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Experimental Investigation of Glass-Carbon/Epoxy Hybrid Composites Subjected to Low Velocity Impact Test

Hybrid composites with multiple reinforcements of high strength are very popular for many engineering applications, especially for impact resistance. In the present work, we report the development of the glass-carbon/epoxy hybrid composites using hand lay technique and investigate its low velocity impact response. Low velocity impact tests were performed on the hybrid composites of two different thicknesses 2 mm and 4 mm to study the impact resistance of hybrid composites with respect to impact energy and impact velocity. In addition to this, defect was embedded in the hybrid composite and its effect on the impact response was studied and compared with the hybird composites without having any defect. The study revealed that the presence of defect in hybrid composite has significant effect on the energy absorbed when compared to that of composite without defect.

Keywords: *Hybrid composites, Epoxy, Polymer-matrix composites, Impact behaviour, Low-velocity impact.*

1. INTRODUCTION

The hybrid composites are a new class of materials where two or more types of reinforcements are used to reinforce polymer matrix. Here, the idea of reinforcing multiple reinforcements to the polymer matrix is to obtain a new hybrid composite with enhanced strength, stiffness and impact resistance when compared to that of single reinforcement based composite material. In this regard, many works have been done in which two types of fibres were used to reinforce polymer matrix material in which low cost and low modulus reinforcement like glass or Kevlar fibres are used along high cost and high modulus reinforcement like carbon or boron fibres. The idea of incorporating low modulus fibre was to improve the damage tolerance and reduce the cost while used of high modulus fibre was to impart stiffness and improve load bearing characteristics of hybrid composites. One can expect that hybrid composites will have high strength, stiffness along with improved impact resistance, fracture toughness and fatigue resistance. Hybrid composites are distinguished as matrix hybrid based composites in which thermoplastic fibres are dissolved in the thermosetting matrix during fabrication process [1-3].

The research work done on woven-fabric based composite laminates is very scarce and most are mainly concentrated on studying the mechanical behaviour. In another work, Hung et al. [4] studied the impact response of four types of hybrid composites made up of E-glass fibre/carbon fibre weaves and epoxy matrix. The hybrid composites of different stacking sequences were produced using vacuum bagging technique and low velocity impact test was conducted under different impact loads. The fibre layer stacking sequence in these hybrid composites highly influenced the impact response. The presence of carbon fibre on the top and bottom layers of the composites tends to reduce the size of damage. The large deflection in the hybrid composite results in mode I and II failure which can introduce inherent delamination. In their work, Pandya et al. [5] studied the mechanical properties of hybrid composites made up of carbon and glass woven fabrics with epoxy resin. Two different lay-up sequences were used to produce the hybrid composites and these were subjected to tensile and compressive testing using universal testing machine. The testing was done according to ASTM standards. It was found that the hybrid composites with glass layers placed at exterior and carbon layers placed at the interior gave highest ultimate tensile strain. While hybrid composite with carbon layers placed exterior and glass layers placed at the interior gave highest tensile strength. However the compressive strains for both the hybrid composites were nearly same as both the carbon and glass layers failed simultaneously under compressive loading conditions.

Although there have been several experimental investigations conducted on laminated composites to analyze its mechanical behaviour, it is equally important to conduct full-scale testing of the components made up of these laminated composites. Rasuo [6] reported the full-scale fatigue testing of helicopter rotor blades made up of fiberglass/carbon filament in epoxy matrix. The results obtained from fatigue testing showed that the laminate composite blade structure met the standard fatigue requirements showing no delamination and permanent deformation. Similarly another work [7] was carried out the same researcher on rotor blade made up of polyurethane foam, aramid honeycomb and phenolic honeycomb. The structural vibratory testing on this

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rotor was carried out to obtain the aeroelastic properties of this laminated composite blade.

