Logesh et al. 2018. *Int. J. Vehicle Structures & Systems*, 10(2), 115-121
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.10.2.08

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Stretch Formability Behaviour of Glass Fibre Reinforced Nanoclay on Fiber Metal Laminated Composites

K. Logesh[a], V.K. Bupesh Raja[b] and C. Krishnaraj[c]

[a]Dept. of Mech. Engg., Sathyabama University, Chennai, India
Correspnding Author, Email: klogesh7@gmail.com
[b]Dept. of Automobile Engg., Sathyabama University, Chennai, India
Email: bupeshvk@gmail.com
[c]Dept. of Mech. Engg., Karpagam College of Engg., Coimbatore, India
Email: Krishna.kce@gmail.com

ABSTRACT:

Innovations and research in material processing have brought forward new and improvised materials that are applied in body panels of automobiles, aircraft cabins and railway wagons. These materials are used widely is because of their good mechanical properties and their high strength to weight ratio. In this paper Fibre Metal Laminates (FMLs) were added with organo modified montmorillonite (MMT) commonly known as nanoclay along with epoxy resin. The homogeneous dispersion of nanoclay in epoxy resin is accomplished by a hand stirrer dispersion method in ethanol. The FML material was processed by hand layup method. In this study the aluminium alloy 5052-H32 was used as a skin material and glass fibre (woven roving) used as core material which is bounded by epoxy with 5 wt.% nano clay (closet 30B). The fabricated sandwich material was cut by using water jet machine as per IS standards for testing. The fabricated material subjected to erichsen cupping test and was observed under Scanning Electron Microscope (SEM). The results from SEM image analysis indicated that the FML had fibre pull out and surface cracks were obtained in the skin material. Progressive loading resulted in ductile fracture which is absorbed in the specimen. Fibres came across brittle failure and the skin through ductile fracture. Non-uniform distribution of reinforcement is observed in the material, SEM micrographs revealed fibre cracks which were oriented in line to the direction of crack growth on the skin material. This study shows that these fibre metal laminates can be safely applied in automotive field.

KEYWORDS:

Fibre metal laminates; Montmorillonite; Erichsen cupping test; Scanning electron microscope

CITATION:

K. Logesh, V.K.B. Raja and C. Krishnaraj. 2018. Stretch Formability Behaviour of Glass Fibre Reinforced Nanoclay on Fiber Metal Laminated Composites, *Int. J. Vehicle Structures & Systems*, 10(2), 115-121. doi:10.4273/ijvss.10.2.08.

1. Introduction

The flourishing research in the field of materials and manufacturing has brought various new materials in existence. These research activities have facilitated in the development of materials with unique characteristics suited for specific applications. Fiber Metal Laminates (FML) was one such material developed during 1967. When compared to a single aluminium sheet the fracture thickness of metal laminate was high [1]. These FMLs were fabricated to enhance the properties such as low density and corrosion resistance [2-3]. The numerous combinations of materials which can be done with the FMLs pave tremendous options for development and research. These were extensively used in aeronautics, automobiles and structural materials [4-5]. The structure of fibre metal laminates consists of skin material and core with a bounding material such as epoxy resin. Aluminium 5052-H32 is one of the strongest non heat treatable aluminium alloys which can be used as the skin material of the FML. It has good characteristics such as resistance to general corrosion, good weald ability and cold forming, which makes it worthy for marine applications [6-8]. E-Glass fibre (woven raven) is one of the most commonly used core materials with density of 610g/m^2. This gives extensibility and toughness to the fabricated fibre metal laminate. This particular material is much economic than any other core materials [9].

Mechanical properties like bulk strength and density of the material is very superior, thus giving it high strength when fabricated [10]. Many research activities were carried out to analyze the properties of FML subjected to quasi-static test conditions. The quasi-static tensile strength of an FML depended upon the properties of the fiber used as its reinforcement [11]. Penetration test performed on FML with carbon, Kevlar and s-glass fiber as reinforcement under Quasi-static condition, revealed that hybridization effect was observed with dominated tension-shear damage mode at SPR = 5 in comparison with SPR = 2 [12]. Many research conducted on natural fibers indicate that the properties of laminates with natural fibers are lower than that of synthetic fiber reinforced laminates. The tensile properties of synthetic fibers such as glass fibers are better than natural fibers, since the latter requires lot more reinforcement materials to provide the same strength compared to its counter-part [13]. Humidity can affect the natural fibers which in turn reduce the overall strength of the fabricated composite material [14]. Epoxy resin is used as a binder polymerizes and cross links when it is combined with a hardener. Production of epoxy is by reacting bisphenol-A and epichlorohydrin. Epoxy is mainly used because of its excellent adhesion and heat resistant properties. The resin which is used in this study is AV138/HV998 [6-8]. The characteristics such as high strength, low viscosity and negligible shrinkage during curing [15].

