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Studies on Effect of Loading Rate of Hybrid Glass/Carbon Composites Subjected to Open Hole Tensile Test

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Abstract

Composite materials are used in aerospace and automotive industries since these materials are ideal candidates for high-strength-to-weight ratio applications. Further, hybrid composites provide specific benefits as per the required application. Any structures that are developed from the composite materials are not fabricated in one go and often require joining of multiple parts leading to development of one large structure. In such a scenario, joining is often achieved through the drilling of holes and in turn through bolted connections. In this article, the tensile strength of the hybrid glass carbon composite is tested in a UTM of 50kN capacity of Wance make for an open hole process using the ASTM D5766 standard, and its corresponding failure mechanism is studied with varying loading rates (1, 5, 10 mm/min). The test results indicate that with increase in loading rate, there is an increase in tensile strength of the composite panel with open hole configuration. The majority of the failure mechanism was attributed to matrix failure followed by fiber debonding at the hole region for higher loading rate, which is also the prime factor as per the ASTM standard. These results help developers to determine the failure process which in turn help in evolving a better composite structure for a specific application.

Keywords: *Open Hole Tensile Test, Peak Force, Loading Rate, Polymer Composites, Ultimate Tensile Strength.*

1.0 Introduction

Composites are widely used in applications that require lightweight materials and in turn involve a high strength-to-weight ratio function. Among the different types of composite materials such as polymer, ceramic, metal, and polymer matrix composites are widely used due to the fact that they can be developed as per the desired end-user requirements and further over the past few decades, polymer matrix composites are preferred class of materials, especially GFRP due to the fact that, they have better corrosion resistance, higher fatigue life, lower density as compared to the metal matrix or ceramic matrix composites. Further, this class of materials is used in the aerospace, automotive, consumer, shipbuilding, and defense domain. They also are used in high-temperature applications since they can be formed with low fabrication cost, especially synthetic materials[1]. Among the available synthetic materials, GFRP and CFRP are widely used in several structural applications. Thermoplastic composites [TP] is used in applications related to automotive such as bumper and interior dashboard which can be subjected to the fatal crash and can result in high strain rate[2,3]. When the composite materials are in use, they can be subjected to quasi-static or dynamic loading and this loading sequence can be either constant or of increasing order[4]. When the loading rate increases, the behaviour of composite materials is different and depends on several parameters such as fiber orientation, stacking sequence, hybrid nature of the

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composites, and the type of matrix used in the fabrication process be in thermoplastic [TP] or thermosetting [TS] resin, including the type of processing such as vacuum bagging, VARTM or compression molding.

Further to this effect, many smaller panels of materials are combined together to form one large structure and this requires a joining process either by adhesives or by bolting[5]. Many researchers have worked on the strain rate of loading and its effects on glass/epoxy composites when subjected to tensile, compressive, shear loading and stiffness and it was found that all the above parameters increased with an increase in strain rate at constant thickness for a range of composite materials such as GFRP and CFRP[6-11]. Similar events were observed by Lie Guo et al, even in bonded joints wherein the tensile strength increased by 28.6% with an increase in loading rate from 1mm/min to 50mm/min for a bond line thickness increase from 30µm to 50µm[12]. A. K. Srivastav et al [13] carried out studies on the loading rate of a 3-point bend test ranging from 2, 50, 100, 200, 500 mm/min of hybrid jute/glass composites, based on surface modifications and found that the stress values increased with increase in cross head velocity. When materials with open hole are subjected to sudden loading according to ASTM D5766[14] the effect is totally different from the materials when tested as per ASTM D3039. Mohammed Azadi et al, carried out effect of tensile loading rate in open hole test for carbon at 3mm thickness by hand layup process and tested at different speeds of 1, 2, 20, 200 mm/min it was found that the max stress increased with increase in loading rate and that the difference between 20 and 200 was only 5 MPa[15]. Sunny et al, carried out loading rate studies on GFRP panels with a central hole and found that tensile load increases with an increase in loading rate and deflection decreases[16]. Based on the literature review, it is found that loading tensile loading rates have been carried out from a range of values usually at an exponential rate, and usually done for individual constituents such as glass, carbon or a hybrid of natural and synthetic materials.

