

Effects Of Stacking Sequence On Compression Response Testing Of Carbon Fibre And Hybrids: Fibrous-Glass/Carbon/Kevlar/ Epoxy Composite Plates

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Abstract— This paper is concerned with evaluation of failure mechanisms under compression loading in unidirectional composites and the in-plane dimensional of fibre-reinforced laminated composites under compression loads. (0/0/0/0/0) oriented cross-ply Fibrous-Glass/Carbon/Kevlar/ Epoxy laminates studied were fabricated and all of the material parameters of laminated composite materials were measured experimentally. On the contrary, the compressive strength and failure mechanisms were investigated for hybrid composites. Static uni-axial compressive tests were performed on unnotched specimens made from double-layer of carbon, glass, and Kevlar fibres and epoxy resin combined to give six different stacking hybrid composite materials.

Keywords— Kevlar fibre, Carbon fibre, Glass fibre, Stacking Sequence, Energy Absorption, Unconfined Compression

I. INTRODUCTION

Progressions in the use of laminated composite materials for the structure of aircraft and automobile industries were increased significantly over the past decade. This was motivated by the need for improved performance requirements in stipulations of stealth, payload, range, stability and simultaneously, a reduction in costs in terms of maintenance, operation and construction. Much experience in the use of hybrid composites in the aerospace industries were achieved from the design of composite airplanes, which were designed using high stiffness requirements and not for all the parts of the current body of airplanes being planned. The stiffness of composites can be determined equitably accurately using the particular tests and material properties from standard material characterisation tests. However, with more demanding requirements, this was changed and the minimisation of damage is something that is now required in order to satisfy higher-performance demands. This is not as simple as optimising the

elastic stiffness of the structure due to the complex damage modes that can occur in hybrid composites.

Compression strength is an important topic as it is one of the design drivers for composite structures. There was considerable research over the years reviewed the earlier work [1]. Scaling effects are also important, as the design of large structures is usually based on data from small coupons, and reduced scale models may be used to investigate full-scale structural behavior. There is substantial evidence of size effects in composites [2]. Reductions of strength with increasing size reported in tensile and flexural strength [e.g. 2-6] and in compression [2, 7-12], but scaling of strength is still not well understood. In composite specimens scaling is accompanied by the well-known hole-size effect whereby strength decreases with increasing hole size. Many researchers investigated this [e.g. 13-19] and a number of models were been proposed which fit the experimental trends. Most studies were kept the width constant and so specimens are not truly scaled, and the varying finite width correction factors can obscure the underlying scale effect.

II. EXPERIMENTAL PROCEDURES

II.1. MATERIALS

Traditionally, aerospace composites were composed of high-stiffness carbon fibres to maintain dimensional stability under high-performance application. The stiffness property is often associated with a particular susceptibility to impact damage and a corresponding reduction of mechanical properties. However, such structures were expected to only encounter few unintentional impacts. Composite structures for military ground vehicles, on the other

hand, were designed to absorb multiple high-energy impacts but they had much less dimensional restrictions. Since softer materials tend to dissipate more energy during impact, a low modulus/high strength alternative may be well suited for backing panel composites. Figure 1 shows the three types of fibres, including glass, carbon, and Kevlar, which were used in fabricating the specimens [20].

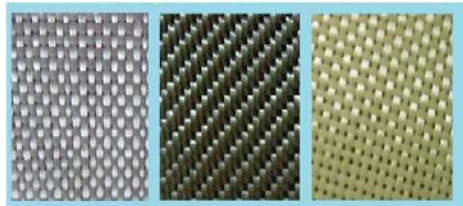


Figure 1: Left to right; Glass, carbon, and Kevlar fibre

Kevlar KM2 fabrics are widely used to produce personnel protection systems because of their impact-resistant properties. To understand the deformation process of a fabric armour system during impact, many aspects of fabric, such as its material properties, fabric structure, projectile geometry, impact velocity, multiple ply interaction, far-field boundary conditions, and friction, must be studied [11]. The Kevlar fabric used in all composite target constructions was plain-woven Hexcel Aramid, high-performance fabric Style 706 (Kevlar KM-2, 600 denier) with a real density of 180 g/m^2 . Room temperature curing and the ratios of 50 parts epoxy resin (EPOKUKDO YD-128) to 50 hardener (Polyamide - Domide (A.V: 350)) by weight being cured after seven days at $20 \text{ }^\circ\text{C}$ [20-22].

