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Augmentation and Extensive Interpretation of Novel Fiber-Foam-Fiber Laminate (FFF) Using Basalt Fiber, Ceramic Mat, and Ceramic Foam

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Abstract

In this study, composite laminates with ceramic mat (M), basalt fabric (B), and ceramic foam (F) at three different stacking sequences were molded using the compression molding technique. The experimental results claim that the inherent properties and flammability characteristics are influenced by the laminate stacking sequence. Composite laminate with basalt fabric in the core and ceramic mat at the outer layers (MBM) was established to have the highest tensile strength of approximately 120MPa.While BMB exhibited the highest impact strength of 21 $J/mm^{2,}$ and MFM had the maximum Shore D hardness of 63.BMB and MBM had superior flammability characteristics, as indicated by the slower burning time. However, the mass loss was higher than the MFM. Delamination was the ruling mode of failure in the specimens subjected to the tension and impact test, as evident from the microstructure images from the scanning electron microscope. Many automobiles and aerospace applications need flexural strength, inflexibility, low concentration, and high thermal resistance to support requirements for space mirrors, control systems, and ballistic armor; not only soldiers and vehicles need a combination of hardness and featherweight for manufacture and motility.

Keywords: Composite laminate; mechanical properties; flammability; basalt; ceramic

1. Introduction

Development in materials science engineering has given birth to a charming, useful material called composites, one of the most advanced and flexible engineering materials. Growing advancement in technology is leading to its usage for multi-disciplinary applications. Currently, the application of composite materials has penetrated numerous fields of science and technology because of their specific physical and mechanical properties. Amongst approximately 1600 engineering substances available in the market, more than 200 materials are composite materials and have established their significance. Composite materials are being substituted for common engineering materials due to their specific stiffness, strength, fatigue limit, damping, and low coefficient of thermal expansion. These desirable properties provide the design of structural components more flexible than traditional metals. The design of lightweight structures is in demand for various industrial applications, particularly in aerospace, wind energy, and automotive. Composite laminates were modified to bestow intended rigidity properties in length wise as well as off-axis orientation between a blend of on-axis together with off-axis stacks. However, in the meanwhile, one another is dominated to quasistatic loading. The matrix normally breaks first, dominant towards micro crack development. Unsteady in nature, the micro cracks rapidly pass over the thickness together with the width of piles crosswise to the loading path. The supplementary rise in the enforced load, additional cracks look within the transverse plies and casting an array of nearly parallel (between lamina thickness plus width), same size, and intermediate fracture planes (Abilash and Shivaprakash 2013).

Composite laminates remain mostly employed as cladding materials within structural and sandwich utilizations, where each other leap toward containing a low-concentration core, including foam-like honeycomb material. The superiority of such a material combination was crystal clear, which incorporates weight savings. The main drawbacks of such a structure are the difficulties in repairing the sandwich as well as the reclamation of the unlike constituents. The best example of the traditional sandwich structure discloses the back and forth between increased functional combination and increased recycling perspective.

Vahid et al. (2016) had calculated the creep behavior of recently basalt fiber metal laminates (BFML) by building standard BFML specimens utilizing several layers of basalt fiber or epoxy laminates accompanied by steel or aluminum layers imposed to a test. The collapse time, the introductory strain, and the change in strain for all the test specimens were computed and combined simultaneously, weighed upped along with naked aluminum layers. Feasibility studies are carried out against two contrasting temperatures greater than that of glass transition temperature regarding epoxy resin to investigate the outcome on creep behavior due to temperature variation. Derived from outcomes acquired, enfold in basalt fiber-reinforced layer significantly pompous one and the other original strain and collapse time. In addition, for different purposes amid basalt together with glass fibers, the creep behavior of basalt or epoxy, as well as glass or epoxy composites, was deliberated by tensile test at sweltering heat. No cold flow rupture failures were detected in the interim sweltering heat; tensile cold flow tests was conducted against loads until 15 percent of peak tensile strength (PTS). This was further initiated where the creep safeguard of basalt fiber reinforced epoxy (BFRE) is lofter when compared with glass fiber reinforced epoxy (GFRE).

DejianShen et al. (2019) in his experimental quest of the study shows the impact of strain amount on the bonding acrimony of concrete elements strengthened with Basalt FRP rebars. Bonding actions of concrete element sharden with FRP rebars was necessary to estimate load bearing ability of concrete element. Even though the bonding behaviour of concrete elements strengthened due to FRP rebars subjected to stable loading was calculated, in this investigation works against bonding behaviour pertaining to concrete elements strengthened as a result of basalt FRP (BFRP) rebarsless than active loading condition were quiet inadequate. Bonding nature of concrete elements strengthened by BFRP rebars below a number of strain conditions are examined. Explored experiment outcomes were examined and displayed that: there are three varying types of bond deterioration methods by which concrete elements were strengthened by BFRP rebars below various active loading conditions are examined including: powdering of concrete, delinquency at interface among resin as well as concrete, and bond failure at interface among fiber together with matrix; from this investigation it is clearly seen that the bonding potential of concrete elements strengthened with Basalt FRP rebars exhibits raised when the strain rates increasing in the meantime slip correlate with bond strength was droped when its strain values rised also the trend related slip coincident towards adherence on concrete elements strengthened by Basalt FRP rebars was suggested by taking strain amount; this forecast modelled towards bond stress-slip association based on concrete elements strengthened by BFRP rebars taking into account strain values suggested.

