Fabrication and Testing of Bio Fiber-Glass Hybrid Composites

K. Sabeel Ahmed [1], G H Manjunath Achar [2], Shreyas S H[3], Sohan M R[4], Sathvik M S[5], Sandeep S[6]

[1]*Professor, Dept. of Mechanical Engineering, JNN College of Engg. Karnataka State, India*
[2]*Assistant Professor, Dept. of Mechanical Engineering, JNN College of Engg. Karnataka State, India*
[3,4,5,6] *Students, Dept. of Mechanical Engineering, JNN College of Engg., Karnataka State, India*

---***---

Abstract - *This paper discusses about the fabrication and testing of flax, hemp and glass fiber reinforced isophthalic polyester hybrid composites. Woven hemp fiber mat and flax fiber mat having a surface density 220 GSM and bi-directional glass fiber mat with surface density 90 GSM were used as reinforcement materials. The specimens prepared from the composites are tested for mechanical properties like tensile, flexural, hardness and impact. The tensile and flexural strength tests were conducted using Zwick Roell Z020 machine and hardness test was conducted using Shore D hardness tester. Izode impact test was conducted using pendulum type impact testing machine. Overall results of the tension test revealed that flax fiber composite exhibited better tensile properties (tensile strength and modulus) when compared to hemp fiber composites. Whereas the trend is opposite in case of flexural properties. Hemp fiber composite exhibited better bending properties (flexural strength and modulus) when compared to flax fiber composites. Further, incorporation of glass in individual bio fiber composite resulted in improved mechanical properties (except the flexural modulus of hemp-glass composite). The mechanical properties of three fiber (flax-hemp-glass) hybrid composites lie in between the properties of individual bio fiber composites and bio fiber glass hybrid composites.*

Key Words*: *Flax fiber, Hemp fiber, Glass fiber, Hybrid composite, Mechanical properties

