EXPERIMENTAL INVESTIGATION OF THE DAMAGE BEHAVIOR OF WOVEN-FABRIC GLASS/EPOXY LAMINATED PLATES WITH CIRCULAR CUT-OUTS SUBJECTED TO COMPRESSIVE FORCE

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ABSTRACT

An experimental study of the behaviour of woven glass-epoxy (800 gm) composite laminated panels under compression is presented. Compression test had been performed onto 16 fiber-glass laminated plates with and without circular cut-outs using the compressed machine. The ultimate load of failure for each of the glass-epoxy laminated plates under compression had been determined experimentally. A parametric study had been performed as well to investigate the effect of varying the centrally located circular cut-out sizes and fiber angle-ply orientations on to the ultimate load. The experimental work revealed that as the cut-out size increases, the ultimate load of the composite plate decreases. Also, it has been observed that cross-ply laminates possess the greatest ultimate strength as compared to other types of ply stacking sequences and orientations.

Keywords*: experimental study, woven glass-epoxy composite, ultimate strength, circular cut-out, compression test.*

INTRODUCTION

Thus far, there have been numerous studies on the fabric woven (textile) composite laminated structures which find widespread applications in many engineering fields namely aerospace, biomedical, civil, marine and mechanical engineering because of their ease of handling, good mechanical properties and low fabrication cost. They also possess excellent damage tolerance and impact resistance [1].

Several studies have been performed previously using woven fabric composite. Roy [2] studied the failure mechanism of woven-fabric composite laminates. Gao et al. [3] described the damage accumulation and residual property changes in various types of woven carbon/polyamide laminates subjected to monotonic loading. Takeda et al. [4] developed the progressive failure methodology for glass/epoxy plain weave fabric-reinforced laminates subjected to tensile loading under cryogenic temperatures. Good agreement of the finite element predictions with the experimental data has been achieved. The work by Wen-Shyong Kuo et al. [5] examines the responses of three-dimensional carbon/carbon composites under axial compression and transverse shear. By using a 3D weaving technique, two types of preforms with different bundle sizes of the weaving yarns were prepared for assessing its influence on the failure behavior. Zhang and Fu [6, 7] proposed a new micromechanical model for predicting the buckling of woven fabrics using a combination of the traditional orthotropic model and their newly developed micromechanical model.

The aim of performing this research is to extend the knowledge of the structural behavior of woven fabric composites subject to compressive load which is lacking. The main objective of this study is to carry out the experiment analysis for the 800gm woven glass-epoxy composite laminated plates with and without holes subjected to quasi-static compressive load. The ultimate load and the structural and material behaviour of the composite laminated plates under compression have also been studied. Finally, a parametric study is performed to investigate the effect of varying the fibre orientations and different central hole sizes onto the strength of the laminates.

PREPARATION OF TEST SAMPLES

Sixteen glass-epoxy flat panels with and without centrally located circular cut-outs which consists of six layers and different fibre orientations were fabricated using the hand lay-up technique and were cure at room temperature. The central holes are made by using a drilling machine, with three different hole diameters of are

22 mm, 28 mm, and 38 mm respectively. The stacking sequence and fibre orientations studied are as follows: $[0^o/90^o/0^o]_s$, $[30^o/60^o/0^o]_s$, $[0^o/45^o/90^o]_s$, and $[45^o/-45^o/45^o]_s$.

Figure 1 shows the fabricated specimens and whereas figure 2 illustrates the geometry of fibre glass laminated plates containing a central circular hole with length *l*, of 400 mm, width *w*, of 60 mm, thickness *t*, of 5.8 mm, and diameter *D*. The plates without holes have the same dimensions and geometry as that of the plates with holes.

