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Mechanical Characterization and Evaluation of Effects of Epoxy in Lamination for Kevlar Composites

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Abstract: **Hybrid type of composites have considerable budding for certain specific strength and stiffness, efficacious in industries such as submarines, aerospace, and medium duty automotives. The macroscopic and microscopic properties of the hybrid composites can be enhanced by making the various layers of the epoxy and Kevlar in various directions. The lay up using the epoxy in various combinations can lead to promote the mechanical properties. Each of the constituent present in the Kevlar composite can make the difference in the tensile strength, bonding strength. The experiments with various combinations of the resin and hardener are always there in the researchers mind to find the effects of each individual over the other properties of the composite. In this voyage the optimal mix of that particular element in this instance the epoxy usage influence will be found out. The mechanical properties such as the tensile strength, binding strength in between the fabric and matrix will be found. 3 unique sheets, namely P (3:2), Q (4:1) and R (2:3) are fixed by the hand layup procedure to make a conglomerate composite. Experimental analysis in accordance with the ASTM standards of 3039, are exhibited to paramount the mechanical properties. Delamination tests are then performed as per ASTM standard to find out the inter layer laminar strength in between the Kevlar fiber and glass layers. The outcomes archived indicate that sample of glass/Kevlar fiber-based hybrid composite in the mix of 3:2 in lamination is best with respect to mechanical properties and it has also shown the least swelling ratio, in addition to it material system composed of 4:1 mix details the optimal adhesion capabilities and inter laminar properties.**

Index Terms: **Mechanical characterization, Evaluation, epoxy, Lamination, Kevlar, Composites.**

I. Introduction

Composite materials usually made by different distinct process few of them are metal matrix composites and fiber-based composites [1]. In any composite the main constituent property that holds the major role is the binding strength in between the inter laminar layers. The strength depends on the quantity and quality of the resin, fiber and hardener used. It also depends upon the orientation of the fiber and also the no of layers of the ply [2]. Likewise, since ages the interest to explore the various facets of the composite material that improvises the mechanical strength, binding energy and inter laminar holding ability. The idea to make the composite has come due to the search for the high strength and temperature resistant materials [3]. It has started from the metals then it went to alloys phase then after the search has stopped at the composite materials. The reason for it lies upon the properties that composite material possesses [4]. Even though the composite material is made by the different materials of different properties as a whole it has started showing the best properties that no one has shown individually. If each constituent is considered separately for the fabrication of a new composite material, it has shown the most adorable result. That is each of the constituent material has some distinct properties for example some of brittle in nature some are ductile in nature, but such distinct materials together have produced a composite material that has both good properties of the parent materials [5]. Usually, it can be experienced in the material world that the materials which strong in tensile strength ate week in compressive strength and vice versa. But a composite material is the one which has the best tensile strength and compressive strength together [6]. It is because of the fact that all original materials possess the isotropic properties and the composite material is anisotropic material. In any distinct position its properties are not same [7].

This feature is obtained to the composite material due the multi-layer foundation it has and also these layers are been bound together by the epoxy resin combined with the silicon powder and hardener. Along with the time the evaluation of the composites is also changed and they broadly divided into MMC, PMC and CMC. MMC is Metal Matric Composite in which the main constituent or dominant material is metal. In the PMC i.e., Polymer Matric Composites the base materials are the polymer and the last one is CMC means Ceramic Matrix Composites these are been fabricated by ceramic materials as the base materials. In the present work the Kevlar epoxy reinforced composite material is used for the determination of the mechanical properties and also to find the effects of the epoxy are been analyzed. The main reason behind selecting the Kevlar composite is due its light weight, high strength, high wear resisting ability. The Kevlar fiber materials are used vividly in the aerospace applications to make the air crafts and space crafts and also it is used in novel marine structural applications [8,9,10]. With respect to strength comparison the Kevlar composites are about five times better than steel. High strength to weight ratio, low wear ability and light weight have made arena towards the popular utilization in the aero space applications. The inter atomic bonding present in the Kevlar composite is much stronger than the conventional van der walls intermolecular connection. But to make the usage of these materials more in terms of cost criterion and hybrid composites came into existence [11,12]. Since the fabrication of the hybrid composites have started the making cost is reduced and the wide spread usability of the Kevlar/ e-glass composites has increased [13]. There are numerous applications that has begun since after glass fiber hybrid composites have made

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particularly in the electronic applications, printed wire boards, circuit boards etc [14,15,16]. The lay direction, Kevlar fibre angle, no of plies, resin to hardener ratio, volume fraction etc. are the key parameters in deciding the strength and other mechanical properties of the Kevlar / e-glass hybrid composites. Out of all the binding ability of the adhesive material and the resin, hardener majorly make the matrix phase that influence the overall competency of the composite.

