An investigation into low-velocity impact resistance and tensile strength of aluminium-glass fabric hybrid composite

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Abstract. Fiber-metal laminated (FMLs) composites; among of a generation of the hybrid composites are always attractive for researchers and manufacturers, particularly in the aerospace industry, due to high strength-to-weight ratio. This study aims to investigate effect of different kinds of glass-aluminium fabrics on their low-velocity impact resistance and tensile strength. The prepared composite fabrics were laminated using an epoxy resin. The results indicate that the structure and orientation of fabric has a significant influence on low- velocity impact resistance and tensile strength of aluminium-glass fabric hybrid composites.
Keywords: Fiber-metal composite, Low-velocity impact, Tensile strength, Epoxy resin

1. Introduction

Fiber-metal laminated (FMLs) composites are consisting of a new generation of the hybrid composites. They are often produced by resin laying-bonding of metal sheet(s), mainly aluminium, with textile products such as aramid, glass, carbon. It is evident that the multi-layer metal-fiber composites can be individually have positive characteristics of metals and fiber. Some of researches have been done on fiber-metal laminated composites. Vasconcelos et al. [1] studied fracture and impact resistance of epoxy matrix composite materials, reinforced with aluminium particles and chopped fibers. They found that although adding fiber to resin, generally improves composite performance, but composite of fiber and aluminium particles shows more impact resistance than resin-fiber composite. Kolahgar Azari et al. [2] studied the vibratory properties, tensile strength and impact resistance of epoxy matrix composites reinforced with aluminium and glass fiber. They observed that the polymer matrix reinforced with glass fiber has an undeniable influence on quantitative improvement of technical performance of the prepared composite such as stiffness, yield strength, fracture strength and toughness; whereas, using glass fiber and aluminium together increases toughness property of the made composite up to seven times.

Alemi Ardakani et al. [3] studied impact resistance of adhesion-composites made by aluminium layers and glass fiber. They observed that the damage size is greater in laminates with poor interfacial adhesion compared to that of laminates with strong adhesion between aluminum and glass layers. The FMLs with higher adhesion bonding also show better resistance under low velocity impact. As far as to contact force in stronger adhesion is concerned, it is about 25% higher than that of specimens with a weak bonding. They

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also observed that the maximum central deflections in laminates with strong bonding are about 30% lower than that of FMLs with poor adhesion.

Sadighi et al. [4] studied on tensile properties of glass fiber/aluminium laminates with various fiber angles, both analytically and experimentally. The theory model was constructed based on elastic-plastic behavior of the aluminium alloy using Kirchhoff-Love assumption. Test results also showed that fiber sheet, with zero angle in laminates, improves the tensile strength. They found that the prepared composite with different fiber orientation vividly changes specimens' mode of fracture. There also are good agreement between the model predictions and the experimental results. Mathivanan et al. [5] studied on impact properties of aluminium-glass fiber reinforced plastics (GFRP) sandwich panels. They found that the bidirectional cross-ply hybrid laminate (CPHL) exhibits impact performance and damage resistance better than the unidirectional hybrid laminate (UDHL). Increase in aluminium thickness fraction (Al_{tf}) and fiber volume fraction (V_f) resulted in an enhancement in the impact energy required for cracking and perforation. On an overall basis, the sandwich panels showed better impact performance than the monolithic aluminium.

Hasan et al. [6] investigated the impact response of composites reinforced with glass fiber and aluminium layer (GFRAL) against conical and blunt nose projectiles. The obtained results showed higher ballistic limit for conical nose projectile compared to blunt nose. Also, failure mode in case of conical nose projectile impact is petal-shape with localized delamination of the GFRAL specimen. Mahesh et al. [7] studied on comparison of mechanical properties for aluminium metal laminates (glare) with three different orientations such as CSM, woven Roving and 45^o stitched mat. They revealed that the mechanical properties of the composite, structured based on 4 layers aluminium and 3 layers of 45^o stitched mat, has superior tensile and flexural strength than that of the other orientation.