1.INTRODUCTION

Bio fibers are natural fibers that are extracted from biological sources like plants, fruits, seeds etc. The main advantage of bio fibers is biodegradability, light weight, low cost and availability in plenty. Bio fiber polymer matrix composites consist of bio-fibers as reinforcement in polymer matrix like unsaturated polyester. The matrix being non-biodegradable; the resulting bio-composite is partial biodegradable. More than one bio-fiber is used as reinforcement with polymer matrix results in hybrid bio-composite. The purpose of hybrid composite is to manipulate the properties of the resulting bio-composites. The properties of hybrid fiber composite depend on the type and form of fibers used, their volume or weight fraction and the type of matrix. Enormous studies were conducted to investigate the properties of hybrid fiber composite with variety of fibers in variety of matrix materials. Flexural and Impact Properties of Kenaf-Glass Hybrid polyester Composite was investigated by Maleque et al., [1] by varying the volume fraction of kenaf (K)and glass(G) fiber in a total of 30% fiber volume fraction. The 30 % kenaf and 30 % glass fiber composites were also prepared and tested for comparison purpose. The kenaf fiber was treated with 6% sodium hydroxide (NaOH) diluted solution for 3 hours. The study showed that the highest flexural strength was obtained from treated kenaf with 15/15 v/v KG fiber reinforced hybrid composite while untreated of 15/15 v/v KG composite showed the highest value of impact strength. Yongli Zhang et al., [2] studied the hybrid effects of the composites made with natural (unidirectional flax fibers) and synthetic (glass) fibers on tensile and interfacial properties. The results showed that the tensile properties of the hybrid composites were improved with the increasing of glass fiber content. A modified model for calculating the tensile strength was given based on the hybrid effect of tensile failure strain. The stacking sequence was shown to obviously influence the tensile strength and tensile failure strain, but not the tensile modulus. The interlaminar shear strength and the interlaminar fracture toughness of flax/glass fiber reinforced hybrid composites were found to be higher than those of GFRP. Tensile and Compressive Properties of Woven Kenaf/Glass fabric Sandwich Hybrid Composites were determined by Mohaiman J. Sharba et al.,[3]. The properties were compared with that of pure glass and pure kenaf fabric composites. It was found that glass reinforced composites possess the superior tensile strength of 215 MPa compared to the poor strength of kenaf-based composites (35 MPa). They noticed that hybridization process of kenaf with glass significantly improves the overall mechanical properties of hybrid composites compared to kenaf composites. It was observed that addition of kenaf layer to the composites has little or no effect on compressive strength of hybrid composites; the strength values were ranging from 85 to 90 MPa. Tensile and Compressive Properties of Woven Kenaf/Glass fabric Sandwich Hybrid Composites were determined by Mohaiman J. Sharba et al.,[4]. The properties were compared with that of pure glass and pure kenaf fabric composites. It was found that glass reinforced composites possess the superior tensile strength of 215 MPa compared to the poor strength of kenaf-based composites (35 MPa). They noticed that hybridization process of kenaf with glass significantly improves the overall mechanical properties of hybrid composites compared to kenaf composites. It was observed that addition of kenaf layer to the composites has little or no effect on compressive strength of hybrid composites; the strength values were ranging from 85 to 90 MPa. Sanjay et al [5] conducted studies on Mechanical Properties of Banana/E-Glass Fabrics Reinforced Polyester Hybrid Composite prepared with different compositions of Banana and E-Glass fabrics. Their results revealed that pure glass fabric laminate exhibited maximum tensile, flexural, impact strength and hardness whereas pure banana fabric laminate exhibited minimum properties. The properties of hybrid composites lie in between the individual fiber composites and vary with stacking sequence. Flexural and Hardness properties of woven hemp and glass fiber hybrid composites (with and without NaOH treatment) was investigated by Velamurugan et al [6] by varying the parameters like alkali treatment of hemp and glass fiber and stacking sequence of the composite plate. They found that the properties of hemp and glass fiber composite was significantly increased (37%) after alkali treatment when compared to raw fiber composites. Meenakshi, A.Krishnamoorthy [7] prepared laminates with different volume of flax and glass fiber and their mechanical properties like tensile strength, impact strength, flexural strength and water absorption nature are tested. The tests are carried out on standard ASTM sized samples the results show that the hybrid composite is showing equally good performance to conventional glass fiber composite and overall better performance than the mono natural Fiber composite. Vijay Chaudhary et al.,[8] investigated the tribological performance of hybrid composites with three different types of natural fibers viz., jute, hemp and flax reinforced with epoxy matrix. The hybrid composites fabricated were jute/hemp/epoxy, hemp/flax/epoxy and jute/hemp/flax/epoxy. Tribological performance of the developed bio-composites was evaluated in terms of frictional characteristics and sliding wear under dry contact condition at different process parameters. Experimental results of wear analysis confirmed that incorporation of natural fibers into epoxy polymer matrix significantly improved the wear behavior of the developed NFRP composites in comparison to neat epoxy polymer. Among all the developed composites, jute/epoxy composite achieved the highest co-efficient of friction, frictional force and specific wear rate. Sumaiya Shahria [9] fabricated the hemp–flax fiber reinforced epoxy hybrid composites with different fiber compositions and determined their flexural properties. The results indicated that the effect of fiber content on the flax –hemp fiber hybrid composite is noticeable. 30 %hemp-10% flax exhibited highest flexural properties in terms of flexural strength and flexural modulus. Noorshazlin Razali et al., [10] fabricated flax/kenaf hybrid composites and analyzed their mechanical properties like tensile, flexural and compression. The ratio of flax to kenaf was 30:70. The results showed that the tensile, flexural, compression properties of kenaf composites were improved by hybridization with flax fabrics.

Although adequate literature is available on characterization of hybrid bio fiber composites, the literature on flax-hemp-glass polyester composite is not noticed in the literature.

2. Fabrication and Testing of Composites

2.1 Reinforcement Materials

2.1.1 Hemp Fiber

Hemp fibers are considered as one of the strong member of bast natural fibers family, which are derived from the hemp plant under the species of *Cannabis*. Nowadays, these fibers have received wide acceptance as reinforcements in composite materials on account of their biodegradability and low density compared with synthetic fibers. Also these materials have inherent mechanical, thermal, and acoustic properties.

2.1.2 Flax Fiber

Flax fiber is extracted from the bast or skin of the stem of flax plant. Flax fibers are arranged in the form of thin filaments, grouped in longitudinal slender bundles distributed circularly around a central wooden cylinder.

The chemical composition of hemp and flax fiber is shown in Table 1.