II.II. PREPARATION OF THE SPECIMENS

Hand lay-up is the simplest and oldest open moulding method of the composite fabrication processes. Glass or other reinforcing mat or woven fabric or roving is positioned manually in the open mould, and resin is poured, brushed, or sprayed over and into the glass plies. Entrapped-air is removed manually with squeegees or rollers to complete the laminate structure. Room temperature curing epoxies are the most commonly used matrix resins. A catalyst initiates curing in the resin system, which hardens the fibre-reinforced resin composite without external heat, and kept them in-room temperature ($19 \text{ }^\circ\text{C}$, Humidity 13%). Table 1 displays the ordering and

sequence of fibres plies in each hybrid composite materials [21].

II. III. EXPERIMENTAL TESTING PROCEDURE

Regarding to ASTM D6641 test method all the specimens are prepared and cut for compression test [23].

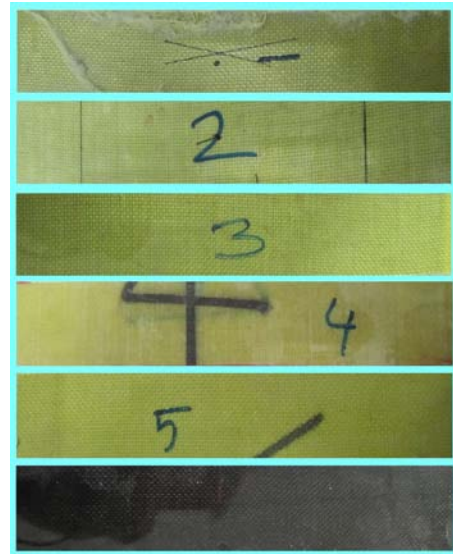


Figure 2 Specimens for compression test.

The compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. It provides data (or a plot) of force versus deformation for the conditions of the test method. When the limit of compressive strength is reached, brittle materials are crushed.

By definition, the compressive strength of a material is that the value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied.

A compression test determines behaviour of materials under the crushing loads. The specimen is

compressed and deformation at various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit, proportional limit, yield point, yield strength and, for some materials, compressive strength.

This method determines in-plane compressive properties by applying the compressive force into the specimen at wedge grip interfaces. The compression test was conducted following the procedure specified in ASTM D6641. The test was performed in the Dual Column Tabletop Universal - 3360 Series from Instron testing machine. Compression coupons were loaded using an end-loaded, side supported (gripping pressure of 8.5MPa), with an unsupported length of 50mm. The test was conducted at a loading rate of 1.00mm/min. Figure 5 shows the test setup used in performing the compression test. Recording of data for compression test was generated using the Bluehill Software for Static Test Systems. Figure 6 shows the geometry of the hybrid composite laminated specimen, and boundary conditions of the test specimen. ASTM D6641 is most appropriate for the composite materials reinforced by high-modulus fibres including tape and textile, but other materials may be tested. The test fixture is designed to provide a compressive load to the unsupported centre 12 to 50 mm gauge length of the specimen.