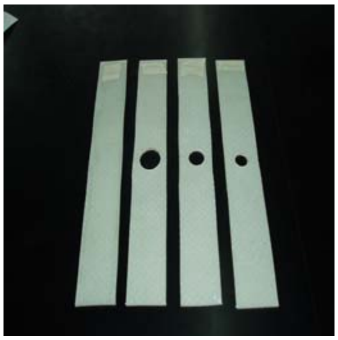

Figure 1: Test specimens

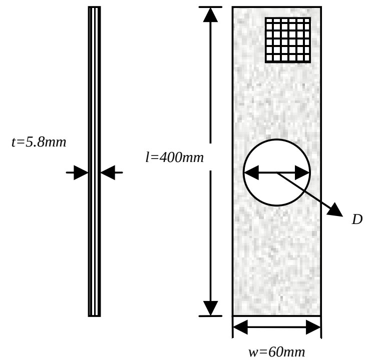

Figure 2: Geometry of the Fiber-glass laminated plate with central hole

EXPERIMENTAL SET-UP

The fine or perforated fiber-glass laminated plates are subjected to uniform uniaxial compression load, *P* in *y*-direction as shown in figure 3. The lower and upper horizontal edges of the plate are clamped into the clamping zone of the INSTRON machine. The depth of the plate which are clamped both top and bottom of the test samples are $d_1=d_2=70$ mm. The two unloaded vertical edges are unconstrained from the transverse in-plane motion, which is defined as a moveable edge or free support. In all cases herein, the cut-out boundary is a free edge as well.

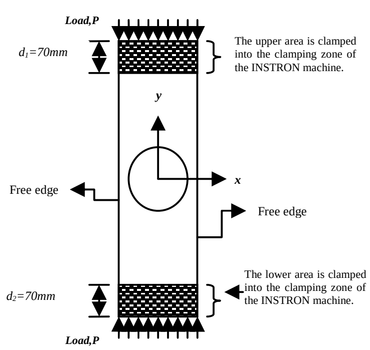

Figure 3: Load and boundary conditions of the test specimen

APPARATUS AND EXPERIMENTAL PROCEDURES

First, all the sixteen specimens (fiber-glass laminated plates) are prepared for running the compression test. The geometry of the specimens, the boundary conditions and the load condition are as discussed in the previous section. The testing facility (Instron machine) has been used for all the compression tests and is shown in figure 5. Figure 6 shows a schematic drawing of the test set-up. The data acquisition system which was linked with the Instron machine was used to record all the necessary results.

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Figure 4: The INSTRON machine

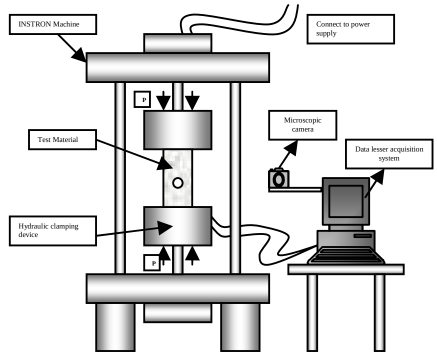

Figure 5: Schematic of apparatus and the compression test set-up

EXPERIMENTAL RESULTS

The experiment has been performed under quasi-static compressive loading for all the sixteen fiberglass panels up to failure. It has been observed that all the laminated plates buckled globally until complete failure occurred as expected (figure 6). Figure 7 shows the final deformed and damaged shapes of all the plates after the compression tests. Figures 7-8 show the comparison of load versus displacement curves for all the 16 fiber-glass laminated plates, with and without holes, different hole diameters and different angle orientations. It is interesting to note that all the laminates behave in a similar fashion where, their behaviour is almost linear before reaching the peak load. On the other hand, beyond that peak points of the load-displacement curves majority of the laminates experienced large displacements before failure, which proved that these woven laminates are able to absorb large amount of energy before failure. For all cases the symmetric angle ply laminates of $[45º/-45º/45º]_s$ underwent the largest inelastic deformation before failure. These findings suggest that this type of ply configuration is capable of absorbing large amount of energy before failure, where the energy absorbed is given by the area under the load-displacement curve.