Table 1: Chemical composition of hemp and flax fibers

Fiber	Cellulose (wt %)	Lignin (wt %)	Hemi Cellulose (wt %)	Pectin (wt %)	Wax (wt %)	Moisture content (wt %)
Hemp	70.2-74.4	3.7-5.7	17.9-22.4	0. 9	0.8	10
Flax	71	2.2	18.6-20.6	2.3	1.7	10

Table 2: Physical and Mechanical properties of hemp, flax and glass fibers

Property	Hemp	Flax	Glass
Density g/cm³	1.48	1.4	2.55
Tensile Modulus GPa	30-70	60-80	73
Specific tensile modulus GPa/g/cm³	20-47	43-57	29
Tensile strength MPa	300-800	500-900	2400

Elongation to failure %	1.6	1.2-1.6	3
Moisture absorption %	8	7	---

Source: https://netcomposites.com/media/1211/biocomposites-guide.pdf

In the present investigation, Woven hemp fiber mat and flax fiber mat having a surface density 220 GSM and bi-directional glass fiber mat with surface density 90 GSM were used as reinforcement materials. These mats was supplied by M/s Vruksha composite Pvt. Ltd., Andhra Pradesh, India.

Figure 1 shows the samples of hemp fiber mat, flax fiber mat and glass fiber mat.

(a) Hemp fiber mat (b) Flax fiber mat (c) Glass fiber mat

Figure 1: Fiber mats

2.2 Matrix Materials

ISO Resin is a medium viscosity, medium reactive polyester resin based on Isophthalic acid and superior glycols. It exhibits good mechanical and electrical properties together with good chemical resistance compared to general-purpose resins. ISO rapidly wets the surface of glass fiber in the form of cloth mat or chopped fiber to produce laminates and moldings. Polyester can withstand temperature up to 80^{o}C. It has relatively low shrinkage between 4-8% during curing. Polyester Resin is also simple to use. It is easily mixed using the MEKP catalyst and cobalt accelerator.

Matrix used for the fabrication of composite consists of Iso-polyester resin and MEKP hardener along with cobalt accelerator in the ratio 20:1:1 (5000ml: 250ml: 250ml). The resin, hardener and cobalt accelerator were supplied by Carbon black composites Pvt. Ltd., Maharashtra, India.

2.3 Fabrication of Laminates

All the laminates were fabricated with 10 layers of mats except all glass composite laminates where 20 layers were used. Hand layup technique followed by compression molding was used for the fabrication of laminates. The fabrication setup is shown in figure 2.

(a) Top and Bottom Molds

(b) Laminates curing under pressure

Figure 2: Fabrication of Laminates

For fabrication of flax fiber composites, 10 flax fiber mats each of size (250×300) mm were used. The weight and dimensions of each mat was noted. Polyvinyl chloride sheets were laid on the surface of the mold to facilitate easy removal of the laminate after curing. The resin mixture is prepared by mixing Iso-polyester with MEKP catalyst and cobalt accelerator at a ratio of 50:1:1. The flax mat is laid on the surface of the bottom part of the mold. The resin hardener mixture is applied on both the surfaces of the flax mat with the help of a brush. After applying the resin mixture uniformly the next layer of the flax mat is placed on top of it and the procedure is continued for all the layers of the flax mat and the mold is closed by placing the top part of the mold on the layers. The curing was done for 24 hours under pressure which as applied by placing weights on the top of the mold.

All the other composites like hemp fiber composite, hemp-glass; flax-glass and hemp-flax-glass composites were fabricated in a similar way. For flax-glass and hemp-glass composites, two extreme layers of glass fiber mat were placed on either side of the composites. The layering sequences of three fiber hybrid laminates are shown in figures 3 and 4.

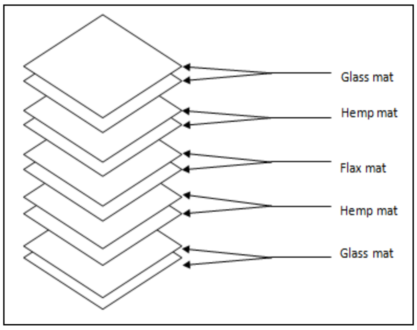

Figure 3: Hemp-flax-glass composite

(GGHHFFHHGG)

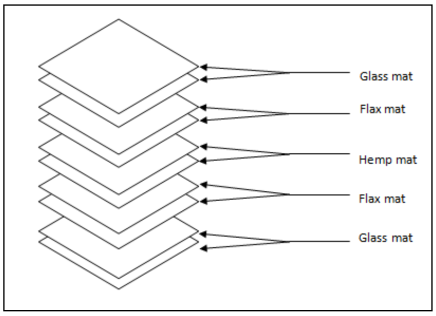

Figure 4: Flax-hemp-glass composite

(GGFFHHFFGG)

In all the composites (except all glass composites), total fiber weight fraction of 28±5% was maintained. Table 3 shows the details of fiber weight fraction of various composites.

