



INVESTIGATION OF IMPACT BEHAVIOR OF CORRUGATED POLYMER SANDWICH STRUCTURE

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ABSTRACT

Fiber-reinforced plastic corrugated core sandwich panels were tested for low velocity impact using drop test method. Three types of epoxy based corrugation i.e sinusoidal, square and triangle of different core thickness and height of the drop were tested. Impact tests were conducted on corrugated sandwiches using a drop weight machine with an impactor mass of about 11.5 kg and different values of impact height 50, 63 and 76 cms, these hold initial impact energy 37, 56 and 64 J respectively. The impact response of corrugated core sandwich structures with sinusoidal, square and triangle profile having the thickness of 0.5mm 0.75mm and 1.0 mm has been evaluated. Sinusoidal and triangular core corrugated specimen causes less damages to lower face sheet compare to square profile, also delamination of lower face is more compare to top skin in all the three profiles.

INTRODUCTION

Sandwiches are relatively new type of material developed from the need to develop high performance light weight structure with excellent properties under the tensile, flexure and impact conditions. They combined both the good characteristics of metal such as ductility, impact and damage tolerance and fiber reinforced composites such as high specific stiffness, corrosion resistance and fatigue resistance [1], which finds applications in aerospace industries. Sandwich with outer metal sheets such as Al or steel and inner layer Fiber reinforced polymers such as Glass fiber reinforced polymers or Carbon fiber reinforced polymers or Aramid reinforced polymers along with Al plates. In other hand FML are very susceptible to impact which can cause significant damage, such as thinning of aluminum sheets [2], delaminating between metal and FRP, matrix cracking and fiber failure; these damages possess significant reduction in the strength and stiffness of sandwich panels.

Impact loads that are common and unavoidable during manufacturing, maintenance and in service life of the structure, such as tool dropping during maintenance, bird strike and hail impacts induces surface and subsurface defects and causes damage to the structures. In view of this, a number of authors have documented the characterization of sandwich panel for to impact behavior. Vlot et al. [3] documented that Glare offers very good damage threshold energy when compared to plain alloy. P.Cortes&W.J.Cantwell [4] highlighted Multi layer magnesium FML improve the resistance to localized impact to that Aluminum FML. Evancho [5] showed that the perforation Resistance of Glare FML was more than 50% when compared to Aluminum alloy of the same thickness.



Addullah & Cantwell[6] noted that low velocity impact on corrugated sandwich structure suffers its load bearing FML capacity. At low velocity impact a failure of corrugated sandwich structure in glass fibers was never detected before aluminum cracking hence the aluminum plate acts as a sacrificing layer. Carrillo & Cantwell reported during impact the fiber-metal interface has not deboned suggesting high degree of adhesion across the interface. In addition, in laminates in both systems (Al and FRP) exhibited a localized indentation failure followed by progressive collapse at higher impact energies [7-9].

A better understanding of interfacial properties, characterization of interfacial adhesion strength and failure mechanisms under repeated impacts on corrugated sandwich structure is required which helps in evaluating the degradation of mechanical properties. However, investigation of impact damage of corrugated sandwich structure is not the final goal. It is the preamble work for prediction of mechanical properties after impact. No work is focused on the effect of repeated impacts on failure mode and damage evolution sequence of adjacent areas of impacted corrugated sandwich structure; they are greatly affected by the constituent properties, lay-up configuration, and thickness and bending rigidity of corrugated sandwich structure. The objectives of the research work are to investigate low velocity repeated impacts and fracture behavior of corrugated FRP laminates.

EXPERIMENTAL PROCEDURE

Sandwich preparation

The corrugated core sandwiches of various thicknesses (0.5mm, 0.75mm, 1mm) and shape (sinusoidal, square, and triangular) were fabricated using epoxy and glass fiber by hand layup technique. The materials used for the preparation of composite laminates are Epoxy resin LY556 (10% amine based hardener), E-Glass Fiber- Plain woven - 0/90 = 200 gsm and Standard Epoxy Adhesive.