A novel approach assisted with solvent was developed to disperse clay into epoxy matrix [16]. Flexural properties of the glass fibre composite increased when nanoclay was added into it [17]. Majority of nano material reinforced fibre metal laminates have high strength and stiffness because of which they are used in aerospace, automobile, marine applications [18], the filler material used with epoxy was 5% nanoclay. Tensile strength and tensile modulus of the composite increased by mixed nanoclay [19]. The nanoclay was added above a fixed level than it decreased the mechanical properties of the fabricated material [20]. The percentage of nanoclay used must be between 3 to 5 wt% so that the fabricated material had the peak properties desired during fabrication [21]. Experiment performed on alkali resistant glass fibres/epoxy composite with 2% nano-silica revealed that the powders dispersed well into the reinforcement and also increased its tensile strength, compression strength and shear strength by 68%, 13% and 32% respectively [22-25]. Attempts were made to analyze the effect of coating over the fibers used in FML. Graphite Oxide coating as low as 0.5% by weight showed that the properties were improvised as 25% max, tensile strength, 9.5% flexural strength and 16% flexural modulus respectively [26-27].

Glass Fibre Reinforced Plastic subjected to biaxial tensile-tensile load scenario was able to with stand higher load compared to uniaxial load [28]. The fabrication of the fibre metal laminate can be done by a very economic technique which is hand layup. In this technique the core is placed between the skin and epoxy is applied on it and a general application of pressure is done by the means of hands or rollers. The hand layup technique is where economy is needed light load bearing components [29]. The nano composites have matrix made of polymers with inorganic particles as fillers which popular composed of polymers and inorganic particles have been very popular among the upcoming researching community. Various new properties are being generated by formulating organic-inorganic hybrid materials using different polymers [6-8]. The mechanical properties of epoxy matrix composite increased after the addition of nanoclay [30]. Epoxy reinforced composites modified with acrylic tri block copolymer and nanoclay were subjected to mechanical testing and was found to have better fracture toughness [31].

FML have drawbacks associated with the tendency to absorb moisture. Properties such as flexural strength, flexural modulus and fracture toughness decreased, while impact strength and impact toughness increased along with moisture in the FML. Addition of nano clay could decrease the moisture absorbing capacity of FML thereby increasing its fracture toughness and crack reduction [1, 32-33]. Twists and crimps in the nano clay synthetic fibres could increase its bond strength with epoxy to 450% [34]. Lesser quantity as low as 1% of addition such as nano-clay in the reinforcements could increase the thermal and anti-corrosion properties of the laminate material [35]. In this paper an effort is taken to study the FML fabricated using hand layup technique. The objective of this material to produce the nanoclay reinforced light weight and high strength FML using hand layup methods, to develop a Fiber Metal Laminate containing nano fillers for applications in auto body panels and enhance the characterization of nano filler FML for use in stretch formability. To study the dependence of the ductile fracture in the aluminium skin, fibre crack and pullout, etc., using to analyze its micro structure to analyses its quality and damage characteristics. The results of the Erichsen cupping test are useful in identifying the material with good formability in reinforced nano-filler FML at 5% by weight of nanoclay.

2. Material investigations

2.1. Aluminium alloy AA5052-H32

Aluminium alloys of series-5 are the strongest and most widely used non heat treatable alloys. These are the most economical alloys when compared to all other alloys made with various distinguished products. These alloys possess high strength and are high corrosion resistant when compared with other alloys of same kind, these are widely use in various applications like industrial and marine as well because they are highly corrosion resistant. These alloys are best suitable for cold forming and posed good weld-ability. The alloy used in the study as the skin material is (AA5052-H32) having the wt. %. of 2.292 Mg, 0.612 Cr, 0.066 Si, 0.341 Fe, 0.009 Cu, 0.050 Mn, 0.007 Zn and remaining are aluminium [6-8].

2.2. Glass fibre

Glass fibres are widely preferred core material for most of the fibre metal laminates. GLARE which is glass fibre reinforced sandwich material which is very common and used in various applications because of its economic ratio and its durability when combined with metal laminates. The glass fibre used in the study is e-glass fibre (woven fabric). The general composition of E-glass fibre is alumina borosilicate glass with measurable amounts of alkali oxides [36-37]. The kind of glass fibres chosen in this study is in form of mat which gives the fabricated material high extensibility and toughness. Generally, the glass fibres poses high strength when combined with metal laminates [9]. The bulk strength and density are better when compared to other materials [10]. This can be manufactured by moulding [6-8].

