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Effect of Intra-Ply Hybridization of Carbon-Aramid/Epoxy Laminates under Tension-Tension Fatigue Loading

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ABSTRACT:

The objective of the research is to investigate the fatigue life of intra-ply hybrid Carbon-Aramid laminate with Epoxy resin in on-axis and off-axis directions. Three different off-axis angles of 15°, 30° and 45° were considered for the present work. The intra-ply hybridization is used to combine the superior mechanical properties of Carbon fibre with excellent elongation-to-failure property of Aramid fibre in the same lamina. The fatigue test was performed using load control using a frequency of 5Hz. The fatigue behaviour was studied for Carbon/Epoxy, Aramid/Epoxy, Carbon-Aramid/Epoxy, Carbon-Aramid/Epoxy - 15°, Carbon-Aramid/Epoxy - 30° and Carbon-Aramid/Epoxy - 45° with the stress ratio of R = 0.1. The ultimate tensile strength decreases progressively for Carbon/Epoxy, Carbon-Aramid/Epoxy, Aramid/Epoxy, Carbon-Aramid/Epoxy - 15°, Carbon-Aramid/Epoxy - 30° and Carbon-Aramid/Epoxy - 45°. The effect of off-axis loading indicates that the increase of fibre angle influences the decrease in tensile strength and fatigue life.

KEYWORDS:

Lamina; Carbon-Aramid reinforced Epoxy; Interlaced; Fatigue life; Intra-ply

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1. Introduction

Now-a-days the primary load bearing structures are replaced with Carbon and Kevlar composites, especially in aerospace structures and other engineering applications [1-2]. They show good fatigue resistance, stiffness-to-weight ratios and higher strength-to-weight ratios, which help to reduce the weight of the aircraft and enhance the performance [3-5]. Recent research is mainly focused on micro level hybridization which enhances the material properties with same strength-to-weight ratio. Hybridization is classified into two types' viz., inter-ply and intra-ply. Inter-ply hybrid composites are made with two or more fibre matt in common matrix while in intra-ply hybridization two or more different fibre yarns are mingled in the same lamina. Attia et al [6] investigated the characterization of mechanical properties of intra-ply and inter-ply hybrid composite materials made by E-glass with polypropylene unidirectional fibre. The results reveal that intra-ply hybrid laminate exhibits more load resistance capacity when compared to inter-ply hybrid composites.

Ying et al [7] compared the mechanical behaviour of different types of Carbon-Aramid/Epoxy laminates under impact loading condition. The comparison of inter-ply hybrid, intra-ply hybrid and sandwich-like inter-ply hybrid laminates reveals that the inter-ply Carbon/Epoxy hybrid laminates have higher impact damage resistance. Also, the results indicate that the mechanical properties and the damage tolerance are increased when the highly stressed regions are modified with high stiffness Carbon fabric as reinforcement. The damage tolerance of inter-ply hybrid composite structure is better than those of other hybrid composites. Dehkordi et al [8] studied the effect of intra-ply hybridization behaviour with different volume percentage composition of nylon/basalt fibre laminate using low velocity impact at different nominal energy levels and the impact performance of these composites are considerably influenced by nylon/basalt. Chamis et al [9] investigated the mechanical properties of interlaced hybrid laminates using graphite as the primary fibre with S-glass and Kevlar as secondary fibre. The performance of the glass and Kevlar intra-ply composition has given better results compared to exiting inter-ply laminates. Pegoretti et al [10] considered low velocity Izod impact characterization of E-glass with polyvinyl alcohol (PVA). They found that the impact crack resistance propagation was quite higher for intra-ply compared to inter-ply hybrid composites.