Table: 3 Fiber weight fraction

Laminate code	Sequence	Flax Wt fraction %	Hemp Wt fraction %	Glass Wt Fraction %	Total fiber wt fraction %	Resin Wt fraction
All Glass (A)	G^{10}	-----	-----	50.96	50.96	49
All Flax (B)	F^{10}	28	-----	-----	28	72
All Hemp (C)	H^{10}	-----	34.5	-----	35%	65.5
Hybrid 1 (D)	$G^2F^6G^2$	21.78	-----	6.67	28.47	71.6
Hybrid 2 (E)	$G^2H^6G^2$	-----	22.85	6.22	29	70.93
Hybrid 3 (F)	$G^2F^2H^2F^2G^2$	13.2	6.6	5.4	25.2	74.8
Hybrid 4 (G)	$G^2H^2F^2H^2G^2$	6.1	12.1	4.95	23.1	76.9

2.4 Testing of Composites

2.4.1 Tension Test

Tension test was conducted on ZWICK ROELL, Z020, having a capacity of 20 KN. The rate of loading was 2 mm/min. The geometry of the test specimen is shown in figure 5. Abrasive paper was used as tabs for gripping. Three identical samples were tested and average results are reported. Stress strain diagram was generated using data acquisition system. The test configuration is shown in figure 6. The Young's modulus was determined from the slope of the initial linear portion of the stress-strain diagram.

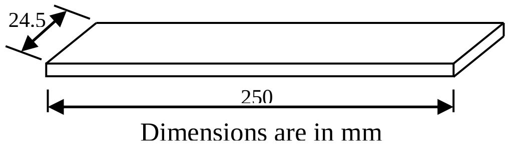

Figure 5: Tension test specimen

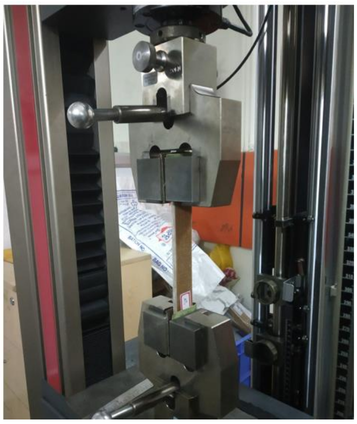

Figure 6: Tension test configuration

2.4.2 Flexural Testing

Flexural test was conducted on the same machine. The specimens were loaded in 3- point bending with L/h ratio of 16. The overall length of the specimen is 130 mm and width of the specimen is 13 mm.

The flexural stress in 3- point bending was determined from the equation (1)

$$\sigma_b = \frac{3P_{max}L}{bh^2} \qquad (1)$$

where P_{max} is the maximum load, L is the span length, b is the width of the specimen and h is the thickness of the specimen. The flexural modulus was calculated from the slope (m) of the initial portion of load deflection curve using equation (2). The bending test setup is shown in figure 7.

$$E = \frac{mL^3}{4bh^3} \qquad (2)$$

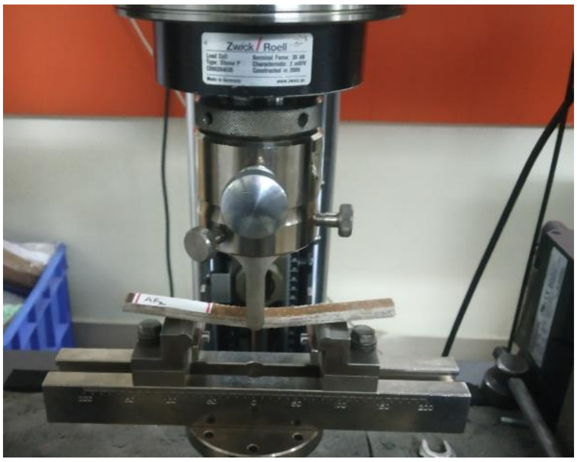

Figure 7: Flexural test set up

2.4.2 Hardness Testing

Square shaped specimens of cross section (30 mm × 30 mm) were prepared for Shore D hardness tester. The test was conducted as per ASTM D 2240 standards. The hardness value was determined by the penetration of Durometer indentor foot into the sample. Shore D hardness measures are dimensionless. It varies between 0 to 100. Higher the number harder is the material.

