Fracture Toughness of a Novel GLARE Composite Material

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Abstract--* A great number of composite materials consist of fibre metal laminates based on light aluminium have been manufactured and tested. Glass laminate aluminium reinforced epoxy (GLARE) is the common types of these composites. (GLARE) is a fibre metal laminate (FML) composed of several very thin layers of metal (usually aluminium) interspersed with layers of glass-fibre ͼpre-preg," bonded together with a matrix such as epoxy. A special surface treatment is made for aluminium sheet plate to increase the debonding strength among the various layers of this composite material. (GLARE) material is manufactured with five stacking sequence using different woven glass fibre layers (1, 2, 4, 6 and 8 layers, respectively). Fracture toughness of such material is of great intense. Therefore, both longitudinal and deboning fracture toughness are measured using double edge notch and double cantilever beam specimen, respectively for each stacking sequence. The longitudinal fracture toughness values are measured as; (228.54, 244.86, 272.632, and 603 MPa√(m))according to the layers number, whereas debonding strength is found as nearly (2 kJ/m^2) for each specimen. Results of both laminate types indicate that the increasing in the volume fraction of composite; (Vc), in the FML results in a significant increase in its tensile strength and consequently in its longitudinal fracture toughness, while little difference in debonding fracture toughness has been reported.

Index Term-- **GLARE, Composite, R-curve, Debonding strength, Fracture Toughness**

INTRODUCTION

Glass fiber reinforced epoxy and aluminum alloy (GLARE) is considered as hybrids composite Fiber–metal laminates (FML's). These types of material have applications in aircraft structures such as the upper fuselage of Airbus A380 industry [1, 2, 3]. FML's are well-known by their high damage tolerance and their relatively very low fatigue crack propagation rates [3, 4]. Machinability and durability related to many metal of superior fatigue properties are advantage of Laminates system [4, 5, 6].

Corte´s and Cantwell [7] investigated the fracture properties of fiber–metal laminates (FML) based on a lightweight magnesium alloy. They used the single cantilever beam geometry (SCB) which has shown that a little or no surface treatment is required to achieve a relatively strong bond between the composite plies and the magnesium alloy. High velocity impact test is carried out in their work to investigated damage tolerance of such material; they found extensive delamination and shear fracture in the outer magnesium alloy plies which contribute in the energy-absorbing capacity of these laminates. On the other hand, damage tolerance related to impact behavior for FMLs had been studied in many works [8, 9, 10].

Castrodeza et al. [11] measured crack resistance curves of a bidirectional (GLARE) laminate using small compact tension (CT) specimens based on the elastic compliance technique. The results showed that the elastic compliance technique seemed to be applicable to bidirectional (GLARE) laminates, and gave good predicting stable crack growth during these tests.

Reyes and Cantwell [12]investigated the mechanical properties of a glass fiber-reinforced polypropylene (FML). They showed that the interfacial fracture toughness increased initially with the crosshead displacement rate up to 100 mm/min before reducing again at higher displacement rates. They concluded that this system offers excellent mechanical properties and, due to the thermoplastic nature of the matrix in the composite, an ease of repair. Many investigations [13, 14, 15] investigated mechanical properties of FMLs in fatigue and tensile strength and they compared the obtained results with the monolithic aluminum alloy.

The novelty of the present paper is to study the fracture toughness of the (GLARE) as sandwich composite and to investigate the debonding strength between the aluminum surface and glass fiber composite laminates using delamination test procedures

Manufacture of GLARE material

The used materials in the manufacturing of (GLARE) composite are woven E-glass fiber, epoxy resin and aluminum alloys sheet of 0.5 mm thickness. Table 1 lists the mechanical properties of these components. The (GLARE) composites are fabricated using hand layup technique according to reference [16]. Mainly, the treatment of aluminum surface should be taken into consideration upon fabrication procedure because it is a dominant factor in increasing the debonding between aluminum and other component of the composite material. The treatment of (GLARE) aluminum surface consists of seven steps that are described in details in reference [17].

(GLARE) specimens have 1, 2, 4, 6 and 8 layers of composite laminates are sandwiched between the two aluminum sheets (see Fig. 1). The obtained thicknesses are 1.1, 1.12, 1.2, 1.26 and 1.3, respectively according to the number of layers.

