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Investigation of Repeated Low Velocity Impact Behaviour of GFRP /Aluminium and CFRP /Aluminium Laminates

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Abstract* - *The objective of this research was to investigate esponse of repeated low velocity impact tests on glass fibre/ epoxy-Al metal laminates (GEAML) and carbon fibre/ epoxy-Al metal laminates (CEAML) at the same location using drop-weight tester. CEAML, GEAML as well as monolithic Al panels of the same thickness were impacted repeatedly up to four impacts. The effect of repeated impacts on specimen is studied on peak load, absorbed energy, decelerated velocity and impact time with respect to deflection at impactor load of 5.2 kg under gravity fall. The result shows the Al plates, GEAML and CEAML exhibit different behaviour for both loading bearing capacity and damage pattern. The maximum load bearing capacity is higher in case of monolithic aluminium but damage spread throughout the specimen, which contribute to the energy-absorbing capacity of these Al plates. In the case of GEAML and CEAML the damage is concentrated only at impact area hence lower energy-absorbing capacity.

Index terms- FML, Low velocity impact, Epoxy, Glass fibre, Carbon fibre

I. INTRODUCTION

Presently, the demand for achieving low weight structure while exhibiting better performance has led the way for use of combination of metal and non-metallic layers. In this regard a new class of materials called fibre metal laminates (FML) have been developed for better mechanical [1] and corrosion properties [2]. FML are multi component materials utilizing metal sheet and fibres reinforced plastics (FRP) layer by layer. When combining these two materials in a layered arrangement, FRP layer is responsible for carrying the majority of load and also performing the important task of resistance to spread off contact forces, whereas the metal layer are expected to absorb impact energy by progressive deformation [3].

Also both layers help them each other in different circumstances, FRP arrest crack growth caused by impact load [4] and aluminium protect FRP layer from picking up moisture [5]. Researchers [6-8] studied extensively and demonstrated that internal impact damage in FMLs is confined to a relatively small area immediately surrounding the point of impact. Clear evidence of the impact shows plastic deformation in the aluminium and ductile tearing in the FRP, are primary energy absorbing members in FML laminates [9]. Although more research works were focused on glass metal laminates only for single impact studies but in general structures are subjected to repeated impacts during routine maintenance activities. The study of repeated impacts is essential for daily life applications. In other words majority aerospace FRP structures are based on carbon fiber but repeated impact study of carbon metal laminates is yet to explore. The aim of work is to investigate the repeated impacts and damage responses of glass fibre/ epoxy-Al metal laminates (GEAML) and carbon fibre/ epoxy-Al metal laminates (CEAML) compared with monolithic aluminium plate (MAP) of same thickness.

II. EXPERIMENTAL WORK

For fabrication of the both FMLs a 1.0 mm thick Al 6061 alloy sheets were used. The FRP layers used in the study were 600 gsm plain woven glass fiber and carbon fiber LY556 epoxy resin with k7 hardener. Both aluminium sheets and fibers were cut to square of dimension 180 mm x 180mm size. Before stacking, the aluminium sheets were cleaned with acetone to remove grease and dirt and were chromated [10] for better adhesion between the layers.

The Al based FMLs were fabricated using hand layup technique. A woven carbon fibre / glass fibre reinforced toughened epoxy with a nominal fibre volume fraction of 40% and thickness 0.175 mm was prepared. The Al alloy sheets were lightly abraded using a 1200 grit paper for increasing the surface area and adhesive properties. Three GFRP laminates / CFRP laminates and metal plies were placed in a picture frame mould with dimension 200 mm x 200 mm and processed according to the manufacturer's recommendation. The FML panels are subjected at pressure of 50 MPa for 24 h at 30°C. GEAML and CEAML have staking sequence of A-G-A-G-A and A-C-A-C-A respectively (A- aluminium, G – glass fibre and C-carbon fibre). For comparison the MAP of the same thickness as of other FML specimens were taken for impact studies.

The specimens were subjected to low velocity impact by using a drop weight impact test (Instron Dyntup-8210). Impact tests were conducted based on ASTM D7136 Standards [11].

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A hemispherical tup projectile of diameter 12.5mm is used as impactor with 5.2kg weight. The specimen is clamped at the bottom of the machine between two rectangular blocks which square opening of 76 mm x 76 mm at the center. A velocity detector measures the velocity of the tup before it strikes the specimen. For each experimental study a total of 4096 data points were collected during impact event by data acquisition system. The numbers of impacts were considered is up to four for each specimen.