In this research work, efforts are made to determine the effect of loading rate at smaller incremental values of 1, 5, 10 mm/min on a hybrid stacking sequence of glass and carbon having a central circular hole since this combination of stacking gives a better cost-effective solution and at the same time, combined advantages of glass and carbon are obtained and can enhance the failure strain to an extent. Further, this combination of materials is widely used in aerospace industries based on effective stacking sequence.

2.0 Materials and Fabrication

For this study, the materials chosen are glass (Style - 92111/7628) and carbon (Style - 450/125) cloth of 200gsm each with a thickness of 0.19mm and 0.33mm respectively. The materials chosen are bi-woven type and purchased from ORION SYSTEMS, DVG Road, Bangalore, the details of cloth fiber are shown in Table 1. The cloth followed a plain weave pattern as shown in Figure 1.

The thermosetting resin system was procured from Herenba Instruments and Engineers, Chennai. The stacking sequence adopted in this study was the 4G4C4G process (8 layers of glass and 4 layers of carbon), all stacked one above the other as shown in Figure 2.

The fabrication was carried out using a vacuum bagging process. To begin with, the matrix material is processed by mixing resin and hardener in a ratio of 10:1 respectively. The

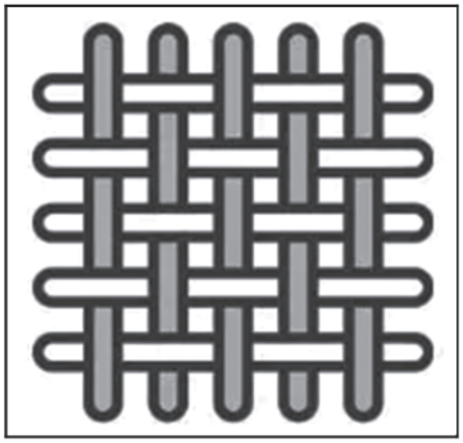

Figure 1: Plain weave pattern of individual glass and carbon fabric

Table 1: Specifications of glass and carbon cloth

	Material	Style	Weight (gsm)	Weave Pattern	Thickness (mm)
1	Carbon	450	200	Plain	0.33
2	Glass	92111	200	Plain	0.19

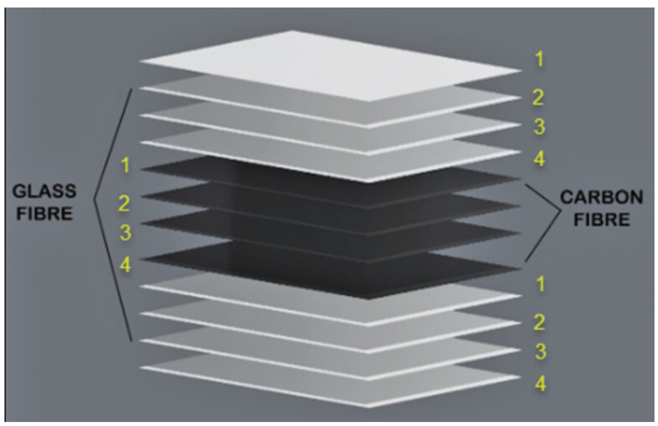

Figure 2: Stacking sequence of glass and carbon cloth

laminate is prepared by applying a layer of wax on a granite table and in turn applying matrix and cloth in sequence. The resin is applied on each layer of glass and carbon cloth uniformly using a roller brush and finally, excess resin is removed using a steel roller and in turn, is packed within a vacuum bagging set up as shown in Figure 3 for a duration of 4 hours using a ½ HP vacuum pump and in turn allowed to cure at room temperature as is for 24 hours. The specimens (200 mm × 36 mm × 3.38 mm) were cut as per the ASTM D5766 dimensions after carefully dividing them using deepnest.io software and in turn using a waterjet cutting machine to ensure that there is no stress induced during cutting. Drilling of 6 mm diameter was created at the center of the specimen as per the ASTM D5766[14] standard as shown in Figure 4.

