianqian S, Xianhua C (2008) Effect of rare earths surface treatment on tribological properties of CFs reinforced PTFE composite under oil lubricated condition. *J Rare Earths* 6(4): 584–592
23. Zhang XR, Pei XQ, Wang QH (2007) The effect of fiber oxidation on the friction and wear behaviors of short-cut CFs/polyimide composites. *Ex Poly Lett* 5: 318–325
24. Su F, Zhang Z, Wang K, Jiang W, Liu W (2005) Tribological and mechanical properties of the composites made of carbon fabrics modified with various methods. *Compos A* 36: 1601–1607
25. Prasanna GV, Jha NK, Harish C (2018) Chemical treatment and analysis of mechanical properties of hybrid biocomposites. *Int J Mech Prod Eng Res Dev*: 189–193
26. Prasanna GV, Subbaiah KV (2013) Modification, flexural, impact, compressive properties and chemical resistance of natural fibers reinforced blend composites. *Malaysian Polym J* 8(1): 38–44
27. Prasanna GV, Jha NK (2019) Optimisation and mechanical testing of hybrid bio composites. *Mater Today*: 1395–1404
28. Punyamurth R, Sampathkumar D, Bennehalli B, Badyankal P, Vekateshappa SC (2014) Surface modification of abaca fiber by benzene diazonium chloride treatment and its influence on tensile properties of abaca fiber reinforced polypropylene composites. *Ciencia Tecnologia dos Mater* 26(2): 142–149
29. Anon A (1992) A guide to unusual natural fibres: pineapple leaf fibre (PALF). *Textiles* 21(3)
30. Morrison RT, Boyd RN (1989) Organic chemistry. Prentice-Hall, London