70(10A): 123-133; 2022. DOI: 10.18311/jmmf/2022/31211

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Comparative Testing of Tensile, Flexural and Impact Analysis on Coated and Uncoated Kenaf Fiber Reinforced Composite

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Abstract

Due to its enhanced strength, stiffness, and tensile qualities, fibre reinforced composites are being employed more and more in the aerospace, automotive, plastic and mineral processing industries. Kenaf, jute, Kemp, and other types of reinforcing fibres are frequently utilized and come in strips. The design and analysis of the mechanical characteristics of the Kenaf fibre reinforced composite is the primary goal of this project. Different combinations of fibre and resin are examined for their various mechanical qualities, such as impact resistance, flexural strength, and tensile strength. By altering the fibre orientation and boosting impact strength, the composite is created. By altering the fibre orientation and boosting impact strength, the composite is created. The composite is personally examined using a variety of testing tools, and it is also examined using design software like Ansys. This research aims to increase the composite's impact strength by adjusting the fibre length. The hydrogen peroxide solution is also coated on the composite before the tests are run. Comparisons are made between the experimental findings for coated and uncoated composites.

Keywords: *Composite materials, Kenaf fiber, Impact testing, Hydrogenperoxide.*

1.0 Introduction

The three parts of a fiber-reinforced composite (FRC), also known as an interface, are the matrix as the continuous phase, the fibres as the discontinuous or dispersed phase, and the fine interphase zone. This category of advanced composite group uses plastic, rice hull, and rice husk as materials. In this technology, natural fibres from cellulosic waste streams are refined, blended, and compounded to create a high-strength fibre composite material in a polymer matrix. The waste thermoplastics and various cellulosic waste categories, such as rice husk and sawdust, are the designated waste or base raw materials in this case.

FRC is a high-performance fibre composite made feasible by a unique molecular re-engineering process that cross-links cellulosic fibre molecules with resins in the FRC material matrix to produce a material with remarkable structural qualities. This accomplishment of molecular re-engineering

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specified physical and structural characteristics of wood is effectively cloned and vested in the FRC product, together with other essential traits, to produce performance properties superior to modern wood. Unlike other composites, this one may be recycled up to 20 times, making it possible to keep using leftover FRC. Jute and Kenaf fibres combined with epoxy increase the materials' tensile, flexural, and impact strength. Natural fibres are used as reinforcement because they can reduce tool wear, respiratory discomfort, and serve as alternatives to artificial fibre composites in the face of an expanding global energy crisis and environmental dangers.

In general, two procedures are used to create composites of PVC and inexperienced coconut fibres. The authors used dynamic modulus measurements to assess the mixer's homogeneity. They determined that there are no physicochemical interactions between the matrix and the fibers.1 examined the micromechanical calculation methods to determine the stiffness and impact resistance of a fibre reinforced epoxy-single-layer-composite. They used cotton, ramie, and synthetic lyocell fibres in their work [2]. They evaluated the bio-composites, technology, and environmental suggestions. They investigated the variables that influence the behaviour of such natural fibre composites [3] they developed simplex perishable composites from Manila hemp fibre bundles and starch-based emulsion-type biodegradable resin. The experiments were conducted at the temperature range of 10-200ºC, 50-60% ratio conditions. The relationship between the particular wear rate and also the friction constant against the Kevlar pulp content were found for each dry and water lubricated condition. Friction constant was reduced with increase in filler content and optimum resolution was obtained once Kevlar pulp content was 60%. A reduction in the particular wear rate was seen once Kevlar pulp content had 40% volume of filler content due to the optimum resolution for the composites [5] abaca fibre reinforced polypropene composites with totally different fibre loadings and flax and jute fibre reinforced polypropene composites with 30% weight. The mechanical properties and structural properties for these composites were investigated. They found tensile, flexural and Charpy impact strength for fibre loadings as up to 40% reduction [6]. The composites with natural and thermosetting matrix made with compression moulding and all chopped natural fibres up to 10 mm long they studied each green composite system's surface shear strength, flexural characteristics, and dynamic mechanical properties. The authors determined that integrating natural fibres into the resin matrix significantly improved the properties of the compound resins [7], reviewed ways for determining the physical phenomena of natural fibres and examined the merits and limitations of approaches used. They determined that the physical phenomenon of the fibre increased the cellulose content of natural fibers [8]. They created a summary of the many factors in green composites. They mentioned that composites supported vital perishable matrices such as rubber, poly-carboxylic acid, etc and created a special stress on natural rubber-based green composites [9]. Prepared factory-made green composites composed of long size fibres and polycaprolactone perishable polyester matrix and investigated the influence of varied parameters on the tensile properties. They discovered the strength and coefficient of elasticity of the composites in the hyperbolic steady reckoning on the rise in fibre space fraction [10]. Did work relating to the replacement of glass fibres by curaua fibre and applied the same for automotive applications that lead to economic, social and environmental benefits [11], fabricated composite panel victimization virgin and recycled High-density synthetic resin and five varieties of natural fibres together with four rice straw elements. They investigated the fibre characteristics and also the influence of fibre sort and loading rate on HDPE crystallization behaviour and mechanical properties [12]. By incorporating sisal and oil palm fibres into a natural rubber matrix, they investigated the influence of fibre quantitative relationship on activity and also analysed the tensile properties of hybrid fibre reinforced natural rubber composites [13]. In their review work, they prescribed the various aspects of plastic fibres and bio-composites. They praised the use of plastic fibre reinforced compound composites in a variety of fields such as industry, automotive trade, and so on [14]. They investigated the mechanical properties of ethylene vinyl acetate and cellulose acetate composites containing udal fibre and attempted to explain them using fibre blending within the composite. They discovered that the addition of fibre lowered the strength of EVA composite [15].