III. RESULTS AND DISCUSSION

Four types of impact behaviours such as load-deflection behaviour (Fig.1a-d), energy-deflection behaviour (Fig. 2a-d), impact velocity-deflection behaviour (Fig. 3a-d) and time-deflection behaviour (Fig. 4a-d) are presented and discussed. Impact deflection is the distance that the impactor has travelled from the point of impact up to the point of maximum load. Each figure having impact behaviour of GEAML, CEAML laminates and MAP for comparison among them.

A. Impact load-deflection behaviour

A typical impact load–deflection curve of MAP, GEAML and CEAML recorded during the impact test for first impact, second impact, third impact and fourth impact are shown in Fig. 1(a), Fig. 1(b), Fig.1(c) and Fig.1(d) respectively. In first impact (Fig. 1(a)), the load increases until reach the peak (5.5 kN), the impact energy completely utilised for specimen deformation both plastic and elastic nature. The elastic behaviour contributed to spring back effect of laminates shown in figures. The first part of curve (loading part) experienced oscillation, which indicates the damage initiation and propagation in the sample [12] whereas the unloading part is instantaneous because of elastic nature of the material (spring back effect). From those plots, it is clear that the impact energy is same for all three specimens but they attain different deformations. The deformation of GEAML laminates, CEAML laminates and MAP experience around 7, 8.5 and 10 mm respectively.

Behaviour second impact is shown in Fig. 1(b), the load increases sharply with increase in deformation and reaches peak then decreases. The curves show more oscillation compared with first impact, which indicates more damage and its propagation in the samples. In GEAML laminate and MAP only partial damage can be seen, this may be evidenced by spring back effect in the graphs. Only CEAML laminates perforated by impact was seen during experiment hence the load drop in forward direction without any spring back effect. The peak loads for GEAML, CEAML and MAP are around 7.5, 5.5 and 7.3 kN at deflection of around 5, 3 and 7mm respectively. In Fig. 1(c) only MAP specimens survive from perforation but it has very large deformation at back face. But the loading curve shows oscillation in third impact and but through hole can be seen in GEAML. By visual inspection the CEAML perforated hole is seen bigger than that of GEAML metal laminates. In fourth impact all four specimens are perforated. Although MAP specimen has small opening but it has elastic nature as shown in Fig. 1(d). This is evident from the figure that the unloading curve has more oscillation (wave nature curves) compared to previous impacts, but maintained the same impact load (≅ 7.5 kN).