II. Experiment

A. Preparation of the Speciemen

In making the E-glass based composite with Kevlar-49 every layer is prepared with a thickness of about 0.5 mm coupled with the hardener and epoxy resin in a of industrial grade for strong adhesive quality for the preparation of the hybrid composites [17,18]. The fabrication begins with the sandwich manner in which the Kevlar-49 fiber is kept in the middle and the e-glass is covered from the top and bottom. In present experimental analysis the laminates of hybrid composites (P, Q, and R) are prepared as shown in Figure 1. During the fabrication the quantities of the epoxy resin & hardener are made with hand layup procedure. It is tabulated in Table I. The properties of materials viz E-glass, epoxy, and Kevlar are detailed in Table II [19,20].

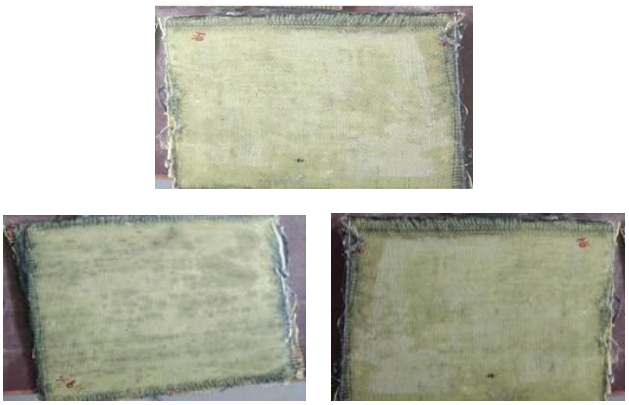

Figure 1. Fabricated Specimens using various ratios of resins

TABLE I.
LAYUP PROCEDURE OF FIBERS

Layer details	P	Q	R
No of layers	3	3	3
E-glass	2	2	2
Kevlar-49 fiber	1	1	1
epoxy/ resin	2	3	4
Hardener	3	2	1

TABLE II.
PROPERTIES OF MATERIALS

Parameter	E-glass	Kevlar	Epoxy
Strength of Fiber	340	2761	-
Strength of Laminate	1510	1445	13-41
Laminate Density (g/cc)	2.596	1.48	1-1.13
Strength to Weight ratio	559	989	27

B. Mechanical Testing-Tensile Test

It is a test intended to know the tensile strength of the given specimen. At first the specimens are shaped into the following shown Figure 2. and Figure 3. to insert them in the tensile testing machine. Usually there is no specific tensile testing machine but on the Universal testing machine only the tensile testing will be performed. The testing is performed as per the ASTM standards.

Figure 2. Test specimen for tensile testing in Universal testing machine

Figure 3. Tensile Test UTM machine

The 3 specimens are of dimensions thickness = 5mm, width = 24mm and length = 150mm are used for the tensile testing. The applied load will start from 0kN to and reach up to 5kN. For the three samples P,Q and R tensile strength, strain rate, ultimate load, ultimate stress and associated parameters will be found [21,22].

C. Removal (Peel) Test

The peel removal test is one of the important test that shoes the ability of the plies of the composite material that bind together. There were many ways to perform this test out of which most commonly used tests are 90° and 180° [23,24]. Here in the present work the 90° peel removal test is used in this the plies are forcefully removed one after another gently perpendicular to the workpiece. See Figure 4.