2.0 Materials and Methodology

KENAF

Kenaf Hibiscus cannabinus is a plant of the Malvaceae family. Hibiscus cannabinus belongs to the Hibiscus genus and is probably native to South Asia, although its exact natural origin is unknown. The name is also applied to the fiber obtained from this plant. Kenaf is one of the related jute fibers and shares similar properties. The fibers in kenaf are found in raffia (bark) and kernel (wood). The bast makes up 40% of the plant. The "crude fibre" is separated from the bast and becomes multicellular, consisting of several interconnected individual cells. Individual fiber cells are 2-6 mm long and thin (6.3 m). The thickness of the cell wall. The core, which makes up roughly 60% of the plant, includes fibre cells with thick (38 mm) but short (0.5 mm) and thin walls (3 mm) walls. Paper pulp is created by using the entire stem, and as a result, it contains both bast and core fibres. The pulp has a comparable quality to hardwood. The fibres used to make Kenaf are blasted from the plant, pounded firmly to remove moisture, and then dried for two to three weeks in the sun at higher temperatures. Water retting has been used to remove the fibres from their stalks over around 20 days. After the water retting process is completed, the fibers were the ncleaned with water and dried under the sunlight. Then the fibers are undergone the alkali treatment.

Alkali treatment

Fibers are treated with the 6% NaoH solution. Fibers were immersed in the 6% NaoH solution for 24 hoursat the room temperature. Fibers were then dried in the absence of sunlight until the fibers are dried completely. The fibers are the nseparated and used for the manufacturing of the composite.

Preparation of Composite

The composite is synthetic with the aid of using the hand lay-up method. A forged iron die of three hundred mm x three hundred mm x four mm ismade. After the Moulds of required

Figure 1: Kenaffiber composite material

dimensions had been prepared, wax became carried out to the internal aspects of the mildew for clean launch of the composite without sticking to the mildew walls. Then hardener combined with epoxy. So matrix became prepared. The epoxy and the hardener ratio had been maintained at 10:1. The suitable amount of fibers became placed such that epoxy combination absolutely spread over the fibers after initial layer of the mildew became full of the epoxyres in and hardener combination but again, epoxy combination became poured at the fiber. As a result, the beginning and finishing of the layers had been of epoxyresin.

A plastic releasing organization becomes positioned at the pinnacle of the uncured mixture. Before software of compression, efforts had been made to put off all bubbles the use of roller. Then the compression stress of 0.05 MPa become implemented and cured for twenty-four h at room temperature evenly. In this, specimens containing 40% quantity fractions of fiber had been prepared. The specimen is prepared according to ASTMD 3039-76 is used for carryingout tests.

After the specimens were made according to the tests. Some of the specimens are coated with the hydrogen peroxide solution to compare the results of the mechanical testing of the composites between the coated and the uncoated composites.

3.0 Tensile Test

The hybrid composite samples S1, S2 and S3 of categories C1, C2 and C3 were tested using a universal testing machine to find the tensile properties. Table 1 shows the tensile values of developed composites. Figure 2 shows the tensile test for C1. The result shows the S2 having a higher tensile strength of 36 N/mm^2. Figure 3 shows the tensile strength C2 of S1 as

Table 1: Tensile test of samples S1, S2 and S3 of categories C1, C2 and C3

	Category	Samples	Ultimate Tensile Load (kN)	Average Ultimate Tensile Load (kN)	Ultimate Tensile Strength (N/mm^2)	Average Ultimate Tensile Strength (N/mm^2)
1	C1	S1	2.18	2.4	31.00	34
		S2	2.54		36.00	
		S3	2.52		34	
2	C2	S1	3.79	2.96	22.00	18
		S2	2.77		17.00	
		S3	2.33		15.00	
3	C3	S1	2.90	3.2	37.00	38
		S2	3.41		40.00	
		S3	3.29		38.00	

22 N/mm². C3 of S2 shows a higher tensile strength of 40 N/mm² (Figure 3). Figure 4 shows the tensile strength for the hybrid composite having a higher tensile value of 38 N/mm². The combination of hemp and flax fibre demonstrated greater tensile strength than the other two composites, according to the tensile test results. The relationship between stress and strain in a tensile test demonstrates a linear increase in stress