Table 1: The fabricated composite sheets are divided into five groups

HYBRID 1	HYBRID 2	HYBRID 3	HYBRID 4	HYBRID 5
Kevlar	Glass	Kevlar	Glass	Kevlar
Carbon	Carbon	Glass	Kevlar	Carbon
Glass	Kevlar	Carbon	Carbon	Glass
Kevlar	Carbon	Glass	Carbon	Glass
Glass	Kevlar	Carbon	Glass	Carbon
Carbon	Glass	Kevlar	Kevlar	Kevlar

III. RESULTS AND DISCUSSION

III.I. UNCONFINED COMPRESSIVE STRENGTH

Figure 3 illustrates the ultimate compressive breakage loads and compressive extension at the failure points of the intact specimens. Hybrid 3 had an ultimate breakage load with about 528N and Pure Carbon Fibre had a minimum with about 162N. Moreover, among the Hybrids, Hybrid 1 had a minimum breakage load with about 341N.

The average of the ultimate compressive breakage loads is about 406N and the average of the compressive extension of the failure points is 0.189mm. The results of specimens experienced much higher-than-average ultimate compressive breakage loads, including Hybrid 2, Hybrid 3, Hybrid 4, and Hybrid 5. Meanwhile, Hybrid 1 and pure carbon fibre were notably lower than the average.

The compressive failure occurred in the range from 0.1mm to 0.32mm as the range of compressive extension points. The stiffness (the slope of the force- displacement curve) of all specimens is approximately same before reaching to the failure points.

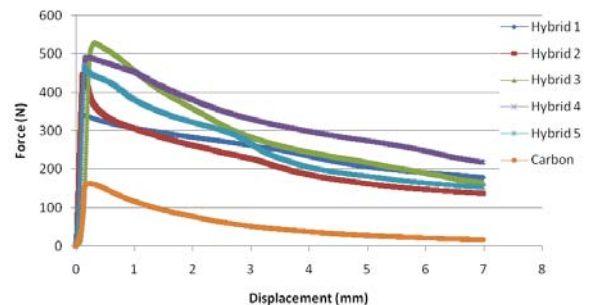


Figure 3 Compressive force–displacement curves of the specimens.

III.I. COMPRESSIVE ENERGY ABSORPTION

Figure 4 illustrates the comparison amount of compressive energy absorption of the intact specimens including the five groups of Hybrids and pure carbon fibre in Joules. All six types of specimens are intact; i.e. all of the specimens are undamaged in any way. Hybrid 4 had a maximum strength against the compressive force with 2286J

and pure carbon fibre had a minimum with 399J. Then again, among the Hybrids, Hybrid 2 had a minimum strength against the compressive force with 1529J. Among the Hybrids; average of the amount of compressive energy absorption is about 1868J, accordingly Hybrid 3 and Hybrid 4 are at the top level of average, and the rest are at the bottom.

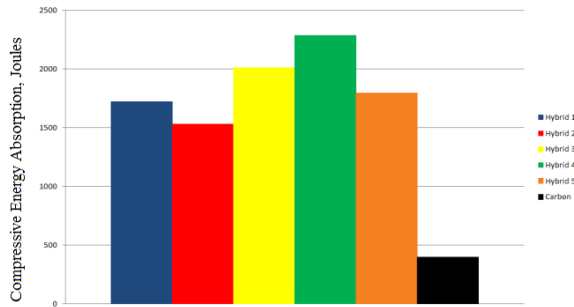


Figure 4 The amount of compressive energy absorption of the specimens including the 5 groups of Hybrids and pure carbon fibre (in Joules).

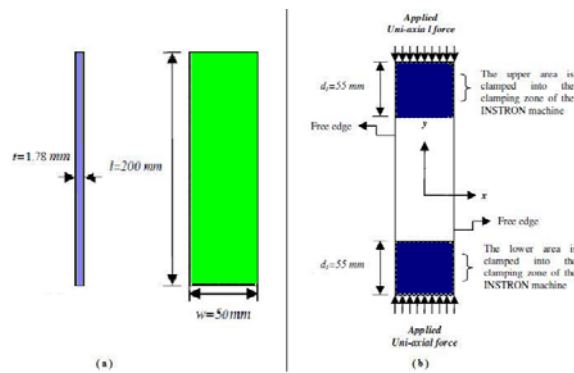


Figure 5 a. Geometry of the hybrid composite laminated plate (specimens), and b. Load and boundary conditions of the test specimen.