Prediction of damage, especially due to impact related such as birds, runaway debris and hail in many automotive and aeronautical structures made up of laminated composites is currently the hot research area. In particular, the impact damages in aircraft structures are very complex and it is very much necessary to predict these damages for better performance of the aircraft structures [8]. Several important research works have been conducted on impact damage modelling in laminated composites. The modelling for studying the impact damage in the composite laminates holds high significance since they can replace expensive experimental testing and save both money and time [9]. Yang et al. [10] performed both experimental and finite element method analysis to study the effect of hybridisation on impact response of woven-fabric hybrid composite laminates. Composite laminate consisting of 25 alternative layers of weave carbon and glass fibre were produced using vacuum assisted prepregs process. All the material parameters obtained from experimentation were used for simulation process. In order to study the damage behaviour of hybrid composite laminates, three dimensional finite element models were developed in ABAQUS. The experimental impact results showed that the damage is initiated at the matrix and then proceed through delamination between the carbon and glass fabrics. So the fibre damage was the main failure mode for composites, where the carbon fabrics break easily due to their brittle nature in carbon fabric composites, while for hybrid composites due to presence of glass fabric layers they were difficult to break. The progressive failure model developed using ABAQUS and experimental failure modes observed were found to be in line with each other with an error of about 10%. Apart from this, other work related to Finite Element Model technqiue has been sucessfully used in obtaining the stress, strain and displacement of composite sandwich panels used in repair of damaged honeycomb sandwich panels used in commerical aircrafts. The finite element analysis was carried out to obtain complete three dimensional stress and strain under bending loads [11]. Similarly shear modulus of composite honeycomb panel can also be obtained using finite element approach [12].

In the present work, we study the low-velocity impact response of glass-carbon/epoxy hybrid composites with and without defects. The importance of this experimental work is that till date meagre amount of information or research work has been done on impact property analysis of woven hybrid composites consisting of defects. The effect of defect on impact response when compared to that without defect will be discussed.

2. EXPERIMENTATION

2.1 Materials & methods

In the present case a hybrid composites based on woven glass-carbon fabric reinforced epoxy composite lami– nates were produced in two different thicknesses namely 2 mm and 4 mm. E –glass plain weave fabric and carbon fabric were procured from by Hindustan Technical Fabrics, India are used as the reinforcements. The bi- woven E- glass has the standard thicknesses of 0.2 mm and carbon fabric has 0.3 mm respectively. The composite laminates were fabricated by hand lay-up technique using epoxy resin Araldite LY 556 with HY 951 grade room temperature curing hardener. The selection of the hardener depends on the curing temperature and heat resistance require. For the fabrication of composite laminates by the hand lay-up technique, there are four basic steps involved: Lay-up, impregnation, consolidation and solidification. All the hybrid composite manufacturing processes carry out the same steps as listed above, but they are accomplished in different ways.

The manufacturing of composite laminate starts with application of Tedlar PVF (poly vinyl fluoride) on the work table for easy removal of composite laminate. The woven glass fabric cloth is placed in an open mould and then resin was applied on the fabric followed by placing the carbon fabric on the glass fabric and again resin was applied on it. These steps were repeated and alternate layers of glass and carbon fabric until required dimensions of 2 mm and 4 mm are obtained. So these fabrics were stacked alternately about 8 layers to attain a thickness of 2mm and 16 layers to attain 4mm. In order to introduce the delamination in the composite laminate a Teflon film of thickness of 0.013mm with dimension 30×30 mm was placed at the center in between 2nd and 3rd layer as shown in Fig. 1.

In second step, for proper impregnation each woven fabric layer is soaked with resin mixture using a squeezing plate or roller. To eliminate the resin entrapment and air entrapment, squeezing plates were used. In the next step, consolidation process was carried out such that applied pressure is partaken by both resin and fabric structure. The layers were trimmed to the required dimensions to form the required thickness. Vacuum of 1hr of 650 Hg/mm^2 was applied for uniform distribution of resin and remove the entrapped air. Then the laminate was made to cure at ambient temperature along with vacuum pressure and later cured in an oven under specified time, temperature and pressure. The final step is solidification in which the laminates were allowed to solidify at room temperature and were further cured in oven. The temperature at 800°C was maintained for first 2 hrs and then 1200°c for next 2hrs. The fully prepared hybrid composite laminates are shown in Fig. 2.

2.2 Testing & characterization

The finished hybrid composites were examined by optical microscope in order to check the defect introduced in to the laminates while manufacturing. For this purpose OLYMPUS BX-60M microscope was used to capture the images of the through-thickness side edge of the un-fractured specimen to observe visible defect in the specimen. The delamination defect created by introduction of Teflon plate seen in optical microscope is shown in Fig. 3. The low velocity impact testing of hybrid composites were conducted at a Dynatup 8250 drop tower facility. The hybrid plates had to be positioned under this drop tower and should also be preloaded in compression. Therefore, a special specimen fixture was designed and fabricated that allows for a specific uniaxial compressive preloading. For all impact tests in this study a hemispherical steel impactor with a diameter of 25.40 mm and a mass of 3.23kg was used. The experimental tests were performed on 6 specimens (3 of 2 mm thickness and other 3 of 4 mm thickness). Tests were performed two times at three energy levels determined by the height, namely 320 mm, 480 mm, and 640 mm. The corresponding values of the nominal impact velocities are 2.50m/s, 3.06m/s, 3.54m/s. The nose of the impactor was made to fall on the specimen mounted on the fixture and test was carried out.