The drilling was carried out using a wooden log as a sacrificial material and ensured that the entry and exit holes are perfect. Further, the drilling on the hybrid glass and carbon laminate was carried out using an HSS uncoated cemented carbide tool at a spindle speed of 7500 rpm and feed rate of 0.08 mm/rev[17]. Further holes were created with the lesser diameter and then reamed for the required diameter and the w/d ratio was maintained at 6, wherein w is the width of the specimen and d is the diameter of the specimen. The thickness of the specimen was 3.38 ± 0.11 mm.

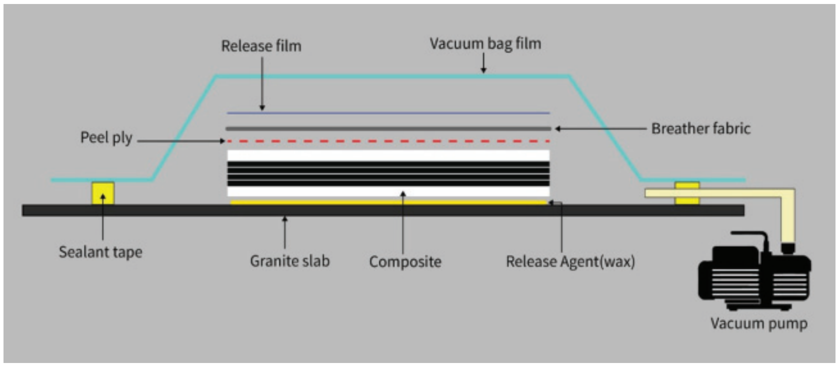

Figure 3: Vacuum bagging setup

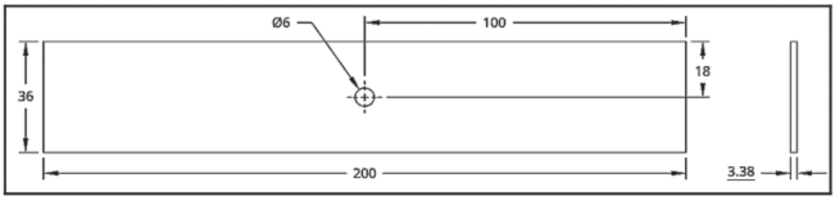

Figure 4: ASTM D5766 dimensions [14]

Table 2: Length and width dimensions of specimen

Specimen Number	Loading Rate (mm/min)	Specimen Length (mm)				Specimen Width (mm)			
		L1	L2	L3	Avg	W1	W2	W3	Avg
1	1	249.5	249	250.5	249.67	35.6	35.8	36.3	35.90
2		250	250	250	250.00	36.02	36.1	35.9	36.01
3		250	250	250	250.00	36.00	36.00	36.02	36.01
4		250	250	250	250.00	35.97	35.85	36.00	35.94
5		250	250	250	250.00	36.02	36.01	36.00	36.01
6	5	250	250	250	250.00	36.01	36.00	36.01	36.01
7		250	250	250	250.00	35.99	36.00	36.03	36.01
8		250	250	250	250.00	36.00	36.00	35.97	35.99
9		250	249.6	249	249.53	36.00	36.01	36.02	36.01
10		250	250	250	250.00	35.92	36.03	36.01	35.99
11	10	250	250	250	250.00	35.94	36.02	35.99	35.98
12		250	250	250	250.00	36.00	35.99	36.00	36.00
13		249.67	250	249.3	249.66	35.97	35.98	36.00	35.98
14		250	250	250	250.00	35.99	36.01	36.00	36.00
15		250	250	250	250.00	36.00	36.01	36.00	36.00