It is evident that the various parameters of reinforcement have an important role in the mechanical properties of composites. The objective of this research was to study the effect of structure and orientation of fabric, as reinforcement, on low-velocity impact resistance and tensile strength of aluminium-glass fabric hybrid composites.

2. Experimental

For the sake of study on two vital mechanical properties of Glass-Aluminium (G-Al) composite such as impact resistance and tensile strength, firstly a number of three different glass fabric samples were prepared, as shown in Table 1.

Table 1. The Used Fabrics

Type	Warp material	Weft material	Woven pattern	Warp density (1/cm)	Weft density (1/cm)	Fabric weight (g/m^2)
Fabric 1	G	G	1/1 plain	8	7	200
Fabric 2	Al Wire/G	Al Wire	2/2 twill	14	7	270
Fabric 3	G	----	Unidirectional (UD)	8	----	104

Then, totally, four various combinations of (G-Al sheet) were layered to make composite samples coded as A to D, based on Table 2. As it is obvious, only fabric sample B was prepared using aluminium wire and glass roving with configuration of one by one, as shown in figure 1.

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The count of glass roving, the diameter of aluminium wire and thickness of aluminium sheet (AL1050) were 1300 dtex, 0.2mm and 0.3mm respectively.

Table 2. Various Laying of the Prepared Composite Samples

Code	Fabric orientation	Layered structure with Al sheet
A	0º	Al+Fabric1+Al+Fabric1+Al
B	0º	Al+Fabric2+Al
C	45º	Al+Fabric1+Al+Fabric1+Al
D	0º	Al+Fabric3+Al+Fabric3+Al

Table 3 shows properties of used epoxy resin, coded as LR2025/HE1515 (hardener) from Pars Co. Hand-layered structures of all composite samples were bonded by epoxy resin; so that, they reach to the same thickness equal to 1.3mm.

Table 3. Resin's properties (LR2025/HE1515)

Viscosity at 25°C (Cp)	Specific gravity (g/cm^3)	Compressive strength (ASTM D695M) (Kg/cm^2)	Impact resistance (ASTM D256) (Kj/m^2)	Tensile strength (ASTM D638M) (Kg/cm^2)	Adhesive strength (ASTM D1002) (Kg/cm^2)	Bending strength (ASTM D790M) (Kg/cm^2)
440	1.1	751	6.398	503	85	652

For making composite samples, the method recommended by Delft University of Technology, Netherlands [8] was initially used to prepare surface of the employed aluminium sheet. In this method to improve to bond, the surface preparation of the aluminium sheets was made according to the four steps, as follow; 1) degreasing: cleaning of metal surface by a soft brush or cloth soaked in acetone, 2) rinsing: washing of the parts by high pressure water at 20-30ºC, 3) Sanding: roughening of the aluminium sheet surface in order to increase the contact surface of the sheet with resin and 4) re-rinsing and drying: high-pressure washing of the aluminum sheet at 20-30ºC to remove remaining particles from the sanded surface and then drying of the prepared sheet in the room weather for 45 minutes. Then, the next steps of the composite making procedure such as hand-laying with resin and also curing were done. The curing process was performed under a pressure of about 2bar for 12 hours. Finally, the composites were fully cleaned and then, examined with the tests such as areal weighing, thickness and also specific gravity.

Figure 1. Image of Fabric 2

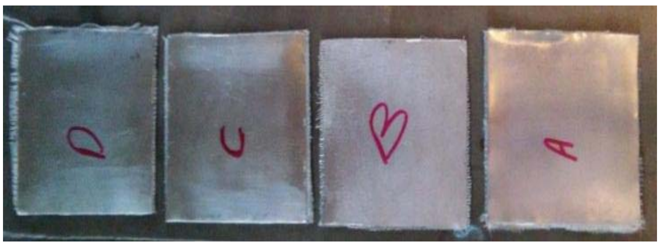

Figure 2. The used composite samples for impact resistance test

In order to evaluate impact resistance, the drop-weight impact test was conducted based on ASTM D7136 standard with five repetitions on each sample. Size of sample was 10 cm × 10 cm, as shown in figure 2. In the drop test, energy level of the impact was considered constant at 10J by setting appropriate height of the drop-weight. The resultant fractured area of the samples was measured using image processing technique written in MATLAB software. It was reported as an indicator of the impact resistance, the smaller the area the greater the impact resistance.