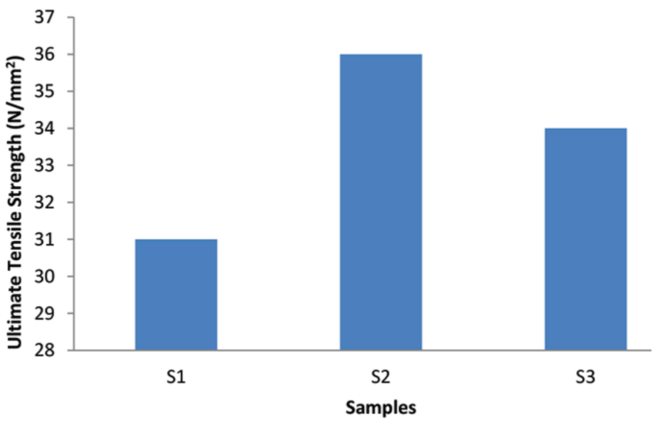


Figure 2: Tensile strength of Composite 1

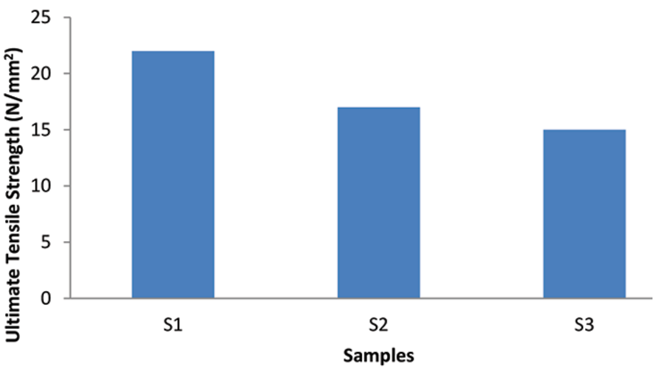


Figure 3: Tensile strength of Composite 2

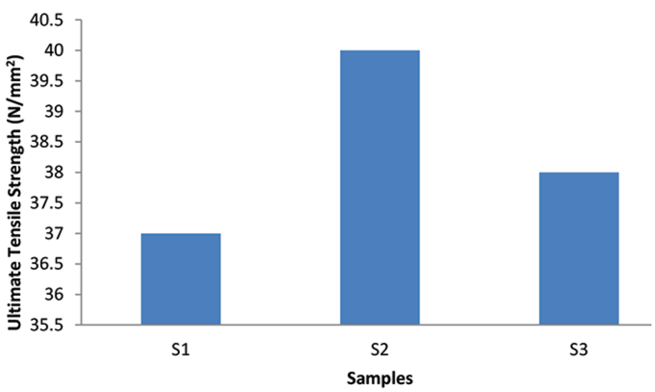


Figure 4: Tensile strength of Composite 3

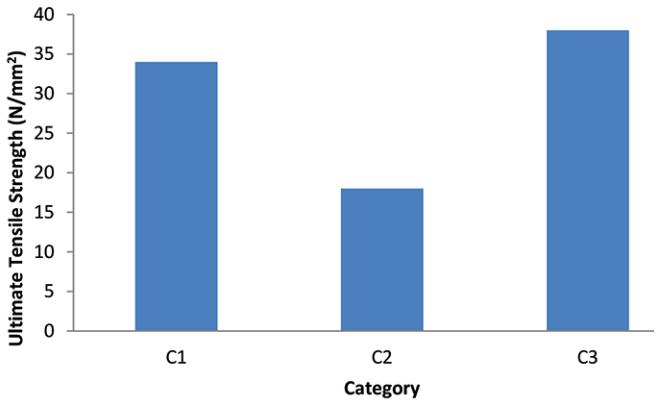


Figure 5: Average tensile strength of samples category

that corresponds to strain. Since, mechanical behaviour of flax is comparably lesser than hemp, C2 shows less tensile strength.

Flexural Test

The hybrid composite samples S1, S2 and S3 of categorized as C1, C2 and C3 were tested using the universal testing machine to find the flexural properties. Table 2 shows the flexural value of developed composites. Figure 6 shows the flexural test for C1. The result shows the S2 with higher flexural, that is, 100.23 N/mm². Figure 7 shows the flexural strength for C2 and S1 as 40.36 N/mm². S2 shows the higher flexural strength of 89.66 N/mm² in C3 in Figures 6 and 7. Figures 6 and 8 show the flexural strength for the hemp composite having higher flexural value with an average of 88.26 N/mm². The flexural result revealed the hemp fibre having impact on increasing the flexural strength. The stress strain relation shows that there is linear increase in stress corresponding to strain in flexural test.

Impact Test

The hybrid composite samples S1, S2 and S3 of categories C1, C2 and C3 were tested in the Charpy impact testing to catch out the impact strength. Table 3 shows the impact value of the developed composites. Figure 10 shows the C2 having a higher impact strength with an average of 4 J. This reveals the exhibition of higher impact strength than the other two composites for flax fibre. Since, strength normally depends on fibre properties not much on fibre orientation, the impact behaviour of all the three categories are nearer to each other.

Double Shear Test

Using a universal testing machine, the hybrid composite samples S1, S2, and S3 of categories C1, C2, and C3 were tested to determine the double shear properties. Table 4 shows the double shear value of fabricated composites.

Table 2: Flexural test of samples S1, S2 and S3 of categories C1, C2 and C3

Sl. No.	Category	Samples	Ultimate Flexural Strength (N/mm^2)	Average Ultimate Flexural Strength (N/mm^2)
1	C1	S1	86.06	88.26
		S2	100.23	
		S3	78.49	
2	C2	S1	40.36	39.51
		S2	38.94	
		S3	39.25	
3	C3	S1	86.77	86.26
		S2	89.66	
		S3	82.37	