V. Manikandan et al. (2011) In his experimental investigation unimpregnated polyester-grounded polymer composites are evolved through reinforcing basalt fabric accompanied by an unimpregnated polyester resin by utilizing the hand layup method close to ambient temperature. The inquest express basalt fiber reinforced unimpregnated polyester composites one along with the other with as well as unaccompanied by acid as well as alkali treatments of the fabrics were made. Intention of the examination is to accomplishthe surface alterations (NaOH& H2SO4) due to trementas far as mechanical properties, inclusive of tensile strength, impact strengthand shear strength. Difference on mechanical properties namely tensile strength, inter-laminar shear strength and the impact strength of a variety of test specimens, were computed employing a computer-aided universal testing machine together with an Izod Impact testing machine. Scanning Electron Microscope (SEM) is used to watch the fractured area of the composites to manifest outside alterations to the fiber as well as enhanced fiber–matrix bonding. The outcome of the examination disclose such inherent properties of basalt fiber-impregnated composites were greater than that off glass fiber-impregnated composites. The experimental study shows that achievement of basalt fiber-impregnated composites, when compared with unimpregnated polyester, was better than glass fiber-impregnated composites. The durability tests result expresses that acidic-treated basalt fiber-impregnated composite has greater tensile strength rates than other amalgamations. Experimental quest shows that glass fiber composite was appreciably better pretentious because of post treatment than the basalt fiber impregnated composites. The impact tests manifested specifically acidic-treated basalt fiber impregnated composite has higher impact strength. In view of entire, study exhibits specifically basalt fiber reinforced composites fabricated advanced substantial material with properties that are normally greater than among glass fiber impregnated polymer composites, subjected to various applied loading conditions. This experimental work validates the relevancy pertaining to basalt fiber being a best suitable alternative strengthening medium of polymer composites.

VivekDhand et al. (2014) contemporary rise in harness of eco-friendly, natural fibers as reinforcing agent for the production of featherweight, inexpensive polymer composites will be glimpse around the world. Including materials of attentiveness presently being broadly exploited is basalt fiber, why because as it is economical and provides extraordinary properties compared to glass fibers. The notable superiorities of the particular composites comprise greater specific mechanical-Physical-chemical properties, on-abrasive, and biodegradability qualities. This article bestows scrutiny about basalt fibers was utilized like a strengthen substance for composites as well as converse about it as a substitute ply of glass fibers. This experimental investigation also confers about the fundamental of basalt chemistry together with its categorization. In addition with some, attempt was made to exhibit the emerging trend in research publications area. Furthermore discuss the development ove rinherent, thermic as well as chemical resistant properties attained for specific industrial utilization purpose. This investigation, mainly focused on employ in view of basalt fiber as a strengthening element of composites, it was mostly used for cloak-and- dagger military actions necessitate the production of strong as well as featherweight materials meant for anti-ballistic use, automobile parts making as well as for aerospace requirements. Resent stage, advanced properties of basalt was innovated and it was opened for civilian research studies. It reveals that Basalt has established own greater properties than the traditional asbestos together with glass fibers compiled. Basalt fibers have better advantageous relative to carbon fibers, also possess an extremity both are environmental-friendly, and harmless. Additionally, basalt was chemically inert, greater immune to erosion, and has low diffusivity because of above said it is high-caliber than any other reinforcement agent exploitable now a days.

2. Materials and Methods

Experimentation set of three dissimilar combinations of laminates were fabricated by using basalt mat, ceramic foam and ceramic mat.Basalt fiber mat is prepared from fine basalt fiber is comprising of pyroxene, plagioclase, and olivine they have better physical and mechanical features when compared to glass fiber and are cost-effective than the carbon fiber. It is used as a fire proof fabric in aerospace and automotive industries in addition with that it can also use as composite to produce wide range of product. It is commercially available in Zigma Nicunj Chennai. The special features of basalt are high strength, high temperature resistance, good corrosive resistance, easy to handle, recyclable, compatible with many resins namely epoxy, polyester, vinyl ester, etc. The elemental composition of basalt fiber mat are as below in Table 1. Also, the physical and mechanical properties of basalt fiber is given in Table 2.

Table 1. Elemental Composition of Basalt Fiber

Elements	**SiO_2**	**Al_2O_3**	**MgO**	**TiO_2**	**FeO_3 + FeO**	**Na_2O + K_2O**	**Others**
Wt.%	51.6-59%	14.6-18.3%	3.0-5.3%	0.8-2.25	9-14	3.6-5.2	0.09-0.13

Table 2. Physical and Mechanical Properties of Basalt Fiber

Fiber	**Physical properties Density (g/cm^2)**	**Mechanical Properties**			**Maximum service temperature °C**
		Tensile strength (MPa)	**Young's modulus (GPa)**	**Elongation (%)**	
Basalt	2.63-2.8	4100-4840	93.1-110	3.1	650
E-glass	2.54-2.57	3100-3800	72.5-75.	4.7	380
S-glass	2.54	4020-4650	83-86	5.3	300
Carbon	1.78	3500-6000	230-600	1.5-2.0	500
Aramid	1.45	2900-3400	70-140	2.8-3.6	250
Ceramic mat	---	---	---	---	760
Ceramic foam	---	---	---	---	---

2.1. Ceramic Fiber Mat and Ceramic Foam

Ceramic fiber mat of thickness 0.5 mm and ceramic foam having thickness 1.5 mm were procured from M/s. Southern Refractories and Minerals, Chennai, India. Ceramic fiber mat is composed ofSiO_2(61wt. %), Al_2O_3(23wt.%) and other wt.% include Fe_2O_3, Na_2O, TiO_2, MgO, and CaO. Commercially available basalt fabric was purchased from Zigma Nicunj Chennai, India. The resin used for binding the lamina together is isophthalic polyester (PE) accompanied by methyl ethyl ketone peroxide as well as cobalt naphthenate used as curing agent and accelerator respectively. PE resin was obtained from the Sigma Aldrich, Chennai, India. The images of the constituents is shown in Fig.1.