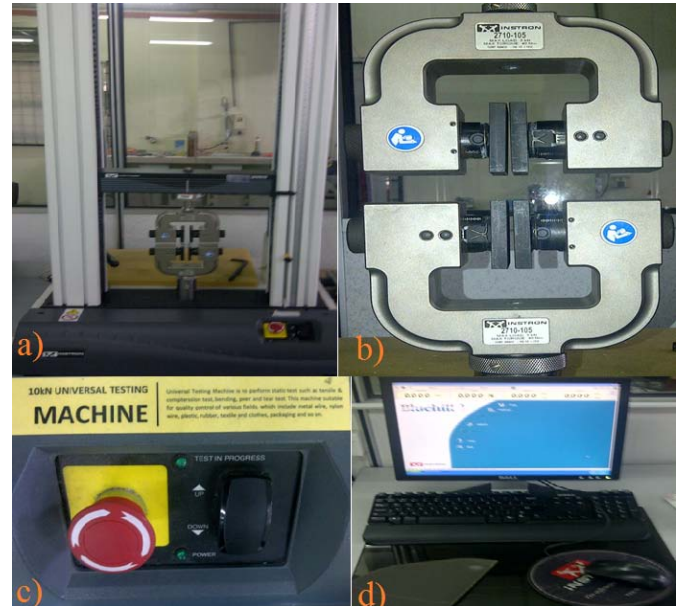


Figure 6 Dual Column Tabletop Universal Testing Systems - 3360 Series from Instron; a. Full-length view of the compression machine, b. Clamp and fixture, c. Joystick Button Control and d. The Bluehill Software for Static Test Systems.

IV. CONCLUSIONS

The results show, first, the Hybrid 4 had the superlative energy absorption. Second, it can be concluded that stacking the first layer with glass fibre is better than to use the Kevlar fibre. Third, using the combination of carbon and glass is more efficient than using in the central layers. Fourth, using the carbon fibre is not recommended at the last layer.

References

- Ataş, A., & Soutis, C. (2014). Strength prediction of bolted joints in CFRP composite laminates using cohesive zone elements. *Composites Part B: Engineering*, 58, 25-34.
- Elavenil, S., & Knight, G. S. (2012). Impact Response of Plates Under Drop Weight Impact Testing. *Daffodil International University Journal of Science and Technology*, 7(1), 1-11.
- Wisnom, M. R. (2010). Modelling discrete failures in composites with interface elements. *Composites Part A: Applied Science and Manufacturing*, 41(7), 795-805.
- Hodgkinson, J. M. (2012). Testing the strength and stiffness of polymer matrix composites. *Failure Mechanisms in Polymer Matrix Composites: Criteria, Testing And Industrial Applications*, 129.
- Czél, G., & Wisnom, M. R. (2013). Demonstration of pseudo-ductility in high performance glass/epoxy composites by hybridisation with thin-ply carbon prepreg. *Composites Part A: Applied Science and Manufacturing*, 52, 23-30.