2.4.3 Impact Testing

Izode impact tests were conducted on unnotched specimens of size (65×15×thickness) mm using pendulum type impact testing machine. The impact energy required to break the material was noted and impact strength was calculated.

3. Results and Discussion

3.1 Tension test results

The tensile strength for various samples is shown in the figure 8. A comparison of tensile strength among the individual fiber composite reveal that, all glass fiber composites has a maximum tensile strength of 143.5 MPa, followed by all flax composites (40.2 MPa) and all hemp composites (27.8 MPa). Among the two fiber hybrid combination, samples D (Flax-glass hybrid composite) exhibited higher tensile strength of 50.2 MPa when compared with Hemp-glass hybrid composite for which the tensile strength is 39.8 MPa. Among the three fiber hybrid combination, samples F with more number of flax fiber layers exhibited higher tensile strength of 50.2 MPa than sample G with more number of hemp fiber layers (47.6 MPa).

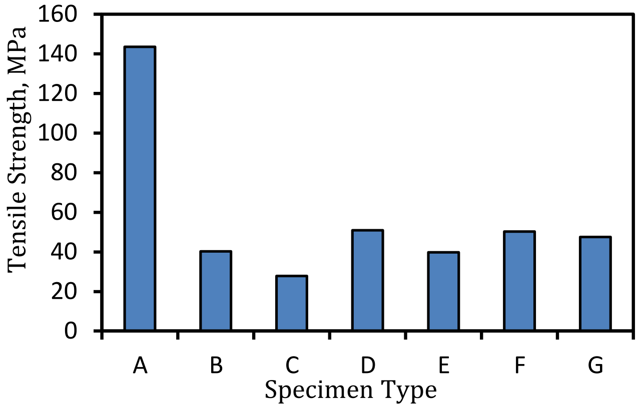

Figure 8: Tensile strength of composites

Overall results of the tensile strength reveal that flax fiber composite is having better load carrying capacity when compared to hemp fiber composites. Further, incorporation of glass in individual bio fiber composite resulted in improved tensile strength.

The tensile modulus for various samples is compared in figure 9. The trend of variation of tensile modulus among various types of samples was similar to that of tensile strength. All glass composites exhibited highest tensile modulus of 1060 MPa followed by all flax composites (324 MPa) and all hemp composites (257 MPa).

Among the two fiber hybrid combination, samples D (Flax-glass hybrid composite) exhibited higher tensile modulus of 488 MPa when compared with Hemp-glass hybrid composite for which the tensile modulus is 398 MPa. Among the three fiber hybrid combination, samples F with more number of flax fiber layers exhibited higher tensile modulus of 430 MPa than sample G with more number of hemp fiber layers (365 MPa)

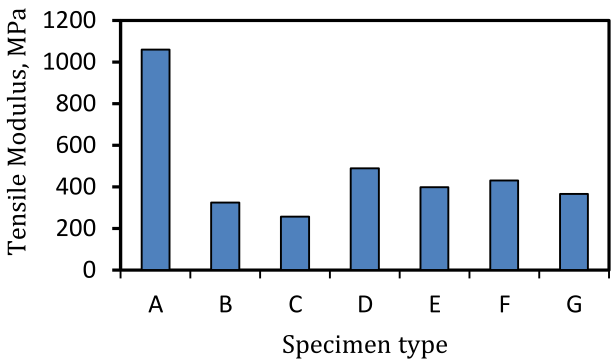

Figure 9: Tensile modulus of composites

Overall results of the tensile modulus reveal that flax fiber composite is having better resistance to deformation when compared to hemp fiber composites. Further, incorporation of glass in individual bio fiber composite significantly improves tensile modulus.

