An Experimental Study on the Impact Resistance of Glass-Fiber-Reinforced Aluminum (Glare) Laminates

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SUMMARY

This paper reports an investigation on the impact resistance and damage characteristics of Glare laminates under low velocity impact loading. A series of impact tests, based on ASTM D7136 standard, with different energies were conducted on three types of Glare laminates, namely Glare4/3, Glare3/2 and GlareWB3/2. In addition to single impact tests, 10 and 20 successive impacts were applied to investigate the effect of repeated impacts on the behavior of laminates. Experimental results show that layout sequence and interfacial adhesive bonding have a considerable effect on the impact behavior of Glare laminates.

Keywords: Composite, Impact, Glare, Adhesion.

INTRODUCTION

Fiber metal laminates (FMLs) are considered as advanced aerospace structures due to their higher fatigue resistance and lower density in comparison with monolithic aluminum sheets [1]. As it has been emphasized by Gunnink et al, the prospect of a possible 20% weight reduction for aircraft structures was the prime driver behind the Glare development [2]. Using 793m^2 Aluminum-Glass/Epoxy (Glare) in the fuselage of Airbus A380, for example, enhances the mechanical properties and at the same time reduces the mass of airplane by almost 800 kg [3]. So, several researches have been done in order to investigate mechanical behavior of this important material. Alderlisten et al. has worked on fatigue behavior of Glare [4-8]. J. Sinke has studied on manufacturing methods of Glare parts and structures. His research show that manufacturing of Glare structures are more like manufacturing of metal sheet structures rather than polymer composites ones [9]. Blast behavior of Glare has been comprehensively studied by Cantwell et al [10-14]. Caprino et al have done comprehensive research on low-velocity impact behavior of Glare laminates [15, 16]. Their studies show that impact resistance of Glare is much better than galss- and carbon-reinforced plastics, but weaker than monolithic metal sheets with the same thickness. Delamination between composite and Aluminum layers was reported as the main cause of this weakness. Alemi Ardakani et al. developed a solution for this problem by creating ALOOH fuzzes on aluminum surfaces which leads to increase of the bonding area [17].

In this study, a comprehensive experimental work is done on the impact behavior of the mentioned novel fabricated Glare laminates. For this purpose, aluminum surface treatment, number of layers, number of repeated impacts and energy of impact have been chosen as variant parameters.

COMPOSITE PRODUCTION

Glare 3/2 laminates consisting of three 0.3 mm thick Aluminum sheets and two E-glass/epoxy (GFRP) plies were fabricated using a hand-lay up procedure (Fig.1). The nominal weight fraction of fibers in GFRP was kept constant at 60%. The plies were laminated in such a way that the warp and weft directions were parallel to the edges of the laminates. The plates were then post-cured in an oven at 100°C for 4 hours after they had been cured under 15 kPa pressure for one day at room temperature. These laminates were then cut up to 100×150 mm rectangular specimens.