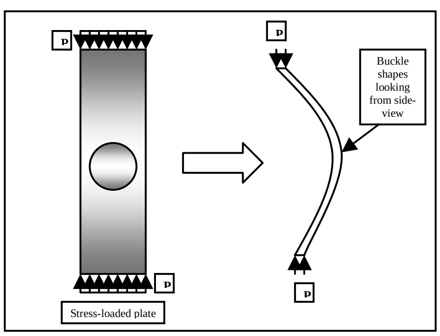

Figure 6: Buckling deformation shapes of the laminate

Figure 7: Final form of the damaged shape of the laminated plates

A similar trend has been observed from the experimental results, in which the ultimate load of the plate with angle orientation of $[0º/90º/0º]_s$ has the highest value, followed by angle orientations of $[0º/60º/30º]_s$, $[90º/45º/0º]_s$ and $[45º/-45º/45º]_s$ irrespective of their hole sizes. It has also been observed in figures 7-8 that the laminates are stronger when the hole size decreases. Table 1 summarizes the ultimate load for all the laminates with the four different types of stacking sequences and cut-out sizes. The results have revealed that fiber orientation directly affects the distribution of load between the fibers and the matrix. The contribution of the fibers to the composite properties is maximum only when they are aligned parallel to the loading direction.

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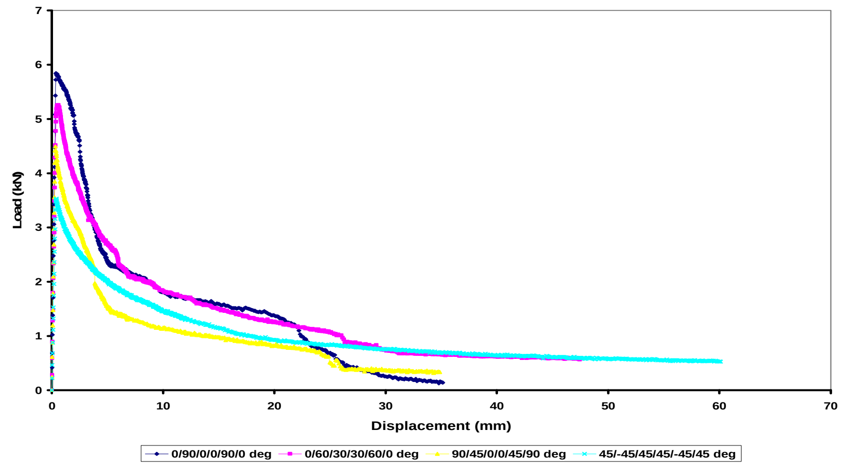

Figure 7: Comparison of load-displacements of laminates with various fibre Orientations(D=22mm)

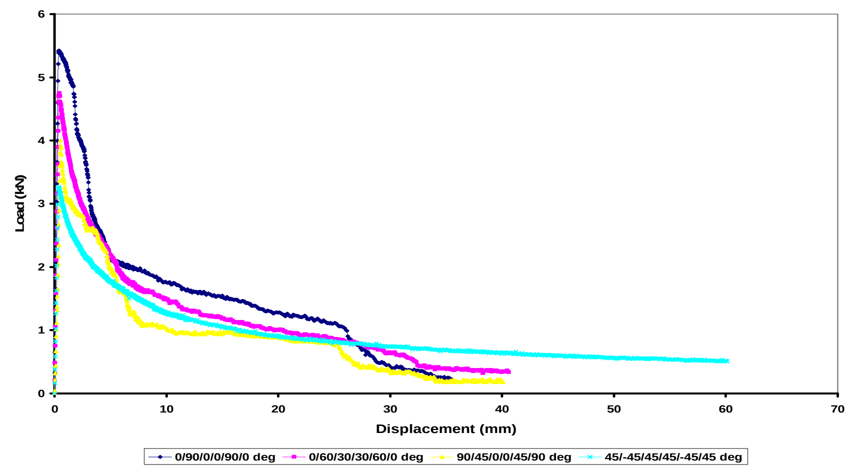

Figure 8: Comparison of load-displacements of laminates with various fibre orientations (D=28mm)