Impact test

Impact test is done according to the ASTM standard D5628 for determining the energy required to crack or break the specimen under various specified condition of a free falling dart (top). Specimens of three types of core geometry and thickness were tested. A free-falling dart (top) is allowed to strike a supported specimen directly. Either a dart having a fixed mass may be dropped from various heights, or a dart having an adjustable mass may be dropped from a fixed height. Test specimens were rectangular in shape with size 153mm X 102mm. The piezoelectric dart (top) has a hemispherical tip of dimension 0.5in (12.7mm) diameter. Total of 27 samples were tested, the different configuration used for testing the specimen are shown in table 1.

Table 1 configuration of specimen for impact test.

Thickness of core in mm	Shape of the core	Load in Kg	Height of falling dart in cm
0.5	Sinusoidal	11.5	76
0.75	Square	11.5	63
1	Triangular	11.5	50



Figure 1(a) Impact test

1(b) Specimen under loading

Machine and Figure

RESULTS AND DISCUSSION

Figure 2,3,4, & 5 shows sample of Impact load v/s time, energy v/s time, velocity v/s time, and deflection v/s time for sinusoidal corrugated sandwich of various core thickness from an impact height of 50 cm. Similarly for results of square and triangular corrugated sandwich of various core thicknesses for impact height of 63 mm, and 76 mm is plotted and analysis is done.

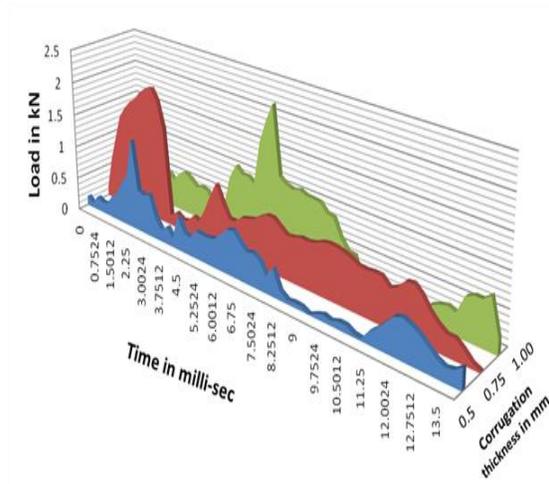


Fig 2 Impact load Vs Time plot of sinusoidal corrugated sandwich of varying core thickness from an impact height of 50 cm

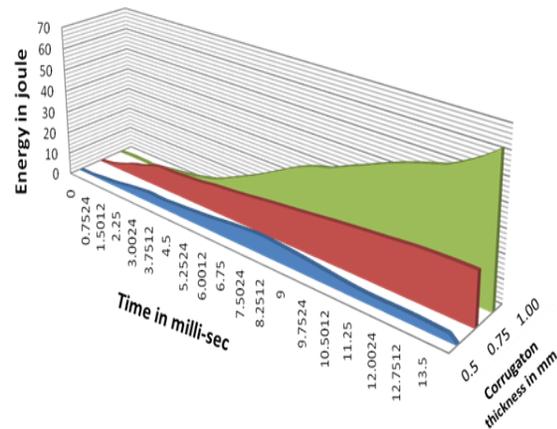


Fig 3 Impact energy Vs time plot of sinusoidal corrugated sandwich of varying core thickness from an impact height of 50 cm

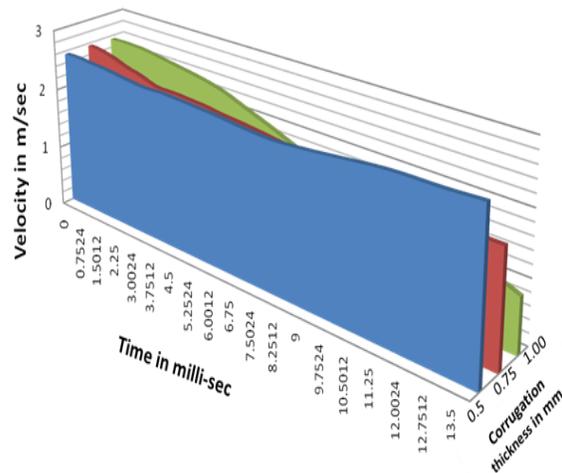


Fig 4 Impact velocity Vs time plot of sinusoidal corrugated sandwich of varying core thickness from an impact height of 50 cm