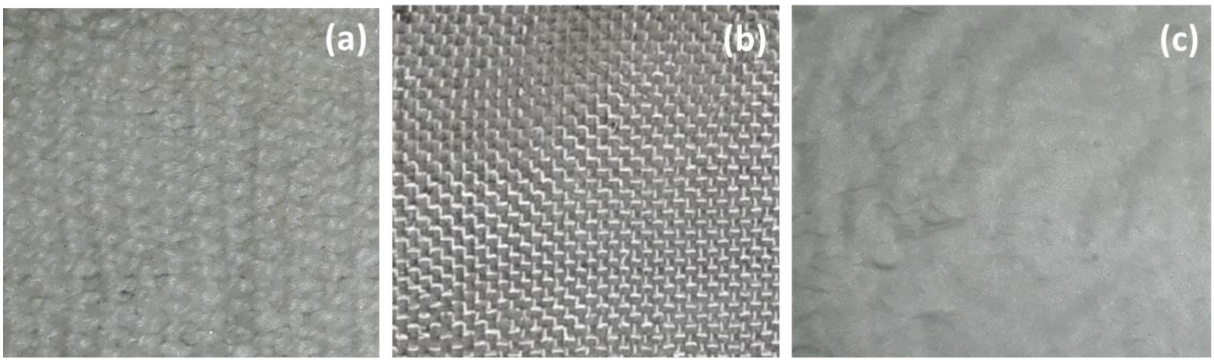

Fig.1. Images of the Laminate Constituents (a) Ceramic Mat, (b) Basalt Fabric, and (c) Ceramic Foam.

2.2. Bonding and Coating Materials

Over the past 30 to 40 years, adhesive bonding is one of the main processes being employed in the fabrication of structural components in electronics, aerospace industries as well as in automotive industries and many other sectors owing to its many good effect like light weight, more economical and enhanced damage tolerance. The low-density sandwich construction and structurally adhesive bonded elements contributes a major part in the latest aircrafts in fastening stringers or tear straps to the fuselage and skins referring to wing for yielding stiffness to the structures during buckling. Moreover, it is in addition operationalized to adherence in metallic beehive structures like lifts, feathers, raiders etc. It was also reported that the adhesive bonded structural materials had exposed more fatigue resistance than the commonly used mechanical fastened assemblies, in addition if it was properly designed can sustain even the implications at higher load levels. Recently, an increasing trend shows the development of metal parts together with structures was noticed in view of replacing the composite materials not only in the area of defence although in aircraft structural designs. It was found that 22% of the total aircraft weight was constituted by the composite materials, since the structural coupling added more structural difficulty and local stress factors leading to appreciable reduction in the lightweight prospects of composite design. Hence, the invention of modern fastening technologies was commercialized to diminish the weight consequences made on structural coupling in place of mechanically fastened joints. Mechanical joining is the one of most commonly employed techniques for connecting composite components with no surface preparations, easy dismantling and to ensure quality inspection of the components.

Table 3. Properties of Isophthalic Polyester Resin

Properties	Basalt fabric	Ceramic mat	PE
Density (g/cm^3)	2.63-2.8	.96-1.6	1.15
Elongation at break (%)	3.1	-	4.8
Tensile strength (MPa)	4100-4840	-	41±1.6
Young’s modulus (MPa)	93.1-110	-	968±4.07

2.3. Preparation of Laminates

Isophthalic polyester resin was assorted together with methyl ethyl ketone peroxide in addition to cobalt naphthenate in percentage about 98:1:1 by employing mechanical agitator. The basalt fiber mat, ceramic fiber mat and ceramic foam were dipped inside the prepared resin mixture and put into the mold of dimension 300 ×130 × $3mm^3$. The top as well as bottom surface of the mold with resin dipped fabric layers were covered with the base plates. The entire mold setup with fabric layers was then placed in a hydraulic compression machine and was allow cooling for 12 hours against elevated ambient temperature under a pressure of 18 MPa. Thesecured composite laminates were subsequently removed from the mold and cut into standard test specimens through the water jet machining process. The abbreviation used for molded specimen is present in Table 4.

Table 4. Abbreviation Used for Molded Specimen

S.No.	Abbreviation	Description
1	MBM	Ceramic Mat + Basalt Mat + Ceramic Mat
2	BMB	Basalt Mat + Ceramic Mat + Basalt Mat
3	MFM	Ceramic Mat + Ceramic Foam + Ceramic Mat

3. Characterization

3.1. Tensile Test

The test specimens for tensile was produced as maintained by ASTM benchmarks (D 638) and test specimen was expose to tensile load in an universal testing machine, Instron (Series 3382) with a cross head velocity of 1 mm/min. The thickness of the all test specimen was kept same for each and every test samples of 3mm, 200 mm long and 20 mm wide. Five different samples were tested for each design conditions and mean is calculated.

3.2. Impact Test

The impact strength of the material was calculated using un-notched Charpy test according to ASTM standards (D256).The proportions of the specimen were taken as65mm×13mm×3mm, machined through water jet machine. The captivated impact energy of each test specimens was computed as well as categorize in Table 3, where an average of 5 specimens were considered for each condition.

3.3. Hardness Test

Hardness is an indication of a material to resist deformation and wear. The hardness of the specimens were determined using Shore D durometer as per the ASTM 2240 standard.