2.3. Binders(epoxy resin AV138 & hardener HV998 along with 5% nanoclay-closite 30B)

The binders which are used in this fabrication is epoxy resin AV138 and hardener HV998 along with 5% nano clay. Epoxy is most commonly used binder for any fibre metal laminate because of its heat resistant and high adhesive nature. The epoxy is a result of reaction between bisphenol-A and epichlorohydrin. Epoxies are even used as a binder in counter-tops or coatings for floors [6-8]. The addition of nano clay in the resin as a filler material increased the flexural, tensile strength of the fabricated metal laminate [38], the impact energy and also hardness of the laminate.

The most soft phyllocilicate materials are montmorillonites (nanoclay) which have a very typical microscopic crystal structure. This is the major member of smectite group it has an arrangement of two tetrahedral sheets of silica between a central octahedral sheet of alumina. The nano particles in this clay are of 9.6 x 10^{-9}m of thickness [5, 39]. To achieve all these properties the nano material should be dispersed properly into the resin and there are various methods for dispersing the nano filler into the resin like mechanical mixing, magnetic stirring, and sonication [40-41]. Complex interaction of the nanostructure and heterogeneous phases makes the nano composites unique from pre-existing traditional methods. It is investigated that the properties of nanomaterials are better than macroscopic specimen of same material. Majorly the combination of organic and inorganic particles may give new properties because of synergistic effect of the two components [42]. The process used for the study is hand stirring. The efficiency of nano composites can be increased by the uniform dispersion of nano materials with a low dosage [43-44].

2.3.1. XRD analysis of nanoclay Closite 30B

The structure of nanoclay powder might have been analyzed utilizing XRD (X-ray diffraction analyses) method, test were directed in SRM University, Kattankulathur, Chennai, India. Fig. 1 indicates the XRD designs of nanoclay powder Closite 30B, those basal reflections about (basal dividing 18. 5 Å) diminishing over force level with expanding times.

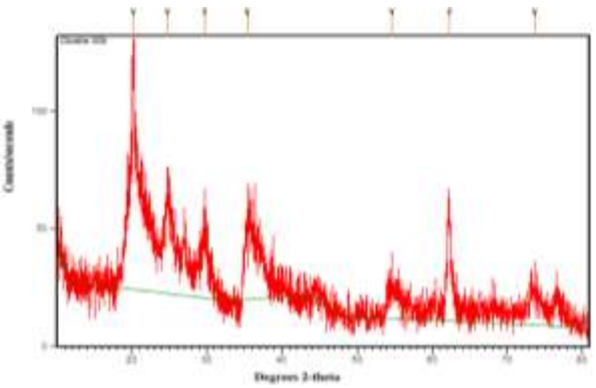


Fig. 1: X-ray diffractograms of cloisite 30B nanoclay powder

Table 1: Peak values of nanoclay filler

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th]	d-spacing [Å]	Rel. Int. [%]
20.1790	88.56	0.9446	4.40067	100.00
24.7586	41.75	0.9446	3.59608	47.14
29.6932	30.15	0.9446	3.00875	34.05
35.3384	31.77	1.1808	2.53998	35.87
54.7072	13.62	1.4170	1.67784	15.38
62.2761	42.98	0.7085	1.49088	48.54
73.6465	13.44	1.4170	1.28629	15.18

For the Closite 30B nanoclay demonstrates a diffraction top for 2θ towards 35.30 furthermore corresponds to an interlayer dividing for d-spacing withdrawal for 4.79 Å were computed from Braggs diffraction theory of $2dSin\theta = n\lambda$. Top qualities of Closite 30B nanoclay powders are provided for Table 1.

3. Methods of fabrication

The material which was prepared for Erichsen cupping test was fabricated by hand layup method. It was used to spread the epoxy resin on the reinforced woven roving E-glass fibre to provide adhesion. This process is effective and economically used for fabrication. The filler material was mixed in the resin mixture by using hand stirrer method [48-49]. The resin contains a mixture of araldite AV138 and hardener 998 mixed in a 5:2 weight ratio. Specified time duration is to be given for the components to set approximately (18-20 hours). The fabricated FMLs material was cut according to the Indian Standards of testing by using a water jet machine. Hand layup is a lucid schema for specimen concoction. Due to the low cost and integrity of hand layup method, this technique is being used in small time industries and for the use of projects. A mould must be used for hand layup parts lest the laminates to be amalgamated directly to some other arrangement. For a few shapes, moulds must be merged in sections so that they can be cleaved apart for part exclusion after curing. Ahead lay-up, the mould is refined with a release agent to ensure that the quarter will not be annexed to the mould. Reinforcement fibres are to be cut and positioned in the mould. It is up to the fabricator to devise the type, volume and orientation of the fibres that are germane. A brush or a roller can be embraced to suffuse the fibres with the resin mixture.