3.0 Testing Process

The test was carried out using a Wance UTM of 50kN capacity refer to Figure 5, a total of 5 trials were carried out for each configuration namely L1, L2, and L3 refer to Table 4 as per the ASTM D5766 standards at a loading rate of 1, 5, 10 mm/min until the specimen completely failed respectively, wherein a total of 15 specimens were tested before obtaining the results. As per the standard, the type of failure was only focused around the hole region was reviewed[14]. The specimen was not fitted with tabs as there was no need for them since the hole acted as a stress raiser. The configuration chosen was A type as per the standard which ranges between 200-300mm.

The maximum tensile strength was estimated as per the equation given below:

$$\sigma_{\max} = \frac{F_{max}}{A} \quad \text{... (1)}$$

Where, F_{max} is the maximum (peak force) measured in (kN) and A is the effective cross-sectional area.

Table 3: Thickness and hole dimensions of specimen

Specimen Number	Loading Rate (mm/min)	Specimen Thickness (mm)				Diameter of Hole after Machining (mm)			
		T1	T2	T3	Avg	D1	D2	D3	Avg
1	1	3.48	3.58	3.41	3.49	6.02	6.01	6.00	6.01
2		3.46	3.51	3.39	3.45	5.99	5.98	6.02	6.00
3		3.42	3.41	3.53	3.45	5.98	6.00	6.01	6.00
4		3.24	3.41	3.5	3.38	5.99	6.00	6.02	6.00
5		3.5	3.39	3.25	3.38	5.98	5.99	6.02	6.00
6	5	3.5	3.43	3.32	3.42	6.02	6.01	6.01	6.01
7		3.49	3.36	3.27	3.37	5.98	6.02	5.99	6.00
8		3.39	3.42	3.44	3.42	6.00	6.01	5.98	6.00
9		3.51	3.77	3.75	3.68	6.00	6.02	5.99	6.00
10		3.39	3.38	3.38	3.38	5.99	6.02	5.98	6.00
11	10	3.51	3.52	3.32	3.45	6.01	6.01	6.00	6.01
12		3.29	3.34	3.34	3.32	6.02	6.00	6.02	6.01
13		3.41	3.54	3.5	3.48	6.02	6.01	6.00	6.01
14		3.43	3.52	3.51	3.49	6.01	6.00	6.00	6.00
15		3.38	3.42	3.47	3.42	6.02	5.99	6.00	6.00

Table 4: Loading rate for open hole test

	Material Configuration	Loading rate (mm/min)	Specimen code
1		1	L1
2	4G4C4G	5	L2
3		10	L3

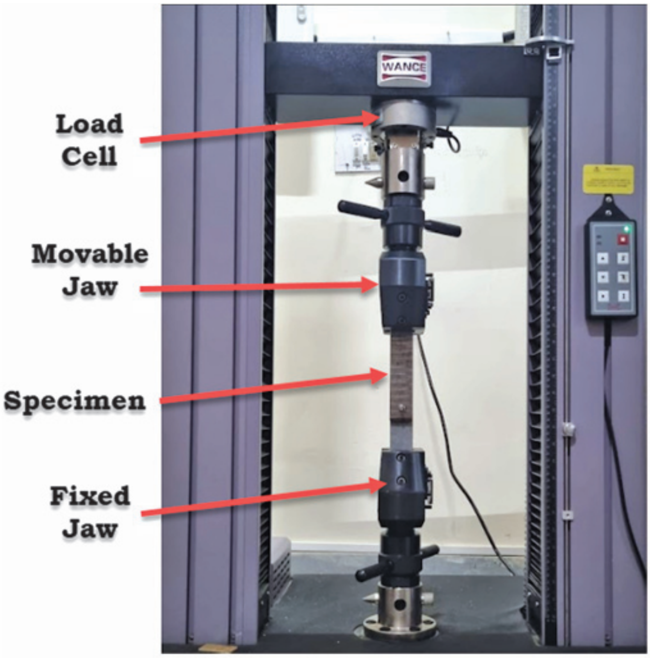

Figure 5: Wance UTM (50 kN capacity)