Figure 1. Introduction of Teflon plates in hybrid composite

Figure 2. Finished glass-carbon/epoxy hybrid composite

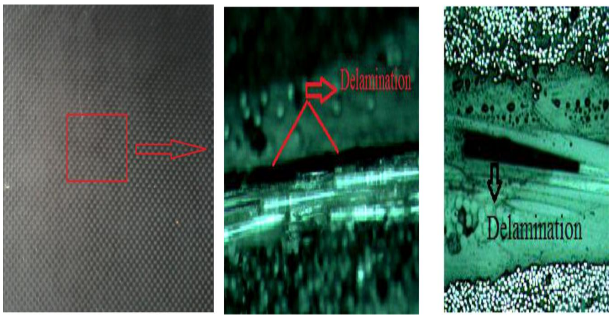

Figure 3. Defect introduction in the glass-carbon/epoxy hybrid composite

3. RESULTS & DISCUSSION

The impact tests was carried out on the three specimens with defect and without defect for hybrid composites of thicknesses 2 and 4 mm. The energy levels were obtained by the falling height namely 320, 480, 640mm. The graph of load versus time and energy versus time obtained from the data acquisition system of the impactor at various levels of impact energy is shown in below figures.

3.1 Specimens subjected to impact load of 3.23 kg at a height of 320 mm

Table 1 shows that the energy absorbed by the composite with defect (WD) is less than the composite without defect (WOD). The energy absorbed by the WD specimen for 2 mm specimen is 10.26 Joules and energy absorbed by the WOD specimen of same thickness is 10.32 Joules. At this energy level, a slight breakage of fibres in WD specimen was found than the WOD specimen. In case of 4mm WD specimen the energy absorbed was found to be 10.36 Joules and in WOD specimen energy absorbed was 10.54 Joules. At this energy level the crack formed on the 4mm specimen was negligible. The graphs of load vs. time and energy vs. time are obtained from the data acquisition for this height of fall.

Table 1. Impact Results of height of fall 320mm

Sl.No. / Parameters	1	2	3	4
Specimen type	WD	WOD	WD	WOD
Thickness (mm)	2	2	4	4
Height of fall (mm)	320	320	320	320
Mass (Kg)	3.23	3.23	3.23	3.23
Impact Energy(Ju)	10	10	10	10
Impact Velocity(m/s)	2.69	2.69	2.69	2.69
Energy at max load(Ju)	10.26	10.32	10.36	10.54

All the graphs obtained from the data acquisition system which were impacted at 10 joules of energy at a height of 320mm are plotted in a single form and are shown in Fig. 3. The respective graph for respective thickness with and without defect specimens are plotted which are indicated in the colors. Fig. 3 shows the energy absorbed for hybrid composites of 4 mm thickness without defect and was found to be 10.54 Joules with impact energy of 10 Joules. The peak load of 5.74 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from the height of 320mm with impact velocity of 2.69 m/sec Further the energy absorbed for hybrid composites of 4 mm thickness with defect and was found to be 10.36 Joules with impact energy of 10 Joules. The peak load of 5.93 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from the height of 320 mm with impact velocity of 2.69 m/sec.

