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Experimental Investigation on the Inter-Laminar Strength in a Hybrid Elastomer Modified Fiber Metal Laminate Under High and Low-Velocity Impact and Quasi-Static Bending

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ABSTRACT: Growing the need to impact resistive structures, hybrid laminates have been absorbed much attention. To reach appropriate strength, high stiffness, and good energy absorption, the interfacial adhesion between different layers is important. The present paper is an attempt to assess the adhesion between different layers in a hybrid laminate consists of natural rubber, glass/epoxy composite and two layers of aluminum under high and low-velocity impact and quasi-static three-point bending conditions. In order to minimize the debonding, three kinds of specimens were made by three different adhesives including Chemosil 222 and its primer, Bylamet S2 and Cyanoacrylate. Based on the results obtained from high and low-velocity impact tests, the best choice for elastomer/composite, composite/aluminum and elastomer/aluminum interfaces are bylamet S2, cyanoacrylate, and chemosil, respectively according to delaminated area. Samples containing bylamet S2 adhesive in all interfaces have a better performance in terms of dynamic stiffness.

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1- Introduction

During recent years, composite materials have attracted much attention in a vast variety of applications. Owing to outstanding features such as low weight, high stiffness, and good thermomechanical properties, these multi-phase materials have found popularity than their monolithic counterparts [1]; however, they suffer from low resistance in impact applications [2]. One solution to improve the perforation properties of composite laminates is to replace the brittle phase by an elastomeric media which in turn not only does reduce the threshold failure load but also retards the metal failure [3-5]. To maintain the structure stiffness, it is reasonable to use both composite and elastomeric phases but the layers' adhesion could be critical.

2- Methodology

2- 1- Materials

The aluminum which has been used is 6061-T6 (AMAG rolling GmbH) with a 0.5 mm thickness; elastomer layer is a natural rubber which has been compounded with different elements such as calcium carbonate, zinc oxide, and sulfur to achieve desirable elastic properties. The composite phase consists of epoxy as the matrix media and 6 layers of woven E-glass fiber as the reinforcement. The composite phase was manufactured by a hand layup process and a layer of peel ply was pulled off from both external surfaces to produce a rough area for better adhesion. Three types of adhesives were used to bond the layers including Chemosil 222 and its primer (Chemosil 211), Bylamet-S2 and 2-ethyl cyanoacrylate.

2- 2- Fabrication process and test procedure

Before the application of each adhesive, the surfaces of aluminum and composite were prepared according to ASTM standard D 2651 and D 2093, respectively. The rubber layer should be cured during a vulcanization process at the temperature of $160\,^{\circ}C$ for 4 minutes (according to the rheometer test). This process was done in a 2 mm thickness mold on a hot press apparatus.

After vulcanization, the bonding between layers was accomplished at room temperature. The thickness of rubber in all types of specimens was about 2 mm. A scheme of the layers' arrangement is presented in Fig. 1.

High-velocity impact tests were carried out using a gas gun apparatus with an impact velocity of about 180 m/s; besides, low-velocity impact and quasi-static indentation tests were also conducted in initial energy of 37.8 joule and constant rate of 2 mm/min, respectively. Each type of sample was tested in two manners. In the first set, the elastomer layer had been located in the front side which will be named Elastomer Forward (EF) in high-speed tests and Elastomer Upward (EU) in low-speed and indentation tests; In another set the elastomer had been located on the backside of the sample which will be named Elastomer Backward (EB) in high-speed tests and Elastomer Downward or (ED) in low-velocity and indentation tests.

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Table 1. Petal crack lengths in Aluminium face sheet

Adhesive	EB Group (mm)	EF Group (mm)
Chemosil	16.5	19.5
Byla-S2	17.3	17.5
Cyanoacrylate	18.3	18

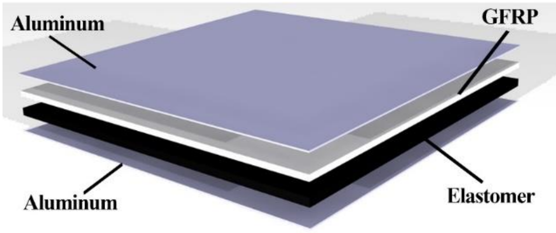

Fig. 1. The layers' arrangement in the hybrid structure

3- Results and Discussion

3- 1- High-velocity tests

The cross-section of samples was analyzed through an image processing software and the delaminated areas were obtained. Besides; the petal crack lengths were also obtained and presented in Table 1.

