

IMPACT CHARACTERISATION OF DOUBLY CURVED COMPOSITE STRUCTURE

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SUMMARY

Under repeated impact composite domes subjected 6 J energy, changes locally with increasing drop height. The action of the dynamic load generates reactions at the support and bending moments at points on the surface of the composite. The peak loads were noted to increase and stabilise about some mean value; and the 150mm diameter shell was more damage tolerant compared to the 200 mm diameter one.

Keywords: Composite domes, dynamic loading, energy, impulse, contact time

INTRODUCTION

Composite materials find uses in structures where excellent mechanical properties and low weight are demanded. The impact energy absorption characteristics is a consideration in the applications, compared to candidate materials, a factor which makes them preferred for applications such as protection of vehicle and personnel. Layered fiber composites are susceptible to impact damage due to the mis-matching of bending stiffness and inter-laminar shear stresses. Chopped strand composites experience localized debonding from impact loading, thought to be because of inter-ply shear stresses. Since the impact resistance properties are not pure material properties, but instead are very much dependent on the dynamic structural behavior, an understanding of the dynamic response of composite structures subjected to impact loading is of great importance.

The impact response and damage of composite structures have been investigated by several authors, providing evidence of reduction in strength and insight as to the modes of failure. The physical phenomena involved in the impact event include structural dynamic response, Hertzian contact effects (indentation), and both in-plane and through-the-thickness wave phenomena. The relative importance of these various effects depends upon the characteristics of both the impactor and the structure, and the nature of the impact. In general, impact of composite structures is a complex event involving several phenomena.

Although material scientists and engineers have invested a lot of efforts to implement means that will enhance the performance of composites under impact loading. The impact behaviour of doubly curved composite structures such as

hemispherical dome considered here has received little or no attention. A lot of studies have been done on flat panels (reviews by Abrate [1 & 2]); also Kistler and Waas [10], Gning et al [5 & 6], Hull [9], David-West et al [4], Huang and Lee [8], Seung et al [13], Kotzalolis et al [11] and Guoqiang Li [12], have conducted some studies on composite single curved structures.

Gupta N K and Velmurugan R [7] has subjected composite domes made of short, randomly oriented glass fibre mats to axial compressions test in both empty and foam filled conditions, and reported that the presence of foam increases the energy absorption capacity, in addition to composite domes being better energy absorbers compared to conical shells of same height. In another investigation carried out by Cui Z et al [3], both woven and knitted doubly curved composite shells with radius to thickness ratios in the range of 22-53 were compressed between rigid platens. The loaded domes demonstrated an initial buckling followed by rolling plastic hinge post buckling response.

In the current studies on composite hemispherical samples, they were subjected to repeated non-penetrating impact loading with an available 12.1mm hemispherical impactor, using an instrumented drop tester. The samples were produced with glass fibre chopped strand mat, along with cristic resin *A* and catalyst *M* produced by Scott Bader limited. Two configurations of the specimens were tested. The actions of the composite domes and transient characteristics investigated and reported.

1. Characterization of impact

Reliable assessment of structural degradation due to impact requires a good understanding of the impact event and response of the structure. The nature of the impact response can influence the type of damage and the extent of degradation. However, it is necessary to identify the parameters that determine the type of the impact behaviour. Effective management of these parameters is therefore very useful. In this study, this is achieved conducting repeated drop test on doubly curved composite domes and analysis of the data obtained here.

2. Design of the support

Due to the specific shape of the specimens studied, a special support was required to perform the drop tests. The samples have to be simply supported. The support was chosen to be rigid enough not to deflect during the impact. It was made of steel material measuring, 250x250x25mm and an aluminium ring (152mm inside diameter, 192mm outside diameter, 10mm thick) screwed to the steel plate.