4.0 Results and Discussion

Each of the specimens namely L1, L2, L3 were tested at a loading rate of 1,5,10 mm/min respectively. Although the loading rate recommended by ASTM D5766 is 1mm/min, the study was mainly focused on the effect of the loading rate on the tensile strength of hybrid glass/carbon composites. The load vs displacement was plotted as shown in Figure 6. Based on the graph it is evident that the load-carrying capacity of hybrid glass/carbon composite with a central hole increases with an increase in loading rate. However, it is clear from the graph that deflection values are decreasing with increasing loading rate since the brittle nature of carbon at the center of the hybrid composite leads to fracture much earlier as compared to the slow movement of the cross-head. The values of the load, extension, and tensile strength are listed in Table 5.

Table 5: Results of load, deflection and tensile strength of the composite

	Specimen number	Load (kN)	Deflection (mm)	Tensile strength (MPa)
1	L1	18.0975	5.183	178.47
2	L2	18.7181	5.099	184.59
3	L3	19.5702	4.456	193.00

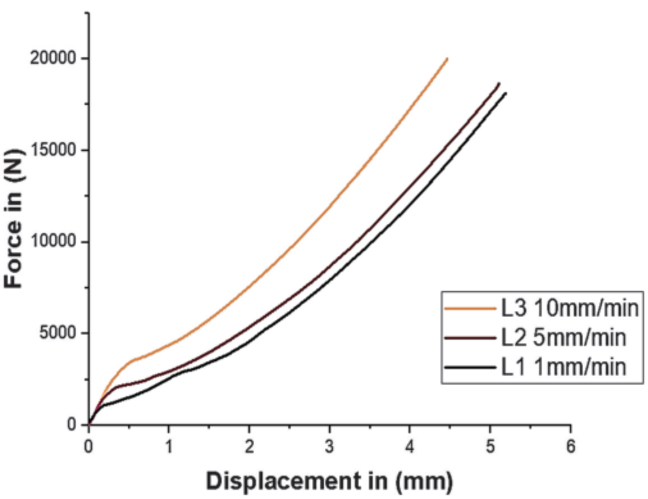

Figure 6: Load Vs displacement curves of hybrid glass and carbon composite

It was observed that the load-carrying capacity of the composites increased by 3% and 8.13% respectively and compared to the slow loading rate of 1 mm/min. However, the tensile strength increased by 3.43% and 8.14% respectively. It was observed since the loading rate was incremental, the difference in load-carrying capacity was also incremental. For an increase in loading rate, a considerable increase was observed. This information becomes very useful to designers when designing composite panels for specific applications which involve loading carrying.