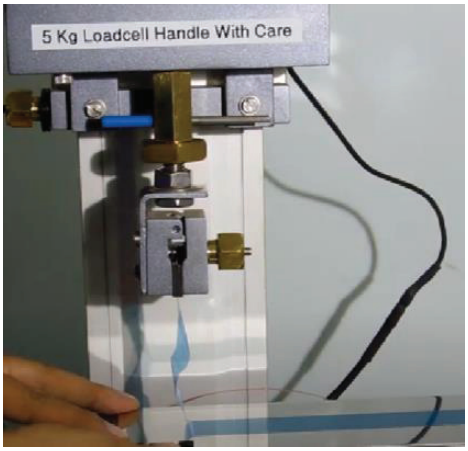

Figure 4. Peel removal test

For the 90°peel removal test. The more is the force required to peel off the strong is the material and its internal bonding, it is as simple as this and vice versa. The measurement of this peel removing is done as force required for unit length. That means N/mm. The results pertaining to the peel removal test are given in the results and conclusions section [25,26].

III. Mechanical Testing

A. Testing of Hardness

Hardness of the composite material is one of the significant parameters to be considered while defining its strength. Here in the present work the hardness of the composite material is been tested on the Rockwell hardness test machine that can show the C number based on that its hardness characteristics can be defined. As shown in the Figure 5. the prepared composite material sample is kept on the pan and an indenter will apply force on the surface of the material and based on the impression made by the indenter the hardness value will be computed, in other words hardness is the ability of the material to withstand the load against failure. The results of the hardness test are given in the results and discussion section [27,28,29].

Figure 5. Rockwell hardness testing

B. Testing of Density

This is one of the fundamental and important tests to ascertain the packing of the material in the given volume. It will lay an arena to understand the material dispersity and uniformity of packing within the given volume. The dimensions of prepared composite specimen considered for testing of the density is length =24 mm, width = 24 mm and thickness = 0.2 mm. The density of the sample is found by keeping the sample in the cuboid channel closely such that no gaps will be found and based on the weight of the material that has occupied for unit volume its density will be assessed and can be expressed in $\frac{N}{mm^2}$ [30,31].

C. Water Absorption Test

This is the test performed to assess the ability of the composite material to show its intendedness to absorb the water. This quality of the material to absorb the water when immersed in the water containing vessel signifies the quality of the material [32,33]. To perform the test at first the sample is weighed and then it is immersed completely in distilled water for about 24 hours at room temperature i.e., 30°C as shown in Figure 6. After the time got lapsed then the sample is been taken out and then its weight will be tested based on the difference in the weights the composite material strength will be assessed.

Figure 6. Test set up for water absorption

IV. Results and Discussions

A. Tensile Test

The results of the tensile test are given in the below Figure 7., Figure 8. and Figure 9. As the 3 samples are prepared from 3 different compositions the variations in the tensile strength are clearly distinguished. From the Figure 7. For the sample P it can be evident that at the strain of 3 mm the tensile strength has changed the slope and increased steeply. The highest tensile strength is observed as 1987 MPa at strain of 5.87mm.