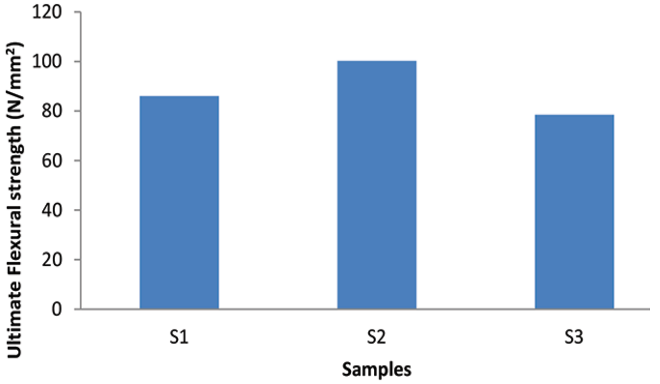


Figure 6: Flexural strength of Composite 1

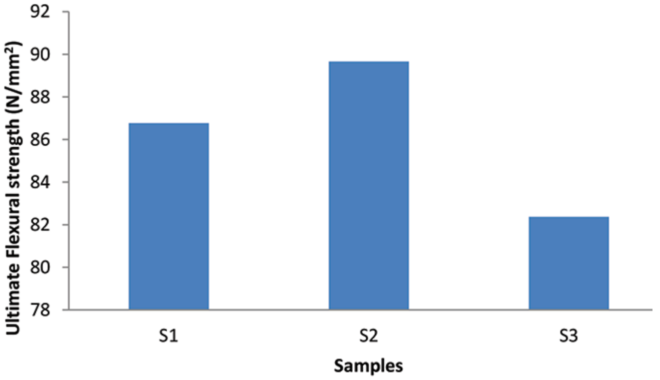


Figure 8: Flexural strength of C3

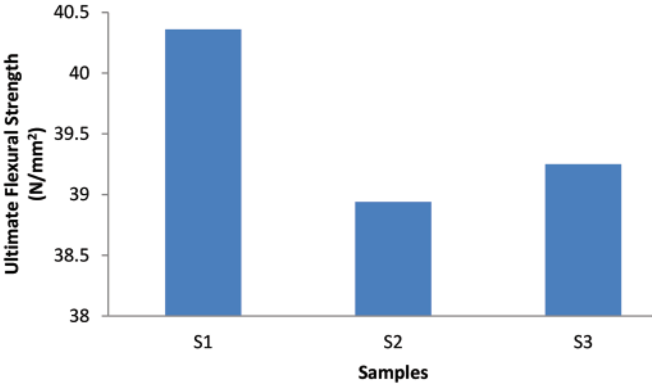


Figure 7: Flexural strength of C2

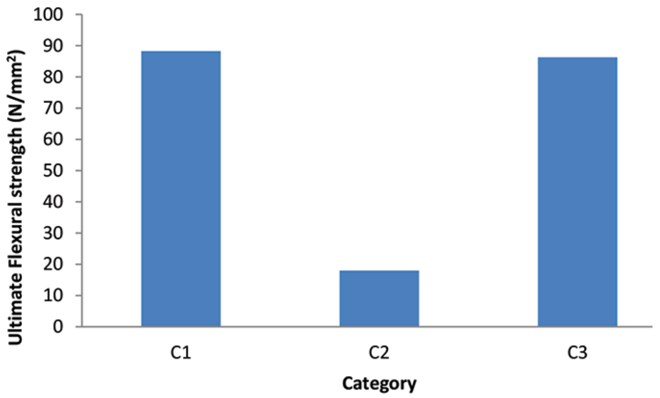


Figure 9: Average flexural strength

Figure 11 shows the double shear strength for C1. The result shows the S3 with higher double shear strength of 1.056 kN. Figures 12 shows the double shear strength of C2 while S3 shows the higher double shear strength of 0.849 kN. Figure 12 shows the double shear strength of C3. The result shows S3 with higher strength double that of that of 1.350 kN. Figure 13 reveals hybrid composite having higher strength of 1.273 kN than the other two composites. The stress strain relation shows that there is linear increase in stress corresponding to strain in double shear test.

Table 3: Impact test of samples S1, S2 and S3 of categories C1, C2 and C3

	Category	Samples	Energy Absorbed (J)	Average Energy Absorbed (J)
1	C1	S1	2	2
		S2	2	
		S3	2	
2	C2	S1	4	4
		S2	4	
		S3	4	
3	C3	S1	2	2
		S2	2	
		S3	2	

Table 4: Double shear test of samples S1, S2 and S3 of categories C1, C2 and C3

Sl. No.	Category	Sample	Break Load (kN)	Average of Break Load (kN)	Maximum Displacement (mm)	Average Maximum Displacement (mm)
1	C1	S1	0.868	0.955	2.91	2.92
		S2	0.941		2.83	
		S3	1.056		3.03	
2	C2	S1	0.729	0.787	3.28	3.3
		S2	0.784		3.22	
		S3	0.849		3.40	
3	C3	S1	1.196	1.273	3.46	3.47
		S2	1.274		3.36	
		S3	1.350		3.60	

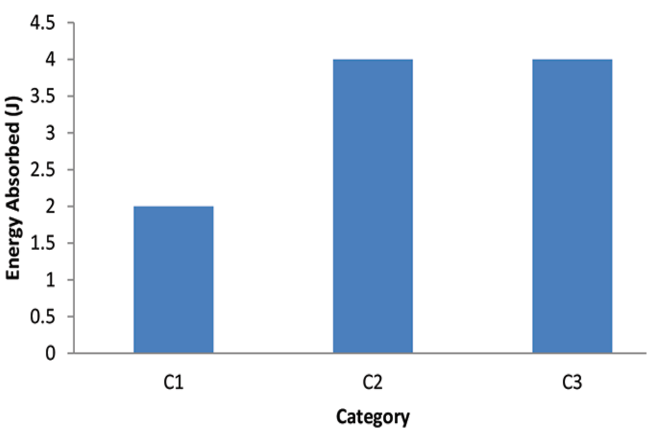


Figure 10: Average impact strength

Hardness Test

Hardness depends on the material property which is about the intended portion that tends to absorb the abrupt shock. The Table 5 shows the hardness value for the all three categories. C1 has hardness value of 92.6 HRL, C2 has 90.6 HRL and C3 has 94.8 HRL. Figure 14 show the Rockwell hardness values. The hybrid composite C3 has higher hardness value than the other composites.

Morphological Analysis after Mechanical Test

Morphological analysis was performed using a scanning electron microscope. The properties of the inner surface of the tested material were examined by SEM. Samples were

