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Evaluation of Mechanical Properties of Kevlar Fibre Epoxy Composites: An Experimental Study

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ABSTRACT:

Kevlar fiber reinforced polymer composites are rapidly growing in manufacturing applications such bicycle tires and racing sails to body armor, bullet proof vests, military helmets, walking boots etc. Kevlar epoxy composite material using the Kevlar fiber and epoxy resin LY-556 was fabricated with manual hand layup procedure. The mechanical characteristics like tensile, impact strength and flexural rigidity were evaluated. With the results obtained it is found that kevlar epoxy composite provides better mechanical characteristics than aluminum. In this work, the possibility of replacing aluminum with Kevlar reinforced epoxy composite material is investigated for various applications viz. manufacturing of bus body frame, bullet proof vests, automobile body, sports applications, fire proof clothing, military helmets etc. Also, the FE analysis is carried out with MIDAS NFX software to correlate the test results with FEA.

KEYWORDS:

Composite material; Kevlar; Mechanical tests; Finite element analysis

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1. Introduction

Fibre reinforced composite materials are being employed as a part of many building applications due to the significant mechanical properties. The sandwich composite materials supplant the metals owing to their splendid quality with low weight. A substantial number of the written work deals with the blend of steel or aluminium reinforced with the glass fibre sustained composites materials (GFRP). The carbon fibre finds application in flying and related fields. The cost of make is diminished by using sandwich structures. Elastic and effect of Kevlar/epoxy overlaid composites has examined break and effect properties of novel Kevlar covered composites. For correlation, standard Kevlar woven composites with and without polyurethane treatment were additionally considered in this investigation [1]. Ballistic impact behavior of thermoplastic Kevlar composites was considered in this work and the effect of Kevlar/polypropylene was examined [2]. Portrayal of Kevlar fibre and its composites were considered in this work. From this work it was seen that the fibre composites (FRCs) has expanded because of its potential for supplanting the customary materials in different applications.

Kevlar fibre, because of its special properties, for example, higher quality to mass proportion and modulus, has turned out to be exceptionally main stream as support in composite materials and its application has development extensively [3]. Investigative models was concentrated to foresee the ballistic conduct of reinforces, however these models frequently give just mean estimations of ballistic exhibitions as a component of fibre/network volume part, of strands mechanical properties or of considered sort of composite overlays [4]. Mechanical characterization studied using tensile, flexural and impact tests in Kevlar-29 fibres composites used for different applications due of their exceptional mechanical properties. More technical significance on these fibres is needed to understand the mechanical behavior [5].

Low speed effect of blend Kevlar/carbon fibre sandwich composites was examined utilizing sway, pressure after effect, and elastic firmness properties of Kevlar mix sandwich composites were researched in this investigation. The diverse specimens comprised of effect side face sheets having distinctive blends of Kevlar fibre [6]. Strain rate and gauge length effects on tensile behaviour of Kevlar are investigated in this paper. The experimental results showed that the material mechanical properties are dependent on gage length and strain rate [7]. Evaluation of composite laminates in Kevlar 29 was assessed in both the composite protective layers made up of Kevlar 29 textures that were impregnated by thermosetting pitch and unwavering quality of an investigative model to foresee ballistic breaking point speed [8]. Wear models and mechanical analysis of Kevlar fabric woven liners was investigated using finite element method. From this work it was noticed that for the radial spherical plain bearing, effects of elastic constants and the wear depth of the liner on surface contact pressures were studied [9].

The aluminium is sandwiched between the carbon layers framed as fibre metal overlays (FML), and it has phenomenal qualities, for example, general decreased weight, consumption protection and condition amicable. Alongside the host of advantages, the primary impediment is the manufacture of these composites which is difficult [10]. The flying machine materials are produced in light of fibre metal covers which need the enhanced split development properties [11]. Contending materials like propelled aluminium compounds and fibre fortified composites can possibly expand the cost adequacy of the structure. Fibre metal overlays (FMLs) have half and half composite structures in view of thin sheets of metal amalgams and utilizes of fibre fortified polymeric materials [12]. The fibre/metal composite innovation joins the upsides of metallic materials and fibre fortified frameworks. Metals are isotropic in light of the fact that they have a high bearing quality and effect protection and are anything but difficult to repair.