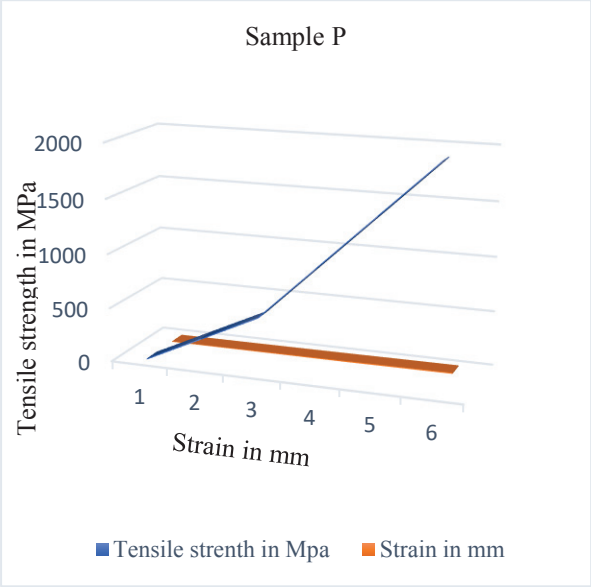

Figure 7. Sample P

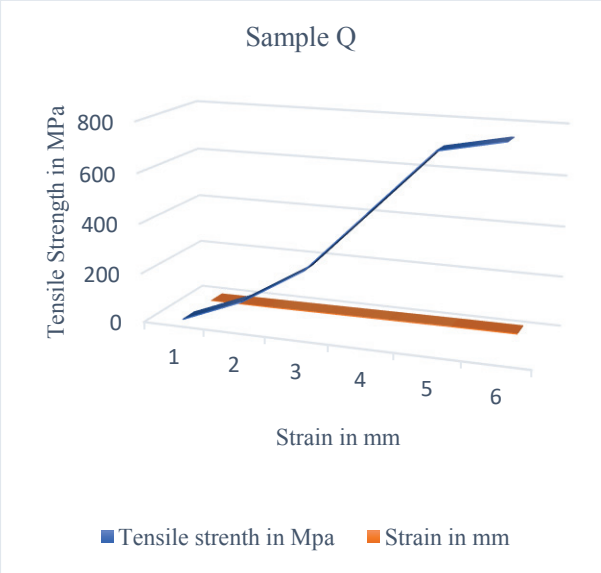

Figure 8. Sample Q

From the Figure 8. For the sample Q it can be evident that at the strain of 3 mm the tensile strength has changed the slope and increased steeply again at the strain of 5 mm the tensile strength has changed its slope and shown a steady downfall. However, the net tensile strength is increased to the end and its value is found to be maximum at 6 mm of strain and corresponding tensile strength is 779 MPa.

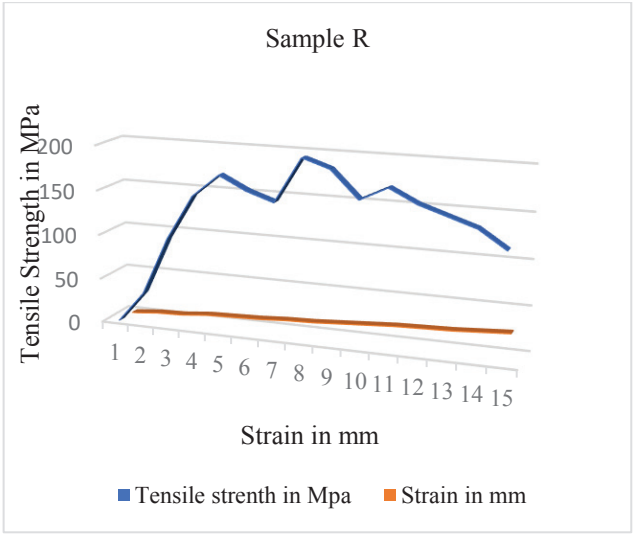

Figure 9. Sample R

From the Figure 9 For the sample R the strength vs strain curve is quite similar to the mild steel. That is the test results have yielded similar properties of isotropic material such as mild steel or aluminum even though the material used is an anisotropic (composite material). The tensile strength is increased till 3.5mm of strain and its value has reached 145 MPa and then it reached to local peak of 160 MPa at 4.5 mm. Then it fell down to a value of 142 MPa at 6.7 mm of strain. In similar fashion it has attained to a peak of 175 MPa for the strain of 7.8mm. Then it went on declining and reached to least value of 105 MPa for the strain of 14.8mm.

B. Peel off Test

Peel off test results shows the significant outcomes in terms of binding strength of the composite material. From Figure 10, Figure 11 and Figure 12 it can be seen that for the sample Q there is a steady and uniform range in peel force is observed. For the sample P and sample R the peel off force has shown more variations in the considered range. As the three samples were made from three different sources of materials hence the peel off force required is also altered accordingly. But as a whole the sample P, Q have resulted in similar outcomes and sample R has shown quite less peel off force.