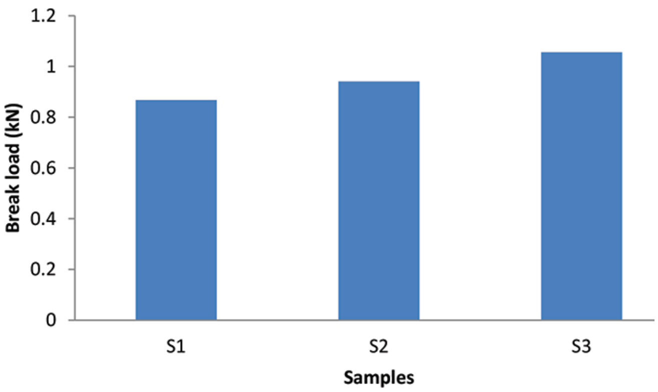


Figure 11: Double shear strength of C1

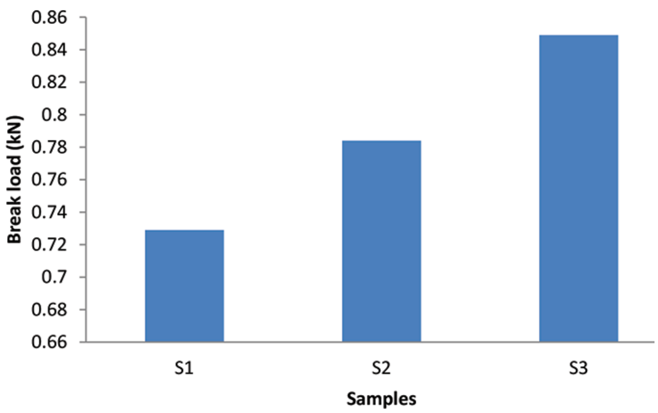


Figure 12: Double shear strength of C2

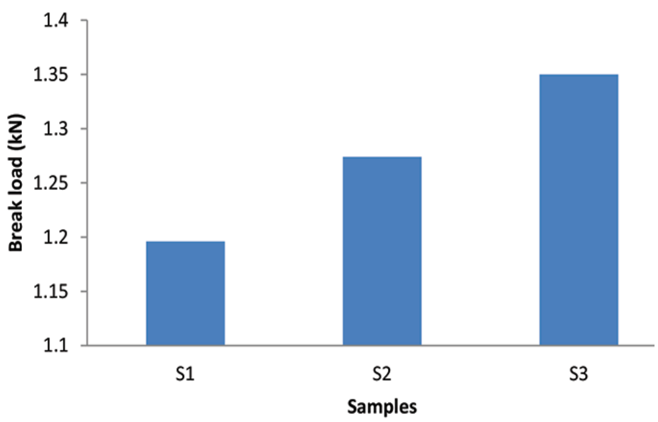


Figure 13: Double shear strength of C3

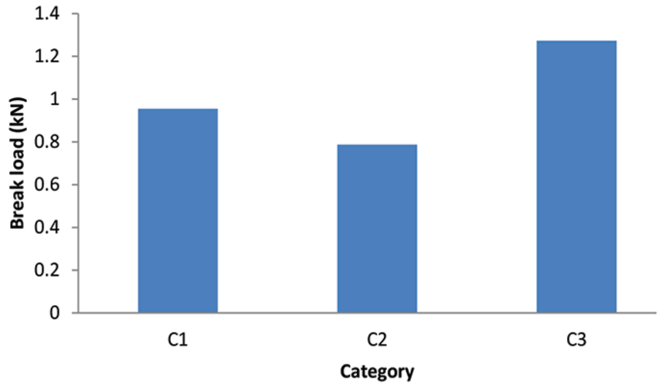


Figure 14: Average break load

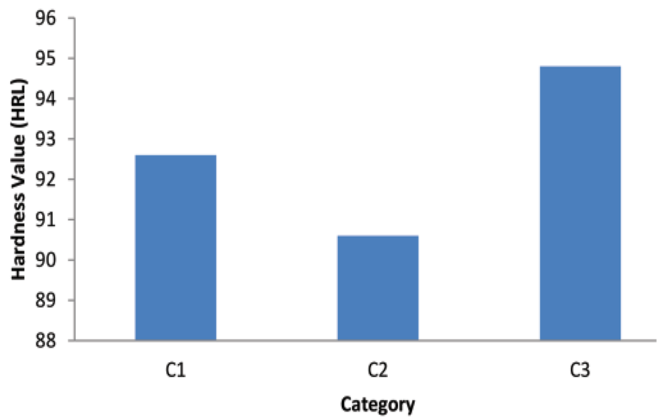
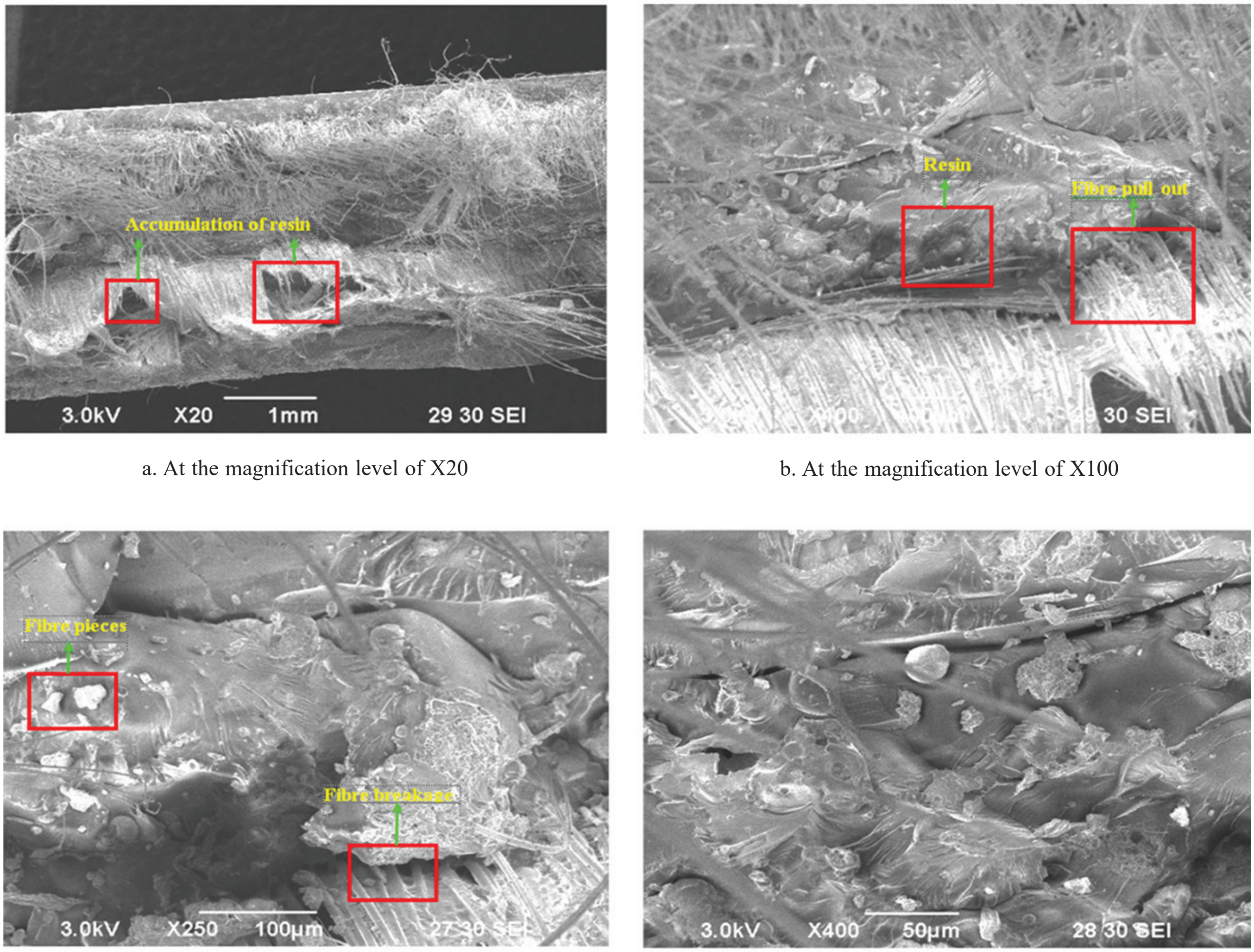