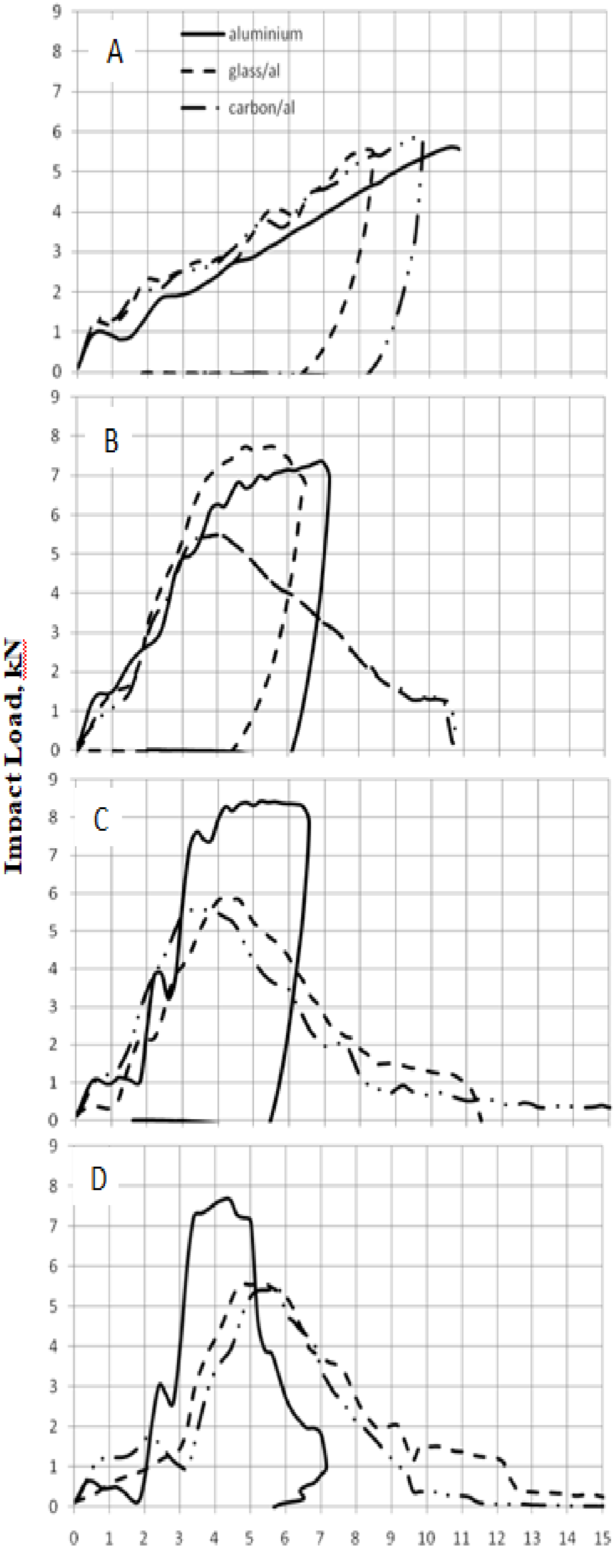

Fig. 1 Impact load as a function of deflection of Al, glass/Al and carbon/Al metal laminates for a) First impact, b) Second impact, c) third impact and d) fourth impact.

B. Energy-displacement behaviour

Fig. 2(a-d) compares the energy-displacement curves of the GEAML, CEAML and MAP specimens for first, second, third and fourth impacts respectively. The behaviour of curve can be separated into three categories 1) increase energy with displacement, 2) maintained constant energy in backward displacement and 3) maintained constant energy level in forward direction. In first category, all the specimens showed steep increase until maximum energy with elastic deflection along with little plastic deformation. This trend of curves can be seen in first (Fig. 2(a)), second (Fig. 2(b)) and third impacts (Fig. 2(c)) for both MAP and FMLs. The shape of the curves indicates the occurrence of no fibre failure in the FRP that is struck by the impactor as visualized by the smooth transition of curve without any sudden energy drop. Visual examination of the impacted samples reveals that the damage in the fibres was developed around the point of impact, which results in considerable strength loss. The second category, due to spring back effect the impactor moves opposite direction with constant energy (30±3 J). The elastic deformation is completely recovered but plastic deformation left in form of dent mark on the specimen. In first impact (Fig. 2(a)) all three specimens shows both first and second category behaviour. This implies that all three specimens are not perforated but with small dent as shown in Fig. 6(a), 7(a) and 8(a). The same trend can be seen in GEAML and MAP specimens at second impact, only MAP at third impact and no specimen in fourth impact. The third category, the impactor continues to move in forward direction but at constant energy level (Marked III). It indicates the failure of specimen with perforated hole throughout the specimen. This trend can be seen in CEAML at second impact, GEAML at third impact and all three specimens at fourth impact.

C. Velocity -displacement behaviour

Fig. 3(a-d) shows the impact velocity behaviour of all three specimens during the impact events. In all four impacts the initial velocity is same (3.5 ms^{-1}) then it decrease at parabolic nature for all specimens at first impact. Deformation of CEAML and GEAML are less than that of MAP specimens (i.e $d_{CEAML} > d_{GEAML} > d_{MAP}$) shown in Fig. 3(a). At second impact CEAML changes its behaviour (Fig. 3(b)) and the same way at third impact both CEAML and GEAML change their velocity behaviour (curve shape changes from spherical to irregular). The impactor displaces maximum (>10 mm) after impact, which leads to perforation through the specimen. Although FML changes their behaviour but the MAP specimen shows similar nature of impact behaviour and a small perforated hole could be seen after fourth impact as shown in Fig.5 g & h. The reason for this behaviour is that continuous impacts lead to work hardening in the behaviour of MAP and increase in its stiffness.