Zeng et al [11] studied the effect of stress concentration on Carbon-glass/Epoxy intra-ply hybrid composite using combination of different fibre in lamina level and laminate level (intra-ply and inter-ply). They found that intra-ply hybrid laminates resist the damage propagation. Cyriac et al [12] investigated the effect of percentage composition of hybrid fiber on the mechanical behaviour of Carbon-Aramid hybrid composites. The mechanical properties decreased with excess amount of fibre present in the laminate. Montesano et al [15] investigated off-axis tensile fatigue behaviour of fibre/bismaleimide laminate. It was observed that there was a three-stage response during the permanent deformation process. The rotation of the yarns was found to be the main mechanism which triggers the initial phase. In the initial phase there was a high permanent strain and a minimal increase in stiffness. In the final phase, when the sample nears the end of its life it was observed that there was a rapid increase in stiffness degradation. Bunsell et al [16] have investigated various mechanical properties such as tensile, fatigue and creep on Kevlar 49 fibre. The fracture morphology of fibres is found to be complex due to splitting. It was observed, under steady loading condition, that the fibre can withstand failure but there is a possibility of failure due to creep when the applied load is near to its tensile breaking load.

Valença et al [17] have done experiment on the effect of hybrid composite fibre architecture on tensile, bending and impact properties. Kevlar /glass hybrid composites increased the flexural strength as well as the impact energy. Ramesh et al [18] investigated the flexural behaviour of hybrid glass Kevlar laminates with acoustic emission monitoring. It has been observed that hybridized laminates showed better properties in terms of flexural and impact strength. Feng et al [19] evaluated the fatigue properties by delamination throughout the gage length. Brittle fracture in small regions was observed during static tensile test. Reis et al [20] investigated the fatigue behaviour of Carbon/Epoxy laminates with different stress ratios as well as with different amplitude block loadings. It was concluded that compressive tensile strength is less than tensile ultimate strength. Composites also behave non-linearly under compressive loading but exhibit brittle behaviour under tensile loading. This behaviour is due to fibre buckling. In this present work, static tension and tension-tension fatigue experiments are conducted for on-axis and off-axis intra-ply hybrid Carbon-Aramid laminate with Epoxy resin. The intra-ply hybridization enables the superior mechanical properties of Carbon fibre with excellent elongation-to-failure property of Aramid fibre in the same lamina.

2. Experimental procedure

Two different fibre yarns are considered for the present work, namely Carbon and Aramid, which are interlaced in the same lamina with three different off-axis angles of 15°, 30° and 45°. The distribution of the fibre yarns is maintained at 50% in both warp and weft directions. The specifications of laminate fibre angle orientations are shown in Table 1. The plain weave of Carbon, Aramid and interlaced Carbon-Aramid fibre mat of 200 gsm is used as reinforcement. Further, araldite Epoxy (GY257) is used as binding material and aradur 140 as hardener. The mixing ratio of resin and hardener is maintained at 2:1. The weight ratio of fibre, resin and hardener is maintained as 1:1:0.5. Conventional hand layup process has been adopted for fabricating the laminate size of 300 mm × 300 mm with a thickness of 2 mm ± 0.1 mm. The laminates are allowed to cure at room temperature. The standard tensile specimens are precisely trimmed from the parent laminate using water jet cutting as per the ASTM standard (D3039). The on-axis and off-axis fibre directions and loading directions are shown in Fig. 1 and the test specimens are presented in Fig. 2.

Table 1: Laminate specifications with angle orientations

Specimen types	Angle
Aramid/Epoxy	0/90°
Carbon/Epoxy	0/90°
Carbon-Aramid/Epoxy	0/90°
Carbon-Aramid/Epoxy	15°
Carbon-Aramid/Epoxy	30°
Carbon-Aramid/Epoxy	45°