4. Erichsen cupping test

The fabricated fibre metal laminates (AA 5052/ glass fibre + nanoclay + epoxy resin/ AA5052) were examined and subjected to Erichsen cupping test for examining its strength, hardness and anisotropic characteristics. A schematic of Erichsen cupping test is shown is Fig. 2. The fabricated material was cut into the desired dimension using water jet. Then the cut specimen was fixed in the Erichsen cupping test set up. Load was applied to the test specimen while it was subjected to the cupping ball. Load was applied until a visible fracture was noticed on the specimen. The depth of the bulge in the fabricated material was measured using a Vernier Caliper. The Erischen number obtained provided the reference to the fracture toughness of the produced laminate material. The formability index was considered to be the height of the cup [44-47].

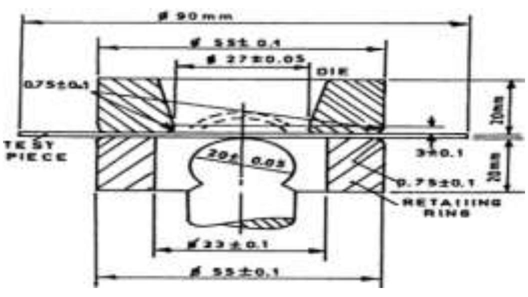


Fig. 2: Schematic representation of the erichsen cupping test [36]

5. Result s and discussion

Fig. 3 shows the fracture zone after the Erichsen cupping test. FML were examined under Erichsen cupping test to check nature of strength, hardness, anisotropy and rate hardening of material considering drawing and redrawing phenomenon of the specimen. Ductile fracture growth was evident in the epoxy based FMLs using hemispherical punch. The upper skin was affected during the test and was revealed to be broad. This happed due to the high drawing force during the input load was applied. This caused significant change in the material shape and size. Fibre and aluminium crack orientation were observed in the fracture section of FML. The Erichsen cupping test were testes according to IS10175 standard shown in Table 2. In this test it was found that the fabricated sandwich material showed better Erichsen index because of the influence of the core material and skin material combined together. Similarly, many authors have reported improvement in forming index values of FML.

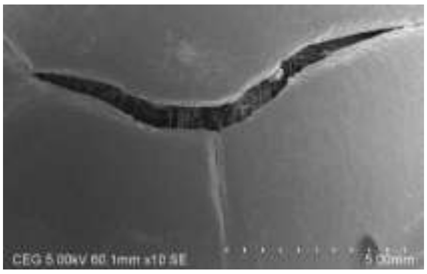
Fig.3: Specimens subjected to Erichsen cupping

Table 2: Erichsen cupping value of FML specimen

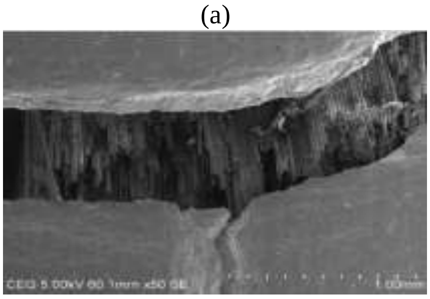
Nature of Specimen	Trial 1	Trial 2	Trial 3	Trial 4
FML+Nanoclay 3% wt.	5.25	4.87	4.61	5.29
FML+Nanoclay 4% wt.	4.76	5.01	4.95	3.95
FML+Nanoclay 5% wt.	6.25	6.04	6.20	5.20

5.1. Microstructure analysis of damage

The FML were analyzed for ductility of the aluminium and fibre fractures which were investigated in fabricated FML sandwich material. The FML specimen which is shown in Fig. 4(a) represents the initial cupping crack in ductility nature. Fig. 4(b) shows the micro-pores on the resin and fibers fracture, crack and visible voids. Fig. 4(c) shows debonding. Figs. 4(d) & (e) show the skin (AA5052) crack and tear on three different sides over the same specimen. Fig. 5(a) shows the Erichsen cupping sample of the ductile nature in the aluminium skin initial portion. Fig. 5(b) shows a magnified portion from that shows the fibre cracks. Fig. 5(c) shows a magnified portion from the Fig. 5(a) that shows the other portion of fibre crack and debonding of skin sheet metal and matrix material. Fig. 5(d) shows the skin (AA5052) crack initiation and tear. Fig.5(e)shows the epoxy resin crack. The fibre pull out is clearly visible in the specimen as shown in Fig. 6(a) with the initial cracking of the skin material and ductile fracture of skin and fibre being clearly visible. In Fig. 6(b) the matrix fracture and fibre pull out is clearly visible. Fig. 6(c) shows the ductile failure of skin material AA5052. Fig. 6(d) shows the fibre pull out. Fig. 6(e) shows the internal cracks of the matrix material.