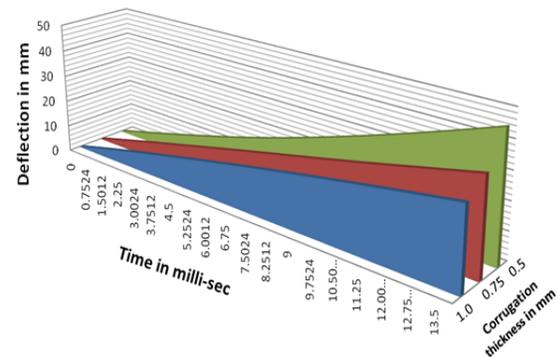


Fig 5 Deflection Vs time plot of sinusoidal corrugated sandwich of varying core thickness from an impact height of 50 cm



Effect of corrugation thickness and impact height on peak load, max. energy, max. Velocity and max. Deflection on sinusoidal, square, & triangular corrugated sandwich profiles.

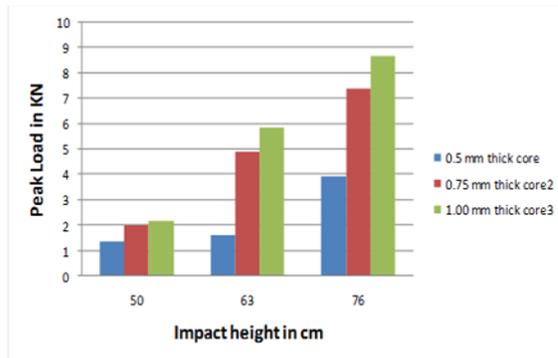


Fig 6 Effect of corrugation thickness and impact height on peak load of sinusoidal corrugated sandwich

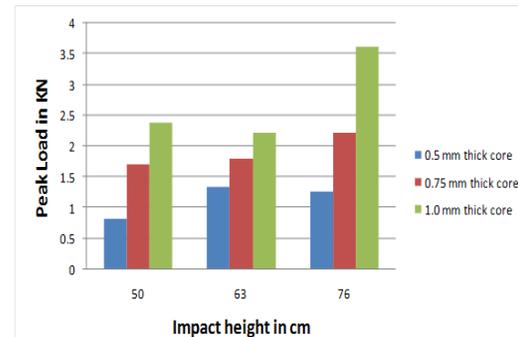


Fig 7 Effect of corrugation thickness and impact height on peak load of square corrugated sandwich

The maximum load is an index closely related to the load carrying capacity and structural integrity. To identify the behavior of maximum impact load, the maximum loads are obtained and shown in Fig. 6. It shows the peak loads of sinusoidal corrugated specimen as a function of corrugation thickness and impact height. It can be seen that as the thickness of the corrugation increases the peak load also increases for all impact heights of 50cm, 63cm and 76cm.

Also the graph shows that the peak load is very less for 0.5mm thick corrugation compared to 0.75mm and 1.0mm thick corrugation when the impact height is 63cm and 76cm. As the impact height is increased the peak load is also seen to increase.

Fig. 7 shows the peak loads of square corrugated specimen as a function of corrugation thickness and impact height. It can be seen that as the thickness of the corrugation increases the peak load also increases for all impact heights of 50cm, 63cm and 76cm except for the 1mm thick corrugation when the impact height is 63cm the peak load is decreased as compared to 0.5mm thick corrugation. Also the graph shows that the peak load is very low for 0.5mm thick corrugation compared to 0.75mm and 1.0mm thick corrugation. The peak load is maximum when the impact height is 76cm and the thickness of corrugation is 1mm. as the impact height is increased the peak load is also seen to increase.