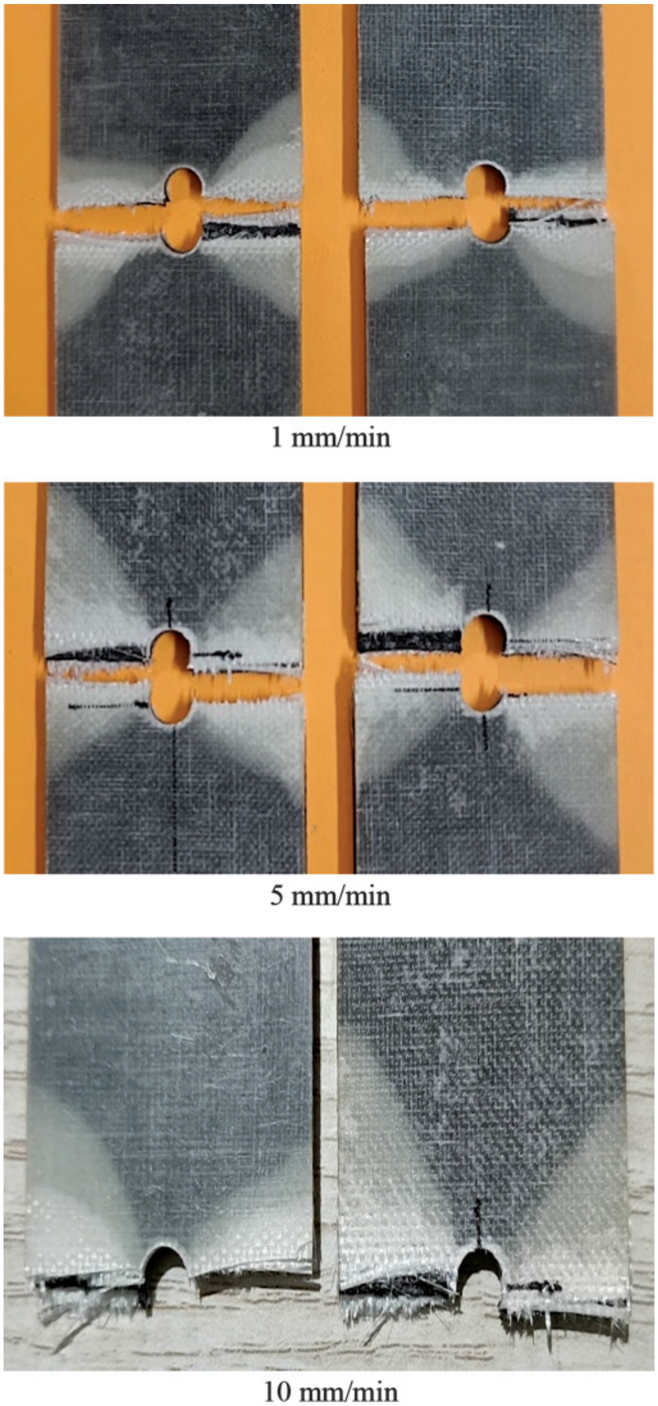

Figure 7: Extent of failure for different loading rates

Although the study involved incremental loading rate and its effects, the loading rate could have been increased to study the percentage variation in load-carrying capacity and tensile strength of hybrid composites. An increase in loading rate from 1 to 10 mm/min saw a decrease in the deflection by 14% and this was due to the presence of carbon at the interface between the glass cloth and primarily due to the initial matrix failure followed by fiber level failure as shown in Figure 7.

One significant observation found during the tensile test on the hybrid glass and carbon laminates was that the failure at the hole region was in line with the type of failure as per the ASTM D5766. The mode of damage for different loading rates is shown in Figure 7. For a loading rate of 1 mm/min the extent of the damaged area apart from the LGM (Linear Gauge Middle) type of failure was less as compared to a higher loading rate of 10 mm/min where the extent of the damaged area was more. This was due to sudden fiber pullout resulting in a higher damage area. Further, it was observed that some of the off-axis fibers were pulled out without causing fiber failure as shown in Figure 7. Delamination at the ply interface was also observed from the LGM region along the specimen length and increased for increasing loading rate. For 10 mm/min the first and second ply failure was noticed very prominently.

5.0 Conclusions

The studies related to the open-hole tensile test were carried out for the hybrid glass and carbon fiber laminates. The load-bearing capacity of hybrid glass/carbon fiber laminated composites increases with increasing loading rate. It is found that with a loading rate of 5mm/min the peak load increased by 3% as compared to the laggard loading rate of 1mm/min. The maximum loading rate increased by 8.13% for 10mm/min. The maximum deflection decreased by 14% for 10 mm/min mainly due to brittle and off-axis failure. A similar trend was observed for tensile strength for an increase in loading rate. Ply failure and fiber debonding was the governing type of failure as compared to matrix, delamination, and fiber breakage failure. The dominant type of failure for all the loading rates was LGM Linear Gauge Middle, which is validated as per ASTM D5766.

6.0 Acknowledgement

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