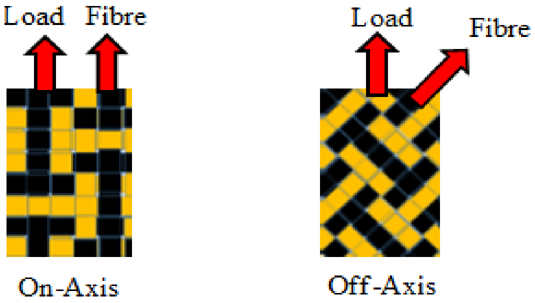

Fig. 1: On-axis and off-axis directions of fibre and loading

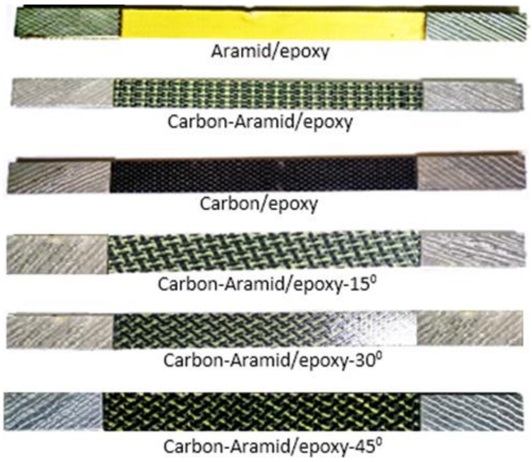

Fig. 2: Test specimens

Quasi static tensile tests are performed using MTS slight universal testing machine equipped with a load cell capacity of 100 kN. The specimens are fixed in the tensile fixture and the same gripping pressure is maintained at both the edges. The cross head travel speed rate is maintained according to ASTM D3039/D3039M [13]. The in-plane axial load is applied to the specimen until fracture. The average value is considered from the test of five specimens in each category and Fig. 3 shows the experimental test setup of tensile testing. The specimens are subjected to tension-tension fatigue load using MTS servo hydraulic fatigue machine with a load control (sinusoidal wave at constant amplitude) according to ASTMD3479/D3479M [14]. Three different load levels of ultimate tensile strength (60%, 70%, 80% of UTS) are selected using loading frequency of 5Hz and stress ratio of R = 0.1 [20]. Ultimate tensile strength of the specimens is considered to analyse the fatigue life for both on-axis and off-axis loadings. The fatigue test experimental setup is shown in Fig. 4. Five samples are taken for testing in each category and their average is considered for the analysis.

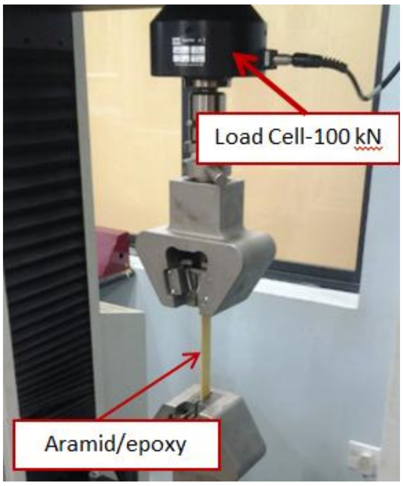

Fig. 3: Tensile test setup

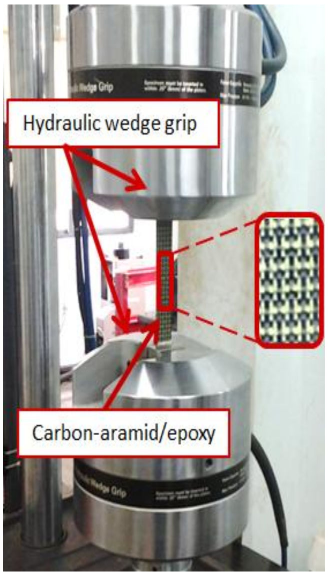

Fig. 4: Experimental setup for fatigue test

3. Results and discussion

The tensile and fatigue tests are represented for three different fibre-matrix combinations and for three orientation of hybrid laminate for off-axis loading. The static properties of laminated composite were obtained by tensile test. The specimens are subjected to tensile load until fracture. The typical load-displacement curves for both on-axis and off-axis are plotted in Figs. 5 and 6.