Figure 15: Hardness test

Table 5: Hardness test of categories C1, C2 and C3

Sl. No.	Category	Hardness Value (HRL)
1	C1	92.6
2	C2	90.6
3	C3	94.8



a. At the magnification level of X20

b. At the magnification level of X100

c. At the magnification level of X250

d. At the magnification level of X400

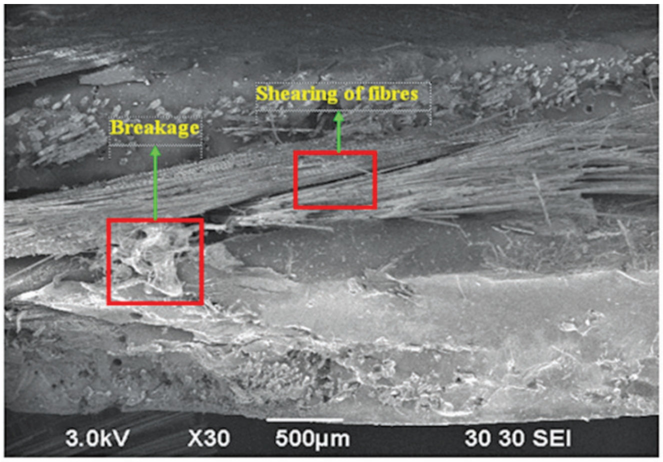
Figure 16: SEM image of C1 after tensile test

taken from each test, dried and coated with a 15-20 nm thick layer of gold using an ion sputter coater. Consequently, the samples were examined by a scanning electron microscope. The interfacial adhesion between the matrix and also the fiber can be clearly seen in the SEM image.

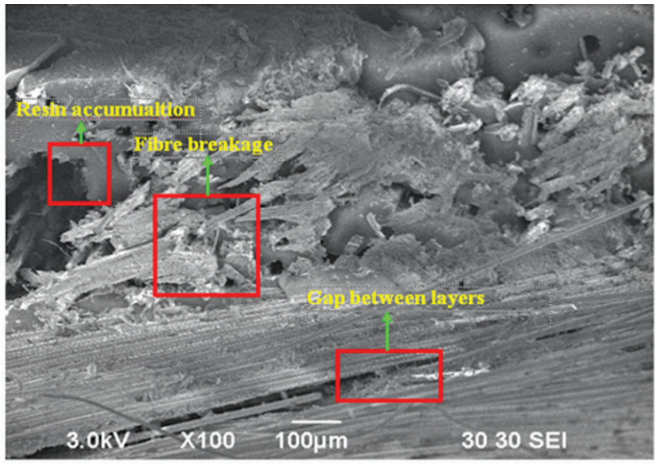
Resin accumulation observed in the tested samples is shown in Figure 16(a), is the result of improper distribution and spreading of resin and hardener mixture. This can be circumvented by a choosing suitable mixing ratio and also proper curing time of laminates under weight. Fibre pullout seen in Figure 16(b) is the result of improper packing of fibres in the composite materials. Fibre breakage seen in Figure 16(c) is due to improper treatment of fibres. This leads to the reduction in tensile strength and some mechanical characteristics of composites. This may be prevented through fibre remedy and right fabrication procedure.

Fibre breakage observed in Figure 17(a) may be the result of improper curing time given while fabricating the composite laminate. Fibre shear observed is meant for implementation of proper fabrication procedure. In Figure 17(d) the fibre breakage is clearly noted. It is the result of a lack in cohesiveness between resin and fibres used. This can be avoided by proper selection of resin fibre volume fraction.

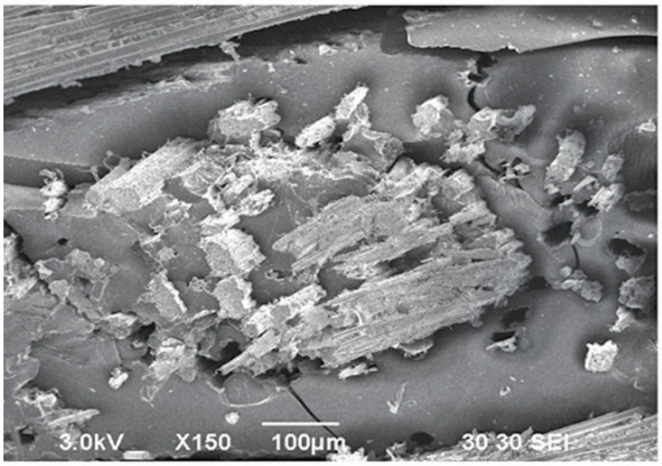
Figure 18(a) shows fibre layer movements while applying a load. In general if proper packing and curing is done the fibre layers should not shear like this. Hence, careful selection of curing and load placed on the composite laminate is required for avoiding this. Some fibre twisting also observed is due to improper combining of fibres. If combining is done properly, the fibres should not get twisted which in turn