3.4. Flammability

Flammability testing is a censorious part to ensure safety and trustworthiness of a consumer product. The flammability test for industry entreaty incorporate the rate of burning, heat and smoke liberate benchmark, fitness to ignite, etc. The test method is prescribed in ASTM D635 UL-94H standards. Based on test standard specimens were prepared of size 125 mm×13 mm×3mm together with line markings are put, at a span of 25 mm and 100 mm out-of one end of the test specimen. The test piece was kept horizontally and 5 mm of its length was showed against the laboratory burner flame, which was held at an angle of 45° to the test specimen for 30 s, and time grasp to completion of combustion up to 25 mm and finalization time was recorded by min. The starting together with ending mass of the specimen are further noted in-order-to distinguish the combustibility about test specimen. The flammability attributes of the specimen were taken down and arranged in Table 5.

3.5. Fractography

Micrographs of the specimens failed out-during test was examined by utilizing Scanning electron microscopy (SEM) (Zeiss, Germany) with energy diffusing spectroscopy (EDS) (Bruker, UK) were employed for fractographical investigation on fractured specimens.

4. Results and Discussions

4.1. Tensile Properties

MBM presented the maximum tensile strength of about 120 MPafollowed by BMB and MFM. The superior tensile strength for the MBM and BMB is credited to the better fibre compatibility and adhesion between the basalt and ceramic mat. These factors allowed those laminates to act as whole unit to withstand the applied load better than MFM. Since MFM with ceramic foam has porous structure, the effective surface area for mechanical interlocking with the ceramic mat decreases. Hence, MFM displayed inferior strength than the other configurations. Similar to the tensile strength, % elongation was also dependent on the fibre type and laminate stacking sequence. MFM was found to exhibit the highest %

elongation as shown in Fig.2(a). This observation for MFM is primarily due to the ductile nature of the foam in the stacking sequence which permits more elongation to the applied load in contrast to the brittle nature of the laminate with ceramic and basalt mats. The ultimate tensile strength for different specimen is shown in Fig.2 (b).

Micrographs of the specimens failed out-during tensile test is shown in Fig. 3(a) & Fig.3 (b). All the specimens subjected to the tensile load showed inter-delamination between the layers which is the typical failure behavior of a composite laminate.

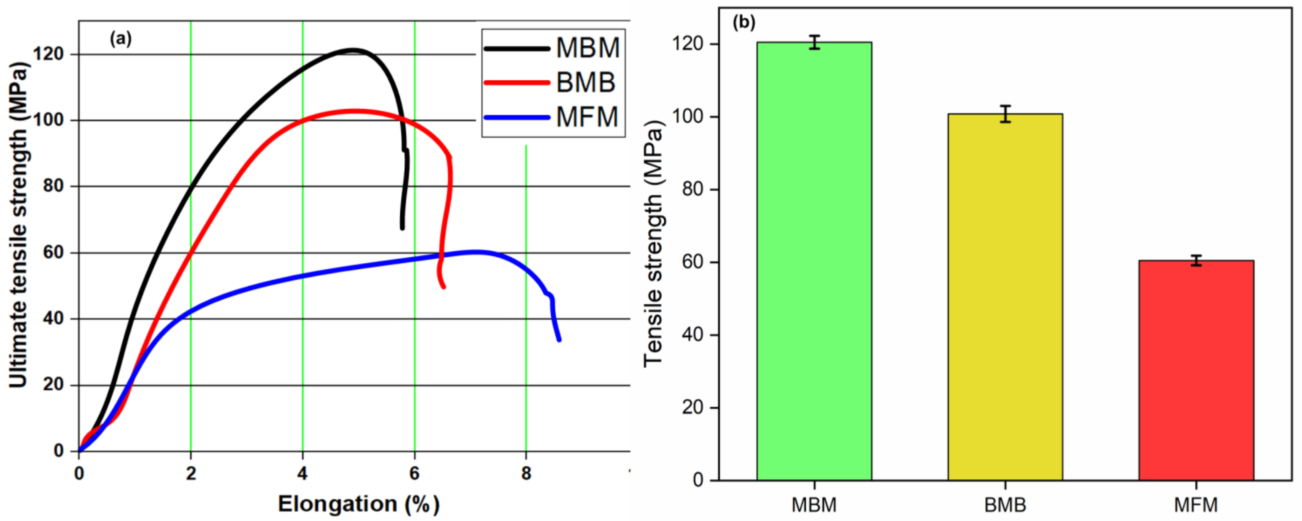

Fig.2. (a) Stress-Strain Curves of Molded Specimens (b) Tensile Strength of Molded Specimens

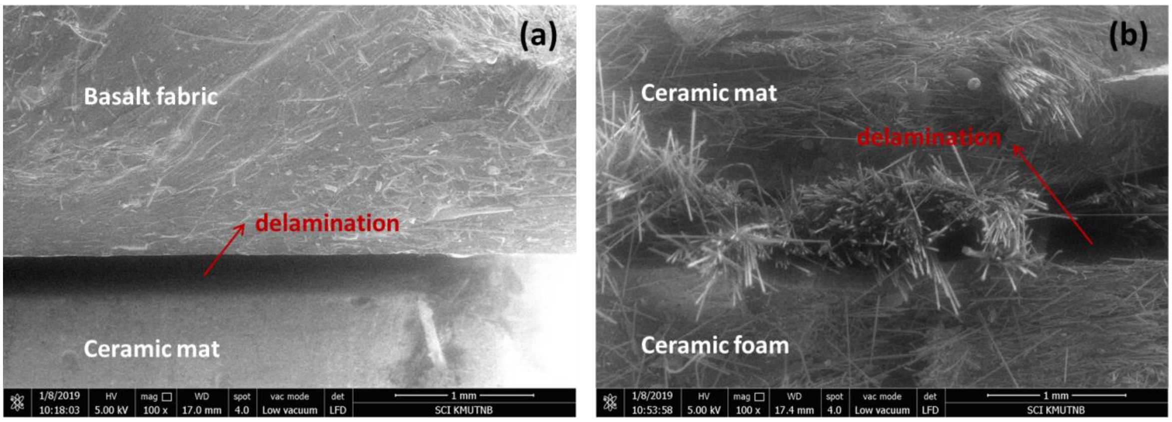

Fig.3. Micrographs of the Tensile Fractured Specimens Showing Delamination (a) BMB and (b) MFM