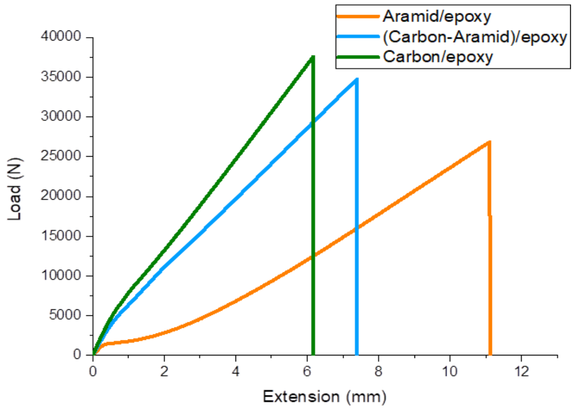

Fig. 5: On-axis load vs. Extension

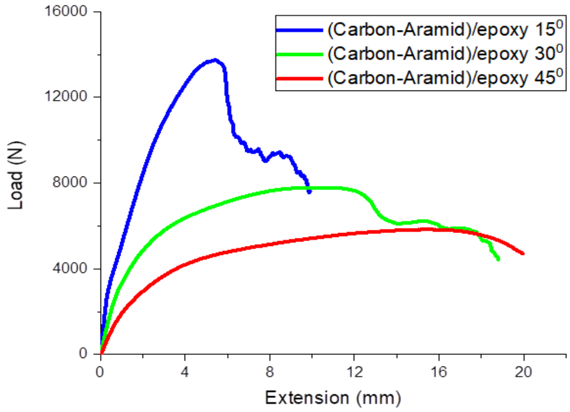

Fig. 6: Off-axis load vs. Extension

The ultimate tensile strength for all tested specimens is summarized in Table 2. In on-axis loading, Carbon/Epoxy and Carbon-Aramid/Epoxy perform better compared to Aramid/Epoxy. There is a progressive increase in the ultimate tensile strength for Aramid/Epoxy, hybrid Carbon-Aramid/Epoxy and Carbon/Epoxy in the range of 537.06 MPa, 683.79 MPa and 749.15 MPa respectively. The increment in fibre angle during off-axis loading influences a gradual reduction in tensile strength of Carbon-Aramid/Epoxy with 15° to 45° off-axis loading. The results indicate that fibre on-axis loading gives better performance compared to off-axis loading.

Table 2: Experimental results obtained in the static test

Specimen	Loading	σ_{UTS}(Mpa)	Average σ_{UTS} (MPa)	Std. Dev. (MPa)
Aramid/ Epoxy	On-axis	Sp_1- 533.68 Sp_2- 549.38 Sp_3- 527.40 Sp_4- 538.91 Sp_5- 535.94	537.06	7.22
Carbon-Aramid/ Epoxy	On-axis	Sp_1- 689.70 Sp_2- 695.21 Sp_3- 678.40 Sp_4- 660.36 Sp_5- 695.26	683.79	13.22
Carbon/ Epoxy	On-axis	Sp_1- 766.37 Sp_2- 726.36 Sp_3- 742.27 Sp_4- 759.53 Sp_5- 751.18	749.15	13.96
Carbon-Aramid/ Epoxy - 15°	Off-axis	Sp_1- 246.95 Sp_2- 239.10 Sp_3- 249.84 Sp_4- 244.84 Sp_5- 245.56	245.25	3.52
Carbon-Aramid/ Epoxy - 30°	Off-axis	Sp_1- 155.77 Sp_2- 161.65 Sp_3- 166.68 Sp_4- 174.74 Sp_5- 151.10	161.98	8.26
Carbon-Aramid/ Epoxy - 45°	Off-axis	Sp_1- 129.26 Sp2-122.79 Sp_3- 116.65 Sp_4- 104.99 Sp_5- 131.39	121.01	9.53

The fatigue life for the on-axis case was estimated for Carbon/Epoxy, interlaced Carbon-Aramid and Aramid/Epoxy fibres. In the off-axis case, interlaced