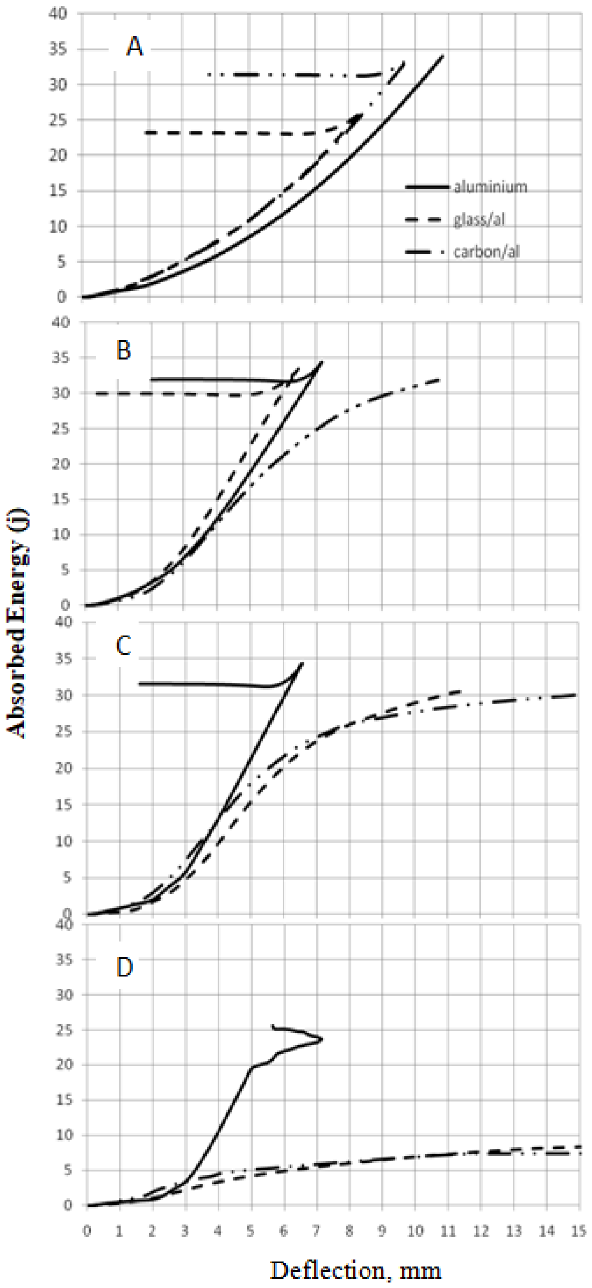

Fig. 2 Absorbed energy due impact as a function of deflection of Al, glass/Al and carbon/Al metal laminates for a) First impact, b) Second impact, c) third impact and d) fourth impact.

D. Impact duration-displacement behaviour

Fig. 4(a-d) shows the behaviour of impact duration as a function of deformation of the specimens. Fig. 4(a) clearly exhibited occurrence of rebound behaviour in all the specimens, which due to elastic nature of the specimens. Whereas in second impact of curves in Fig. 4(b) show near-perforation of CEAML laminates. MAP and GEAML specimens time- deflection records become less negative during rebound. In third impact Fig. 4(c) and fourth Fig. 4(d) shows perforation in both FML composites. In fourth impact, the curves of FML were almost flat, implying the condition of near-perforation.

For the MAP specimen, the slope of the deflection record less rebound, indicating the appearance of perforation. Since the MAP specimen still possessed some resistance to impact, it bounced the impactor back, which is represented by the portion of the deflection curve with negative slopes.

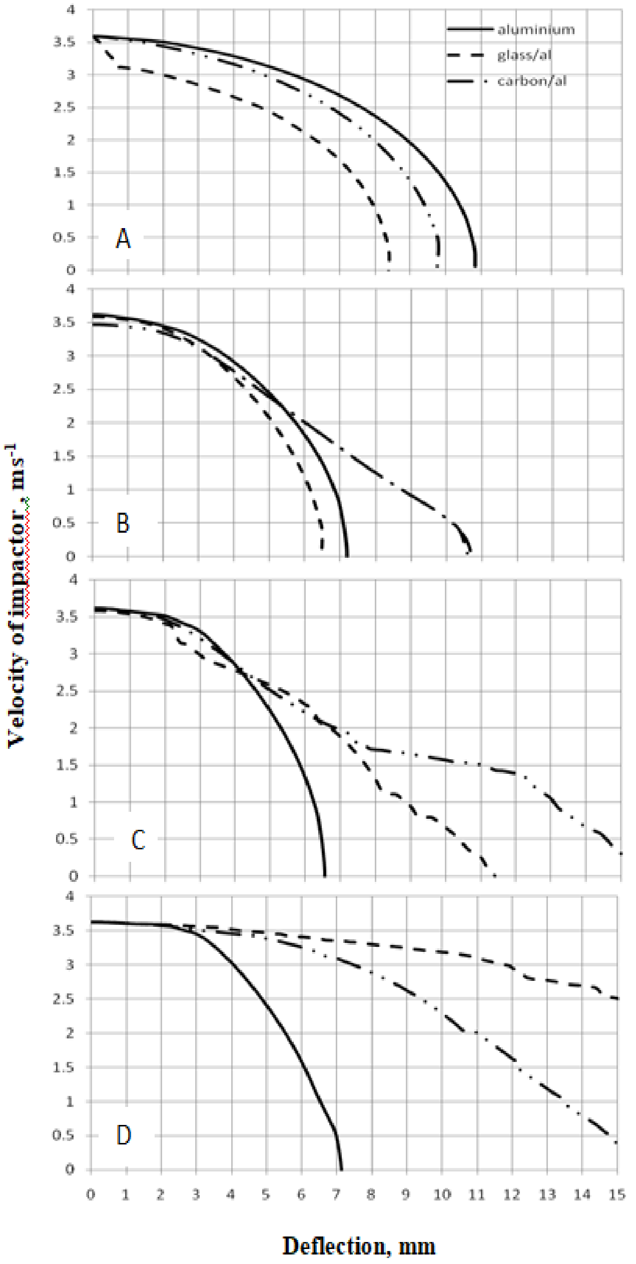

Fig. 3 Impactor velocity as a function of deflection of Al, glass/Al and carbon/Al metal laminates for a) First impact, b) Second impact, c) third impact and d) fourth impact.