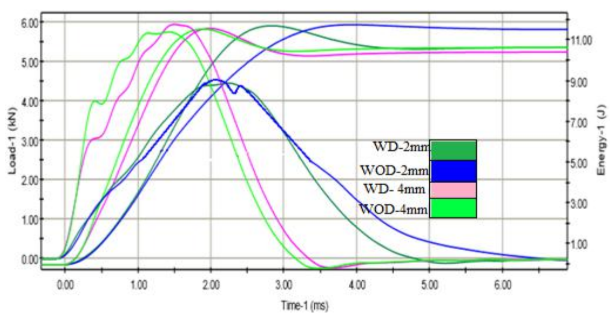

Figure 3. Specimens impacted at height of 320mm

Fig. 4 explains the picture of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 2 mm thickness with defect specimen which was impacted at 320mm height. The SEM image of defected specimen was captured at ×100 magnification. It can be seen that the front face has been damaged slightly and there is light breakage of fibre. At the back face of the specimen there was no damage formed. From this, we can conclude that at low velocity there will be a slight damage for this thickness which leads to failure of materials with defects. Figure 5 shows the picture of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 2mm thickness without defect specimen which was impacted at 320mm height. The SEM image of without defect specimen was captured at ×10 magnification. It can be seen that the front face has no damage and there was no breakage of fibre. At the back face of the specimen there was no damage formed. From this we can conclude that at low velocity there will be very slight damage for this thickness.

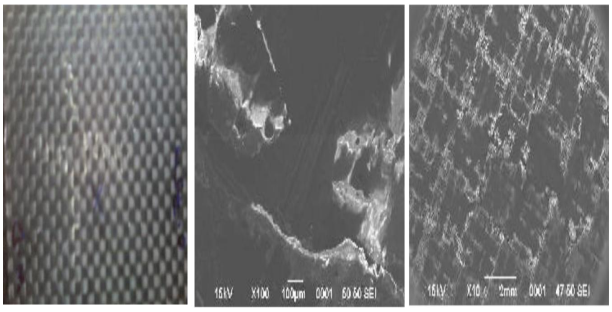

Figure 4. Photograph of specimen and SEM Image of 2 mm thickness with defect specimen

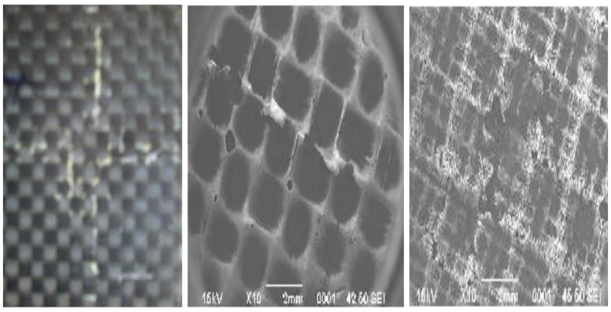

Figure 5. Photograph of specimen and SEM Image of 2 mm thickness without defect specimen

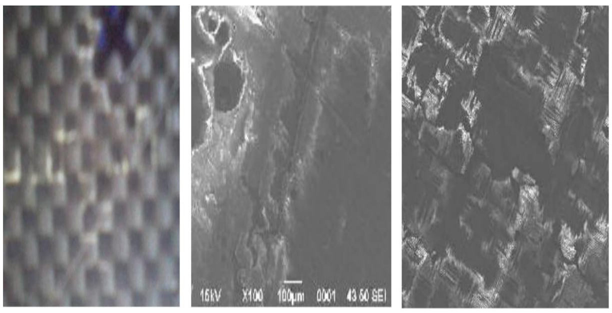

Figure 6. Photograph of specimen and SEM Image of 4 mm thickness with defect specimen

Figure 6 provides the picture of the photograph specimen and SEM image of the impacted test specimen. The specimen shown in the figure is of 4 mm thickness with defect specimen which was impacted at 320mm height. The SEM image of defected specimen was captured at ×100 magnification. It can be seen that the front face has damaged slightly and there is light breakage of fibre. At the back face of the specimen matrix crack was found. From this we can conclude that at low velocity there will slight damage for this thickness. Fig. 7 shows the picture of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 4 mm thickness without defect specimen which was impacted at 320mm height. The SEM image of without defect specimen was captured at ×10 magnification. It can be seen that the front face has no damage and there was no breakage of fibre. At the back face of the specimen there was no damage formed. From this, we can conclude that at low velocity there will be very minor damage for this thickness.