3. Materials

The basic materials employed to manufacture the composite domes for this study were:

1. E-glass chopped-strand-mat 350 g/m² in areal weight by Vetrotex
2. Resin A, by Scott bader
3. Catalyst M, by Scott bader

4. Manufacturing of samples

The material used for the construction of the moulds is a hard wood, easy to machine and cheap. The moulds are of two configurations, each to produce composite domes of base diameter 150mm and the dome diameters were 150mm and 200mm. The edge of the marks is cylindrical (150mm diameter 10mm height). This gives to the samples the shape of the part which is going to fit in the aluminium ring of the support. In order to obtain a flat base, which will be in contact with the steel support, a flat wood with a 135mm diameter central hole to permit laying of the chopped strand mat, is fixed on each mould with four screws on the face with circular hole. This flat wood is removable and the mould contact surface was made smoother with abrasive paper.

From the roll of chopped strand mat, some squares are cut with dimensions 230x230mm. The number of squares is equal of the total number of layers required (the composite domes for this study were made of 5 layers of the chopped strand mat). Circles were drawn with diameters as the distance between opposite ends and tangents cut at the edges with notches created half way towards the centre to help the disk of chopped strand mat take the exact shape of the mould.

A solution of silicone is spread on the surface of the moulds with a spray. These operations help the removal of the samples from the moulds. The matrix was made of the mixture of resin and catalyst (where the catalyst is just 2% by mass of the resin). Each ply is applied in the mould and impregnated of resin with a brush. A particular care is taken to not have bubbles, which cause discontinuity in the composite. When all the plies are laid, the moulds are placed 24 hours under an extractor hood. *Figures 1 & 2* are the photographs of samples manufactured.



Figure 1. Photograph of manufactured 150mm diameter composite.



Figure 2. Photograph of manufactured 200mm diameter composite

5. Drop impact test

The samples were simply supported in the instrumented drop tester [*Figure 3*] and impacted with a cross-head mass of 30kg. Transient response of the composite was measured and stored. The impact parameters obtained include load, energy, velocity and displacement as a function of time. The system measures the load – time response through the load cells. The other parameters were calculated by the application of the laws of motion. The energy that goes into the composite is calculated based on conservation of energy principles and is calculated based on the potential energy of the impactor, initial kinetic energy of the impactor at the time of impact and instantaneous kinetic energy. *Figure 4* is a photograph of the composite on the support and schematic set-up for testing shown in *Figure 5*.

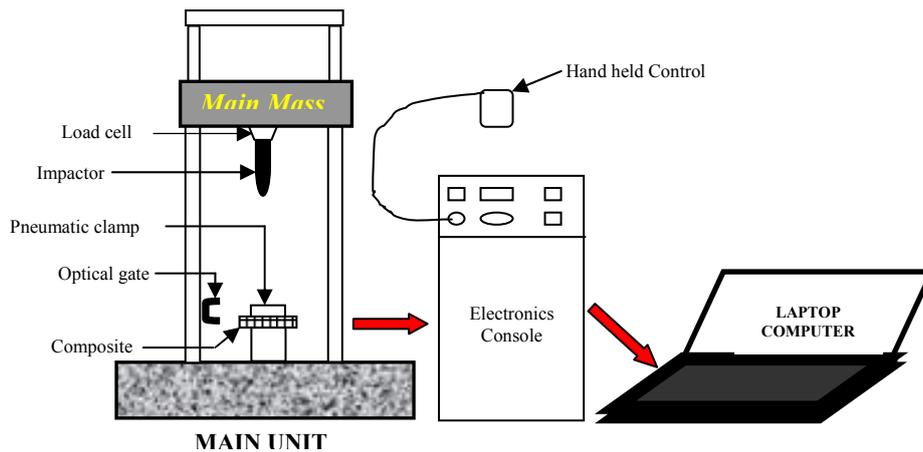


Figure 3. Schematic of the impact test arrangement.



Figure 4. Impacted composite dome.