It is well known that tensile properties are highly dependent on the outer fibre layer than the core in a composite laminate [1]. Apart from this factor, the distinctive and inherent characteristic of the fibre arrangement in the basalt &ceramic fiber mat was also responsible for the distinctness in tensile strength between the BMB and MBM stacking sequence. In case of basalt fabric (Figure 3(a)), individual fibres are stacked together in their fabric structure whereas for the ceramic mat (Figure 3(b)), a single fiber bundle is formed by a cluster of individual ceramic fibers.

It could also be noticed that fiber fraying and fibre splitting occurred in basalt due to the individual fiber arrangement in basalt while ceramic fibers remained intact due to the fiber clusterFig.4(a). This feature of the ceramic mat helps to retain the tensile strength better than the basalt mat in the outer layer. Hence, MBM has superior tensile strength than the BMB configuration. For MFM, initially the applied load is carried by outer ceramic mat layers. As the applied load increases, delamination occurs between the ceramic mat and ceramic foam as shown in Fig.4(b). At this point, the applied load is completely taken by the softer foam core. However, due to their porous structure and lower stiffness, ceramic foam cannot withstand the load unlike stiffer core in case of MBM and BMB. Thus, MFM failed easily at lower loads than the other configurations.

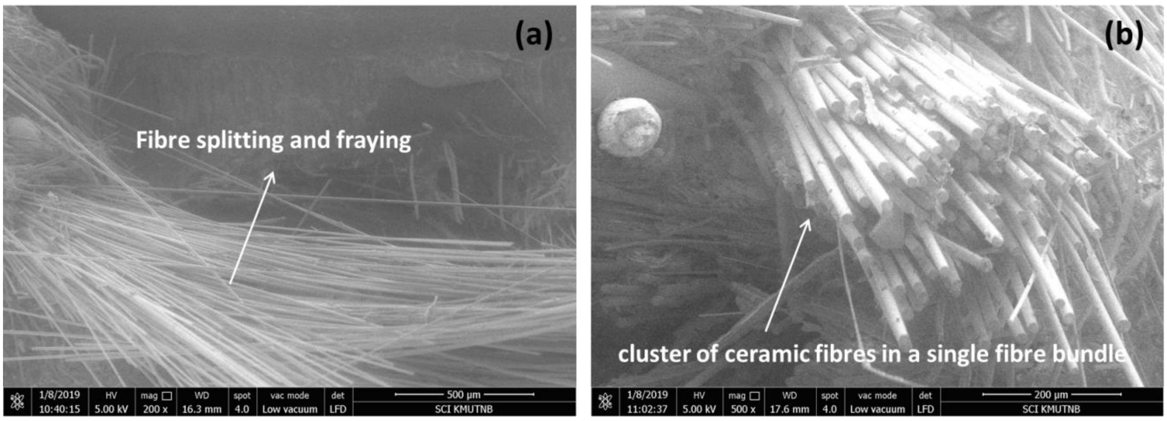

Fig.4. Micrographs of Tensile Failure in (a) BMB and (b) MFM

4.2 Impact Properties

The impact strength in respect to tested composite laminates followed the trend: BMB >MBM >MFM. This trend indicates that the core material was a deciding factor of the impact strength about laminates. Higher impact strength for BMB is due to the fact that individual fibres in the basalt mat breaks easily with the application of impact load and leads to intra-layer delamination within the fabric as shown in Fig.5(a). The impact energy is virtually distributed along the ceramic mat on the failure in basalt mat due to the impact force and further energy is absorbed by the ceramic mat in BMB. This phenomenon seen in BMB could not be noticed in MBM (Fig.5(b)) and MFM (Fig.5(c)) which showed signs of sudden collapse in the form of inter-layer delamination in their stacking sequence.