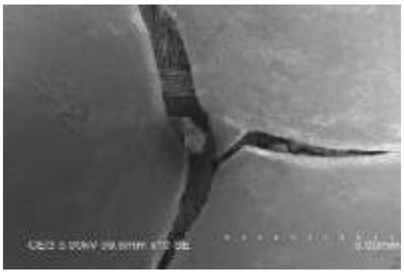


(a)

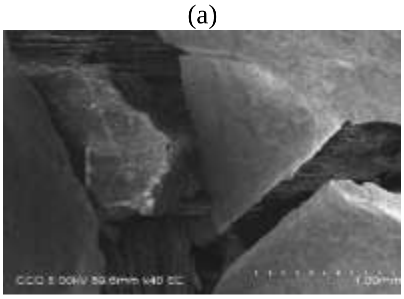


(b)

Fig. 4: SEM images of fractured erichsen cupping test specimens with 3 wt. % of nanoclay filled FML material



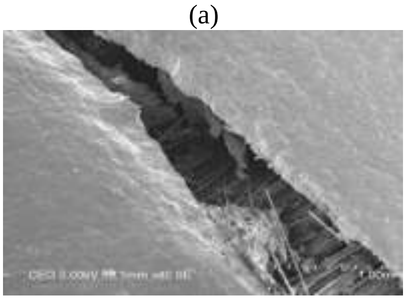
(a)



(b)

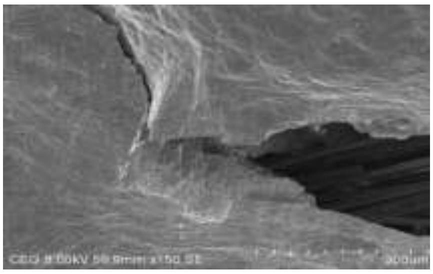
Fig. 5: SEM images of fractured erichsen cupping test specimens with 4 wt. % of nanoclay filled FML material

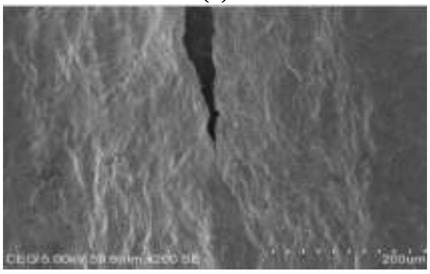
(a)



(b)

Fig. 6: SEM images of fractured erichsen cupping test specimens with 5 wt. % of nanoclay filled FML material


(c)


(d)

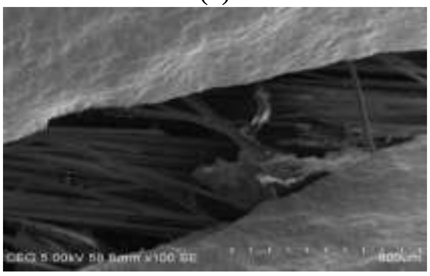

(e)

Fig. 4 (contd.): SEM images of fractured erichsen cupping test specimens with 3 wt. % of nanoclay filled FML material


(c)


(d)

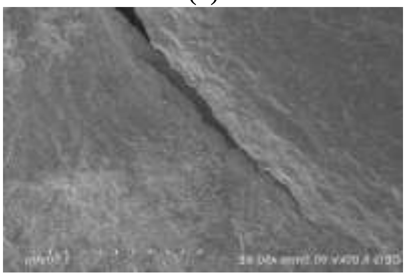
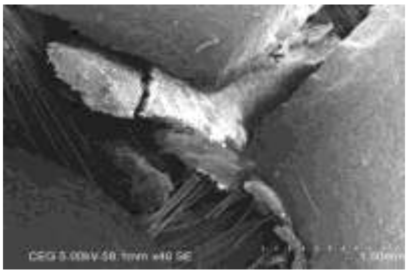
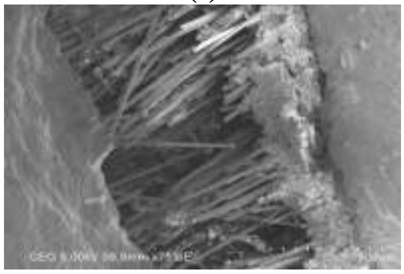

(e)

Fig. 5 (contd.): SEM images of fractured erichsen cupping test specimens with 4 wt. % of nanoclay filled FML material


(c)


(d)