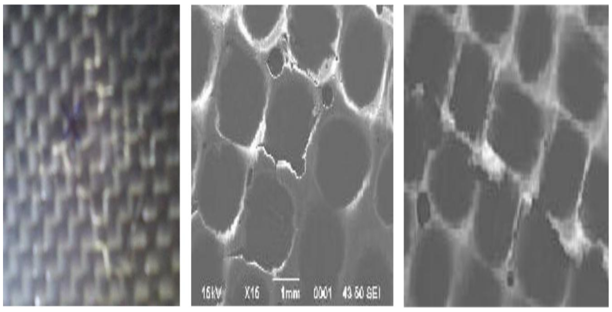

Figure 7. Photograph of specimen and SEM Image of 4 mm thickness without defect specimen

3.2 Specimens subjected to impact load of 3.23 kg at a height of 480 mm

The specimen is tested to a height of 480 mm and the obtained result is given in Table 2. The table shows that 4mm thickness specimen holds good absorption of energy comp aired to 2 mm thickness. The WD specimen of 2 mm thickness has absorbed 9.97 joules of energy, while the WOD of same thickness specimen gives the energy of 11.57 joules. In case of 4mm thickness, the WD specimen has absorbed 12.71 Joules of energy which is less than the WOD specimen i.e., 13.26 Joules. At this fall of height, it was observed that the fibre breakage in WD specimen was more than the WOD specimen for both thicknesses. The graph of load vs. time and energy vs. time are obtained from data acquisition system for this height of fall.

Table 2. Impact Results of height of fall 480 mm

Sl.No. / Parameters	1	2	3	4
Specimen type	WD	WOD	WD	WOD
Thickness (mm)	2	2	4	4
Height of fall (mm)	480	480	480	480
Mass (Kg)	3.23	3.23	3.23	3.23
Impact Energy(Ju)	15	15	15	15
Impact Velocity(m/s)	3.01	3.01	3.01	3.01
Energy at max load(Ju)	9.97	11.57	12.71	13.26

All the graphs obtained from the data acquisition system which were impacted at 15 Joules of energy at a height of 480mm are plotted in a single form shown in Figure 8. The respective graph for respective thickness with and without defect specimens are plotted which are indicated in the colors. Figure 8 shows the Load and energy as a function of time for hybrid composite of 2 mm thickness without defect and the energy absorbed was found to be 11.57 Joules with impact energy of 15 Joules. The peak load of 4.90 kN was obtained from the graph. This graph was obtained from the data acqui–sition system of drop weight impact testing tower when subjected from height of 480mm with impact velocity of 3.01 m/sec. Further it can be seen from Fig. 8 that the toad and energy as a function of time for hybrid composite of 4 mm thickness without defect and describes that the energy absorbed was found to be 13.26 Joules with impact energy of 15 Joules. The peak load of 6.45 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from the height of 480mm with impact velocity of 3.01 m/sec.

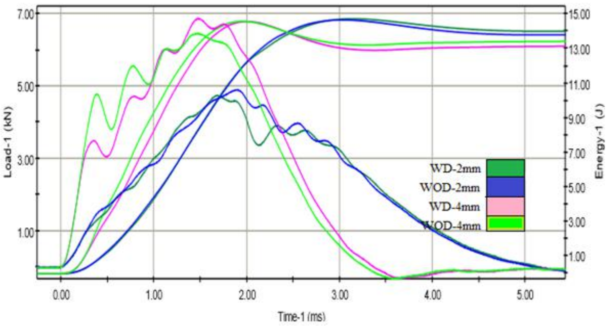

Figure 8. Specimens impacted at height of 480 mm

The Load and energy as a function of time for hybrid composite of 2 mm thickness with defect and energy absorbed was found to be 9.97 Joules with impact energy of 15 Joules. The peak load of 4.74 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from height of 480 mm with impact velocity of 3.01 m/sec. The Load and energy as a function of time for hybrid composite of 4 mm thickness with defect and energy absorbed was found to be 12.71 Joules with impact energy of 15 Joules. The peak load of 6.86 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from height of 480mm with impact velocity of 3.01 m/sec.

Figure 9 shows the picture of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 2 mm thickness without defect specimen which was impacted at 480mm height. The SEM image of without defect specimen was captured at ×50 magnification. It can be seen that the front face has damage and there was no breakage of fibre. At the back face of the specimen there was no damage formed only matrix crack was found. From this, we can conclude that at low velocity there will be very slight damage for this thickness. Fig. 10 shows the image of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 2 mm thickness with defect specimen which was impacted at 480mm height. The SEM image of with defect specimen was captured at ×50 magnification. In the figure 5.101 it can be seen that the front face has damaged with matrix cracking and slight fibre is been broken. The back face of specimen is formed with crack. At the back face of the specimen crack formation is seen. From this we can conclude that at low velocity there will be damage for this thickness.