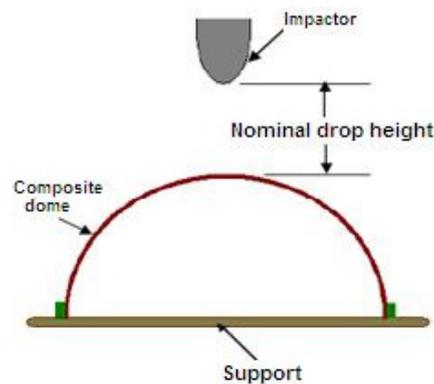


Figure 5. Schematic set-up for drop impact test

6. Test programme

An experimental schedule has been developed with special attention to the dome diameter and repeated impact. Two configurations (*Table 1*) of the specimens were tested. The nominal drop height was set at 0.02m, which is expected to change under repeated impact as damage on the composite dome progresses.

Table 1 Test programme

Curvature diameter (mm)	Base diameter (mm)	Thickness (mm)	Number of impact tests
150	150	3.25	10
200	150	3.25	10

7. The actions from the dynamic load

Figure 6. illustrates the phenomena of forces and bending moments generated during impact, causing inter-laminar shear stresses. If we simplify all the actions applied on the dome during the impact, we can consider the impact force F , the reaction R on the support, and the bending moment M .

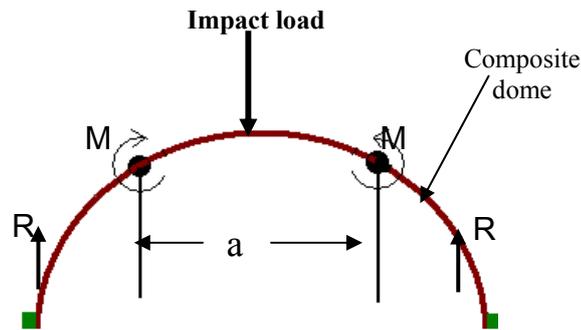


Figure 6. Diagram of the actions

More the diameter of the curvature the larger, the distance ' a ' and more the surface becomes quasi perpendicular to the impact load F . This implies that as moment is applied farer from the impact point; the bending moment is very significant and generates larger shear stresses and damages.

8. Damage Inspection

The impact damage mechanism in composite structures is a very complex process, because various failure modes occur simultaneously during impact; fiber breakage, matrix deformation and cracking, fiber debonding, fiber pullout, etc. Also, the delamination caused by the interface shear stresses between the layers.

Figures 7 & 8 are top view photographs of the composite domes after the repeated drop impact tests. The localized damaged boundary has an irregular shape that is difficult to predict. Some of the features seen include indentation and cracking. Also the specimens were sectioned through the impact zone, the cut surface ground with 800, 1200 and 2400 grit silicon carbide papers with water; and macro photographs (*Figure 9.*) obtained with Sony digital still camera DKC-CM30. The image revealed failure modes such as debonding, matrix crack and fibre pull-out.



Figure 7. Damaged 150mm diameter composite dome due to repeated impact.



Figure 8. Damaged 200mm diameter composite dome due to impact.



Figure 9. Through the impact point sectioned macro-photograph damaged composite dome.

The micro-structural photos were taken with a Nikon Epihot metallurgical microscope at x 50 magnification. In preparing of samples for these photos, they were (in addition to being sectioning through the impact point of the composite with an abrasive cutting disc and cooling water) mounted on Struers Durofix-2 cold mounting acrylic resin [Figure 10]. Then ground with 220grit SiC paper with cooling water at 300rpm, followed with 800, 1200, 2400 grit papers to reduce scratch pattern. Finally, they were polished with 3 micron diamond suspension with DP blue lubricant on DP-Dur polishing pad at 150rpm. The micro-photographs were taken at four locations on the surface as marked in Fig. 10. The Figures 11 to 14 are the micro-images taken from location x0 to x3 respectively, revealing damage modes such as the cracking of the matrix material and delamination. The inter-laminar delamination seems to dominate and might have taken a greater percentage of the absorbed energy because of the inter-laminar stresses and moments generated by the actions of the impact event.