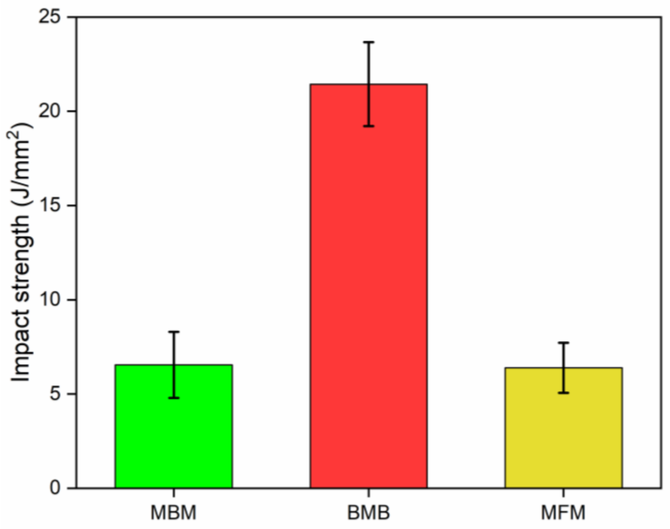

Fig.4. Impact Strength of Molded Specimens

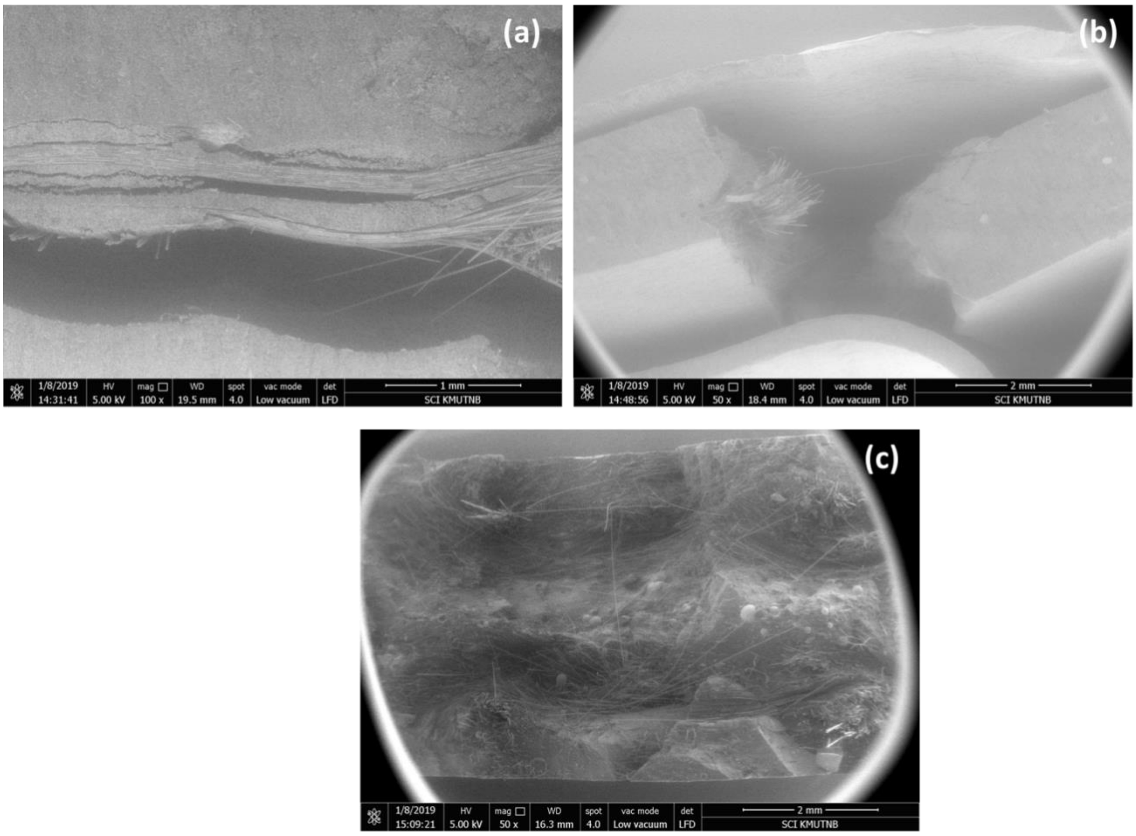

Fig.5. Micrographs of the Impact Fractured Specimens (a) BMB, (b) MBM, and (c) MFM

4.3. Hardness

Hardness value of the composite laminates with different stacking sequence is given in Fig.6.

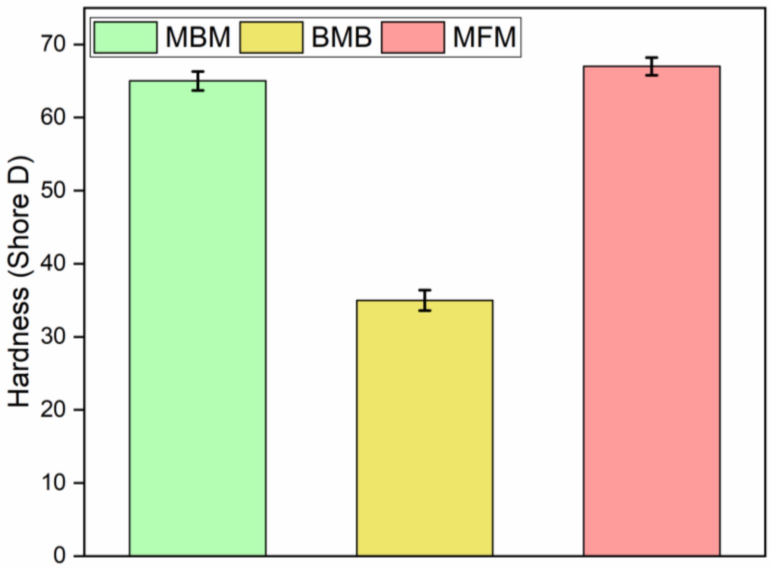

Fig.6. Shore D Hardness of the Laminate Configurations

Since the hardness values indicate the resistance to indentation, higher hardness values for MFM and MBM with the ceramic mat as outer layer indicates their superior resistance to indentation than the BMB. The reason for these observations in MBM and MFM is the resistance to the localised plastic deformations by ceramic mat in the outer layer which is susceptible to indentation.

4.4. Flammability

Table 5 summarizes the flammability characteristic of composite laminates under investigation. As per Table 5, only laminate BMB ignited first during the initial stages of combustion testing at 30 seconds. It could also be noticed that both BMB and MBM took longer time to burn until 25 mm and 125 mm respectively. The enhanced thermal resistance offered by BMB is credited to the natural fibre retardant capability of the basalt fibre [2]. MFM laminates with the ceramic foam and ceramic mat had least flame resistance as reflected from their faster burning time.