E. Impact damage

Figs. 5, 6 and 7 illustrate the top and bottom surfaces of the impacted MAP, CEAML laminates and GEAML respectively. The MAP has good resistance against perforation hence only partial damage can be seen as shown in Fig. 5 (a-h). The size of impact dent spread along the x-y direction (x-y plane) is increased with number of impacts but little higher than that of the diameter of the impactor. Due to plasticity of Al, the permanent deformation was not limited to a local area but also surrounding the impact location as shown in Fig. 5(a&b). The impact dent mark is more clear at second impact (Fig.5 c & d) and it deepens for third (Fig. 5(e & f)) and fourth (Fig. 5(g & h)) impacts. Rather, only the portion of the specimen boundaries clamped within the test frame was unaltered at the end of the impact event, where as the rest of the plate exhibited a pronounced bending seen by visual inspection. The damage takes the form of a large top surface dent and thin localised crack surrounding circumference of the hole.

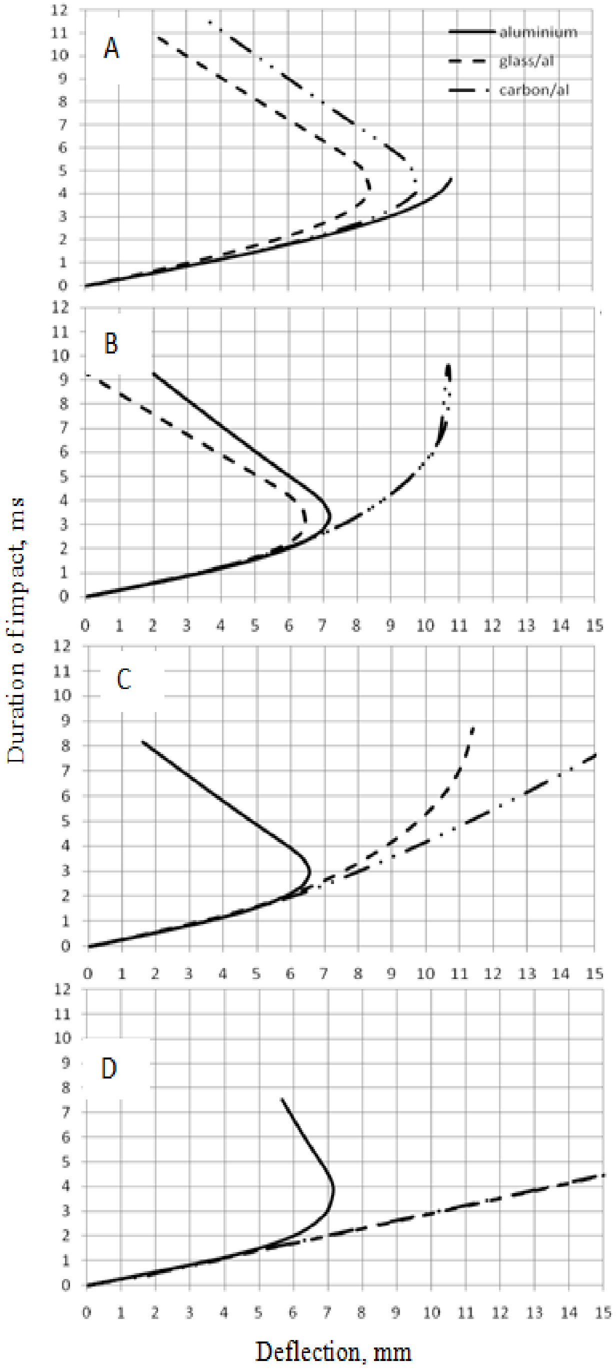

Fig. 4 Impact duration as a function of deflection of Al, glass/Al and carbon/Al metal laminates for a) First impact, b) Second impact, c) third impact and d) fourth impact.

Different failure mechanisms have been observed for CEAML tested for various impacts due to the orthotropic properties of FRP skin layers. Even at fist impacted specimen has been showed clear impact dent mark as show in Fig. 6(a&b). For second impact damage takes place at top surface as a dent and a localised straight crack parallel to one axis is seen in rear surface although there is no perforation at front face as shown in Fig. 6(c & d). This is due to built up of tensile stresses at the rear face results in cross shape fiber stretching, followed by delamination along the direction of the fibers. Clearly, the perforation process involved at third impact, significant local damage failure in both the aluminium and FRP plies as well as fracture of the constituent materials were seen (Fig. 6 (e & f)) An oval shape in front skin and diamond shape petalling in rear faces can be observed at the third impact. This damage is caused by debonding of the Al from the CFRP beneath the impactor. The complete failure can be seen as a through hole from front to rear surface of the fourth impacted sample.