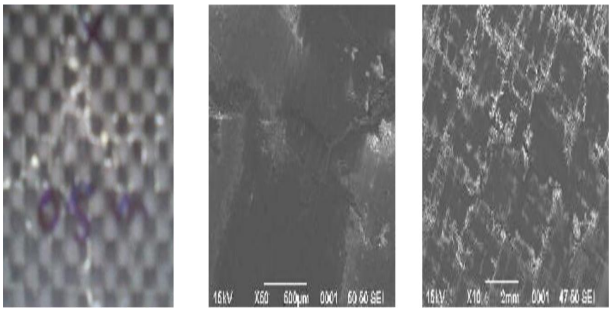

Figure 9. Photograph of specimen and SEM Image of 2 mm thickness without defect specimen

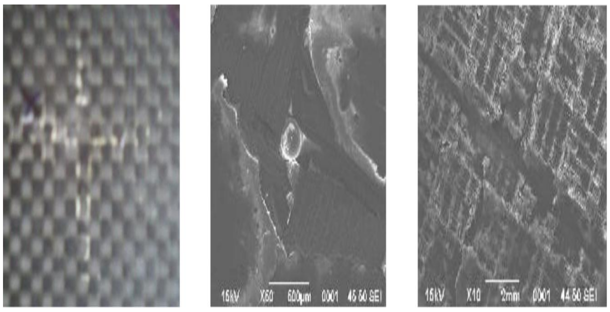

Figure 10. Photograph of specimen and SEM Image of 2 mm thickness with defect specimen

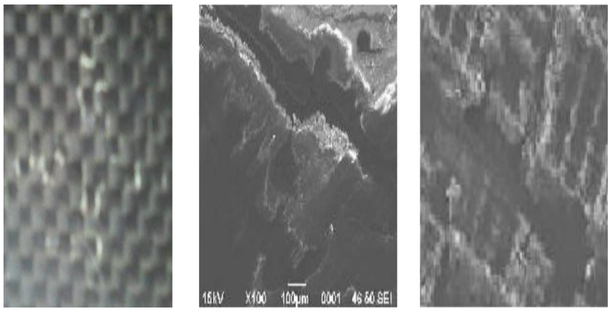

Figure 11. Photograph of specimen and SEM Image of 4 mm thickness with defect specimen

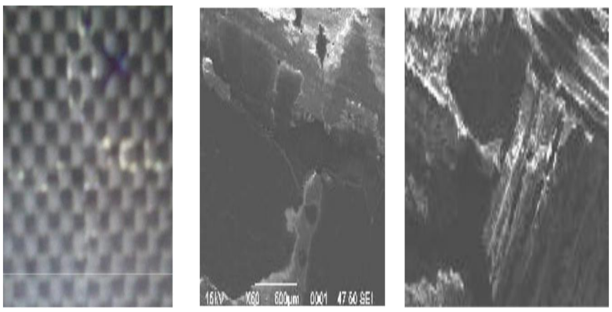

Figure 12. Photograph of specimen and SEM Image of 4 mm thickness with defect specimen

Figure 11 shows the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 4mm thickness without defect specimen which was impacted at 480mm height. The SEM image of without defect specimen was captured at ×100 magnification. It can be seen that the front face has damage with only matrix crack and there was no breakage of fibre. At the back face of the specimen there was no damage formed. Figure 12 shows the picture of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 4mm thickness with defect specimen which was impacted at 480mm height. The SEM image of with defect specimen was captured at ×50 magnification. It can be seen that the front face has damage and there was no breakage of fibre. At the back face of the specimen there was no damage formed. From this we can conclude that at low velocity there will be very slight damage for this thickness.

3.3 Specimens subjected to impact load of 3.23 kg at a height of 640 mm

The specimen is tested at a height of 640 mm and the obtained results are tabulated in Table 3. The table shows that WD specimen has absorbed energy of 10.19 Joules compared to WOD specimen which has absorbed 15.19 Joules for 2mm thickness. From the results it can be concluded that 4mm thickness without defect has absorbed more amount of energy that is about 16.91 Joules than the 4mm specimen with defect which is 16.25 Joules. This gives a very good impact resistance than the 2mm thickness. At this energy level back face split up and perforation is observed in the 2mm WD specimen. The graph of load versus time and energy versus time were obtained from data acquisition system for this height of fall.