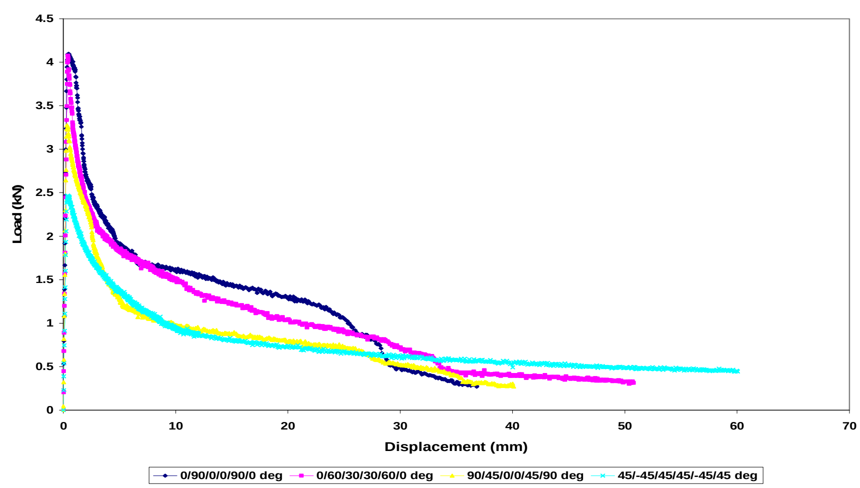

Figure 9: Comparison of load-displacements of laminates with various fibre orientations (D=38mm)

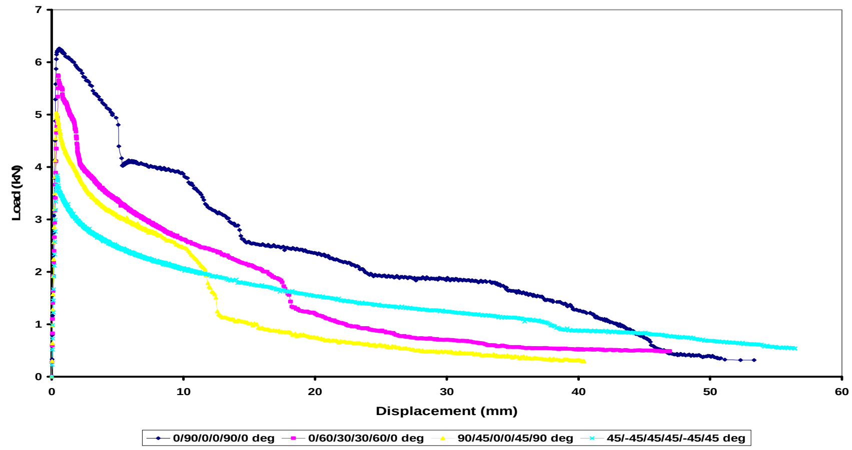

Figure 10: Comparison of load-displacements of laminates with various fibre orientations (without hole)

Table 1: Ultimate loads of the woven glass/epoxy laminates

Stacking Sequence	Cut-out diameter size, D			
	Without hole	22 mm	28 mm	38mm
$[0^o/90^o/0^o]_s$	6.2585 kN	5.8438 kN	5.4224 kN	4.0975 kN
$[30^o/60^o/0^o]_s$	5.7322 kN	5.2595 kN	4.7533 kN	4.0756 kN
$[0^o/45^o/90^o]_s$	5.0429 kN	4.4975 kN	4.0018 kN	3.2764 kN
$[45^o/-45^o/45^o]_s$	3.8456 kN	3.5326 kN	3.2692 kN	2.4648 kN

CONCLUSION

An experimental study of the behavior of the woven glass/epoxy laminated plates subjected to quasi-static axial compressive load has been presented. Sixteen fiber-glass laminated plates had been fabricated including the plates with and without central hole, with different hole sizes, and with different angle-ply orientations. The ultimate load of the woven fiber-glass laminated plates under quasi-static compression load had been found and compared with various orientation angles. A parametric study has also been performed to investigate and compare the behaviour and the ultimate strength of each of the fiber-glass laminated plates by varying the central hole sizes and fiber angle-ply orientations respectively.

From the experiment, it has been found that the cross-ply laminated plates possess the highest ultimate load as compared to the other types of orientation angles and ply stacking sequences. On the other hand, the angle ply laminated plates of $[45^o/-45^o/45^o]_s$ experience the largest displacement before failure as compared to the rest of the ply stacking sequences and orientation angles even though they possess the lowest ultimate strength.

ACKNOWLEDGEMENT

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