Carbon-Aramid with fibre angles of 15°, 30° and 45° were considered. The percentage of maximum stress versus logarithm of fatigue cycles to failure for on-axis and off-axis are plotted in S-N curve and shown in Figs. 9 and 10 respectively. The results are listed in Table 3. It is clearly seen from the result that the on-axis fatigue life is more when compared to the off-axis conditions. The increase of maximum load during fatigue testing process accelerates the fracture of the specimen leading to reduction the fatigue life [20-21]. The result indicates that on-axis loading shows a progressive increase in fatigue life in Carbon/Epoxy, Carbon-Aramid/Epoxy and Aramid/Epoxy respectively. Carbon-Aramid interlaced combination exhibited a significantly higher fatigue life than Aramid/Epoxy and a moderately increased life than Carbon/Epoxy. Off-axis interlaced hybrid specimens show a gradual decrease in fatigue life for Carbon-Aramid/Epoxy with off-axis loading from 15° to 45°.

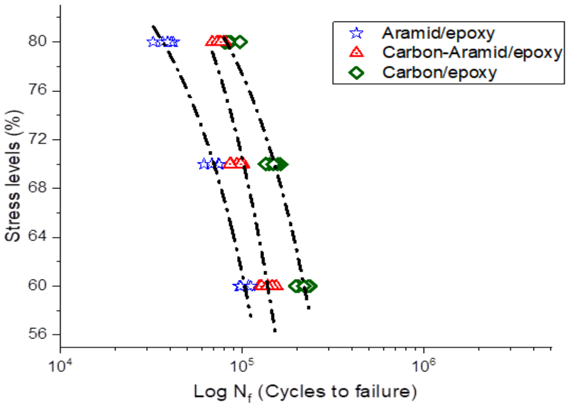

Fig. 9: Stress-life curve for on-axis loading

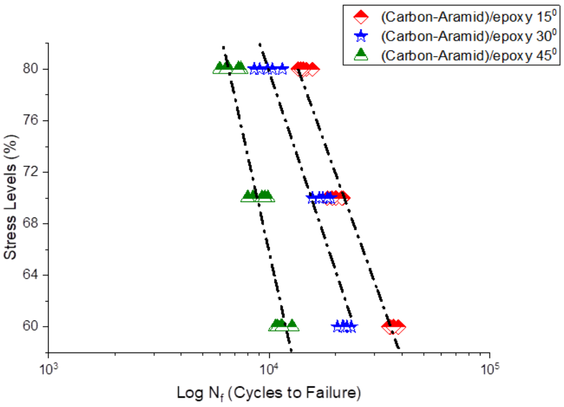

Fig. 10: Stress-life curve for off-axis loading

With on-axis loading, the Carbon/Epoxy fibres exhibit superior tensile and fatigue behaviour compared to the interlaced Carbon-Aramid/Epoxy and Aramid/Epoxy fibres. This is due to the fact that when the direction of loading and that of the fibre coincide, there is a perceptible improvement in the in-plane load bearing capacity of the fibres with less damage to the matrix phase and failure along the axis occurs chiefly due to the fracture of the fibres. On the other hand, the performance of interlaced Carbon-Aramid/Epoxy fibres is better than that of Aramid/Epoxy fibres as a result of improvement in the load bearing capacity due to the contributions of superior mechanical properties of Carbon fibres coupled with the excellent elongation-to-failure property of the Aramid fibres.

With off-axis loading, it is seen that the tensile and fatigue behaviour of all the three combinations of fibre angle show quite a large difference when compared to the on-axis loading. It is also observed that an increase in fibre angle results in a decrease in the tensile and fatigue behaviour. Primarily, off-axis loading causes maximum damage to the matrix phase. This is evident from the fact that no fibre fracture occurs in all the three cases of off-axis loading. Further, observations of off-axis loading vs. Extension (Fig. 6) show that the non-linear behaviour is more likely due to occurrence of delamination as a result of inter-fibre fracture.