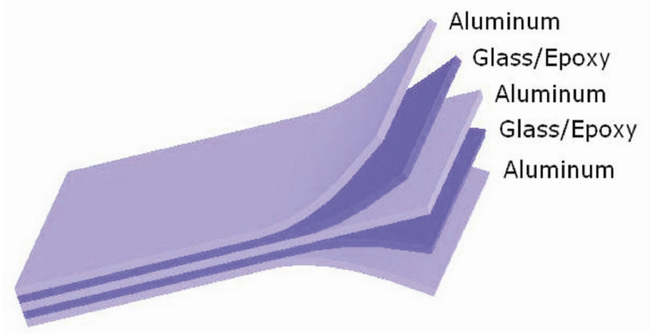


Fig 1: schematic figure of Glare 3/2

The manufacturing process of Glare laminates was: a) removing the thin aluminum oxide film from the surface of aluminum with 1: immersing Al sheets in Methyl Ethyl Ketone (MEK) for degreasing, 2: water break test for inspection of cleaning procedure, 3: hand abrasion with 400 and 200 grit aluminum-oxide papers respectively, to create macro roughness, and 4: etching in alkaline, b) rinsing in hot water and then etching Al sheets in sulfochromic solution (FPL-Etch) based on ASTM D2674 [18] and D2651 [19] standards, c) creating a fuzzy layer of aluminum oxyhydroxide (ALOOH) on Al surface and d) coating aluminum surfaces with an organosilane adhesion promoter, γ-Glycidoxypropyltrimethoxy silane (γ-GPS) to improve the strength and durability of adhesion followed by drying process in an oven at 100̊C for 60 min. In order to study the role of interfacial adhesion on impact behavior of Glare, several specimens were manufactured with a weaker adhesion bonding named GlareWB. In this group of materials, aluminum surface was prepared without neither growing ALOOH nor using adhesive promoter.

LOW VELOCITY IMPACT TEST

A series of drop weight impact tests were done based on ASTM D7136 standard [20] with 4 gripper clamps and 1cm^2 tips area. These tests were conducted on more than 50 specimens comprised of monolithic 1050 aluminum and 200g/m^2 E-glass plain woven layers with 3/2 (3 aluminum and 2 GFRP layers) and 4/3 (3 Al and 2 GFRP layers) layouts. Although mass and geometry of the projectile were constant, impact energy due to falling height varied between 7.5, 10 and 20J. Moreover, to investigate the effect of repetition of impact, the test repeated for 10 and 20 times with impact energy of 1J. Damage characteristics were evaluated by data analysis and image processing method. Table.1 and Fig. 2 show characteristics and shape of the projectile, respectively.

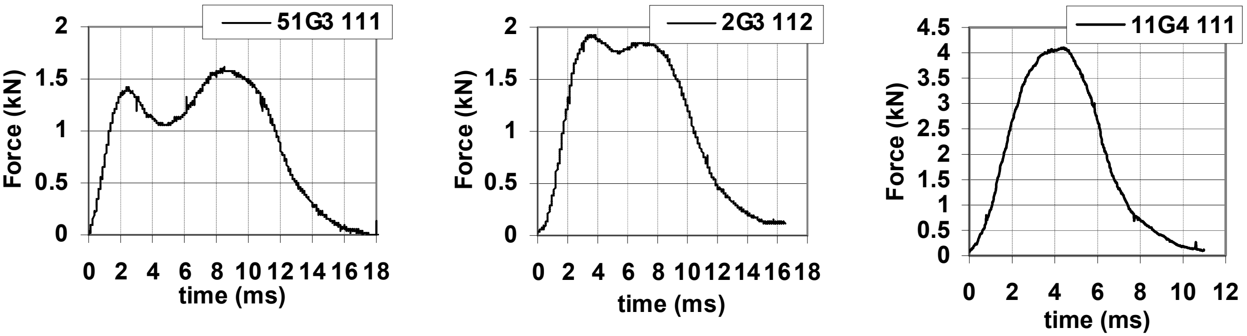
Table 1: Characteristics of Projectile

Material	Net Weight	Tip Shape	Diameter
Steel 316	7.5 kg	Hemispherical	12.7 mm (0.5 in)