Full composites have a brilliant exhaustion trademark and have high quality and solidness. The weariness and consumption qualities of metals and the low bearing quality, affect protection and reparability of composites have overwhelmed by the blend of metal and strands [13, 14] these material frameworks are made by holding composite cover handles to metal employs [15]. The idea is generally connected to aluminium with aramid and glass filaments; additionally it is connected to different constituents [16]. A few articles have demonstrated that, FMLs have both the great effect protection attributes of metals and the alluring mechanical properties of fibre strengthened composite materials [17, 18]. The presence of aluminium layer provides good impact resistance. Combination of high stiffness, strength and good impact resistance gives GLARE an excessive improvement as an application to the structures of aircraft, space, helicopter, robot, laminated pipe, drive shaft and so on [19, 20]. Material characterization of the carbon-aluminium (C/Al) composites is presented in [21]. The microstructure and mechanical properties of Aluminium 1050/6061 laminated composite processed by accumulative roll bonding was estimated in this work [22].

In this work, Kevlar fibre reinforced composite was fabricated. Tensile, flexural properties were evaluated. These results are compared with aluminium composite materials. Result showed that Kevlar composite materials showed offer of better prospectus.

2. Fabrication of Kevlar composite

The details of processing of the composites and the experimental procedures followed for their characterization and tri biological evaluation. The raw materials used in this work are Kevlar fibre and Epoxy resin.

2.1. Preparation of Kevlar fibre

There are two primary strides in making Kevlar utilizing hand layup process. The initial step is delivering the fundamental plastic from which Kevlar is made which a synthetic is called poly-para-phenylene terephthalamide. Second, is transforming it into solid strands. Fundamentally, the initial step is about science and the second one, about transforming the synthetic item into a more valuable, viable material. Just like the generation of nylons, Kevlar fibres are created by expelling the forerunner through a spinneret. The bar type of the para-aramid particles and the expulsion procedure make Kevlar strands anisotropic which implies that they are more grounded and stiffer the pivotal way than the transverse way. Fig. 1 demonstrates the Kevlar fibre utilized for this examination.

Fig. 1: Kevlar fibre

Polyamides like Kevlar are polymers made by repeating amides over and over again. By the way, polymers are large molecules composed of repeating structural units typically connected by covalent chemical bonds. Although polymers of natural and synthetic materials with a wide variety of properties. Amides are simply chemical compounds in which part of an organic (carbon-based) acid replaces one of the hydrogen atoms in ammonia (NH_3). Amides are amine derivatives of carboxylic acids. So the basic way of making a polyamide is to take an ammonia-like chemical and react it with an organic acid. This is an example of condensation reaction because two substances fuse together into one. The result is a polymeric aromatic amide with alternating benzene rings and amide groups. When they are produced, these polymer strands are aligned randomly. To make Kevlar, they are dissolved and spun, causing the polymer. Kevlar has a high price at least partly because of the difficulties caused by the use of concentrated sulphuric acid in its manufacture. These harsh conditions are needed to keep the highly insoluble polymer in solution during synthesis and spinning.

2.2. Preparation of epoxy hardener

To a 2000 ml beaker, epoxy (LY556) of 180 grams and 10% of hardener (K6) 18 grams, were added to the beaker and thoroughly mixed for 3 mins. Epoxy resin has modulus of 3.42GPa and possesses density 1100 kg/m^3 which are a low viscosity room temperature curing liquid hardener. It is commonly employed for hand lay-up applications. The choice of hardener depends on the processing method to be used and on the properties required of the cured composite. Hardener K6 being rather reactive, it gives a short pot life and rapid cure at normal ambient temperatures. Fig. 2 shows the epoxy resin used for this investigation and Table 1 shows the properties of hardener used. The bonding of the fibres particles is in the matrix form. The resin properties can change by changing the ratios of the epoxy and hardener. So, in this project we use epoxy and hardener has to be mixed in the ratio of 10:1 for five to seven minutes. This resin takes 12 to 15 hours for setting and bonding the composite and also it's comparatively low in cost. Since that we can get quick and high strength hardener resin.