Front face exhibits smaller damage whereas rear face damage is more because the CFRP transfers most of energy to rear surface of the specimen as shown in Fig. 6(g-h). Similar trend can be seen in GEAML with slight difference in shape of damage of the laminates. In case of CEAML shows oval shape but in the case of GEAML shows circular shaped damage. The intensity of impact damage is more in the case of CEAML compared to GEAML as shown in Fig. 7 (a-h). The layers in the carbon fibers are formed by strong covalent bonds and readily allow the propagation of cracks within the FML but not in the case of CEAML. At first impact and second impact, no crack was seen in both front and rear surface of the glass-Al laminates (Fig.7(a-d)). But at third impact petalling shaped (cross shaped hole) hole is formed at the back face shown in Fig. 7(e & f). At fourth impact the higher hole dimension. Two cracks propagated mutually perpendicular to each other and damage follows pattern of cross shape that reproduces the direction of fibers.

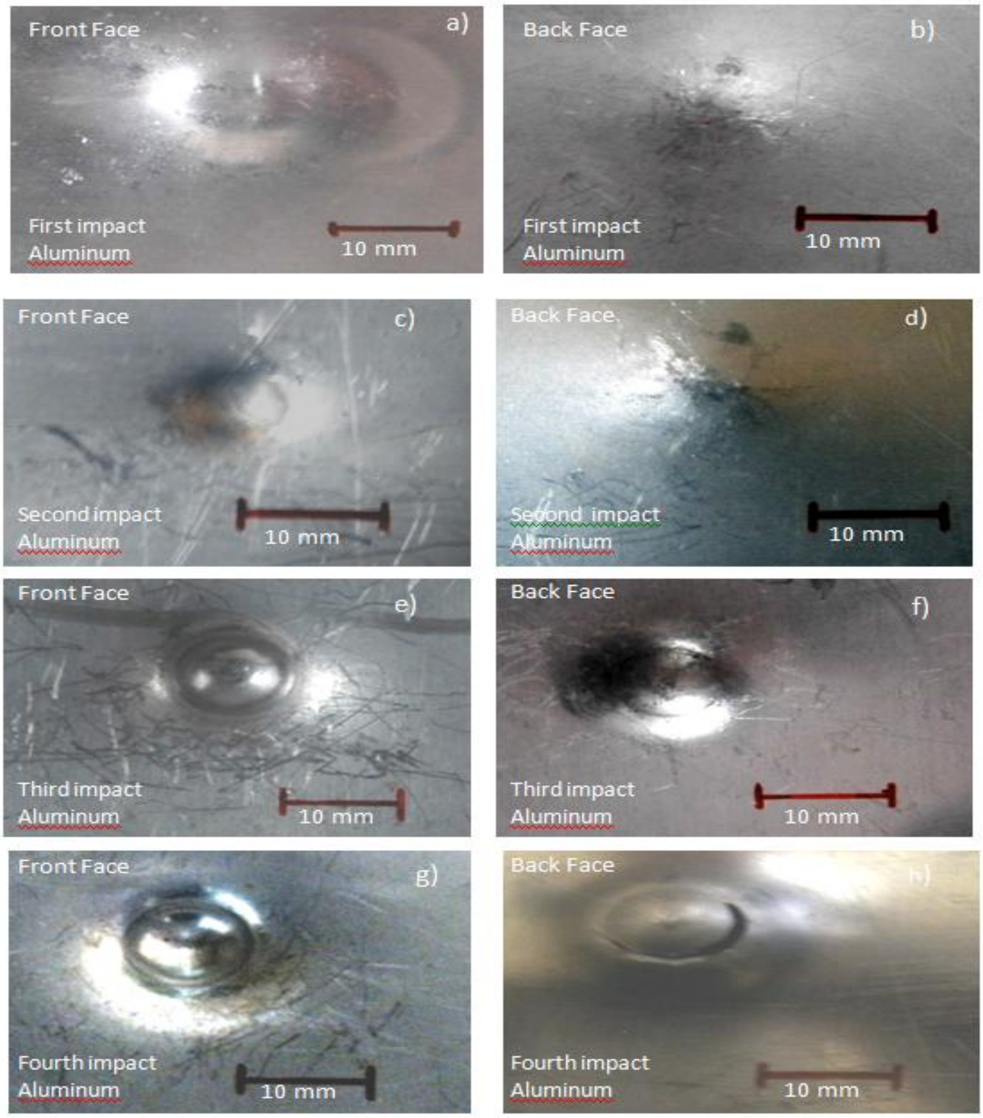

Fig. 5. Low magnification optical micrographs of impact damaged Monolithic Al-(Impacted surface and Rear surface)