Fig 2: projectile figure

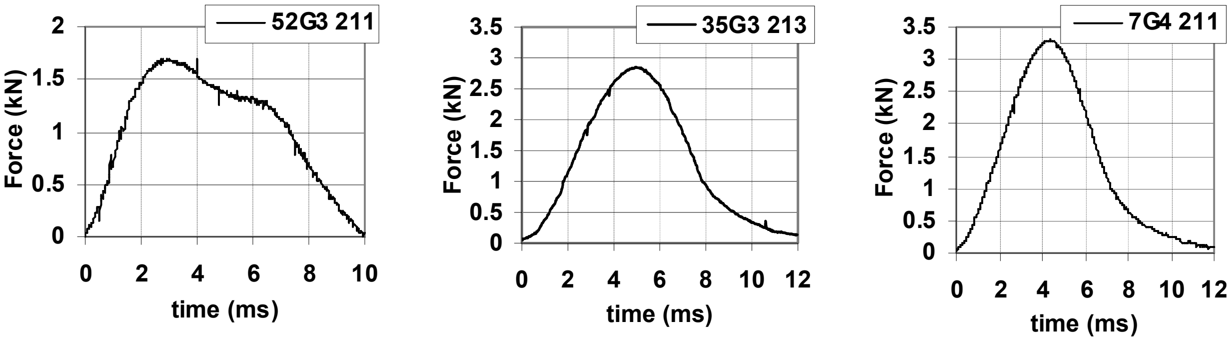
RESULTS

Tests were conducted with a drop weight impact testing machine with a 50 kHz piezoelectric sensor. The force-time data for Glare laminates subjected to 20J, 10J and 7.5J impact energies are shown in Figs. 3-5, respectively. In all cases, GlareWB 3/2 shows somehow lower resistance compare to that of Glare 3/2. Figs. 6-8 illustrate damage zone of Glare laminates after 20J, 10J and 7.5J impact tests. Considering force-time diagrams with these figures, it can be seen for specimens with full penetration, i.e. Glare 3/2 and GlareWB 3/2 under 20J impact energy, force-time diagram shows two peaks points. The first peak is due to the resistance of composite laminate against projectile penetration. Fiber breakage, delamination, fracture of polymer and aluminum layers and crack growth are the main mechanisms that consume the energy of projectile. The second peak is arising because of friction due to increasing of contact area. Figs. 3-5 show that Glare 4/3 has exerted the most force to projectile in comparison to that of Glare 3/2 and GlareWB 3/2. Based on these observations it can be concluded that Glare 4/3 is the strongest material under all conditions. Comparing Glare 3/2 with GlareWB 3/2 diagrams, it can be identified that Glare 3/2 is stronger than GlareWB 3/2 and has approximately exerted 1.6 times more force to the projectile than that of GlareWB 3/2.



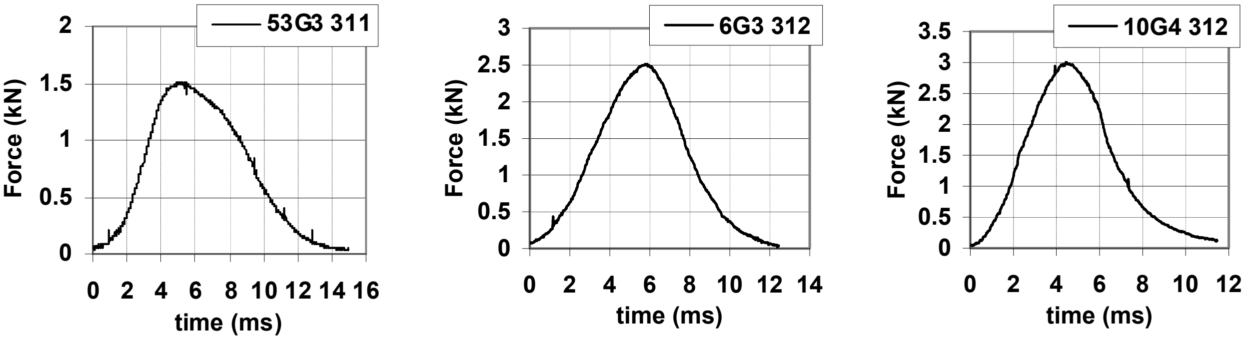
Glare WB 3/2 **Glare 3/2** **Glare 4/3**

Fig 3: Force-time diagram of Glare laminates subjected to 20J impact energy



Glare WB 3/2 **Glare 3/2** **Glare 4/3**

Fig 4: Force-time diagram of Glare laminates subjected to 10J impact energy.



Glare WB 3/2 **Glare 3/2** **Glare 4/3**

Fig 5: Force-time diagram of Glare laminates subjected to 7.5J impact energy.