Fig. 2: Epoxy resin and hardener

Table 1: Properties of used hardener

Description	Values
Glass transition temperature	120-130°C
Tensile strength	85 N/mm
Elongation at break	0.8 %
Flexural strength	112N/mm^2

2.3. Hand layup process

The plastic sheet is placed on the dam. Silicon spray is sprayed on the plastic sheet to remove minute dust particles. Epoxy resin and hardener is mixed in a bowl together for two minutes until it turns in to a fine solution. The solution is poured over the layout, then the Kevlar fibre (30cm length) are arranged horizontally in X direction on the dam plate. The solution is poured again over it and the Kevlar fibre is placed above it, the whole layer is pressed evenly by hand laminating moulding method by help of hand roller. The force is applied in equal intervals of time by making the correct bonding structure and the air gap is thoroughly removed. Another layer is created by following the same method but the fibres are placed vertically in Y direction and the epoxy solution is poured over it. Fig. 3 shows the fabricated material.

Fig. 3: Fabricated Kevlar composite material

This process is repeated up to 9 layers. Finally the entire mould is placed inside the compression moulding machine under the pressure of 350psi. After 24 hours the fibre is dried under sunlight to make in the form of laminated or reinforced composite material, then the pattern is disassembled to take out laminated composite fibre, then this fibre material is cut for our required dimensions. Specimens of suitable dimension are cut for different tests.

3. Results and discussion

Elastic test was done according to ASTM standard. Examples are put in the grasps of a universal test machine at a pre-defined hold detachment and pulled until disappointment. For ASTM D638 the test speed can be dictated by the material detail or time to disappointment (1 to 10 minutes). An ordinary test speed for standard test examples is 2 mm/min (0.05 in/min). An extensometer or strain gage is utilized to decide prolongation and tractable modulus. Contingent on the support and sort, testing in more than one introduction might be essential.

3.1. Tensile test results

Fig. 4 demonstrates the test example utilized for testing and Table 2 demonstrates the ductile test outcomes acquired from the lab. Fig. 5 portrays the examination of tractable properties of Kevlar composite with that of the aluminium.

Fig. 4: Tensile test specimen

Table 2: Tensile test comparison over aluminium

Test Specimen	Ultimate tensile load (kN)	Ultimate tensile strength (N/mm^2)
Aluminium	14.31	117.00
Kevlar epoxy	27.59	333.00

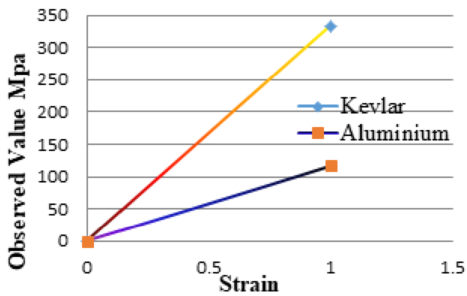

Fig. 5: Properties of Kevlar with Al

3.2. Flexural test results

The flexural test measures the power that required mixing a shaft under three focuses stacking circumstances. That information is regularly used to choose components for parts that will underpins the heaps with no adjustment in the shape in intonation. Flexural modulus is utilized as a sign of materials solidness amid intonation. Since the physical properties of numerous components differ contingent upon the surrounding temperature it is conceivable to test materials under specific temperatures that recreate the expected end utilizing condition. Fig. 6 demonstrates the test example for flexural test and Table 3 demonstrates the flexural test comes about got from the lab. Fig. 7 delineates the correlation of flexural properties of Kevlar composite with that of the aluminium.