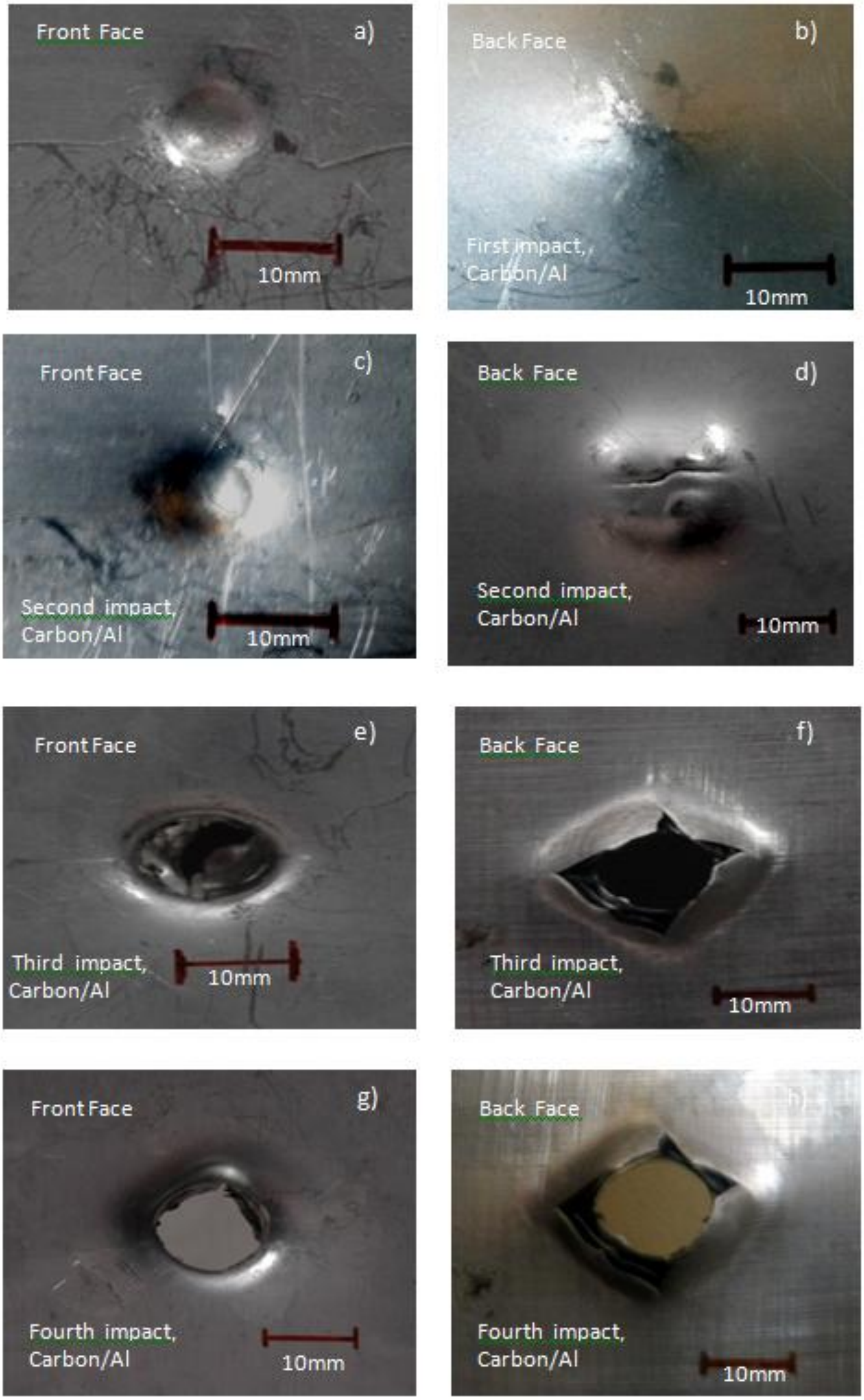

Fig 6. Low magnification optical micrographs of impact damaged AL-Carbon fiber FML. (Impacted surface and rear surface