Fig. 8 shows the peak loads of triangle corrugated specimen as a function of corrugation thickness and impact height. It can be seen that as the thickness of the corrugation increases the peak load also increases for all impact heights of



50cm, 63cm and 76cm except for the 0.5mm thick corrugation when the impact height is 76cm the peak load is decreased compared to 63cm impact height.

Also, the graph shows that the peak load is low for 0.5mm thick corrugation compared to 0.75mm and 1.0mm thick corrugation. The peak load is maximum when the impact height is 76cm and the thickness of corrugation is 1mm. as the impact height is increased, the peak load is also seen to increase.

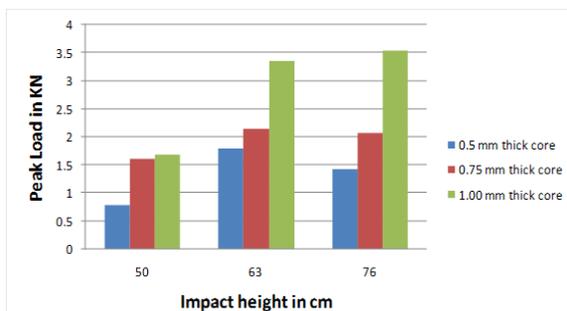


Fig 8 Effect of corrugation thickness and impact height on peak load of triangle corrugated sandwich

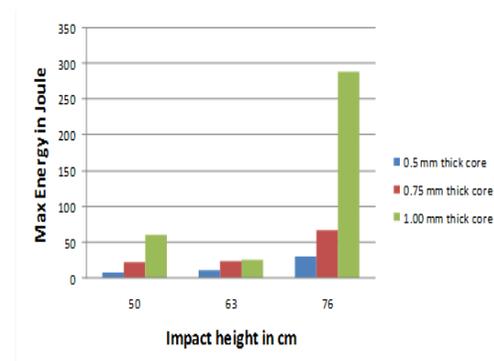


Fig 9 Effect of corrugation thickness and impact height on maximum energy of sinusoidal corrugated sandwich

Fig. 9 shows the maximum energy of sinusoidal corrugated specimen as a function of corrugation thickness and impact height. It shows that the maximum energy of the 0.5mm thick corrugation is very low and as the impact height is increased the maximum energy also increases. The maximum energy of 0.75mm corrugation is more compared to 0.5mm but less when compared to 1mm corrugation. It can be seen that as the impact height is increased the maximum energy also increases for 0.75mm corrugation. The maximum energy of the 1mm thick corrugation is more compared to 0.5mm and 0.75mm thickness. As the impact height is increased from 50cm to 63cm the value of maximum energy decreases but it increases as the impact height is increased to 76cm and it has the highest value.

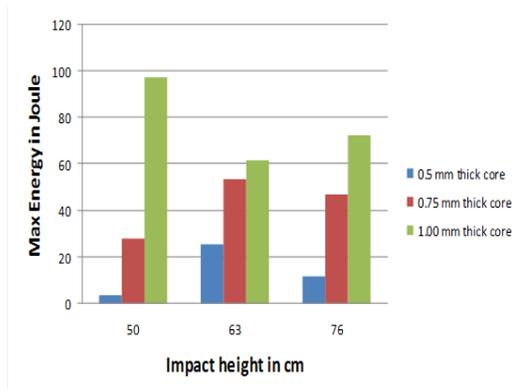


Fig 10 Effect of corrugation thickness and impact height on maximum energy of square corrugated sandwich

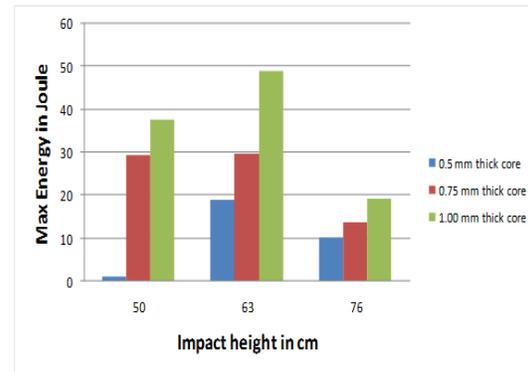


Fig 11 Effect of corrugation thickness and impact height on maximum energy of triangle corrugated sandwich