Table 5. Flammability Characteristics of the Composite Laminates

Laminate	Ignition status of the specimen after 30 s	Burning time for 25mm length from ignition (t_1)	Burning time for the next 100 mm length (t_2)	Complete Burning time of the specimen (t_1+t_2)	Initial mass of the specimen	Final mass of the specimen	Mass loss
		Minutes	**Minutes**	**Minutes**	**g**	**g**	**%**
MBM	Not ignited	2	7	9	18.18	13.51	25.69
BMB	Ignited	14	5	19	15.54	11.4	26.64
MFM	Not ignited	1	4	5	22.41	17.84	20.39

Thermal resistance is not only dictated by the ability of the material to ignite at a lengthy period but also on the mass loss during the burning and residual char after complete burning. The higher degree of mass loss despite of their longer burning BMB and MBM laminate could be accounted to the evaporation of moisture content in the basalt fibre. Thus, the configurations with BMB and MBM not only produced higher mass loss but also lower char than the MFM specimens. On the other hand, the mass loss for MFM was significantly lower than the other laminates.

5. Conclusions

Composite laminates made up of basalt fabric (B), ceramic mat (M) and ceramic foam (F) were conquered to tensile, impact, hardness and flammability tests. The laminate properties were dependent on the assembling sequence of the individual lamina within the matrix. Tensile strength was superior for MBM come after BMB and MFM. In the event of impact strength, the successive order was noticed: BMB ≥ MBM ≥ MFM. The difference in strength under tension and impact could be attributed to the individual lamina characteristic. Delamination was the only mode of failure in MFM while fibre fraying and fibre splitting were also observed along with the delamination in BMB and MBM. All the specimens were burnt to residues on ignition. MFM exhibited highest residue or least mass loss at the end of ignition while the BMB and MBM showed a slightly higher mass loss. However, they burnt slower than MFM. The difference in the flammability properties of the laminate is associated to the physical characteristic of the basalt, ceramic mat and ceramic foam. Basalt mat has moisture which evaporates while heating and contributes to higher mass loss. On the other hand, ceramic foam has porous structure and permits the burning process to occur easily.

References

1. Gonzalez-Canche, N. G., Flores-Johnson, E. A., Cortes, P., & Carrillo, J. G., 2018. 'Evaluation of surface treatments on 5052-H32 aluminum alloy for enhancing the interfacial adhesion of thermoplastic-based fiber metal laminates', International Journal of Adhesion and Adhesives, vol. 82, pp. 90-99.
2. Guoxin, S., Benlian, Z., Zongguang, Z., Chengti, Z., &Changxu, S., 1993. 'A new superhybrid composite material: Vinylon-reinforced aluminiumlaminate (VIRALL)'. Composites, vol. 24(5), pp. 433-435.
3. Hagenbeek, M., &Sinke, J., 2019. 'Effect of long-term thermal cycling and moisture on heated Fibre Metal Laminates and glass-fibre epoxy composites', Composite Structures, vol. 210, pp. 500-508.
4. Hao, X., Nie, H., Ye, Z., Luo, Y., Zheng, L., & Liang, W., 2019. 'Mechanical properties of a novel fiber metal laminate based on a carbon fiber reinforced Zn-Al alloy composite'. Materials Science and Engineering: A, vol. 740, pp. 218-225.
5. Hu, Y. B., Li, H. G., Cai, L., Zhu, J. P., Pan, L., Xu, J., & Tao, J., 2015. 'Preparation and properties of Fibre–Metal Laminates based on carbon fibre reinforced PMR polyimide'. Composites Part B: Engineering, vol. 69, pp. 587-591.
6. Hu, Y., Zhang, Y., Fu, X., Hao, G., & Jiang, W., 2019. 'Mechanical properties of Ti/CF/PMR polyimide fiber metal laminates with various layup configurations'. Composite Structures, vol. 229, 111408.
7. Jiao, F., Liu, M., Jiang, F., Zhao, J., Li, P., & Wang, Z., 2019. 'Continuous carbon fiber reinforced Ti/Al3Ti metal-intermetallic laminate (MIL) composites fabricated using ultrasonic consolidation assisted hot pressing sintering', Materials Science and Engineering: A, vol. 765, 138255.
8. Jin, K., Wang, H., Tao, J., & Zhang, X., 2019. 'Interface strengthening mechanisms of Ti/CFRP fiber metal laminate after adding MWCNTs to resin matrix', Composites Part B: Engineering, vol. 171, pp. 254-263.
9. Joesbury, A. M., Colegrove, P. A., Van Rymenant, P., Ayre, D. S., Ganguly, S., & Williams, S., 2018, 'Weld-bonded stainless steel to carbon fibre-reinforced plastic joints', Journal of Materials Processing Technology, vol. 251, pp. 241-250.
10. Kern, F., Palmero, P., Marro, F. G., &Mestra, A, 2015. 'Processing of alumina–zirconia composites by surface modification route with enhanced hardness and wear resistance', Ceramics International, vol. 41(1), pp. 889-898.

11. Khoramishad, H., Alikhani, H., &Dariushi, S., 2018. ‘An experimental study on the effect of adding multi-walled carbon nanotubes on high-velocity impact behavior of fiber metal laminates’, Composite Structures, vol. 201, pp. 561-569.

12. Khurram, A. A., Hussain, R., Afzal, H., Akram, A., &Subhanni, T., 2018. ‘Carbon nanotubes for enhanced interface of fiber metal laminate’, International Journal of Adhesion and Adhesives, vol. 86, pp. 29-34.

13. Laban, O., & Mahdi, E., 2017. ‘Enhancing mode I inter-laminar fracture toughness of aluminum/fiberglass fiber-metal laminates by combining surface pre-treatments’, International Journal of Adhesion and Adhesives, vol. 78, pp. 234-239.

14. Léonard, F., Shi, Y., Soutis, C., Withers, P. J., & Pinna, C., 2014. ‘Impact damage characterisation of fibre metal laminates by X-ray computed tomography’, In The Conference on Industrial Computed Tomography.