All the graphs obtained from the data acquisition system which were impacted at 20 joules of energy at a height of 640mm are plotted in a single form which is given Fig. 13. The respective graph for respective thickness with and without defect specimens are plotted which are indicated in the colors. Figure 13 shows the Load and energy as a function of time for hybrid composite of 2 mm thickness without defect and the energy absorbed was found to be 15.19 Joules with impact energy of 10 Joules. The peak load of 5.37 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from height of 480mm with an impact velocity of 3.01 m/sec. Load and energy as a function of time for hybrid composite of 4 mm thickness without defect energy absorbed was found to be 16.90 Joules with impact energy of 10 Joules. The peak load of 7.35 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from height of 480mm with impact velocity of 3.01 m/sec.

Load and energy as a function of time for hybrid composite of 2 mm thickness with defect and the energy absorbed was found to be 10.19 Joules with impact energy of 20 Joules. The peak load of 4.54 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from height of 640mm with impact velocity of 3.4 m/sec. Load and energy as a function of time for hybrid composite of 4 mm thickness with defect and energy absorbed was found to be 16.25 Joules with impact energy of 10 Joules. The peak load of 7.09 kN was obtained from the graph. This graph was obtained from the data acquisition system of drop weight impact testing tower when subjected from height of 480mm with impact velocity of 3.01 m/sec.

Table 3. Impact Results of height of fall 640 mm

Sl.No. / Parameters	1	2	3	4
Specimen type	WD	WOD	WD	WOD
Thickness (mm)	2	2	4	4
Height of fall (mm)	640	640	640	640
Mass (Kg)	3.23	3.23	3.23	3.23
Impact Energy(Ju)	20	20	20	20
Impact Velocity(m/s)	3.4	3.4	3.4	3.4
Energy at max load(Ju)	10.19	15.19	16.25	16.91

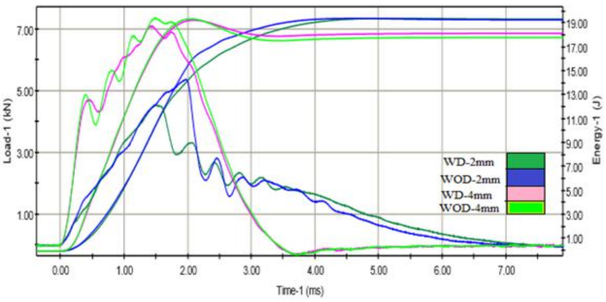

Figure 13. Specimens impacted at height of 640 mm

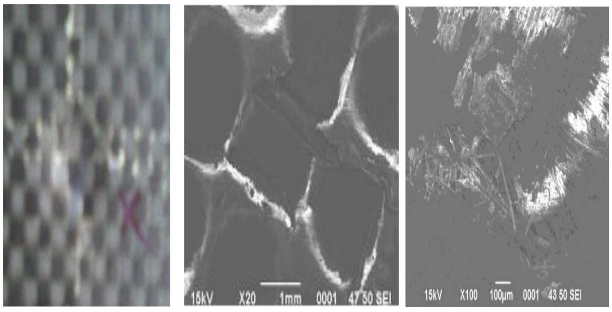

Figure 14. Photograph of specimen and SEM Image of 2 mm thickness without defect specimen

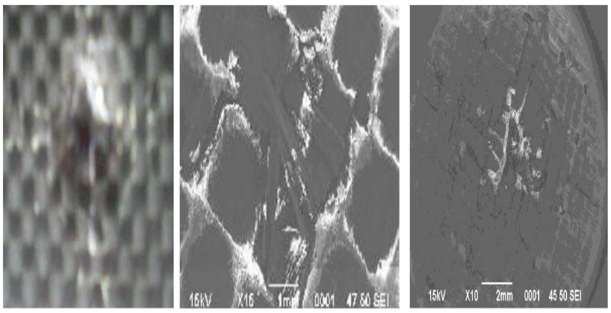

Figure 15. Photograph of specimen and SEM Image of 2 mm thickness with defect specimen

Figure 14 shows the picture of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 2 mm thickness without defect specimen which was impacted at 640 mm height. The SEM image of without defect specimen was captured at ×100 magnification. It can be seen that the front face has damage with dent on the specimen and there was breakage of fibre. At the back face of the specimen fibre breakage was found. From this we can conclude that at low velocity there will be severe damage for this thickness. Figure 15 shows the specimen of the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 2mm thickness with defect specimen which was impacted at 640mm height. The SEM image of with defect specimen was captured at

×16 magnification. It can be seen that the front face has damage with fibre breakage with matrix cracking and fibres were split up. At the back face of the specimen there was through perforation.