Fig. 10 shows the maximum energy of square corrugated specimen as a function of corrugation thickness and impact height. It can be seen that as the thickness increases the maximum energy also increases at all impact heights. The 0.5mm thick corrugation has very low maximum energy at 50cm impact height and it increases as the impact height is increased to 63cm but it is observed to reduce when the impact height is further increased to 76cm. the 0.75mm thick corrugation behaves in a similar way as that of 0.5mm thick corrugation but the 1.0mm corrugation has the maximum energy value greater when the impact height is 50cm and reduces to lower value when the impact height is increased to 63cm, but a slight increase in the maximum energy is seen when the impact height is increased to 76cm.

Fig. 11 shows the maximum energy of triangle corrugated specimen as a function of corrugation thickness and impact height. It can be seen that as the thickness increases the maximum energy also increases at all impact heights. The 0.5mm thick corrugation has very low maximum energy at 50cm impact height and it increases as the impact height is increased to 63cm, but it is observed to reduce when the impact height is further increased to 76cm. The 0.75mm thick corrugation behaves in a similar way as that of 0.5mm thick corrugation but it has the low maximum energy value when the impact height is 76cm and maximum energy at 50cm impact height is slightly lesser than that at 63cm impact height. The 1.0mm corrugation has the higher maximum energy value when the impact height is 63cm and reduces to lower value when the impact height is increased to 76cm. When the impact height is 50cm the maximum energy value is lesser compared to 63cm impact height.

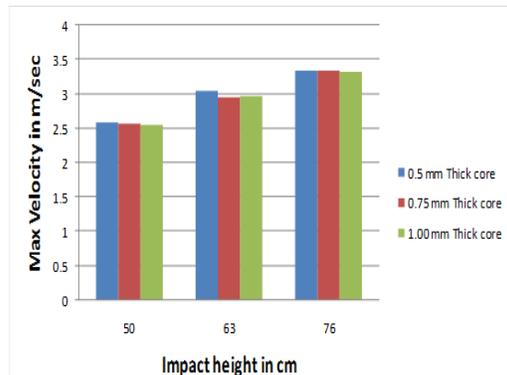


Fig 12 Effect of corrugation thickness and impact height on maximum velocity of sinusoidal corrugated sandwich

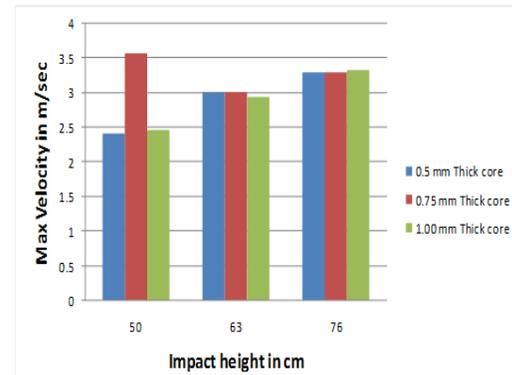


Fig 13 Effect of corrugation thickness and impact height on maximum velocity of square corrugated sandwich

Fig. 12 shows the maximum impact velocity of sinusoidal corrugated specimen as a function of corrugation thickness and impact height. It can be seen that the maximum impact velocity is almost constant with respect to thickness but is seen to increase as the impact height is increased. For 50 cm impact height, the maximum velocity is around 2.5m/s for all thickness and for 63cm, it is around 3m/s and for 76cm impact height it is around 3.34m/s.

Fig. 13 shows the maximum impact velocity of sinusoidal corrugated specimen as a function of corrugation thickness and impact height. It can be seen that the maximum impact velocity is almost constant with respect to thickness but is seen to increase as the impact height is increased. For 50 cm impact height, the maximum velocity is around 2.4m/s for all thickness except for 0.75mm corrugation, where the value is 3.568m/s and for 63cm it is around 3m/s and for 76cm impact height it is around 3.34m/s.