Fig. 6: Test specimen for flexural test

Table 3: Flexural result

Test parameters	Observed values (N/mm^2)
Aluminum	216.28
Kevlar epoxy	330.38

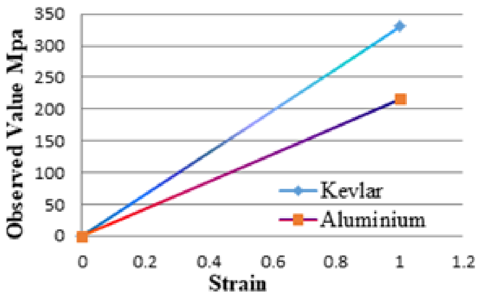

Fig. 7: Flexural results over aluminium

3.3. Impact test results

The Charpy tests otherwise called the Charpy v-indent test. The heap connected all of a sudden the anxiety actuated in the parts are ordinarily more than the anxiety created by continuous stacking. The effect tests are performed to discover the stun retaining limit of materials subjected to all of a sudden connected load in Charpy test. Example is created as cantilever pillar, the example has angular score of 45° and U-shape indent is additionally utilized usually. The score is situated on strain side of example amid affect stacking profundity of indent by and large taken as t/5 to t/3. Fig. 8 demonstrates the test example utilized for affect test and Table 4 demonstrates the flexural test comes about got from the lab. Fig. 9 delineates the correlation of effect quality of Kevlar composite with that of the aluminium.

Fig. 8: Impact test specimen

Table 4: Impact test results

Test specimen	Specimen size (mm)	Notch type	Test temperature	Absorbed energy J
Aluminium	2.5×10×55	"V"	24°C	03
Kevlar Epoxy	2×16.85×130	Unnotched	24°C	06

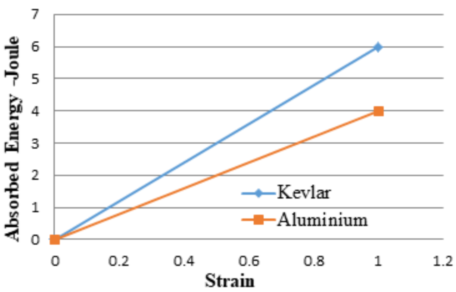

Fig. 9: Impact strength comparison of Kevlar and aluminium

4. Finite element analysis

The FE analysis is undertaken with MIDAS NFX software to validate the tests.

4.1. Tensile test

The boundary condition for tensile test of Kevlar epoxy composite is applied by creating a rigid body covering 25mm on both the sides. The left side of the model is fixed. The load is applied at the master node of the rigid body created at the right side of the model. Due to the stress co-efficient of 1.6, the load applied for the tensile test was 28558 kN instead of 17849 kN. The classical laminate analysis ABD matrix was used to find the stress at the resin layer to correlate the calculated values and FEA results. The details of hand calculated results and FEA results are given in Table 5. The tensile elongation and the stress at the resin layers of the Kevlar epoxy composite are shown in Fig. 10 and Fig. 11 respectively. The comparison of calculated results with FEA results of tensile displacement and stress are given in Table 6. The deviation of displacement is due to a mismatch between the strain in the FE model and the actual test strain.

Table 5: Tensile test FEA vs theory

Tensile test	Kevlar epoxy
Length (mm)	120
Dist. Betw. clamps,, L (mm)	42
Width, b (mm)	20
Thickness, d (mm)	2.68
Test tensile strength, S (MPa)	333.00
Section elastic modulus, E (MPa)	18572
FEA applied load, P = S*b*d (N)	17849
Tensile strain, e = P/(E*b*d)	0.0179
Test stress at resin layer, S_1 3300 * e (MPa)	59.17
FEA stress at resin layer, S_2 (MPa)	58.36
Test vs. FEA, stress at resin = S_1/S_2-1 (%)	1.39
Test disp., x1 = e * L (mm)	0.7531
FEA disp., x2 (mm)	0.579
Test vs. FEA, disp. error = x_1/x_2-1 (%)	30.06