3.2 Flexural test results

The flexural strength for various samples is shown in the figure 10. A comparison of flexural strength among the individual fiber composite reveal that, all glass fiber composites has a maximum flexural strength of 139 MPa, followed by all hemp composites (93 MPa) and all flax composites (62 MPa). Unlike tensile strength, the flexural strength of hemp fiber composite is more than flax fiber composite. Among the two fiber hybrid combination, samples E (Hemp-glass hybrid composite) exhibited higher flexural strength of 94 MPa when compared with Flax-glass hybrid composite (sample D) for which the flexural strength is 87.5 MPa. Among the three fiber hybrid combination, samples G with more number of hemp fiber layers exhibited higher flexural strength of 98 MPa than sample F with more number of flax fiber layers (83 MPa).

Overall results of the flexural strength reveal that hemp fiber composite is having better bending load carrying capacity when compared to flax fiber composites. Further, incorporation of glass in individual bio fiber composite resulted in improved flexural strength.

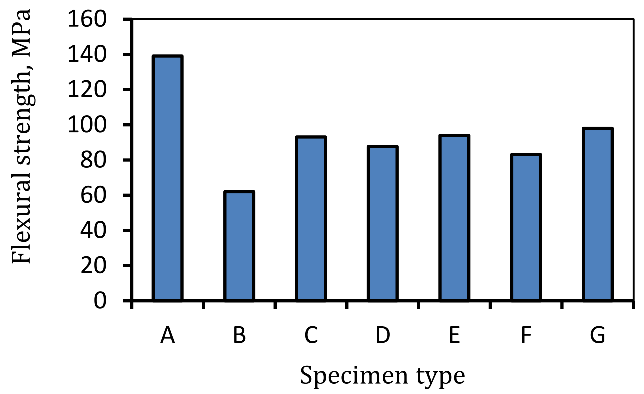

Figure 10: Flexural strength of composites

The flexural modulus for various samples is compared in figure 11. The trend of variation of flexural modulus among various types of samples was similar to that of flexural strength except that all glass composites exhibited flexural modulus of 7295 MPa which is slightly less that the flexural modulus of all hemp composites (7365 MPa). All flax composites exhibited the lowest flexural modulus of 3810 MPa.

Among the two fiber hybrid combination, samples E (Hemp-glass hybrid composite) exhibited higher flexural modulus of 6560 MPa when compared with flax-glass hybrid composite for which the flexural modulus is 5275 MPa. Among the three fiber hybrid combination, samples G with more number of hemp fiber layers exhibited higher flexural modulus of 5570 MPa than sample F with more number of flax fiber layers (4685 MPa).

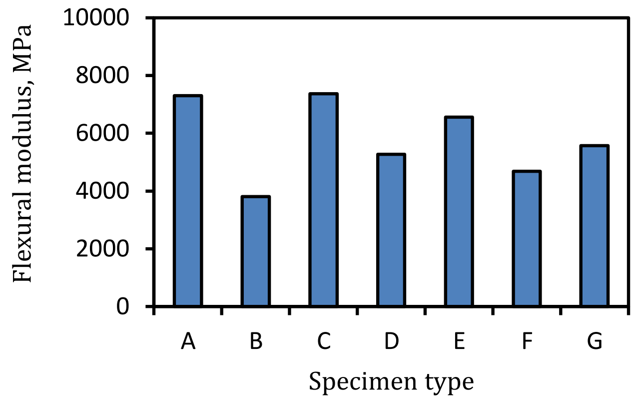

Figure 11: Flexural modulus of composites

Overall results of the flexural modulus reveal that hemp fiber composite is having better resistance to lateral/bending deformation when compared to flax fiber composites. Further, incorporation of glass in flax fiber composite significantly improves flexural modulus, whereas incorporation of glass in hemp fiber composite does not reveal any improvement in flexural modulus.

3.3 Hardness test results

The hardness for various samples is shown in the figure 12. The hardness test results of the individual fiber composite and hybrid composites reveals that, the hybrid composite F (Flax-Hemp-Glass hybrid) exhibits better hardness (89.33) and the laminate C (all hemp composite) as the least hardness (82.33) compared to other laminates. Overall results of the hardness test reveal that the hardness of all flax fiber composites is comparable to that of all glass fiber composites. No significant change in the hardness was noticed among flax/glass and hemp/glass composites. Among the three fiber hybrid composites, sample F with more number of flax fiber layers indicated higher value of hardness.