Figure.6 shows front, back and lateral faces of specimens subjected to 20J impact energy. Only Glare 4/3 was not penetrated. Just two cross cracks aligned to fiber directions can be seen on the rear face of Glare 4/3. Glare 3/2 and Glare WB 3/2 have been fractured and penetrated completely. Extensive interfacial debonding has also been occurred. Image processing analysis show that damaged area in GlareWB 3/2 is 1.5 times greater than that of Glare 3/2.

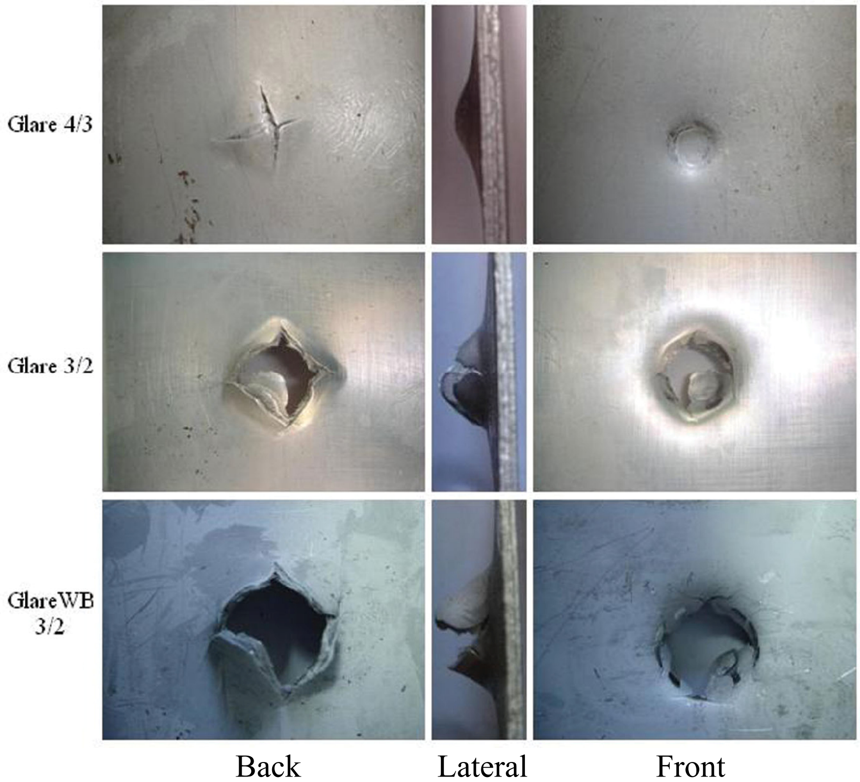


Fig 6: The Front, Lateral and Rear surfaces of the impact-damaged specimens under impact energy of 20J.

Fig.7 shows damaged specimens subjected to 10J impact energy. Same as 20J, Glare 4/3 have shown the best resistance and only a small crack is observed on its rear face. The cross crack aligned to fiber direction shows a considerable damage on Glare 3/2. GlareWB 3/2 has shown the weakest resistance and has fractured completely. Fig.8 illustrates a similar behavior for 7.5J impact tests. Both rear and front faces of GlareWB 3/2 has been damaged and fibers also have been fractured completely.