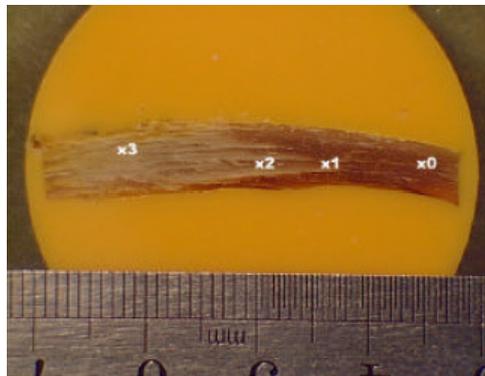


Figure 10. Sectioned composite impregnated in a resin for micro-photographs.

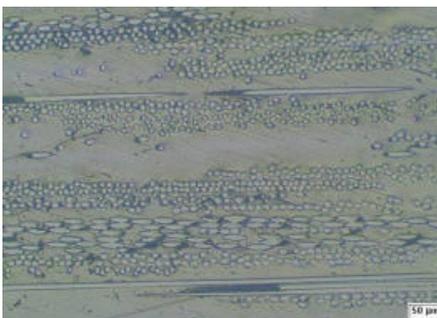


Figure 11. Micro-photograph at point X0 in Fig. 10

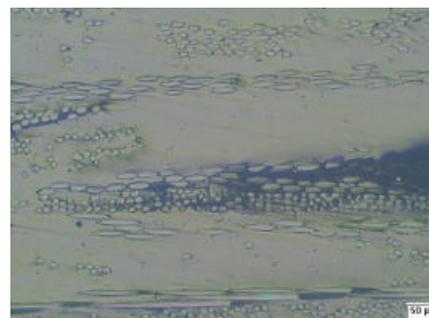


Figure 12. Micro-photograph at point X1 in Fig. 10



Figure 13. Micro-photograph at point X2 in Fig. 10 Figure 14. Micro-photograph at point X3 in Fig. 10

9. Experimental results

The load histories of the composite domes due to repeated hit of the striker at same location are displayed in *Figures 15 and 16* illustrating the salient features of the behaviour. The peak loads in both situations increase and stabilize about some mean value as the number of impact hits continue to increase.

Although the magnitude of the first impact on both domes configurations is the same different stress waves are expected propagate through the composite. The thresholds of the Hertzian failure are different for the composite domes (obtained from the first hit) implying that each composite has it own unique load-bearing ability. The values are 1.016kN for the 150mm diameter dome and 0.514kN for the 200mm diameter dome. The difference in the impact behaviour implies that the dome diameter has an effect on the impact response of composite domes.

As the composites do not deform plastically, a great quantity of the energy is absorbed result in fracture areas, reduced strength and stiffness. The damage towards the base is mainly because of bending stresses, moments and the inter-ply shear stresses.

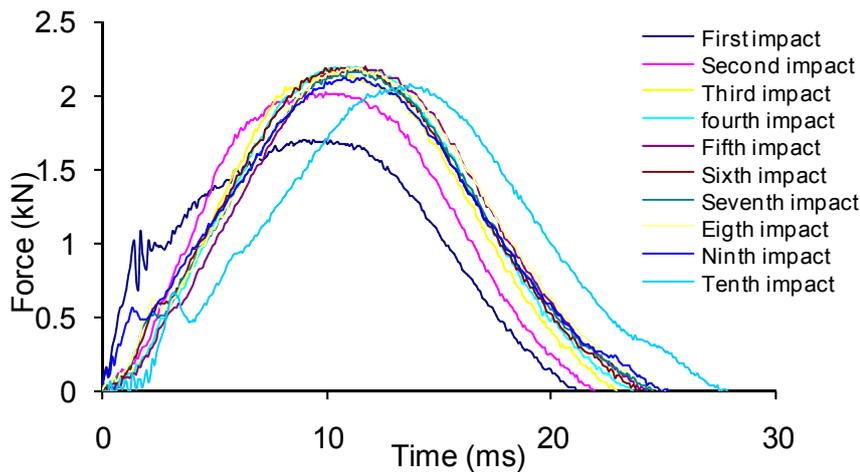


Figure 15. Force history plot of repeated impact response of the 150mm diameter composite dome