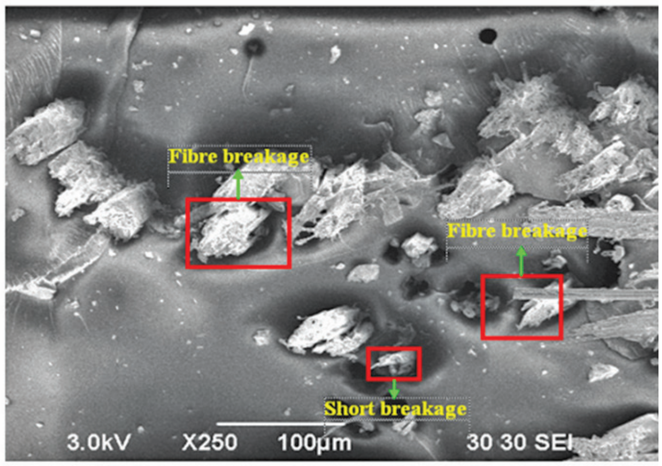
a. At the magnification of X30



b. At the magnification of X100



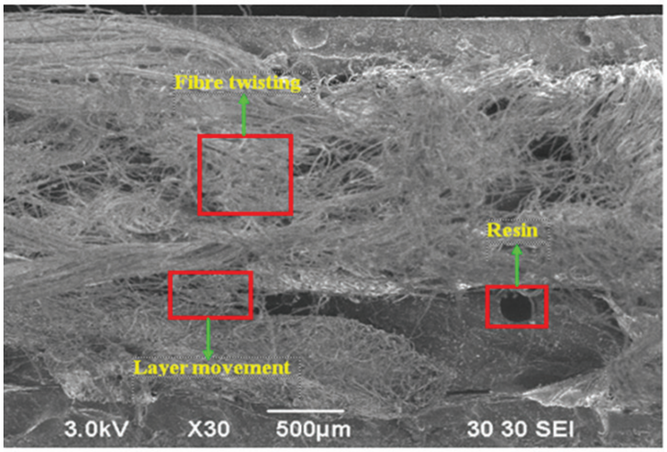
c. At the magnification of X150



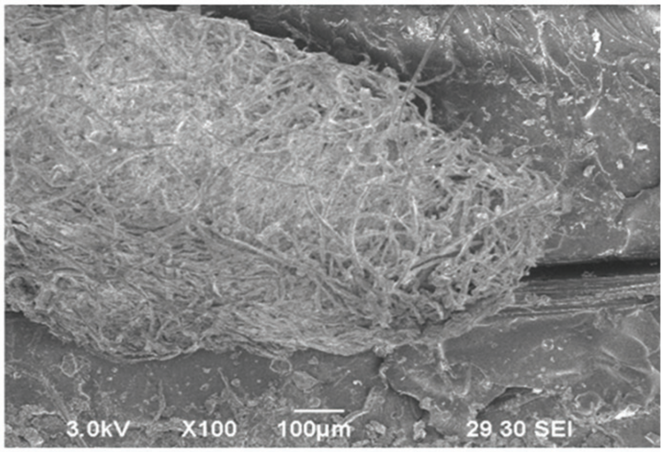
d. At the magnification of X250

Figure 17: SEM image of C2 after the tensile test

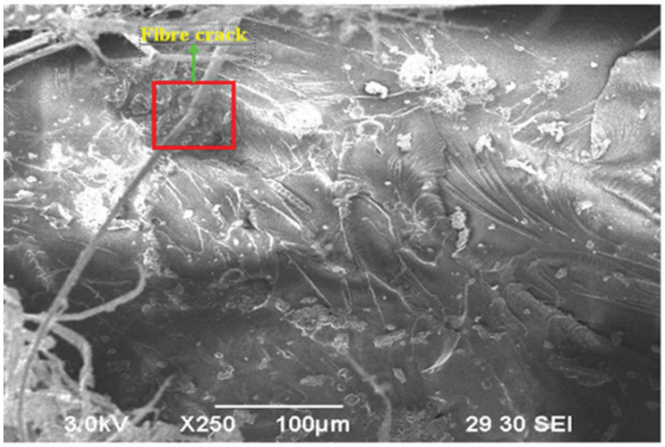
increases the strength of composite laminate. Resin accumulation noted can be avoided by proper distribution of resin during fabrication. Fibre crack is observed in the figure 18(c) which is the result of applied tensile load. Normally, fibre crack should be avoided by proper packing of fibres in the laminate while fabricating it. It may also be avoided by treating the fibre before going for fabrication of composite laminate. From the figure 18(d) accumulation of resin and hardener mix is found which the result of improper mixing. It can be avoided by proper selecting of resin, hardener mixing ratio and also applying on fibre layers before their solidification.



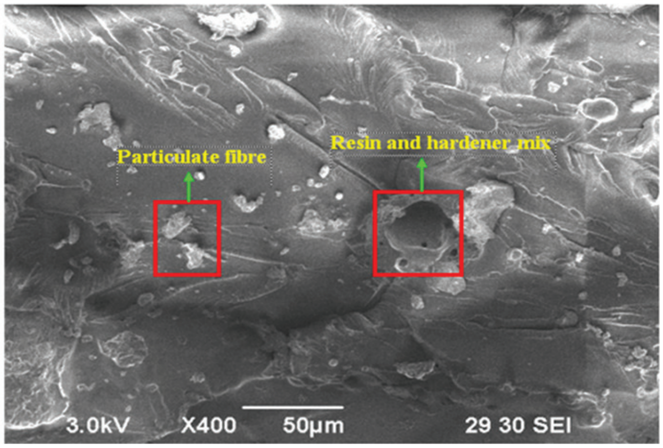
a. At the magnification of X30



b. At the magnification of X100



c. At the magnification of X250



d. At the magnification of X400

Figure 18: SEM image of C3 after the tensile test

4.0 Conclusion

In this work, the hybrid composite samples S1, S2 and S3 of categories C1, C2 and C3 are tested with the universal testing machine to sort out the tensile properties. The tensile result shows that the C1 of S2 has higher tensile strength of 36 N/mm^2. It is also noted that the tensile strength C2 of S1 is 22 N/mm^2. The C3 of S2 shows higher tensile strength of 40 N/mm^2. Hence, from this it can be concluded that the tensile strength of the hybrid composite has a higher tensile value of 38 N/mm^2. Tensile results show that the combination of hemp and flax fibers has superior tensile strength to the other two composites.

Hybrid composite specimens S1, S2 and S3 of categories C1, C2 and C3 are tested for bending properties in a universal testing machine. The result shows the C1 of S2 with higher flexural that is 100.23 N/mm^2. The flexural strength of C2 of S1 is 40.36 N/mm^2. It is noted that C3 of S2 shows the higher flexural strength of 89.66 N/mm^2. Hence, it is concluded that the flexural strength for the hemp composite has higher flexural value with an average of 88.26 N/mm^2. The flexural result reveals that the hemp fibre has main impact in increasing the flexural strength.The hybrid composite samples S1, S2 and S3 of categories C1, C2 and C3 are tested in the Charpy impact testing to find out the impact strength. The result shows that all the three samples S1, S2 and S3 has the same impact strength of 2 J. C2 also has an average of 4 J as an impact value. C3 has the impact value of 2 J. Hence, it is concluded that the C2 shows the higher impact strength with an average of 4 J. This reveals that flax fibre exhibits higher impact strength than the other two composites.