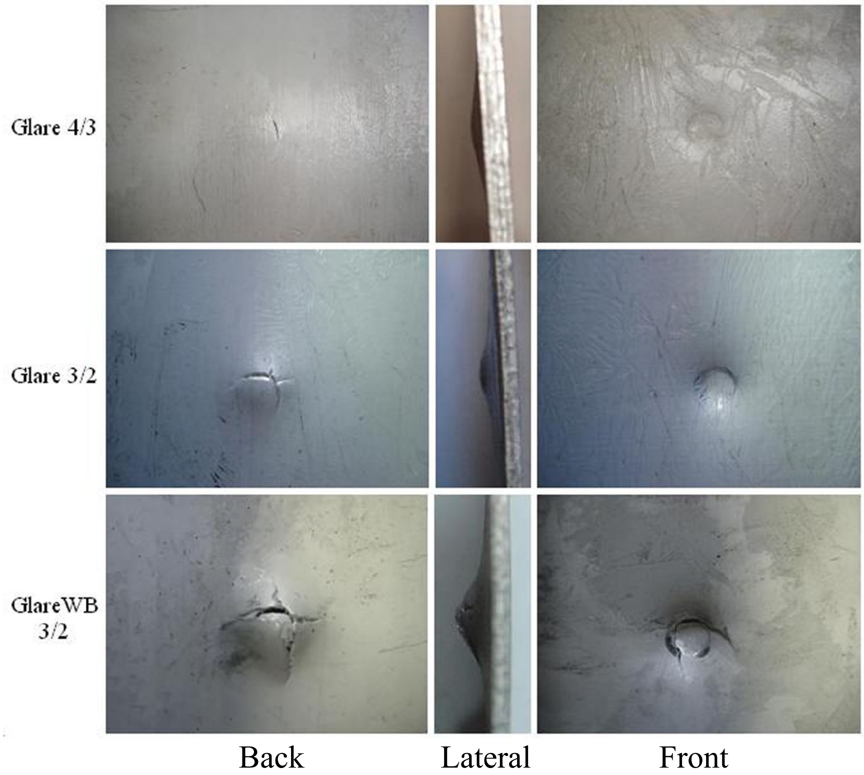


Fig 7: The Front, Lateral and Rear surfaces of the impact-damaged specimens under impact energy of 10J.

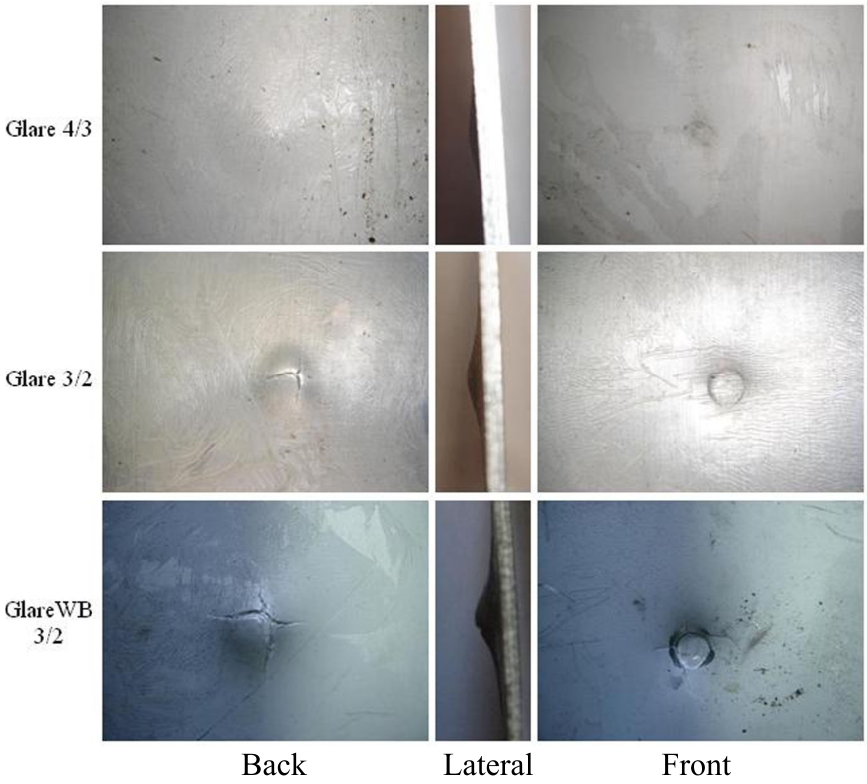


Fig 8: The Front, Lateral and Rear surfaces of the impact-damaged specimens under impact energy of 7.5J.