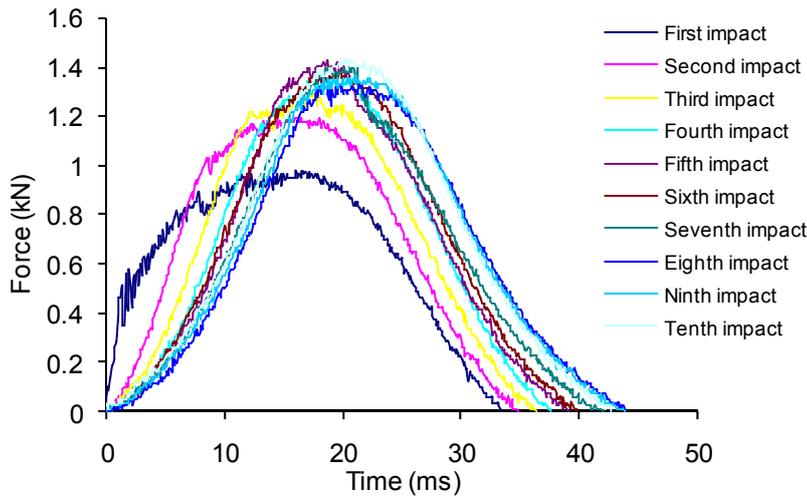


Figure 16. Force history plot of repeated impact response of the 200mm diameter composite dome.

The hypothesis behaviour of the doubly curved quasi isotropic composite structure, under low energy impact is non-linear [Figures 15 & 16]. As seen a lot of the damages are generated by the first strike, because of the series of ‘stick-slip’ response. The almost consistent value of peak loads as the number of hits increase is thought to be because of the loss of stiffness at the contact zone and reduction in the rate of increase of \mathbf{a} [shown in Figure 6]. This reduction in stiffness results in lower energy dissipation as damages and reduction in post impact incremental displacement [Figures 17 & 18]. Hence, composite domes could be appropriate in crashworthiness applications, because the brittle characteristics and the progressive damage, which is gradual.

The dome that is more curved (ie the 150mm diameter one) on the first impact response showed a higher peak load and the unloading plot is curving back to the origin while the other diverges (usually clearer in the force – displacement plot). Considering energy distribution due the impact, the initial kinetic energy of the impactor caused the deformations. These deformations of the structure involve bending, shear deformation, membrane stiffening effect, and the local deformation in the vicinity of the impact point.

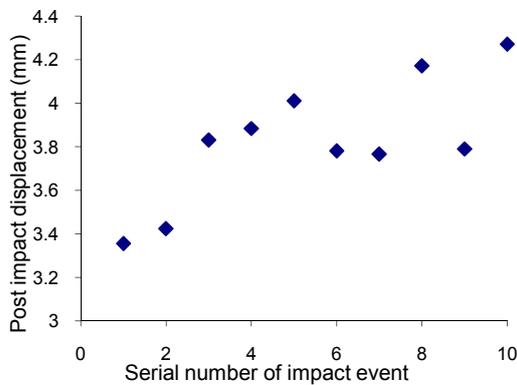


Figure 17. After each impact displacement for the 150mm diameter dome.

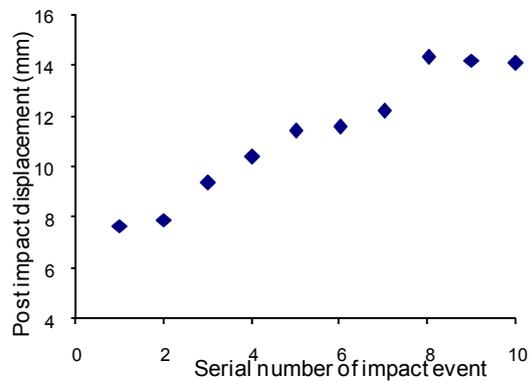


Figure 18. After each impact displacement for the 200mm diameter dome.