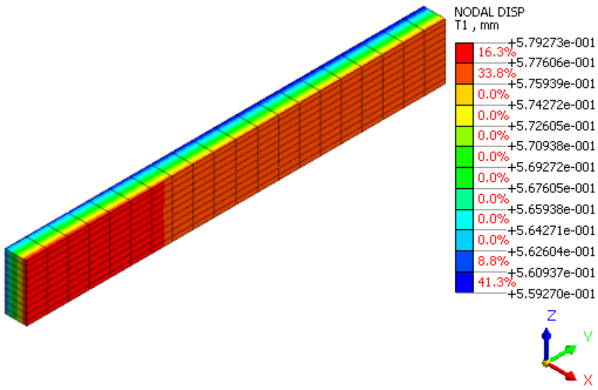

Fig. 10: Tensile elongation of Kevlar epoxy (mid-span)

Table 6: Comparison of calculated tensile test values with FEA results

Tensile displacement		Tensile stress	
FEA	Test	FEA	Test
0.579	0.7531	58.36	59.17

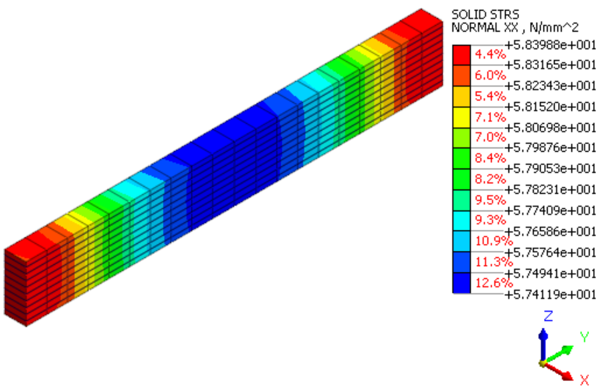

Fig. 11: Tensile stress at the resin layer (mid-span)

4.2. Flexural test

The boundary conditions used for the flexural test was TX = 0 and TZ = 0 at the roller support nodes to obtain no slip condition, TX = 0, TY = 0 and Fz = 1262.078N at the master node of the rigid body created at the top layer (mid-span to simulate three point bend test). The flexural stress at the resin layer was calculated using ABD matrix by applying the running moment which was calculated theoretically. The details of calculated results and FEM results are given in Table 7. The flexural displacement and the stress at the resin layers of the Kevlar epoxy composite is shown in Fig. 12 and Fig. 13 respectively. The comparison of calculated results with FEA results of flexural displacement and stress are given in Table 8. The deviation of flexural stress is due to the simplified boundary conditions at the roller contact in the FE model when compared with the actual test strain.

Table 7: Flexural test FEA vs theory

Flexure test	Kevlar epoxy
Length (mm)	120
Support roller span, L (mm)	50
Width, b (mm)	39.89
Thickness, d (mm)	2.68
Test flexure load, F (N)	1262.078
Section flexural modulus, E (MPa)	19058
Layer stress, $S_0 = 3*F*L/(2*b*d_2)$ (MPa)	330.38
Test stress at resin, $S_1 = S_0 * 3300/E$ (MPa)	57.21
FEA stress at resin layer, S_2 (MPa)	69.97
Test vs. FEA, stress at resin error = S_1/S_2-1 (%)	-18.24
Test disp., $x_1 = F*L3/(48*E*I)$ (mm)	2.695
FEA disp., x_2 (mm)	2.783
Test vs. FEA, disp. error = x_1/x_2-1 (%)	-3.15