Damaged areas of all specimens were evaluated by image processing method. Figs. 9-10 show damaged area of front and rear faces, respectively. It is obvious that the novel manufacturing method, specially creating ALOOH fuzzes on Al surface, has played a vital role in increasing of the impact resistance of Glare sandwiches. If A, B and C stand for characteristic ratio of damaged area in ${}^{Glare3/2}\!/_{GlareWB3/2}$, ${}^{Glare4/3}\!/_{Glare3/2}$ and ${}^{Glare4/3}\!/_{GlareWB3/2}$, respectively, for the front face damage area for A, B and C are 0.28, 0.25 and 0.1 while for the back face damage area these values are 0.31, 0.21 and 0.06, respectively.

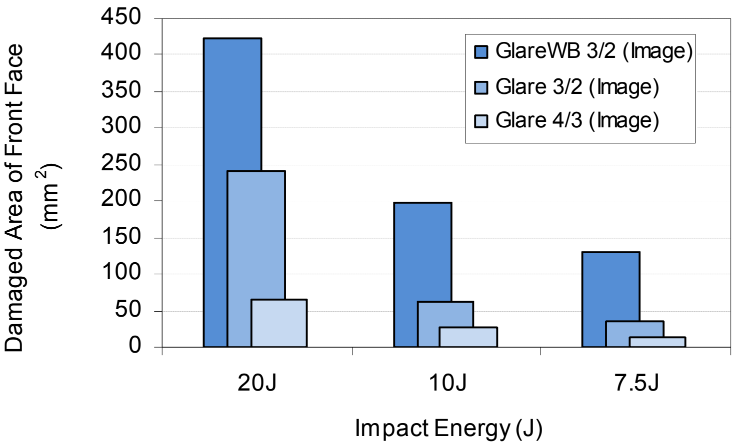


Fig 9: The Front face damaged area of Glare laminates under impact energies 20, 10 and 7.5J.

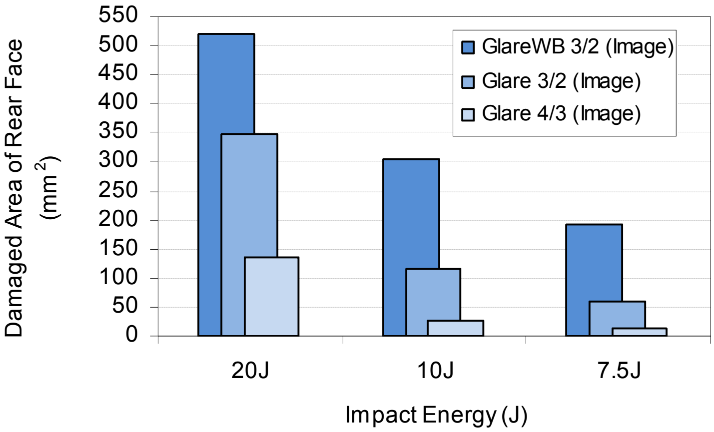


Fig 10: The Rear face damaged area of Glare laminates under impact energies 20, 10 and 7.5J.

Repeated impacts

Figs. 11-12 show Glare laminates under 10 and 20 repeated impacts, respectively. All tests were conducted with 1J impact energy. It is observed that Glare 4/3 resisted 10 successive impacts and only a very small surface crack has been revealed on its rear face. But, a very large cross crack can be seen on rear surface of Glare 3/2. Continuing the repetition of impacts up to 20 times, the crack in Glare 4/3 didn't grow considerably, but Glare 3/2 resisted only 17 successive impacts and after 17th impact the projectile was penetrated completely. From these figures one can conclude that the resistance of Glare laminates against repeated impact loading is very dependant on the laminate thickness.