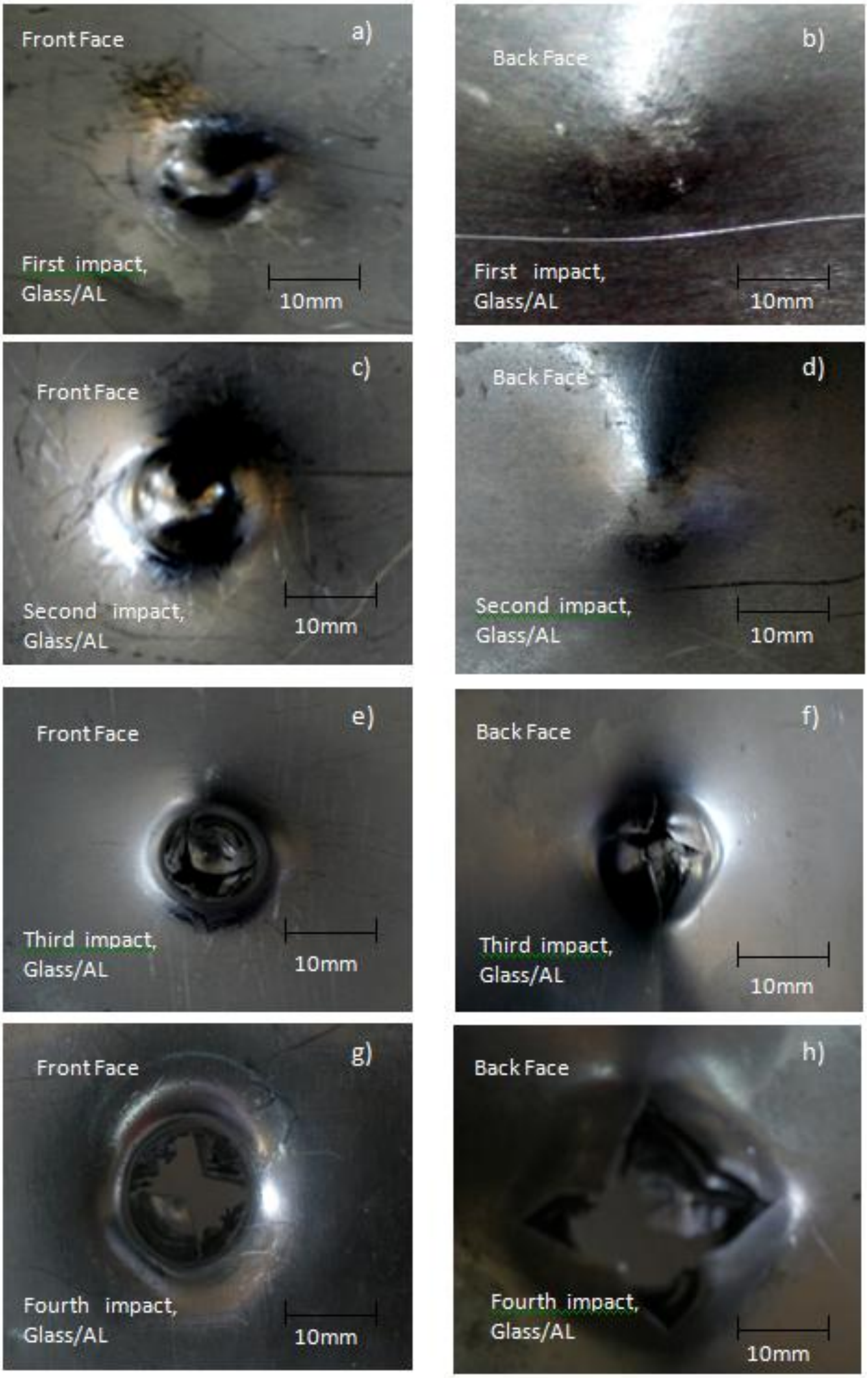

Fig 7. Low magnification optical micrographs of impact damaged Al-Glass fiber FML.(Impacted surface and Rear surface)

IV. CONCLUSION

The study presents experimental investigation of repeated low velocity impact behaviour of GEAML and CEAML laminates and they are compared with AMP. Based on the experimental results the following conclusions are drawn.

- A higher perforation resistance (loading) of the MAP over Al based FMLs are likely to be due to the superior energy-absorbing behaviour of Al alloy.
- GEAML offer a better energy absorption than CEAML due to carbon based FML allows the propagation of cracks within the structure. However, a MAP alloy of equivalent thickness is more effective than GEAML in preventing penetration.
- GEAML exhibits an excellent impact damage resistance and showing a small damaged area even at complete penetration.
- The size of the impact damage zone increases with increase in number of impacts irrespective of specimen systems but the damage pattern is different shape around the point of impact such as ring shape in the Al, round and diamond shape petalling in FML structure.

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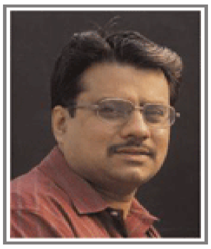

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