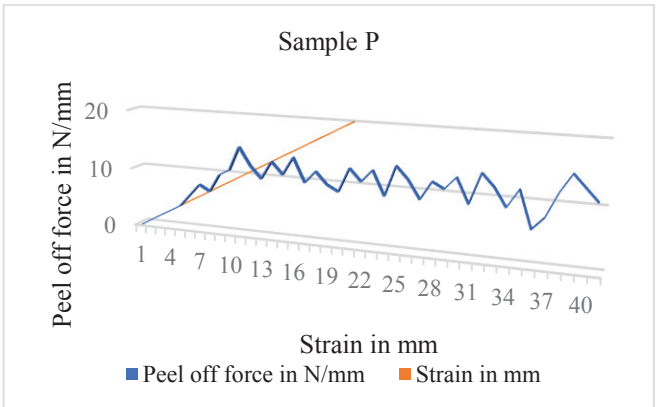

Figure 10. Sample P

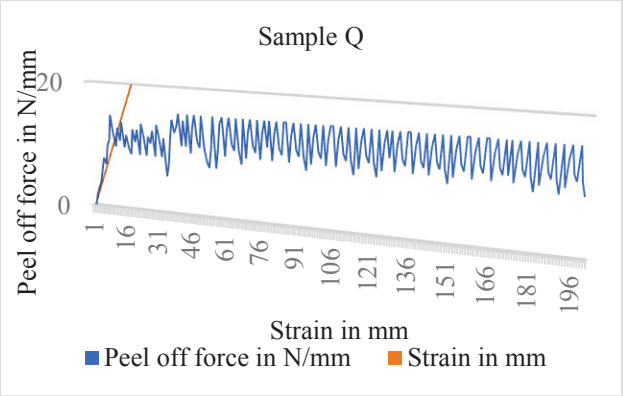

Figure 11. Sample Q

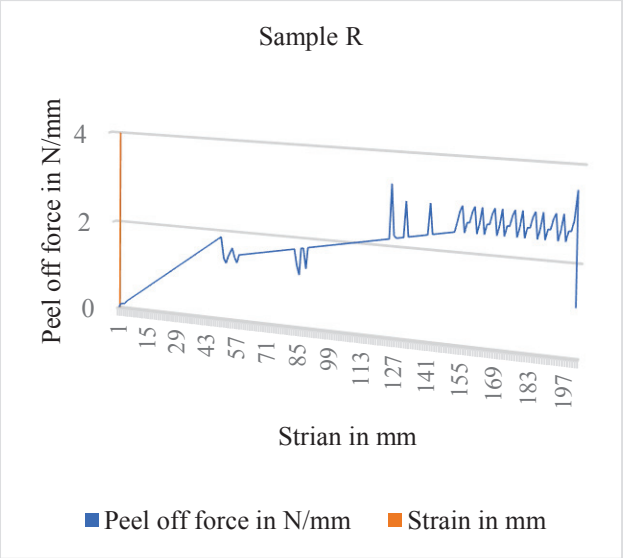

Figure 12. Sample R

C. Hardness Test

The hardness for the samples P,Q and R have resulted in different outcomes as it can be seen in Figure 13. Sample P has obtained the hardness value of 94.887 and sample Q has observed 91.66 and sample R has observed 83.67. From this outcomes it can be witnessed that sample P is harder among the three samples and sample R is least in hardness.

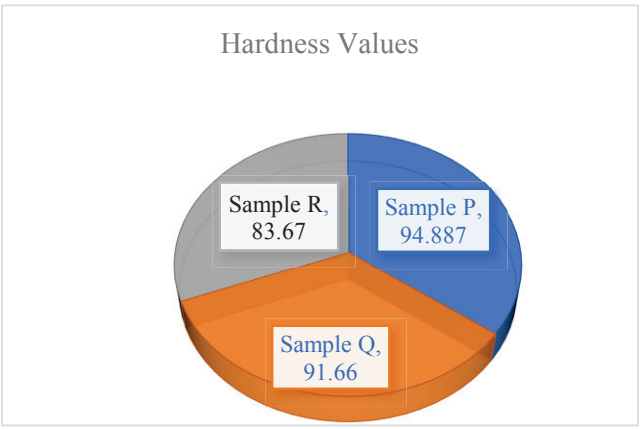

Figure 13. Hardness test results

D. Density Test

The outcomes of the density test are given below in Figure 14. In the graph three parameters are interpreted and they have shown the sample P density is higher than other samples and the density is found least for sample R. However, sample Q and R density are nearer compared P and Q. The weights and Mean values are also obtained in similar fashion.