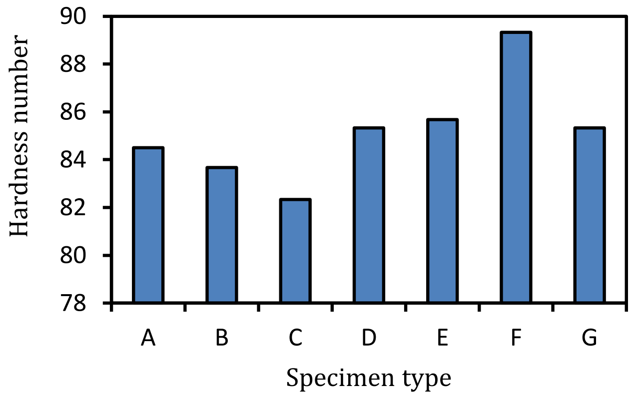

Figure 12: Hardness of composites

3.4 Impact test results

A comparison of impact strength among the individual fiber composite reveal that, all glass fiber composites has a maximum impact strength of 55.2 kJ/m^2, followed by all hemp composites (29.7 kJ/m^2) and all flax composites (25.6 kJ/m^2). Among the two fiber hybrid combination, samples E (Hemp-glass hybrid composite) exhibited higher impact strength of 35.5 kJ/m^2 when compared with Flax-glass hybrid composite (sample D) for which the impact strength was 30.72 kJ/m^2. No significant variation in the impact strength was noticed among the three fiber hybrid samples F and G.

Overall results of the impact test reveal that hemp fiber composite is having better resistance to impact when compared to flax fiber composites. Further, incorporation of glass in both flax fiber and hemp fiber resulted in marginal improvement in the impact strength of the resulting hybrid composite.

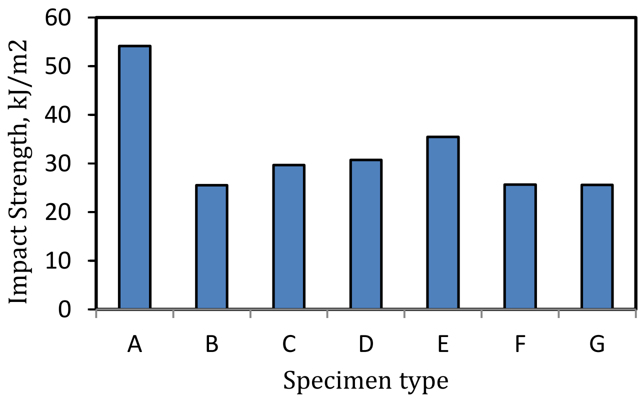

Figure 13: Impact Strength of composites

4. Conclusions

Composite laminates with all glass fiber mats, all flax fiber mats, all hemp fiber mats and hybrid composites laminates with glass/flax, glass/hemp and glass/flax/hemp fiber mats were fabricated and tested for mechanical properties. Overall fiber weight fraction was maintained at 28±5%. The results of the test indicated the following:

1. Tensile properties (tensile strength and modulus) of all flax fiber composites are better than all hemp fiber composites.

2. Glass/flax (samples D) and Glass/hemp (sample E) composites exhibited the tensile strength 25% and 43% higher than the tensile strength of all flax (sample B) and all hemp composites (sample C) respectively. Similarly, the tensile modulus of Glass/flax composites and Glass/hemp composites was found to be 48% and 51.9% higher than the tensile modulus of all flax and all hemp composites respectively.

3. The tensile properties of three fiber hybrid composites $G^2F^2H^2F^2G^2$ with more flax fiber layers are found to be in between the tensile properties of all glass and all flax hybrid composites. Similarly, the tensile properties of three fiber hybrid composites $G^4F^2H^4$ with more hemp fiber layers were found to be in between the tensile properties of all glass and all hemp hybrid composites.

4. Glass/flax (samples D) composites exhibited the flexural strength 41% higher than the flexural strength of all flax (sample B). Similarly, the flexural modulus of Glass/flax composites was found to be 38.5% higher than the flexural modulus of all flax composites. However, Glass/hemp (sample E) composites have not revealed any improvement in flexural properties when compared to all hemp composites.