6. Wisnom, M. R., Hallett, S. R., & Soutis, C. (2010). Scaling effects in notched composites. *Journal of composite materials*, 44(2), 195-210.
7. Chandraseker, K., Patro, D., Nayak, A., Quek, S. C., & Yerramalli, C. S. (2010, January). Scaling Studies in Modeling for Compressive Strength of Thick Composite Structures. In *ASME 2010 International Mechanical Engineering Congress and Exposition* (pp. 519-525). American Society of Mechanical Engineers.
8. Gdoutos, E. E., & Bažant, Z. P. (2010). Size Effect on Fracture of Composite and Sandwich Structures. In *Major Accomplishments in Composite Materials and Sandwich Structures* (pp. 305-338). Springer Netherlands.
9. Li, D., Li, C. C., & Li, X. (2011). Influence of sample height-to-width ratios on failure mode for rectangular prism samples of hard rock loaded in uniaxial compression. *Rock Mechanics and Rock Engineering*, 44(3), 253-267.
10. Zhang, C., & Binienda, W. K. (2014). Numerical Analysis of Free-Edge Effect on Size-Influenced Mechanical Properties of Single-Layer Triaxially Braided Composites. *Applied Composite Materials*, 1-19.
11. Hodgkinson, J. M. (2012). Testing the strength and stiffness of polymer matrix composites. *Failure Mechanisms in Polymer Matrix Composites: Criteria, Testing And Industrial Applications*, 129.
12. Soutis, C. (2013). Compressive strength of composite laminates with an open hole: Effect of ply blocking. *Journal of Composite Materials*, 47(20-21), 2503-2512.
13. Camanho, P. P., Erçin, G. H., Catalanotti, G., Mahdi, S., & Linde, P. (2012). A finite fracture mechanics model for the prediction of the open-hole strength of composite laminates. *Composites Part A: Applied Science and Manufacturing*, 43(8), 1219-1225.
14. Hwan, C. L., Tsai, K. H., Chiu, C. H., & Huang, Y. S. (2013). Strength prediction of braided composite plates with lateral holes by a finite element-based point stress criterion. *Journal of Composite Materials*, 47(9), 1161-1168.
15. Martin, E., Leguillon, D., & Carrère, N. (2012). A coupled strength and toughness criterion for the prediction of the open hole tensile strength of a composite plate. *International Journal of Solids and Structures*, 49(26), 3915-3922.
16. Lagace, P.A. (1986). Notch Sensitivity and Stacking Sequence of Laminated Composites, In: Whitney, J.M. (ed.), *Composite Materials: Testing and Design* (Seventh Conference), pp. 61-176, ASTM STP 893, Philadelphia.
17. Bai, J., Xiong, J., & Cheng, X. (2011). Tear resistance of orthogonal Kevlar-PWF-reinforced TPU film. *Chinese Journal of Aeronautics*, 24(1), 113-118.
18. Zhou, Z. Q., Fang, X. J., Cox, B. N., & Yang, Q. D. (2010). The evolution of a transverse intra-ply crack coupled to delamination cracks. *International journal of fracture*, 165(1), 77-92.
19. Hwan, C. L., Tsai, K. H., Chiu, C. H., & Huang, Y. S. (2013). Strength prediction of woven hybrid composite laminates each with a center hole. *Journal of Composite Materials*, 0021998313488810.
20. Randjbaran, E., Zahari R., Majid, D.L., Jalil N.A.A., Vaghei R., Ahmadi R. (2013). The Effects of Stacking Sequence Layers of Six Layers Composite Materials in Ballistic Energy Absorption, *International Journal of Material Science Innovations*, 1 (6): 293-305.
21. Randjbaran, E., Zahari R., Majid, D.L., Jalil N.A.A., Vaghei R., Ahmadi R. (2013). An Experimental Investigation Of The Effects Of Stacking Sequence On Hybrid Composite Materials Response To Open-Hole Compression Strength., *Matrix Academic International Journal of Engineering and Technology*, 1 (2):1-7.
22. Randjbaran, E., Zahari R., Majid, D.L., Jalil N.A.A., Vaghei R., Ahmadi R. (2013). The Effects of Stacking Sequence Layers of Hybrid Composite Materials in Energy Absorption under the High Velocity Ballistic Impact Conditions: An Experimental Investigation *Matrix Academic International Journal of Engineering and Technology*, 1 (2):30-37.
23. Carlsson, L. A., Adams, D. F., & Pipes, R. B. (2013). Basic Experimental Characterization of Polymer Matrix Composite Materials. *Polymer Reviews*, 53(2), 277-302.