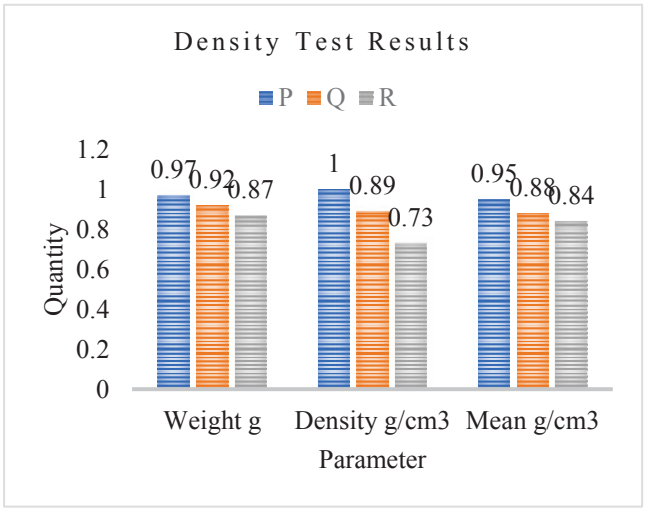

Figure 14. Density test results

E. Water Absorption Test

The water absorption test has yielded the result of material strength with respect to swelling ratio. The swelling ratio can be calculated using below equation no 1.

$$\text{Swelling ratio \%} = \left(\frac{Wet\ laminate - Dry\ Laminate}{Dry\ laminate}\right) * 100 \quad (1)$$

Out of the three samples analyzed the sample B has got more swollen and its swelling ratio is 1.31 followed by A 1.23 and least swelling ratio is for sample C i.e., 1.19. Usually, the materials with less swelling ratio are preferrable for all practical purposes.

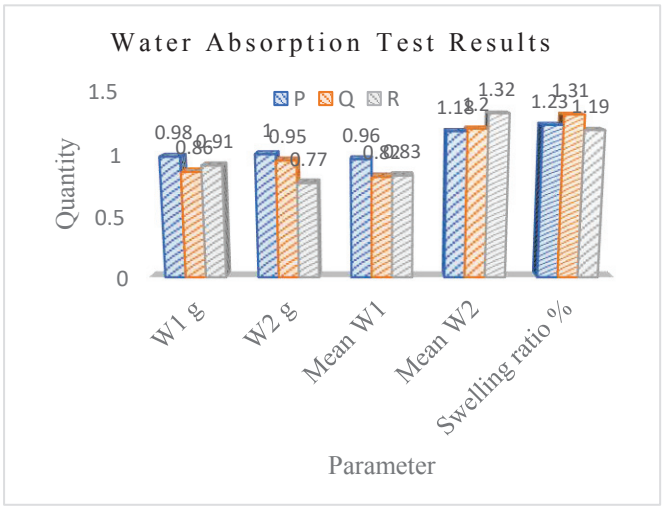

Figure 15. Water absorption test results

V. Conclusions

From the above experimental analysis, it can be concluded that the samples three have shown the significant outcomes with respect to the mechanical properties. However, the following observatory conclusions are arrived by the end of the experimental and testing work.

- Tensile test has shown that P is stronger than other two.
- Peel off test has shown that sample P and Q are moderate and sample R is stronger.
- According to hardness test sample P is harder among all.
- As per density test sample P is denser than all other samples.
- As per water absorption test Q and P are stronger followed by R.

As a whole sample P is preparatory method and composition is suggested for further analytical investigations.

References

[1] P V Sai Swaroop, A. Suresh, Effects of Fiber Orientation on Mechanical Properties and Analysis of Failures for Kevlar Epoxy Reinforced Composites, CVR Journal of Science and Technology, June 2021, 142-146, DOI: 10.32377/cvrjst2022.

[2] Ms. B Reetha, Mr. B. Nikhil, P. Mamatha, A. Suresh, Evaluation of Mechanical Properties and Simulation of Kevlar Epoxy Reinforced Composite with Silicon Carbide filler, I nternational Journal of Advances in Engineering and Management, Volume 3, Issue 5 May 2021, pp: 33-42, D OI: 10.35629/5252-03053342.

[3] Kashif, M.; Ngaini, Z.; Harry, A.V.; Vekariya, R.L.; Ahmad, A.; Zuo, Z.; Alarifi, A. An experimental and DFT study on novel dyes incorporated with natural dyes on titanium dioxide (TiO2) towards solar cell application. Appl. Phys. A 2020, 126, 1–13.