Table 3: Comparison of fatigue life

Specimen	Loading	Stress level	No. of cycles to failure
Aramid/Epoxy	On-axis	60% UTS	102508
		70% UTS	69299
		80% UTS	38072
Carbon-Aramid/Epoxy	On-axis	60% UTS	138024
		70% UTS	93120
		80% UTS	74505
Carbon/Epoxy	On-axis	60% UTS	217599
		70% UTS	148772
		80% UTS	85676
Carbon-Aramid/Epoxy- 15°	Off-axis	60% UTS	36346
		70% UTS	20100
		80% UTS	14429
Carbon-Aramid/Epoxy- 30°	Off-axis	60% UTS	21913
		70% UTS	17458
		80% UTS	9841
Carbon-Aramid/Epoxy- 45°	Off-axis	60% UTS	11407
		70% UTS	9023
		80% UTS	6711

4. Conclusion

Quasi-static tensile and fatigue behaviour of Carbon/Epoxy, Aramid/Epoxy and interlaced Carbon-Aramid/Epoxy composite laminates are investigated. The tensile and fatigue tests were conducted for two different categories of fibre orientation with respect to loading namely, on-axis and off-axis with three different angular orientations. It is identified that on-axis fibre loading conditions show better load bearing capacity compared to off-axis conditions and this is based on whether the fibre or the matrix phase suffers the maximum damage. In the case of on-axis loading, it is the fibre which bears the maximum damage and for off-axis loading it is the matrix phase that suffers the maximum damage. This leads to the conclusion that on-axis loading is more suitable for primary load bearing structures and off-axis loading for that of secondary load bearing structures.

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REFERENCES:

[1] J. Montesano, M. Selezneva and M. Levesque. 2015. Modelling fatigue damage evolution in polymer matrix composite structures and validation using in-situ digital image correlation, *Compos. Struct.*, 125, 354-361. https://doi.org/10.1016/j.compstruct.2015.02.035.

[2] P. Selvum, K.V. Uday and M.J. Gregg. 2009. Effects of moisture and UV exposure on liquid moulded Carbon fabric reinforced Nylon 6 composite laminates, *Composite Sci. Tech.*, 69, 839-846. https://doi.org/10.1016/j.compscitech.2008.03.021.

[3] F. Awaja, B. Arhatari, K. Wiesauer, E. Leiss and D. Stifter. 2009. An investigation of the accelerated thermal degradation of different Epoxy resin composites using X-ray micro computed tomography and optical coherence tomography, *Polym. Degrad. Stab*, 94, 814-824. https://doi.org/10.1016/j.polymdegradstab.2009.06.005.

[4] C. Santiuste, S.S. Saez and E. Barbero. 2010. Residual flexural strength after low velocity impact in glass /polyester composite beams, *Compos. Struct.*, 92, 25-30. https://doi.org/10.1016/j.compstruct.2009.06.007.

[5] M. Saleem, L. Toubal and R. Zitoune. 2013. Investigating the effect of machining processes on the mechanical behavior of composite plates with circular holes, *Composites Part A,* 55, 169-177. https://doi.org/10.1016/j.compositesa.2013.09.002.

[6] M.A. Attia, M.A.A. El-baky and A.E. Alshorbagy. 2016. Mechanical performance of intraply and inter-intraply hybrid composites based on e-glass and polypropylene unidirectional fibers, *J. Composite Materials*, 51(3). https://doi.org/10.1177/0021998316644972.

[7] S. Ying, T. Mengyun, R. Zhijun, S. Baohui and C. Li. 2016. An experimental investigation on the low-velocity impact response of Carbon-Aramid/Epoxy hybrid composite laminates, *J. Reinforced Plastics and Composites*, 36(6), 422-434. https://doi.org/10.1177/0731684416680893.

[8] M.T. Dehkordi, H. Nosraty, M.M. Shokrieh, G. Minak and D. Ghelli. 2010. Low velocity impact properties of intra-ply hybrid composites based on basalt and nylon woven fabrics, *Materials and Design*, 31, 3835-3844. https://doi.org/10.1016/j.matdes.2010.03.033.