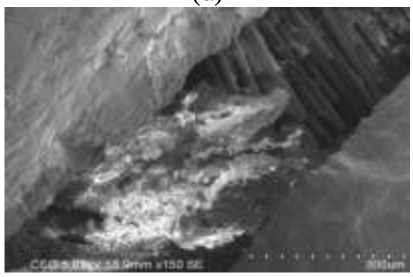

(e)

Fig. 6 (contd): SEM images of fractured erichsen cupping test specimens with 5 wt. % of nanoclay filled FML material

6. Conclusion

Ductile fracture was inspected in the fabricated FML specimens due to the effect of dynamic loading by means of Erichsen cupping mechanism. A specimen with (6.25) at 5 wt.% in the Erichsen index revealed that, there was a trivial increase in the thickness of the composite materials. There was sporadic distribution of reinforcement in material. Microstructure examination revealed that the fibre cracks were aligned in line to the crack build-up on the skin material. There were no other defects detected in the specimen. Test results recorded that the Erichsen index was in line with the results as noticed in the literature.

REFERENCES:

[1] H. Alamri and I.M. Low. 2013. Effect of water absorption on the mechanical properties of nanoclay filled recycled cellulose fibre reinforced epoxy hybrid nanocomposites, *Composites: Part A*, 44, 23-31. https://doi.org/10.1016/j.compositesa.2012.08.026.

[2] A. Chira, A. Kumar, T. Vlach, L. Laiblova, A.S. Skapin and PetrHajek. 2016. Property improvements of alkali resistant glass fibres epoxy composite with nanosilica for textile reinforced concrete applications, *Materials and Design*, 89, 146-155. https://doi.org/10.1016/j.matdes.2015.09.122.

[3] S. Tamer, A. Egemen, O.B. Mustafa and C. Onur. 2011. Fibre metal laminates background bonding types and applied test methods, *Materials and Design*, 32(7), 3671-3685. https://doi.org/10.1016/j.matdes.2011.03.011.

[4] A.H. Hemmasi, I. Ghasemi, B. Bazyar and A. Samariha. 2011. Influence of nanoclay on the physical properties of recycled high-density polyethylene bagasse nano composite, *Middle-East J. Scientific Research*, 8(3), 648-651.

[5] A.W. John, B.A. Richard, B.W. Kenneth and C. Nichols. 2011. *Montmorillonite*. Handbook of Mineralogy Society of America.

[6] S. Bernhardt, M. Ramulu and A.S. Kobayashi. 2007. Low-velocity impact response characterization of hybrid titanium composite laminate, *J. Engineering Materials and Technology*, 129(2), 220-226. https://doi.org/ 10.1115/1.2400272.

[7] K. Logesh, V.K. Bupesh Raja and P. Sasidhar. 2015. An experiment about morphological structure of Mg-Al layered double hydroxide using field emission scanning electron microscopy with EDAX analysis, *Int. J. Chem. Tech. Research*, 8(3), 1104-1108.

[8] K. Logesh and V.K. Bupesh Raja. 2015. Formability analysis for enhancing forming parameters in AA8011/PP/AA1100 sandwich materials, *Int. J. Advanced Manufacturing Tech.*, 81, 1-4. https://doi.org/10.1007/s00170-015-7832-5.

[9] L.R. Hawtin and Johnson. 1963. *Appraisal Current Information on the Erichsen Test*, Sheet metal industries, 495-499.

[10] J. Datsko. 1966. *Material Properties and Manufacturing Processes*, John Wiley and Sons, New York, 34-45.

[11] V.S. Juan, E. Fernandez, G. Pincheira, M. Melendrez and P. Flores. 2016. Evaluation of the fill yarns effect on the out-of-plane compressive fatigue behavior for an unidirectional glass fiber reinforced epoxy composite, *Composite Structures*, 138, 237-242. https://doi.org/ 10.1016/j.compstruct.2015.11.061.

[12] M. Bulut, A. Erklig and E. Yeter. 2016. Hybridization effects on quasi-static penetration resistance in fiber reinforced hybrid composite laminates, *Composites Part B*, 5(25). https://doi.org/10.1016/j.compositesb. 2016.05.025.

[13] M.F.M. Alkbir, S.M. Sapuan, A.A. Nuraini and M.R. Ishak. 2016. Fiber properties and crashworthiness parameters of natural fiber-reinforced composite structure, *Composite Structure*, 148, 59-73. https://doi.org/10.1016/j.compstruct.2016.01.098.

[14] C.A. Fuentes, K.W. Ting, C.D. Gillain, M. Steensma, A.G. Talma, R. Zuijderduin and A.W.V. Vuure. 2016. Effect of humidity during manufacturing on the interfacial strength of non-pre-dried flax fibre unsaturated polyester composites, *Composites: Part A*, 84, 209-215. https://doi.org/10.1016/j.compositesa. 2016.01.023.