The tensile strength testing was performed by SANTAM Strength Tester, STM-150 according to standard test method of ASTM D3039. Five tests of each sample in size 250 mm × 25 mm were done with the same constant rate of elongation of 2mm/min. The one-way ANOVA statistical analysis by SPSS software was also employed to investigate signification effect of the studied variables. The independent and response variables were different structures of the composites, as input and values of the low-velocity impact resistance and tensile strength, as output respectively.

3. Results and Discussion

The obtained illustrated-results of the low-velocity impact test were shown in figure 3. As seen, magnitude of the fractured area can be considered as an index for identification of the impact resistance. Figure 4 typically shows successive steps of defect finding process which is due to the fractured area. It is evident that the illustrated-results can be easily converted to the numerical values of the area. The quantitative results of the low-velocity impact resistance test, based on area of the fractured zone, are also shown in Table 4.

Table 4. The low-velocity impact test results

Code	Spec. gravity (g/cm^3)	Fractured area (mm^2)
A	2.42	2325
B	1.92	4447.5
C	2.42	2880
D	2.34	6622.5

The results indicate that the sample A, with zero degree of fabric1 as reinforcement, has more impact resistance than other samples. On the other hand, the sample D, with UD-fabric, shows the minimum resistance. There was also no significant difference between samples A and C, based on ANOVA statistical analysis. Though, Sample B shows more impact resistance than sample D, but it is weaker than samples A and C. Therefore, it can be argued that for increasing impact resistance, orientation in multi-directions is better than orientation in single-direction.

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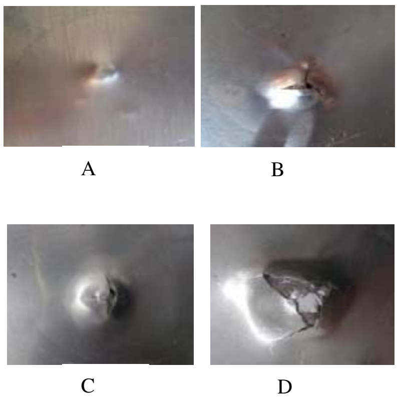

Figure 3. Low-velocity impact test of first sample of four kinds composites.

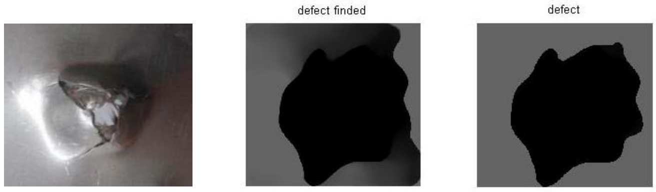

Figure 4. Finding steps of the defect

Tensile strength behavior of the samples was also conducted by a heavy-duty universal strength tester. The force versus elongation curves of the samples are shown in figure 5. The summary of the obtained results is also presented in Table 5.