15. Li, H., Hu, Y., Fu, X., Zheng, X., Liu, H., & Tao, J., 2016. ‘Effect of adhesive quantity on failure behavior and mechanical properties of fiber metal laminates based on the aluminum–lithium alloy’, Composite Structures, vol. 152, pp. 687-692.

16. Li, H., Hu, Y., Liu, C., Zheng, X., Liu, H., & Tao, J., 2016. ‘The effect of thermal fatigue on the mechanical properties of the novel fiber metal laminates based on aluminum–lithium alloy’, Composites Part A: Applied Science and Manufacturing, vol. 84, pp. 36-42.

17. Li, H., Hu, Y., Xu, Y., Wang, W., Zheng, X., Liu, H., & Tao, J., 2015. ‘Reinforcement effects of aluminum–lithium alloy on the mechanical properties of novel fiber metal laminate’, Composites Part B: Engineering, vol. 82, pp. 72-77.

18. Li, X., Zhang, X., Guo, Y., Shim, V. P. W., Yang, J., & Chai, G. B., 2018. ‘Influence of fiber type on the impact response of titanium-based fiber-metal laminates’, International Journal of Impact Engineering, vol. 114, pp. 32-42.

19. Liu, C., Zhang, Y. X., & Li, J., 2017. ‘Impact responses of sandwich panels with fibre metal laminate skins and aluminium foam core’, Composite Structures, vol. 182, pp. 183-190.

20. Liu, Q., Ma, J., Kang, L., Sun, G., & Li, Q., 2015. ‘An experimental study on fatigue characteristics of CFRP-steel hybrid laminates’, Materials & Design, vol. 88, pp. 643-650.

21. Liu, Y., &Liaw, B, 2010. ‘Effects of constituents and lay-up configuration on drop-weight tests of fiber-metal laminates’, Applied Composite Materials, vol. 17(1), pp. 43-62.

22. Mallick, P. K, 2007. ‘Fiber-reinforced composites: materials, manufacturing, and design, CRC press.

23. Marissen, R., 1984. 'Flight simulation behaviour of aramid reinforced aluminium laminates (ARALL)', Engineering Fracture Mechanics, vol. 19(2), pp. 261-277.

24. Medjahed, A., Derradji, M., Zegaoui, A., Wu, R., & Li, B., 2019. 'Mechanical and gamma rays shielding properties of a novel fiber-metal laminate based on a basalt/phthalonitrile composite and an Al-Li alloy', Composite Structures, vol. 210, pp. 421-429.

25. Mehr, M. E., Aghamohammadi, H., Abbandanak, S. H., Aghamirzadeh, G. R., Eslami-Farsani, R., &Siadati, S. M. H., 2019. 'Effects of applying a combination of surface treatments on the mechanical behavior of basalt fiber metal laminates', International Journal of Adhesion and Adhesives, vol. 92, pp. 133-141.

26. Montinaro, N., Cerniglia, D., &Pitarresi, G., 2018. 'Evaluation of interlaminardelaminations in titanium-graphite fibre metal laminates by infrared NDT techniques', NDT & E International, vol. 98, pp.134-146.

27. Myung, N., Seo, J., & Choi, N. S., 2019. 'Cyclic elastic modulus and low cycle fatigue life of woven-type GFRP coated aluminum plates', Composites Part B: Engineering, 107004.

28. Pan, G., Guo, Q., Zhao, Z., Wang, S., Qin, Y., & Wang, L, 2011. 'Tribological properties of solid multilayer composite coatings in dry rolling contact', Tribology International, vol. 44(7-8), pp. 789-796.

29. DejianShen[a,b,c], , Chengcai Li [a,b], ZhizhuoFeng[a,b], ChuyuanWena,[b], BinodOjha[a,b]Influence of strain rate on bond behavior of concrete members reinforced with basalt fiber-reinforced polymer rebars 2019 Construction and Building Materials 228 116755 0950-0618/ 2019 Elsevier Ltd.

30. V. Manikandan, J.T. WinowlinJappes⇑, S.M. Suresh Kumar, P. AmuthakkannanInvestigation of the effect of surface modifications on the mechanical propertiesof basalt fibre reinforced polymer composites 2011 Composites: Part B 43 (2012) 812–818 1359-8368. doi:10.1016/j.compositesb.2011.11.009

31. VivekDhand a, Garima Mittal a, KyongYop Rhee a,⇑, Soo-Jin Park b, David Huic.A short review on basalt fiber reinforced polymer composites 2014 Composites: Part B 73 (2015) 166–180 http://dx.doi.org/10.1016/j.compositesb.2014.12.011 1359-8368.

) V. N. Anbazhagan1, R. Edwin Raj2, and J. T. Winowlin Jappes3, "Development and characterization of novel fiber-metal-laminate (FML) using aluminium sheet and ceramic mat" American Scientific Publishers Material Express pp 358-364 vol-9 no-4 (2019).

32. Bright Brailson Mansingh1 | Joseph Selvi Binoj2 | Vadivel Nayanar Anbazhagan3 | Shukur Abu Hassan4 | Kheng Lim Goh5 Characterization of Cocos nucifera L. peduncle fiber reinforced polymer composites for lightweight sustainable applications |Received: 13 November 2021

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33. Binoj, J.S, Manikandan, N, Mansingh, B.B, Anbazhagan, V. N, Taguchi's Optimization of Areca Fruit Husk Fiber Mechanical Properties for Polymer Composite Applications. *Fibers Polym* **23**, pp.3207–3213 (2022). https://doi.org/10.1007/s12221-022-0365-2