[15] P. Schlack, I.G. Farbenindustrie. 1938. German Patent, *US Patent 2*, 136-928.

[16] L. Wang, K. Wang, L. Chen, Y. Zhang and C. He. 2006. Preparation, morphology and thermal/mechanical properties of epoxy nanoclay composite, *Composites: Part A*, 37, 1890-1896. https://doi.org/10.1016/ j.compositesa.2005.12.020.

[17] A.N. Rahman, A. Hassan, R. Yahya and R.A.L. Araga. 2013. Glass fiber and nanoclay reinforced polypropylene composites: morphological, *Thermal and Mech. Properties*, 42(4), 37-54.

[18] R.E. Farsani, M.R.S. Khalili, Z. Hedayatnasab, N. Soleimani. 2013. Influence of thermal conditions on the tensile properties of basalt fiber reinforced polypropylene-clay nanocomposites, *Materials and Design*, 7.

[19] M.S. Senthil Kumar, N.M. Sundara Raju, P.S. Sampath and U. Vivek. 2014. Tribological analysis of nanoclay epoxy glass fiber by using taguchi’s technique, *Materials and Design*, 12.

[20] M. Chan, K. Lau, T. Wong, M. Ho and D. Hui. 2011. Mechanism of reinforcement in a nanoclay/polymer composite, *Composites: Part B*, 42, 1708-1712. https://doi.org/10.1016/j.compositesb.2011.03.011.

[21] G. Wu and J.M. Yang. 2005. The mechanical behaviour of glare laminates for aircraft structures, *J. The Minerals*, 57 (1), 72-79.

[22] J.G. Kaufman. 1967. Fracture toughness of 7075-T6 and T651 sheet, plate and multilayered adhesive-bonded panels, *J. Basic Engg.*, 89 (3), 503-507. https://doi.org/10.1115/1.3609649.

[23] K. Logesh, V.K. Bupesh Raja, R. Velu. 2015. Experimental investigation for characterization of formability of epoxy based fiber metal laminates using erichsen cupping test method, *Indian J. Sci. and Tech.* 8(33). https://doi.org/10.17485/ijst/2015/v8i33/72244.

[24] G.R. Villanueva and W.J. Cantwell. 2004. The high velocity impact response of composite and FML-reinforced sandwich structures, *Composites Science and Tech.*, 64(1), 35-54. https://doi.org/10.1016/S0266-3538(03)00197-0.

[25] K. Giasin, S.A. Soberanis, A. Hodzic. 2016. Evaluation of cryogenic cooling and minimum quantity lubrication effects on machining GLARE laminates using design of experiments, *J. Cleaner Production*, 135, 33-548. https://doi.org/10.1016/j.jclepro.2016.06.098.

[26] E.H. Albuja, J.A. Szpunar, G. Akindele and Odeshi. 2016. Ballistic impact response of laminated hybrid materials made of 5086-H32 aluminum alloy, epoxy and Kevlar® fabrics impregnated with shear thickening fluid, *Composite Part A*.

[27] S. Du, F. Li, H. Xiao, Y. Li, N. Hu and S. Fu. 2016. Tensile and flexural properties of graphene oxide coated-short glass fiber reinforced polyethersulfone composites, *Composites Part B 99*, 407-415. https://doi.org/ 10.1016/j.compositesb.2016.06.023.

[28] A. Rashedi, I. Sridhar and K.J. Tseng. 2015. Fracture characterization of glass fiber composite laminate under experimental biaxial loading, *Composite Structures*, 11, 17-29.

[29] G.R. Rajkumar, M. Krishna, H.N.N. Murthy, S.C. Sharma and K.R.V. Mahesh. 2012. Investigation of repeated low velocity impact behaviour of GFRP aluminium and CFRP aluminium laminates, *Int. J. Soft Computing and Engg.*, 1(6), 50-58.

[30] L.B. Manfredi, H.D. Santis and A. Vázquez. 2008. Influence of the addition of montmorillonite to the matrix of unidirectional glass fibre epoxy composites on their mechanical and water absorption properties, *Composites: Part A*, 39, 1726-1731. https://doi.org/10.1016/ j.compositesa.2008.07.016.

[31] M. Bashar, U. Sundararaj and P. Mertiny. 2012. Microstructure and mechanical properties of epoxy hybrid nanocomposites modified with acrylic tri-block-copolymer and layered-silicate nanoclay, *Composites: Part A*, 43, 945-954. https://doi.org/10.1016/ j.compositesa.2012.01.010.