The hybrid composite samples S1, S2 and S3 of categories C1, C2 and C3 are tested using the universal testing machine to find out the double shear properties. The result shows that the C1 of S3 with higher double shear strength of 1.056 kN. The double shear strength of C2 of S3 shows the higher double shear strength of 0.849 kN. The result shows C3 of S3 with higher double strength that of 1.350 kN. The Figure 13 reveal that the hybrid composite has higher strength of 1.273 kN than the other two composites. Hardness especially depends on the material property during which the intended portion tends to absorb the abrupt shock. The C1 has the hardness value of 92.6 HRL, C2 has 90.6 HRL and C3 has 94.8 HRL. The hybrid composite C3 has higher hardness value than the other composites. The wear test result shows that, experiment 1 gives best performance.

5.0 References

1. Naveenkumar, Sharun V, Dhanasakkara varthi B, Paul The ophilus, Rajakumar I., 2015.Comparative study on Jute and Kenaf fiber composite material.
2. Kotresh Sardar, Dr. K. Veeresh, Manjunatha Gowda., 2014. Characterization and In vestigation of Tensile Teston Kenaf Fiber Reinforced Polyester Composite Material.
3. N. Saba, M. T. Paridah, M. Jawaid., 2014. Mechanical properties of kenaf fibrere inforced polymer composite.
4. Mohd Suhairil Meona, Muhamad Fauzi Othmana, Hazran Husaina, Muhammad Fairuz Remelia, Mohd Syahar, Mohd Syawala., 2012. Improving tensile properties of kenaf fibers treated with sodium hydroxide.
5. S. Jeyanthi and J.Janci Rani., 2012. Improving Mechanical Propertiesby KENAF Natural Long Fiber Reinforced.
6. Mohd Yuhazri, Y., Phongsakorn, P. T., Haeryip Sihombing, Jeefferie A.R., Puvanasvaran Perumal, Kamarul, A.M, and Kannan Rassiah., 2011. Mechanical Properties Of Kenaf/Polyester Composites.
7. M. R. Ishak1, Z. Leman, S. M. Sapuan, A. M. M. Edeerozey and I. S. Othman., 2010. Mechanical properties of kenaf bast and core fiber reinforced unsaturated polyester composites.
8. Seong Ok Han, Mehdi Karevan, I. Na Sim, Md A. Bhuiyan, Young Hun Jang, Jonathan Ghaffar, and Kyriaki Kalaitzidou., 2012. Understanding the Reinforcing Mechanisms in Kenaf Fiber/PLA and Kenaf Fiber/PP Composites: A Comparative Study.
9. Jong Sung Won, Ji Eun Lee, Da Young Jin, and Seung GooLee., 2015. Mechanical Propertiesand Biodegradability of the Kenaf/Soy Protein Isolate-PVA Biocomposites.
10. Suhad D. Salman, Mohaiman J. Sharba, Z. Leman, M.T.H. Sultan, M.R. Ishak, and F. Cardona., 2015. Physical, Mechanical, and Morphological Properties of Woven Kenaf/Polymer Composites Produced Usinga Vacuum Infusion Technique.
11. M. Thiruchitrambalam, A. Alavudeen, A. Athijayamani, N. Venkateshwaran and A. Elaya Perumal., 2009. Improving Mechanical Properties Of Banana/Kenaf Polyester Hybrid Composites Using Sodium Laulryl Sulfate Treatment.
12. Olusegun David Samuel, Stephen Agbo, Timothy Adesoye Adekanye., 2012. Assessing Mechanical Properties of Natural Fiber Reinforced Composites for Engineering.
13. Nur Hafizah Bt Abd Khalid1 and Jamaludin Mohamad Yatim., 2010. Tensile Behaviour Of The Treated And Untreated Kenaf Fibers
14. Saiful Izwan Abd Razak, Wan Aizan Wan Abdul Wahman, Mohd Yazid Yahya., 2013. Novel epoxy resin composites containing polyanilinecoatedshort kenaf bast fibers and polyaniline nano wires: mechanical and electrical properties.
15. A. Bovas Herbert Bejaxhin, G. M. Balamurugan, S. M. Sivagami, K. Ramkumar, V. Vijayanand S. Rajkumar, “Tribological Behaviour and Analysis on Surface Roughness of CNC Milled Dual Heat Treated Al6061 Composites”, Advances in Materials Science and Engineering, Volume 2021, Article ID 3844194,14 pages, https://doi.org/10.1155/2021/3844194.
16. Muthu Mekala N, Balamurugan C, Bovas Herbert Bejaxhin, “Deform 3D Simulation and Experimental Investigation of Fixtureswith Support Heads”, MECHANIKA. 2022 Volume 28(2): 130"138, ISSN1392"1207.http://dx.doi.org/10.5755/j02.mech.29468.
17. J Jones Praveen, M Vinosh, A Bovas Herbert Bejaxhin, G Paulraj, “Embedded effect of ZrB2-Si3N4 on tribological behaviour of Al8011 metal matrix composite”, Materials Today: Proceedings, Elsevier.https://doi.org/10.1016/j.matpr. 2020.10.954.
18. L. Natrayan and M. Senthil Kumar, “An integrated artificial neural network and Taguchi approach tooptimize the squeeze cast process parameters of AA6061/Al_2O_3/SiC/Gr hybrid composites prepared by novel encapsulation feeding technique,” *Materials Today Communications*, vol.25, p.101586, 2020.
19. L. Natrayan, M. Ravichandran, Dhinakaran Veeman, P. Sureshkumar, T. Jagadeesha, Wubishet DegifeMammo, “Influence of Nanographite on Dry Sliding Wear Behaviour of Novel Encapsulated Squeeze CastAl-Cu-Mg Metal Matrix Composite Using Artificial Neural Network”, Journal of Nanomaterials, vol.2021, pp.1-14, 2021.https://doi.org/10.1155/2021/4043196.
20. L. Natrayan, Anjibabu Merneedi, Dhinakaran Veeman, S. Kaliappan, P. Satyanarayana Raju, Ram S ubbiah, S. Venkatesh Kumar,” Evaluating the Mechanical and Tribological Properties of DLCN anocoated Aluminium 5051 Using RF Sputtering”, *Journal of Nanomaterials*, vol. 2021, pp. 1-7, 2021.https://doi.org/10.1155/2021/8428822