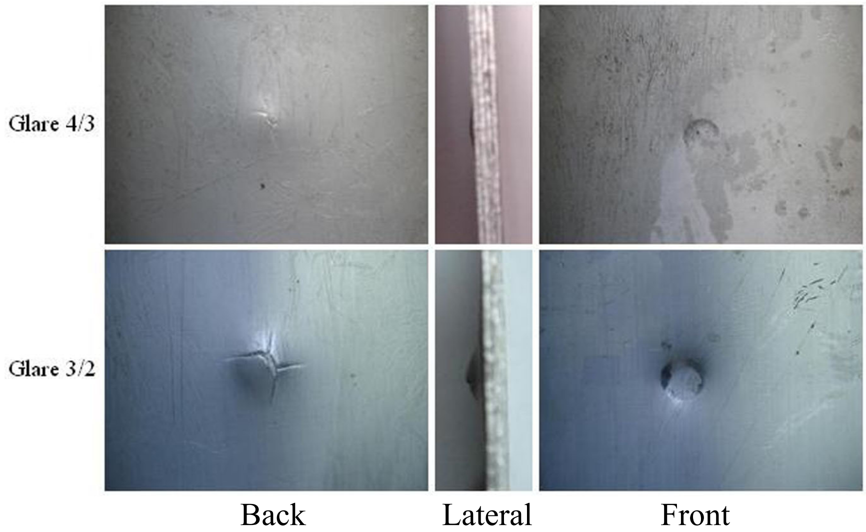


Fig 11: The Front, Lateral and Rear surfaces of the impact-damaged specimens under 10 successive impacts of 1J impact energy.

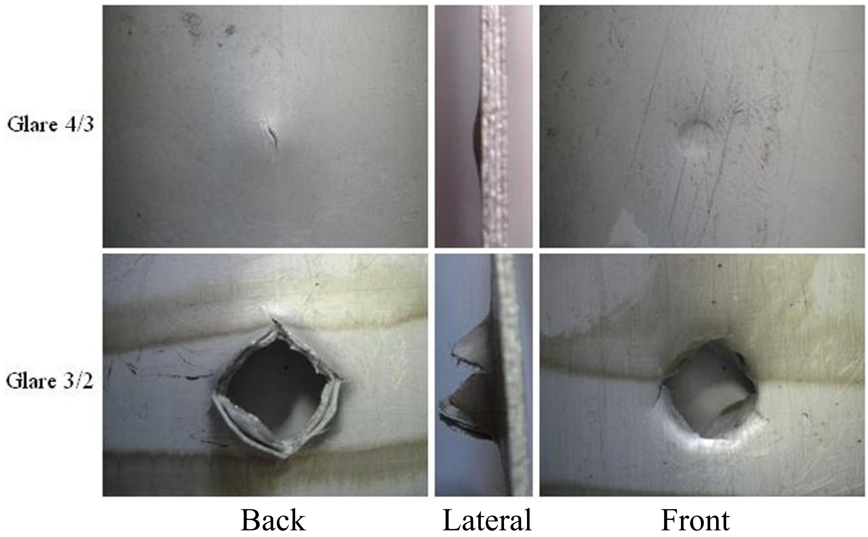


Fig 12: The Front, Lateral and Rear surfaces of the impact-damaged specimens under successive impacts of 1J impact energy. (Glare 4/3 has resisted against 20 successive impacts, however Glare 3/2 has been fully penetrated after only 17 impacts)

CONCLUSION

Experimental results show that for achieving high impact resistance, the use of silane coupling agent such as γ-GPS and creating ALOOH fuzzes on Al surface is necessary. Damaged area of Glare laminates with poor interfacial adhesive bonding was much larger than that of with good bonding. In some cases, the ratio between damaged areas of these laminates was up to 3.5 times higher for GlareWB laminates. Moreover, it was shown that the impact behavior of Glare laminates is very dependant on their thickness. Damaged area in thin Glare 3/2 was 3 to 5 times larger than thick Glare 4/3. In repeated impact loading, the sensitivity of impact resistance of a Glare laminate to its thickness is more considerable.

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