[32] M. Alphonse, V.K. Bupesh Raja, K. Logesh and N.M. Nachippan. 2017. Evolution and Recent Rrends in Friction Drilling technique and the Application of Thermography, *Conf. Series: Mater. Sci. and Engg.* 197.

[33] K. Iqbal, S. Khan, A. Munir and J. Kim. 2009. Impact damage resistance of CFRP with nanoclay-filled epoxy matrix, *Composites Sci. and Tech.*, 69, 1949-1957. https://doi.org/10.1016/j.compscitech.2009.04.016.

[34] S. Lee and J. Won. 2015 Interfacial phenomena in structural polymeric nano-clay synthetic fiber reinforced cementitious composites, *Composite Structures*, 133, 62-69. https://doi.org/10.1016/j.compstruct.2015.07.096.

[35] M.D. Tomic, B. Dunjic, V. Likic, J. Bajat, J. Rogan and J. Djonlagic. The use of nanoclay in preparation of epoxy anticorrosive coatings, *Progress in Organic Coatings*, 77, 518-527. https://doi.org/10.1016/j.porgcoat.2013.11.017.

[36] M. Eesaee and A. Shojaei. 2014. Effect of nanoclays on the mechanical properties and durability of novolac phenolic resin-woven glass fiber composite at various chemical environments, *Composites: Part A*. 63,149-158.

[37] P. Sathyaseelan, K. Logesh, M. Venkatasudhahar and N. Dilip Raja. 2015. Experimental and finite element analysis of fibre metal laminates FML subjected to tensile, flexural and impact loadings with different stacking sequence, *Int. J. Mech. and Mechatronics Engg.*, 15(3), 23-27.

[38] G.J. Withers, Y. Yu, V.N. Khabashesku, L. Cercone, V.G. Hadjiev, J.M. Souza and D.C. Davis. 2014. Improved mechanical properties of an epoxy glass - fiber

composite reinforced with surface organomodified nanoclays, *Composites: Part B*, 51(22).

[39] H. Li, Y. Hu, X. Fu, X. Zheng, H. Liu and J. Tao. 2016. Effect of adhesive quantity on failure behavior and mechanical properties of fiber metal laminates based on the aluminium-lithium alloy, *Composite Structures*, 152, 687-692. https://doi.org/10.1016/j.compstruct.2016.05.098.

[40] B. Jo, S. Park and D. Kim. 2008. Mechanical properties of nano-MMT reinforced polymer composite and polymer concrete, *Constr. Build. Mater*, 22, 14-20. https://doi.org/10.1016/j.conbuildmat.2007.02.009.

[41] S. Zainuddina, M.V. Hosura, Y. Zhou, A.T. Narteh, A. Kumar and S. Jeelani. 2010. Experimental and numerical investigations on flexural and thermal properties of nanoclay-epoxy nanocomposites, *Mater. Sci. Eng. A*, 527, 7920-7926. https://doi.org/10.1016/j.msea.2010.08.078.

[42] E.R. Hitzky. 2003. Functionalizing inorganic solids: towards organic-inorganic nanostructured materials for intelligent and bio-inspired systems, *Chem. Rec.*, 3(2), 88-100. https://doi.org/10.1002/tcr.10054.

[43] T.N. Babu, D.R. Prabha. 2015. Vibration characteristics of j. bearing with various damping materials, *Int. J. Vehicle Structures and Systems*, 7(4), 161-164. http://dx.doi.org/10.4273/ijvss.7.4.09.

[44] A. Ramazan, O.C. Richard. 2004. Corrosion protection of materials by applying nanotechnology associated studies, *Proc. Symp. Mat. Res*.

[45] D. Banabic. 2010. *Sheet Metal Forming Processes*, Springer berlin-heidelberg.

[46] W.F. Hosford and R.M. Caddell. 1983. *Metal forming: mechanics and metallurgy*, Eglewood Cliffs, 303.

[47] N. Thota, J. Epaarachchi and K.T. Lau. 2013. CAE simulation based methodology for airbag compliant vehicle front protection system development, *Int. J. Vehicle Structures and Systems*, 5(3-4). http://dx.doi.org/10.4273/ijvss.5.3-4.04.

[48] M. Quaresimin, M. Salviato and M. Zappalorto. 2012 Fracture and interlaminar properties of clay-modified epoxies and their glass reinforced laminates, *Engg. Fracture Mechanics*, 81, 80-93. https://doi.org/10.1016/j.engfracmech.2011.10.004.

[49] K. Logesh, V.K. Bupesh Raja, J.V. Rayudu, N.S. Ganesh and R.A.A. Shaik. 2017. A review on sheet metal forming and its latest development of sandwich materials, *Int. J. Mech. Engg. and Tech.*, 8(8), 369-385.