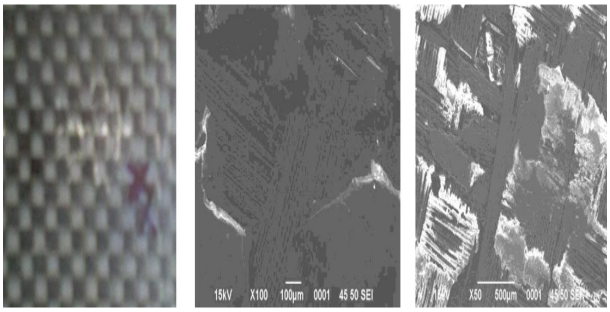

Figure 16. Photograph of specimen and SEM Image of 4 mm thickness without defect specimen

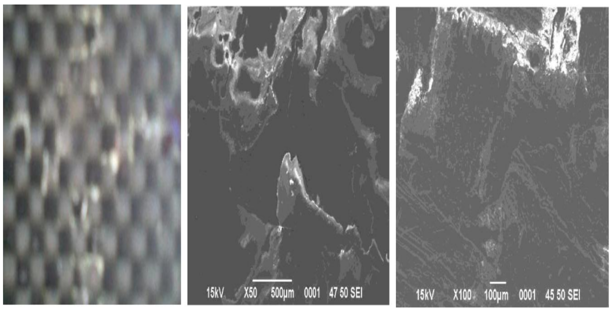

Figure 17. Photograph of specimen and SEM Image of 4 mm thickness with defect specimen

Figure 16 shows the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 4mm thickness without defect specimen which was impacted at 640 mm height. The SEM image of without defect specimen was captured at ×100 magnification. It can be seen that the front face has damage and there was no breakage of fibre. At the back face of the specimen there was no damage formed. From this we can conclude that at low velocity there will be slight damage for this thickness. The graphs of impact energy versus absorbed energy are also plotted for better conclusion and veri–fication of results which are given below. Figure 17 shows the specimen and SEM image of the impacted test specimen. The specimen shown in figure is of 4mm thickness without defect specimen which was impacted at 640mm height. The SEM image of without defect speci–men was captured at ×100 magnification. It can be seen that the front face has damage and there was breakage of fibre. At the back face of the specimen there was damage formed. From this we can conclude that at low velocity there will be slight damage for this thickness.

4. CONCLUSION

The conclusions drawn from this work are as follows,

- The test series have shown the reduced amount of energy absorption for the specimen with defect than the specimen without defect. The maximum energy absorbed for 4mm thickness specimen without defect was observed to be 16.90 joules. The maximum energy absorbed for 2mm thickness specimen without defect was observed to be 15.19 joules.
- Maximum extent of damage was found in the specimen with defect of 2mm thickness than in the specimen with defect of 4mm thickness, when dropped from a height of 640mm. at this height specimen with defect of 4mm thickness showed a matrix cracking on the specimen but 2mm thickness specimen resulted in back face split up and finally perforation. The laminate sustained catastrophic failure at 3.5 m/s on 2mm thickness specimen. The 4mm thickness gives higher strength than 2mm thickness for this hybrid material**.**

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ЕКСПЕРИМЕНТАЛНА ИСТРАЖИВАЊА СТАКЛО-УГЉЕНИК/ЕПОКСИ ХИБРИДНИ КОМПОЗИТИ ПОДВРГНУТИ ПРОВЕРАМА НА УДАР НИСКЕ БРЗИНЕ

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Хибридни композити са вишеструким ојачањем велике чврстоће су веома популарни у инжењерству, пре свега због отпорности на удар. У раду је приказан развој стакло-угљеник/епокси хибридног композита применом технике ручног лепљења и истражен је његов одговор на удар мале брзине. Провере на удар мале брзине обављене су на хибридним композитима са аспекта енергије удара и брзине удара. Осим тога, у хибридни композит је уграђен дефект и проучен је његов утицај на одговор на удар, и извршено је упоређивање са хибридним композитима који немају никаквих недостатака. Утврђено је да присуство недостатка код хибридног композита има значајног утицаја на апсорбовану енергију у поређењу са композитом без дефекта.