5. The flexural properties of three fiber hybrid composites $G^2F^2H^2F^2G^2$ with more flax fiber layers were found to be in between the flexural properties of all glass and all flax hybrid composites. The flexural strength of three fiber hybrid composites $G^4F^2H^4$ with more hemp fiber layers are comparable with the flexural strength of all hemp hybrid composites, whereas the flexural modulus of this composite was found to be less than flexural modulus of all hemp hybrid composites.

6. The hardness number of various composites under investigation was found to lie in between 82 to 90. All hemp composites (sample C) exhibited lowest hardness number whereas three fiber hybrid composite (sample F) exhibited highest hardness number.

7. Glass/flax (samples D) and Glass/hemp (sample E) composites exhibited the impact strength 20% and 19.6% higher than the impact strength of all flax (sample B) and all hemp composites (sample C) respectively. The impact strength of three fiber hybrid composites was found to be comparable with two fiber hybrid composites.

8. Overall result revealed that, flax fiber based composites have better tensile load carrying capacity, whereas hemp fiber based composites have better bending load carrying capacity.

REFERENCES

[1] M. A. Maleque, A. Atiqah and M. Iqbal, "Flexural and Impact Properties of Kenaf-Glass Hybrid Composite", Advanced Materials Research Vol. 576, 2012, pp. 471-474.

[2] Yongli Zhang, Yan Li , Hao Ma and Tao Yu, "Tensile and interfacial properties of unidirectional flax/glass fiber reinforced hybrid composites", Composite Science and Technology, Vol.88, 2013, pp.172-177.

[3] R. Bhoopathia , M. Ramesha, and C. Deepa, "Fabrication and Property Evaluation of Banana-Hemp-Glass Fiber Reinforced Composites", Procedia Engineering 97, 2014, pp. 2032 – 2041.

[4] Mohaiman J. Sharba, Z. Leman, M. T. H. Sultan, M. R. Ishak, and M. A. Azmah Hanim, "Tensile and Compressive Properties of Woven Kenaf/Glass Sandwich Hybrid Composites, International Journal of Polymer Science", Volume 2016, March 2016, pp.1-6, http://dx.doi.org/10.1155/2016/1235048

[5] M. R. Sanjay, G. R.Arpitha, L.Laxmana Naik, K.Gopalakrishna, B. Yogesha, "Studies on Mechanical Properties of Banana/E-Glass Fabrics Reinforced Polyester Hybrid Composites", J. Mater. Environ. Sci. Vol.7, No.9, 2016, pp. 3179-3192.

[6] G.Velmurugan, Md. Asad Salman Pasha, V.Arasu,Woven "Hemp and Glass Fiber Hybrid Composite - A Comparative Study on Flexural and Hardness Properties with and without NaOH Treatment", International Journal of Pure and Applied Mathematics, Volume 119, No. 10, 2018, pp. 1973-1978.

[7] C.M. Meenakshi and A.Krishnamoorthy, "Preparation and mechanical characterization of flax and glass fiber reinforced polyester hybrid composite laminate by hand lay-up method", Materials Today: Proceedings: Volume 5, Issue 13, Part 3, 2018, pp. 26934-26940.

[8] Vijay Chaudhary, P.K. Bajpai, and Sachin Maheshwari, "An Investigation on Wear and Dynamic Mechanical behavior of Jute/Hemp/Flax Reinforced Composites and Its Hybrids for Tribological Applications". Fibers Polym, Vol. 19, 2018, pp. 403–415. https://doi.org/10.1007/s12221-018-7759-6

[9] Sumaiya Shahria, "Fabrication and Property Evaluation of Hemp–flax Fiber Reinforced Hybrid Composite", Chemical and Materials Engineering, Vol. 7, No.2, 2019, pp. 17-23. doi: 10.13189/cme.2019.070202.

[10] Noorshazlin Razali, Mohamed Thariq Bin Hameed Sultan, Mohammad Jawaid, Ain UMAIRA Md Shah, In book: Structural Health Monitoring System for Synthetic, Hybrid and Natural Fiber Composites, pp.177-194.

BIOGRAPHIES

Author 1 is presently Professor in J N N College of Engg., Shivamogga, Karnataka, India having an experience of 37 years. He pursued Ph.D from Anna University, Chennai. He has published several research

Author 2 is an Assistant Professor in J N N College of Engg., Shivamogga, Karnataka, India from past 15 years. He pursued Ph.D from VTU, Belagavi, Karnataka. His research area is Polymer Composites