[4] A Suresh, P Bhargavi, M Kiran Kumar, Simulation and Mechanical Characterization on Kevlar epoxy reinforced composite with silicon carbide filler, Materials Today: Proceedings, June 2020, Volume 38, Part 5, 2021, Pages 2988-2995, https://doi.org/10.1016/j.matpr.2020.09.321

[5] Zhang, X.Z.; Xu, P.H.; Liu, G.W.; Ahmad, A.; Chen, X.H.; Zhu, Y.L.; Qiao, G.J. Synthesis, characterization and wettability of Cu-Sn alloy on the Si-implanted 6H-SiC. Coatings 2020, 10, 906.

[6] Aravind, M.; Ahmad, A.; Ahmad, I.; Amalanathan, M.; Naseem, K.; Mary, S.M.M.; Zubair, M. Critical green routing synthesis of silver NPs using jasmine flower extract for biological activities and photocatalytical degradation of methylene blue. J. Environ. Chem. Eng. 2020, 9, 104877.

[7] Hussain, S.; Khan, A.J.; Arshad, M.; Javed, M.S.; Ahmad, A.; Shah, S.S.A.; Khan, M.R.; Akram, S.; Zulfiqar; Ali, S.; et al. Charge storage in binder-free 2D-hexagonal CoMoO4 nanosheets as a redox active material for pseudocapacitors. Ceram. Int. 2020.

[8] Saleem, M.; Irfan, M.; Tabassum, S.; Alothman, Z.; Javed, M.S.; Hussain, S.; Zubair, M. Experimental and theoretical study of highly porous lignocellulose assisted metal oxide photoelectrodes for dye-sensitized solar cells. Arab. J. Chem. 2020, 14, 102937.

[9] Mr. A. Suresh, Ms. B. Vidhya Darshini, C. Laxmi Sruthi, Madhusudhan Reddy, Mechanical Characterization and Failure analysis of Kevlar epoxy reinforced composites with alterations in fiber orientations, 2021, National Conference on Recent Innovations in Science and Technology, CVR College of Engineering, Hyderabad.

[10] Madkour, L.H. Nanoelectronic Materials: Fundamentals and Applications; Springer: Berlin/Heidelberg, Germany, 2019; Volume 116.

[11] Zhan, M.; Hussain, S.; AlGarni, T.S.; Shah, S.; Liu, J.; Zhang, X.; Liu, G. Facet controlled polyhedral ZIF-8 MOF nanostructures for excellent NO2 gas-sensing applications. Mater. Res. Bull. 2021, 136, 111133.

[12] Kashif, M.; Jaafar, E.; Bhadja, P.; Low, F.W.; Sahari, S.K.; Hussain, S.; Al-Tamrah, S.A. Effect of potassium permanganate on morphological, structural and electro-optical properties of graphene oxide thin films. Arab. J. Chem. 2020, 14, 102953.

[13] Tang, L.; Dang, J.; He, M.; Li, J.; Kong, J.; Tang, Y.; Gu, J. Preparation and properties of cyanate-based wave-transparent laminated composites reinforced by dopamine/POSS functionalized Kevlar cloth. Compos. Sci. Technol. 2019, 169, 120–126.

[14] Pandey, J.; Nagarajan, V.; Mohanty, A.K.; Misra, M. Commercial potential and competitiveness of natural fiber composites. In Biocomposites; Elsevier: Amsterdam, The Netherlands, 2015; pp. 1–15.

[15] Ahmad, A.; Mubharak, N.M.; Naseem, K.; Tabassum, H.; Rizwan, M.; Najda, A.; Hussain, S. Recent advancement and development of chitin and chitosan-based nanocomposite for drug delivery: Critical approach to clinical research. Arab. J. Chem. 2020, 13, 8935–8964.

[16] Reis, P.N.; Neto, M.A.; Amaro, A.M. Effect of the extreme conditions on the tensile impact strength of GFRP composites. Compos. Struct. 2018, 188, 48–54.

[17] Mustafa, E.H.B.; Dyadyura, K.; Jan, V.; Harniˇcárová, M.; Zajac, J.; Modrák, V.; Pandová, I.; Vrábel, P.; Nováková-Marcinˇcínová, E.; Pavelek, Z. Manufacturing Technology of Composite Material Structure; Sudan University of Science and Technology: Khartoum, Sudan, 2017.