[9] C.C. Chamis, R.F. Lark and J.H. Sinclair. 1979. Mechanical property characterization of intraply hybrid composites, *Pentagon Reports,* Report number A301566.

[10] A. Pegoretti, E. Fabbri, C. Migliaresi and F. Pilati. 2004. Intraply and interply hybrid composites based on E-glass and poly (vinyl alcohol) woven fabrics: Tensile and impact properties, *Polym. Int.*, 53(9), 1290-1297. https://doi.org/10.1002/pi.1514.

[11] Q. Zeng, X. Huang, X. Lin. 2001. Study on stress concentrations in an intraply hybrid composite sheet, *Appl. Math Mech*., 22, 154-9. https://doi.org/10.1023/A:1015528528946.

[12] G. Cyriac, B. Paul, K.T. Akhil and K. Shunmugesh. 2017. The effect of fibre loading on the mechanical behaviour of Carbon Aramid hybrid composites, *Polymers & Polymer Composites*, 25(3), 225-228. https://doi.org/10.1177/ 096739111702500308.

[13] ASTM D3039/D3039M-17. 2017. Standard test method for tensile properties of polymer matrix composite materials, *ASTM Int.*, 13.

[14] ASTM D3479/D3479M-12. 2012. Standard test method for tension-tension fatigue of polymer matrix composite materials, *ASTM Int.*, 6.

[15] J. Montesano, M. Selezneva, Z. Fawaz, C. Poon and K. Behdinan. 2012. Elevated temperature off-axis fatigue behaviour of an eight-harness satin woven Carbon-fibre/bismaleimide laminate: Composites Part A, *Applied Sci. and Manuf.*, 43, 1454-1466. https://doi.org/10.1016/j.compositesa.2012.04.016.

[16] A.R. Bunsell. 1975. The tensile and fatigue behaviour of Kevlar -49 (PRD-49) fibre, *J. Materials Sci.*, 10, 1300-1308. https://doi.org/10.1007/BF00540819.

[17] S.L. Valença, S. Griza, V.G.D. Oliveira, E.M. Sussuchi and F.G.C.D. Cunha. 2015. Evaluation of the mechanical behaviour of Epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabric, *Composites Part B: Engg.*, 70, 1-8. https://doi.org/10.1016/j.compositesb.2014.09.040.

[18] C. Ramesh, H. Ragesh, V. Arumugam and A.J. Stanley. 2012. Effect of hydrolytic ageing on Kevlar /polyester using acoustic emission monitoring, *J. Non-destructive Evaluation*, 31, 140-147. https://doi.org/10.1007/s10921-012-0129-9.

[19] Y. Feng, C. Gao, Y. He, T. An, C. Fan and H. Zhang. 2016. Investigation on tension-tension fatigue performances and reliability fatigue life of T700/MTM46 composite laminates, *Compos Struct.*, 136, 64-74. https://doi.org/10.1016/j.compstruct.2015.09.057.

[20] P.N.B. Reis, J.A.M. Ferreira, J.D.M. Costa and M.O.W. Richardson. 2009. Fatigue life evaluation for Carbon/Epoxy laminate composites under constant and variable block loading, *Composites Sci. and Tech.*, 69, 154-160. https://doi.org/10.1016/j.compscitech.2008.09.043.

[21] J. Llobet, P. Maimí, J.A. Mayugo, Y. Essa, F.M.D.L. Escalera. 2017. A fatigue damage and residual strength model for unidirectional Carbon/Epoxy composites under on-axis tension-tension loadings, *Int. J. Fatigue*, 103, 508-515. https://doi.org/10.1016/j.ijfatigue.2017.06.026.

[22] C. Ganesan, P.S. Joanna. 2018. Fatigue life and residual strength prediction of GFRP composites: An experimental and theoretical approach, *Latitude American J. Solids Struct.,* 15(7), 1-6.