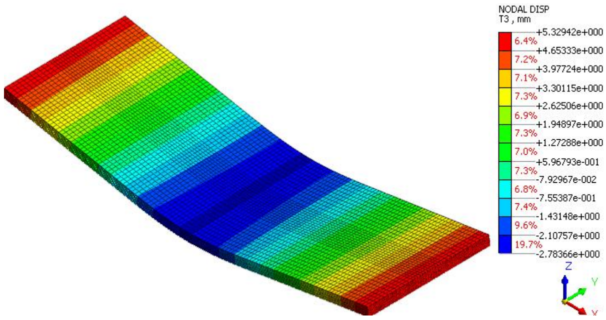

Fig. 12: Flexural displacement of Kevlar epoxy

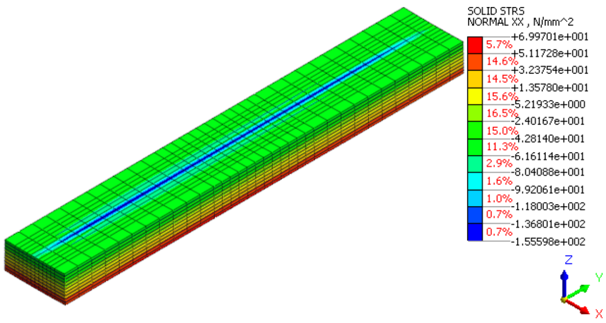

Fig. 13: Flexural stress at the resin layer (mid-span)

Table 8: Comparison of calculated flexural test values with FEA

Flexural displacement (mm)		Flexural stress (MPa)	
FEA	Test	FEA	Test
2.783	2.695	69.97	57.21

5. Conclusion

This work demonstrates that fruitful manufacture of a Kevlar epoxy fibre strengthened epoxy composites by straight forward hand lay-up procedure. Mechanical qualities of these composites have been examined and it is discovered that polymer fortified Kevlar epoxy composite gives preferred mechanical characteristics over that of the aluminium. The predominance of the Kevlar fibre epoxy composites over that of the aluminium is extremely apparent from the outcomes acquired from malleable, flexural and affect tests. The FE analysis is done to correlate the test values. The error obtained for the displacement in the tensile test is 30%, and for tensile stress is 1.3%. This is due to the inaccurate arc geometry of the tensile specimen and when the distance of the gauge length is increased the error can be decreased. The FEA flexural stress is under-estimated by 18% and flexural displacement is under-estimated by 3%. This may vary due to the distance between the support rollers.

REFERENCES:

[1] P.S.A. Khalil, S. Hanida, C.W. Kang and N.A. Nikfuaad. 2007. Agro hybrid composite: The effects on mechanical and physical properties of oil palm fibre (EFB)/glass hybrid reinforced polyester composites, *J. Reinforced Plastics and Composites*, 26(2), 203-218. https://doi.org/10.1177/0731684407070027.

[2] N. Bilash. 2013. Benefits of Kevlar fibre reinforced polymeric composite materials, *Int. J. Application or Innovation in Engg. & Management*, 2(1).

[3] U.S. Bongarde and V.D. Shinde. 2014. Review on Kevlar fibre reinforcement polymer composites, *Int. J. Engg. Sci. and Innovative Tech.*, 3(2).

[4] D. Chandramohan and Marimuthu. 2011. Review on Kevlar fibers, *Int. J. Engg. and Tech.*, 8(2).

[5] C. Girisha. 2012. Kevlar fibres - epoxy composites: water absorption and mechanical properties, *Int. J. Engg. and Innovative Tech.*, 2(3).

[6] S. Harish and D.P. Michael. 2008. Mechanical property evaluation of Kevlar fibre coir composite, *J. Materials Characterization*, 12(4).

[7] S. Luo and A.N. Netravali. 1983. Mechanical and thermal properties of environmentally friendly a novel

fatigue degradation model, *Ind. Eng. Chem. Prod. Res. De.*, 22, 643.

[8] S. Mishra, A.K. Mohanty and S.K. Nayak. 2003. Studies on mechanical performance of bio fibre/glass reinforced polyester hybrid composites, *Composites Sci. and Tech.*, 63(10), 1377-1385. https://doi.org/10.1016/S0266-3538(03)00084-8.