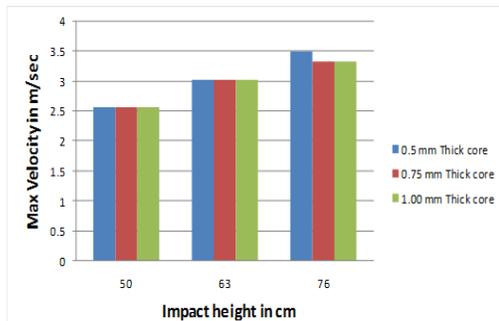


Fig 14 Effect of corrugation thickness and impact height on maximum velocity of triangle corrugated sandwich

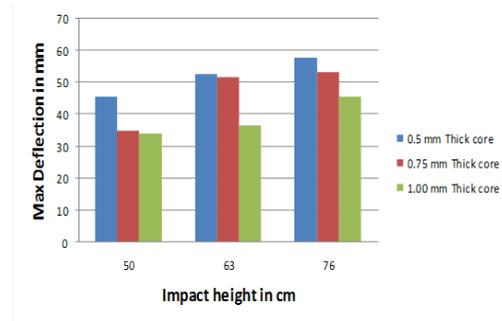


Fig 16 Effect of corrugation thickness and impact height on maximum deflection of square corrugated sandwich

Fig. 14 shows the maximum impact velocity of triangle corrugated specimen as a function of corrugation thickness and impact height. It can be seen that the maximum impact velocity is almost constant with respect to thickness but is seen to increase as the impact height is increased. For 50 cm impact height, the maximum velocity is around 2.4m/s for all and for 63cm it is around 3m/s and for 76cm impact height it is around 3.34m/s. except for 0.5mm corrugation which has the value 3.5m/s as maximum velocity.

Fig. 15 shows the maximum deflection of sinusoidal corrugated specimen as a function of corrugation thickness and impact height. It shows that as the thickness is increased, the deflection decreases for all impact heights but for the 0.5mm thick specimens it can be seen that as the impact height is increased the deflection also increases where as for the 0.75 and 1mm thick corrugation, the maximum deflection decreases as the impact height is increased.

Fig. 16 shows the maximum deflection of square corrugated specimen as a function of corrugation thickness and impact height. Similar to sinusoidal specimen it shows that as the thickness is increased the deflection decreases for all impact heights, but for the 0.5mm thick specimens it can be seen that as the impact height is increased, the deflection also increases also for the 0.75 and 1mm thick corrugation, the maximum deflection increases as the impact height is increased.

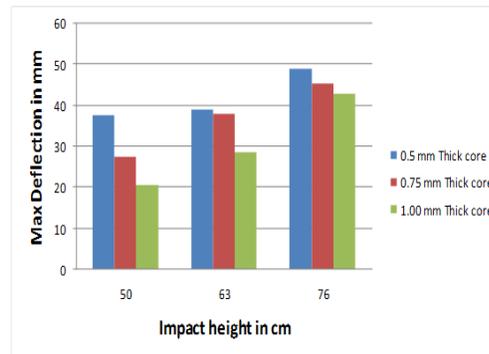


Fig 17 Effect of corrugation thickness and impact height on maximum deflection of triangle corrugated sandwich

Fig. 17 shows the maximum deflection of triangle corrugated specimen as a function of corrugation thickness and impact height. It can be seen that as the thickness of the corrugation is increased the maximum deflection of the specimen decreases and the maximum deflection is seen to increase as the impact height is increased. The 1mm thick corrugation under the impact height of 50cm has the minimum deflection and the 0.5mm corrugation under 76cm height has the maximum deflection.

Fig 18 shows the damage caused on a sinusoidal corrugated specimen due to impact. From 18(a) which shows the top side of the specimen after impact, it can be seen that the upper face sheet is clearly penetrated by the dart crushing the face sheet and corrugation, the bright white area around the hole is due to the failure of the matrix and the light shade around this area represents the delamination caused due to impact.