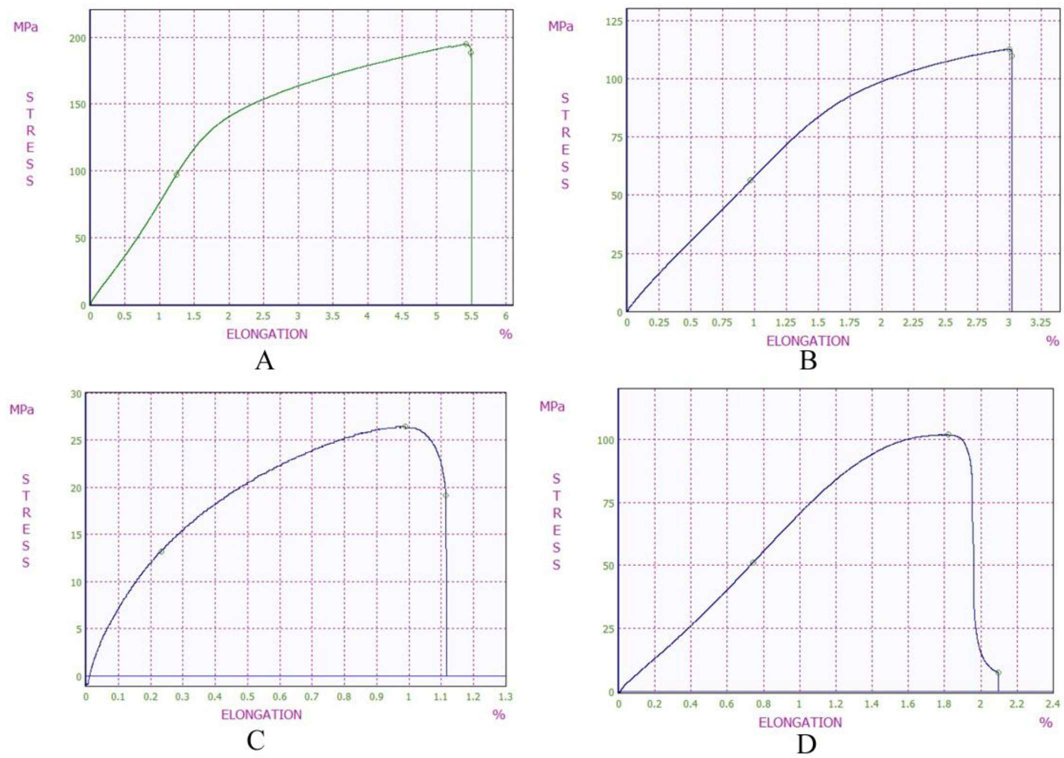

Figure 5. Tensile strength test curves. First sample of four kinds composites

The results indicated that the sample A, with zero degree of Fabric1 as reinforcement, has the highest tensile strength and sample C, with angle 45 degree of Fabric1, shows the lowest strength at yield point and minimum tensile elongation. Difference between samples A and C indicates importance of the orientation of fabric at multilayer composites.

There was no significant difference between the samples B and D at the yield point, based on ANOVA statistical analysis. whereas, the sample B has the lower specific gravity and less number of layers, compare to other samples, but shows better tensile strength than samples C and D, although is weaker than sample A. This is due to the fact that, appropriate adhesion between layers of sample B.

Table 5. The tensile strength test results

Code	Spec. gravity (g/cm^3)	Force (N)			Stress (Mpa)			Elongation (%)		
		Yield	Uts	Break	Yield	Uts	Break	Yield	Uts	Break
A	2.42	2904.7	6021.7	5778.4	89.744	185.67	179.55	1.071	4.997	5.08
B	1.86	1688	3257.2	3134.6	52.37	103.66	99.77	0.902	2.12	2.72
C	2.38	441.12	891.6	629.95	13.82	27241	20.04	0.302	1.01	1.27
D	2.33	1571.4	3114.6	361.2	51.041	102.94	11.28	0.89	1.912	2.43

4. Conclusion

The obtained results denote that the studied independent variables have a considerable significant effect on impact resistance as well as tensile strength. Less fractured area signified more impact resistance. Using from 100% glass plain-weave fabric without any orientation in laying, shows higher tensile strength and less fractured area due to increase in effective contact surface of bonding areas and also higher bonding strength between resin and glass. It is used aluminum wire and glass fiber combinations (Fabric2) as reinforcement in sample B, which is almost 20% lighter than other examples at the same thickness. It has better performance in impact resistance compared to the sample D and more tensile strength compared with samples C and D. By considering samples A and C, it can be seen that, although, the orientation of fabric in multi-layer composites has no signification effect on impact resistance. But, this is very important for tensile strength behavior.

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