[18] Xiong, J.; Du, Y.; Mousanezhad, D.; Asl, M.E.; Norato, J.; Vaziri, A. Sandwich structures with prismatic and foam cores: A review. Adv. Eng. Mater. 2019, 21, 1800036.

[19] Kwonpongsagoon, S.; Jareemit, S.; Kanchanapiya, P. Environmental impacts of recycled nonmetallic fraction from waste printed circuit board. Int. J. Geomate 2017, 12, 8–14. [CrossRef]

[20] Qi, L.; Ju, L.; Zhou, J.; Li, S.; Zhang, T.; Tian, W. Tensile and fatigue behavior of carbon fiber reinforced magnesium composite fabricated by liquid-solid extrusion following vacuum pressure infiltration. J. Alloys Compd. 2017, 721, 55–63.

[21] Pervaiz, M.; Ahmad, I.; Yousaf, M.; Kirn, S.; Munawar, A.; Saeed, Z.; Rashid, A. Synthesis, spectral and antimicrobial studies of amino acid derivative Schiff base metal (Co, Mn, Cu, and Cd) complexes. Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 2019, 206, 642–649.

[22] Rajesh Kumar, G.; Hariharan, V.; Saravanakumar, S.S. Enhancing the free vibration characteristics of epoxy polymers using sustainable phoenix Sp. fibers and nano-clay for machine tool applications. J. Nat. Fibers 2019, 1–8.

[23] Kabir, S.M.F.; Mathur, K.; Seyam, A.M. A critical review on 3D printed continuous fiber-reinforced composites: History, mechanism, materials and properties. Compos. Struct. 2020, 232, 111476.

[24] Anjum, N.; Suresha, B.; Prasad, S.L.A. Influence of Water ageing on mechanical properties of CaCO3 filler filled epoxy resin and sansevieria/carbon fiber reinforced composites. Open J. Compos. Mater. 2019, 9, 1–20.

[25] Liu, M.; Rohde, B.J.; Krishnamoorti, R.; Robertson, M.L.; Dawood, M. Bond behavior of epoxy resin–

polydicyclopentadiene phase separated interpenetrating networks for adhering carbon fiber reinforced polymer to steel. Polym. Eng. Sci. 2019, 60, 104–112.

[26] de Souza, L.C.; Rodrigues, N.S.; Cunha, D.A.; Feitosa, V.P.; Santiago, S.L.; Reis, A.; Loguercio, A.D.; Paris, T.; Saboia, V.d.A.; Perdigao, J. Two-year clinical evaluation of proanthocyanidins added to a two-step etch-and-rinse adhesive. J. Dent. 2019, 81, 7–16.

[27] Braga, R.; Magalhaes, P., Jr. Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites. Mater. Sci. Eng. C 2015, 56, 269–273.

[28] A. Suresh, A. Sai Kiran Goud, R. Srilekha, A. Praneeth, Testing and analysis of Kevlar epoxy reinforced composites made from 3D printing process, 2021, National Conference on Recent Innovations in Science and Technology, CVR College of Engineering, Hyderabad.

[29] Xavier, J.; Rodney, K.D.; Prakash, S.J. Mechanical characterisation of epoxy polymer composite reinforced with ramie and synthetic fiber. SSRN Electron. J. 2019. [CrossRef]

[30] Kader, W.B. Physico-mechanical properties of typha angustata (elephant grass) fiber reinforced thermoplastic composites. IJAR J. 2019.

[31] Dolan, G.K.; Cartwright, B.; Bonilla, M.R.; Gidley, M.J.; Stokes, J.R.; Yakubov, G. Probing adhesion between nanoscale cellulose fibres using AFM lateral force spectroscopy: The effect of hemicelluloses on hydrogen bonding. Carbohydr. Polym. 2019, 208, 97–107. [CrossRef]

[32] Dia, A.; Dieng, L.; Gaillet, L.; Gning, P.B. Damage detection of a hybrid composite laminate aluminum/glass under quasi-static and fatigue loadings by acoustic emission technique. Heliyon 2019, 5, e01414.

[33] Phuong, P.T.M.; Won, H.J.; Oh, Y.J.; Lee, H.S.; Lee, K.D.; Park, S.Y. The chemistry and engineering of mussel-inspired glue matrix for tissue adhesive and hemostatic. J. Ind. Eng. Chem. 2019, 80, 749–756.