According to the results, the best adhesion for the elastomer/aluminum interface is observed to be obtained when using chemosil adhesive.

In the aluminum/composite interface the preliminary result was that the chemosil had the best performance from the kind of failure (adhesive or cohesive) point of view. Because of the more petal crack lengths in the case of chemosil, the degradation of the composite phase is the reason for the cohesive failure and therefore the use of chemosil for composite phase is not recommended. In the composite/elastomer interface, the byla-S2 had the best performance according to the damage length.

Table. 3. Flexural properties of the samples under quasi-static flexural loading

Adhesive	Configuration	Flexural strength (kN)	Flexural stiffness (kN/mm)
Cyanoacrylate	ED	10.09	0.019053
	EU	12.94	0.0208
Byla S2	ED	8.43	0.02471
	EU	12.5	0.0255
Chemosil	ED	7.96	0.02178
	EU	7.6	0.02327

3- 2- Low-velocity impact

The delaminated length is obtained for the specimens and it was observed that the best adhesive for bonding elastomer/aluminum interface was chemosil. This preference was because of the minimum damage and delamination lengths, which shows better adhesion compared to the other adhesives. For the aluminum/composite interface the primer result was that the chemosil had the best performance from the kind of failure (adhesive or cohesive) point of view; however, according to the high-velocity test results and degradation of composite phase, the next choice for this interface could be cyanoacrylate. For the composite/elastomer interface, the chemosil had the best performance according to the damage length.

According to the force-displacement diagrams, the required mechanical parameters were extracted and presented in Table 2. As observed, the specimens made by Byla-S2 adhesive have the highest stiffness; therefore, the overall layer adhesion in this specimen is better than the two other adhesives.

3- 3- Quasi-static three-point bending

According to the force-displacement diagrams, the flexural strength and stiffness were extracted and presented in Table 3.

This table illustrated that the specimens made by Byla-S2 adhesive have the highest stiffness than the two other specimens; therefore, the best choice to have an optimum adhesion could be the Byla-S2 adhesive.

4- Conclusions

In the present study, a four-layer laminate consist of

Table. 2. Dynamic stiffness and maximum force obtained from displacement diagrams

Parameters	Chemosil EU	Chemosil ED	Cyanoacrylate EU	Cyanoacrylate ED	Byla EU	Byla ED
F_{max} (N)	2992	3077	2930	3485	3076.6	3277.4
K (kN/mm)	0.42067	0.42	0.43984	0.42644	0.50694	0.47284
Absorbed energy (J)	25.9832	26.6813	24.9295	24.9538	18/7438	26.2671

aluminum, elastomer, and composite was fabricated and the layers' adhesion was studied under high and low impact and quasi-static three-point bending. The results could summarize as below:

• In high-velocity impacts, the best adhesion between aluminum and elastomer was achieved when using the chemosil adhesive which was according to minimum petal crack length and damaged area.

• In high and low-velocity impact tests, the cyanoacrylate adhesive had the best performance in aluminum/composite interface.

• In the composite/elastomer interface, the byla-S2 has the best performance according to the minimum damaged area; however, due to the proximity of the results, the Cyanoacrylate could also be a reasonable choice. In low-velocity impact tests, all three adhesives have similar behaviors and each could be used based on the designer's opinion.

• Based on the low velocity and quasi-static three-point bending tests, dynamic stiffness in the case of using Byla-S2 is higher than the two other adhesives; therefore, this adhesive is a suitable choice in low strain rate applications.

• The results demonstrate that chemosil is the best choice for aluminum/elastomer interface in all loading conditions which is approved by other published papers; besides, the same results have been obtained in both low and high-velocity impact tests which indicates that the loading rate has a minimum effect on adhesive performance.

• To sum up, if the laminate is exposed to complete failure and the aim is to maintain the structure coherent, the results of the high and low impact tests in delamination filed should be considered; however, if the aim is to design a structure to bear loads lower than the threshold, dynamic stiffness results obtained from low-velocity impact and quasi-static tests are recommended.

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