Damage Studies

Fig 18 shows the damage caused on a sinusoidal corrugated specimen due to impact. From 18(a) which shows the top side of the specimen after impact, it can be seen that the upper face sheet is clearly penetrated by the dart crushing the face sheet and corrugation, the bright white area around the hole is due to the failure of the matrix and the light shade around this area represents the delamination caused due to impact. Fig 18(b) shows that in the lower face sheet, it can be seen that the dart caused lesser damage and there is a crack in the center surrounded by the bright white area where the matrix has failed. Also delamination is more compared to the top skin which can be seen as the shaded area around the impact position.

Fig 19 shows the damage caused on a square corrugated specimen due to impact. From Fig 19(a) which shows the top side of the specimen after impact, similar to sinusoidal specimen it can be seen, that the upper face sheet is clearly penetrated by the dart crushing the face sheet and corrugation. The bright white area around the hole is due to the

failure of the matrix and the light shade around this area represents the delamination caused due to impact and it is more compared to the sinusoidal and triangle specimen. Fig 19(b) shows the lower face sheet, where it can be seen that the dart caused lesser damage and there is a crack in the center surrounded by the bright white area where the matrix has failed and the fibers are stretched out. Also delamination is more compared to the top skin which can be seen as the shaded area around the impact position.

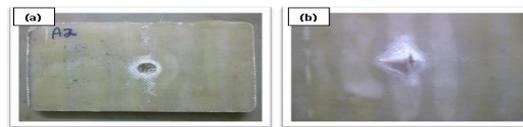


Fig 18 Image of sinusoidal corrugation specimen after impact (a) Top side (b) bottom side

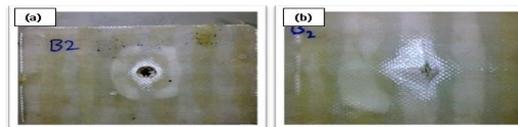


Fig 19 Image of square corrugation specimen after impact (a) Top side (b) bottom side

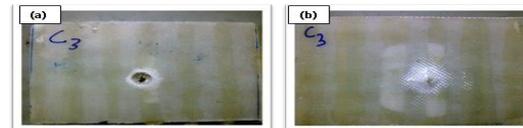


Fig 20 Image of triangle corrugation specimen after impact (a) Top side (b) bottom side

Fig 20 shows the damage caused on a triangle corrugated specimen due to impact. From Fig 20(a) which shows the top side of the specimen after impact, it can be seen that the upper face sheet is clearly penetrated by the dart crushing the face sheet and corrugation. The bright white area around the hole is due to the failure of the matrix and the delamination in the upper skin is very less as it can be seen that there is no shaded area around the penetrated hole. Fig 20(b) shows the lower face sheet and it can be seen that the dart caused lesser damage and there is a crack in the center surrounded by the bright white area where the matrix has failed also delamination is more compared to the top skin which can be seen as the shaded area around the impact position. be seen that the dart caused lesser damage and there is a crack in the center surrounded by the bright white area where the matrix has failed also delamination is more compared to the top skin which can be seen as the shaded area around the impact position.



CONCLUSION

Different shaped core based corrugated sandwich structures were fabricated as per standards with different thicknesses. The impact response of corrugated core sandwich structures with sinusoidal, square and triangle profile having the thickness of 0.5mm 0.75mm and 1.0 mm has been evaluated. The tests carried out at impact height of 50 cm did not produce the complete failure of the specimens. The impactor penetrated the upper face and partially the core when the core thickness was 0.75 and 1.0mm. The complete failure, characterized by the penetration of face sheets and corrugation of the specimen occurred for impact height of 63 and 76 cms and for 0.5 mm thick corrugation in case of 50 cm impact height. Sinusoidal and triangular core corrugated specimen causes less damages to lower face sheet compare to square profile, also delamination of lower face is more compare to top skin in all the three profiles.

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