The propagation energy and total energy were obtained from the impact response data (Table 2). The total impact energy was defined as the sum of the energy absorbed until the maximum load (initiation energy) and the energy absorbed after the maximum load (propagation energy). The energy absorbed to failure in the composite can be obtained from the experimental results or calculated by integrating the force – displacement plot from zero to damage threshold and the impulse to failure by integrating the force history between same ranges.

Table 2. Impact characteristics obtained from the first impact

	Damage load (N)	Impulse to failure (Ns)	Energy to failure (J)	
			Calculated	Experiment
200mm diameter dome	514.1	0.354	0.32	0.20
150mm diameter dome	1015.7	0.698	0.33	0.29
	Total Energy (J)	Propagation energy (J)	Displacement at damage (mm)	Post impact displacement (mm)
200mm diameter dome	5.56	1.01	1.3	7.68
150mm diameter dome	4.30	0.21	0.7	3.35

10. Contact time

The contact time between the specimen and the striker was obtained when the contact force returns to zero. Figures 19 & 20, are plots of the contact time observed during the test and the increase in time can be associated with the formation of indentation, compression of the composite and the effect of the moments generated by the impact process. The 150mm dome composite shows a monotonic increase in the contact time, while the 200mm dome showed almost stable contact time from the eighth impact. This implies that, the dome diameter affects the contact time and the saturation value for α [shown in Figure 6].

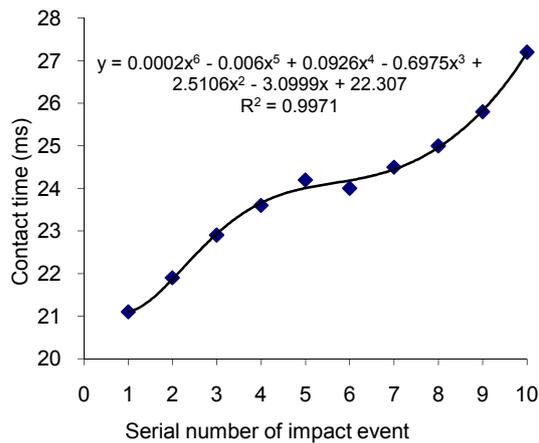


Figure 19. Contact time for the 150mm diameter dome.

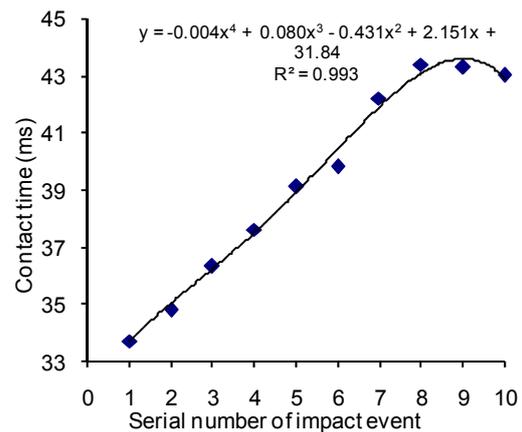


Figure 20. Contact time for the 200mm diameter dome.

CONCLUDING REMARKS

Composite domes (thickness = 3.25mm) of curvature diameters 200mm and 150mm were subjected to repeated low energy impact using an instrumented drop tester and samples simply supported. The first impact energy was set at 6J. Some deformation modes such as debonding, matrix crack, fibre pull out were identified through macro and micro-photographs of sectioned shells. The energy dissipation characteristics of the shells differ.

The peak loads taken from the force history due to the impact increased for both domes and stabilizes about some average value as the number impact strike increase. Comparison of the characteristics obtained from the first hit, revealed the following:

1. The dome that is more curved showed the higher peak load.
2. Higher damage threshold with the curvier shell.
3. Damage propagation energy higher for the greater curvature diameter dome.
4. Greater post impact displacement with the greater curvature diameter shell.

As the impact loading was at the top centre of the domes, the saturation distance between the moments generated is affected by the curvature diameter. The dynamic loading causes localized loss of stiffness in the contact area and progress under the repeated loading, but stabilise about some mean geometry (damage area). Composite shells such as this may be suitable for crashworthiness applications, as it is brittle and the damage is gradually progressive.

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