[9] J. Madhukiran, S. Srinivasa and S. Madhusudan. 2013. Fabrication and testing of Kevlar fibre reinforced hybrid composites, *Int. J. Modern Engg. Research*, 3, 2239-2243.

[10] M. Reddy. 2014. Mechanical properties of Kevlar fiber reinforced polymer composite, *IOSR J. Mech. and Civil Engg*, 11(4), 05-11.

[11] G. Nilza and J. smith. 2007. Potential of Kevlar fibres as composite materials, *J. Material Characterization*, 34(3).

[12] K. Oksman, M. Skrivars and J.F. Selin. 2003. Kevlar fibres as reinforcement in polylactic acid (PLA) composites, *Composites Sci. and Tech.*, 63(9), 13172. https://doi.org/10.1016/S0266-3538(03)00103-9.

[13] P. Sirmah and F. Muisu. 2013. Evaluation of Kevlar fibre properties as an alternative to wood shortage in Kenya, 12(4).

[14] M.A.J. Bosco, K. Palanikumar, B.D. Prasad and A. Velayudham. 2015. Analysis on influence of machining parameters on thrust force in drilling GFRP-armor steel sandwich composites, *J. Composite Materials*; 49(13), 1539-1551. https://doi.org/10.1177/0021998314536068.

[15] A. Asudi and A.Y.N. Choi. 1997. Fibre metal laminates: an advanced material for future aircraft, *J. Materials Proc. Tech.*, 63(1-3), 384-394. https://doi.org/10.1016 /S0924-0136(96)02652-0.

[16] P. Cortes and W.J. Cantwell. 2006. The prediction of tensile failure in titanium-based thermoplastic fibre-metal laminates, *Composites Sci. and Tech.*, 66(13), 2306-2316. https://doi.org/10.1016/j.compscitech.2005.11.031.

[17] R.C. Alderliesten and R. Benedictus. 2007. Fibre/metal composite technology for future primary aircraft structures, *Proc. 48th AIAA/ASME/ASCE/AHS/ASC Structures, Struct. Dynamics and Mat. Conf., Honolulu. Reston: AIAA*, 1-12.

[18] P.Y. Chang, P.C. Yeh and J.M. Yang. 2008. Fatigue crack initiation in hybrid boron/glass/aluminium fiber metal laminates, *Materials Sci. and Engg.*, 496(1-2), 273-280. https://doi.org/10.1016/j.msea.2008.07.041.

[19] L.B. Vogelesang and A. Vlot. 2000. Development of fibre metal laminates for advanced, *J. Materials Proc. Tech.*, 103(1), 1-5. https://doi.org/10.1016/S0924-0136(00)00411-8.

[20] R. Alderliesten. 2009. On the development of hybrid material concepts for aircraft structures, *Recent Patents in Engg.*, 3(1), 25-38. https://doi.org/10.2174/187 221209787259893.

[21] S. Krishnakumar. 1994. Fibre metal laminates: the synthesis of metals and composites, *Materials and Manufacturing Proc.*, 9(2), 295-877. https://doi.org/10. 1080/10426919408934905.

[22] V.G. Reyes and W.J. Cantwell. 2000. The mechanical properties of fibre-metal laminates based on glass fibre reinforced polypropylene, *Composites Sci. and Tech.*, 60(7), 1085-1094. https://doi.org/10.1016/S0266-3538(00)00002-6.

[23] *Quick Start Guide to midas NFX*, Version 2018. MIDAS Information Technology, Korea.

[24] *Hex Ply Prepreg Tech.*, Publication No. FGU 017c, January 2013, Hexcel Corporation (Solvay).

[25] *Expandable laminate explorer, eLamX²*, Institute of Aerospace Engg. Technische Universität Dresden, Germany.

[26] O. Ishai. 1994. *Engineering Mechanics of Composite Materials*, Oxford University Press.