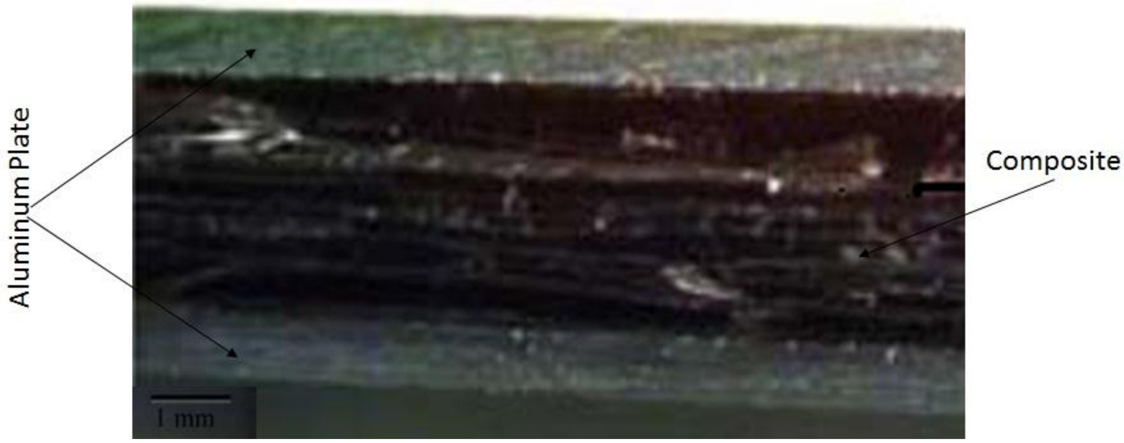

Fig. 1. GLARE specimen cross section

The volume fraction of glass fiber composite laminate sandwiched between the two aluminum plates is determined using ignition removal technique according to ASTM D3171-99 standard [18]. Ignition technique results showed that the glass fiber volume fraction is about 45% and 55% of the epoxy resin volume fraction.

Mechanical testing

The fracture toughness in longitudinal direction is investigated using double edge notch specimen (DEN) which has dimension as shown in Fig. 2 and thickness of 1.3 mm. This type of specimen is suitable for (GLARE) material. The test is performed according to ASTM E399-81 [19] and [[20, 21]. The load displacement diagram is recorded and obtained through computerized system, which is attached to the testing machine. The delamination test is carried out using double cantilever beam as shown in Fig. 3. The test is performed according to ASTM- D 55280 stander [22]. The tests are carried out on universal testing (***machine model WDW-100***) of load capacity **200** kN and at a controlled cross head speed of 2 mm/min.

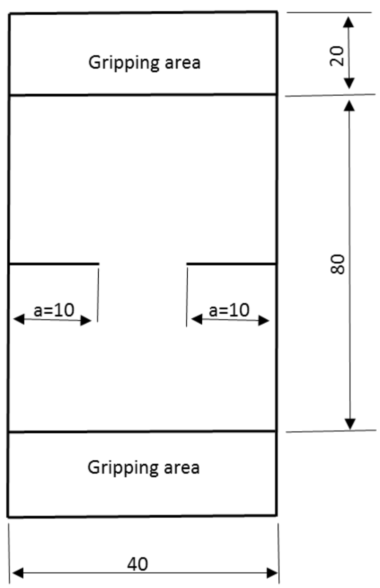

Fig. 2. Geometry of Double edge notch specimen

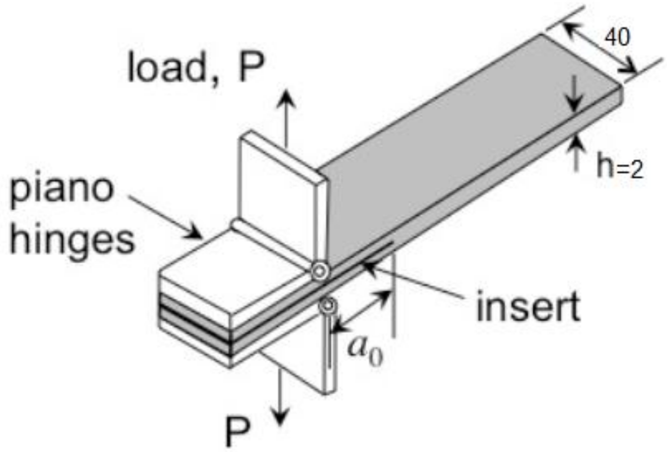

Fig. 3. Double cantilever beam

Result and Discussion

Double edge notch

The fracture toughness of GLARE is measured using data reduction of (DENS) through the load displacement diagram of each specimens. The fracture toughness (K_{IC}) then can be calculting using Eqn. 1 [23].

$$K_{IC} = \alpha\sigma\sqrt{\pi a} \qquad 1$$

Where ($\sigma = \frac{p}{BW}$) is stress at maximum load or failure stress, (B, W) thickness and width of tested specimen respectively, (a) crack length, (P) maximum load capacity and (α) geomtric correction factors which can be calculated by Eqn. 2.

$$\alpha = 1.12 + 0.41(a/w) - 4.78(a/w)^2 + 15.44(a/w)^3 \qquad 2$$

Therefore, the surface release energy can be calculated as follows in Eqn. 3 [23]:

$$G_{IC} = \frac{{K_{IC}}^2}{E} \qquad 3$$

The maximum load capacity (P) is measured from Fig.4 for each layup specimen. Fig. 4 illustrates crack resistance for each specimen with different glass fiber layers, it is observed that, crack resistance (σ) increase with increasing number of layers. The obtained results are listed in Table 1. Values of young modulus is obtained for each specimens from flexural test that performed in previously work by author [17]. The failure modes for all specimen is net tension test modes and it is shown in Fig. 5. Increasing of glass fiber reinforced composites into the specimen increase ductility as shown in Fig. 4. Fracture toughness increase with increasing number of layers but the manufacturing need very careful to avoid delamination. For specimen with 4 layers as its stiffness is very high with small fracture stress due to delamination occurred through the specimen. It is clearly shown that exists of aluminum plates smoothness the flow of curve. It is well known the glass fiber composite laminates cracked tension specimen have roughly flow curves with a lot of steps which is due to crack bridging.

Table I Mechanical properties measured

Stacking sequence	Maximum strength, MPa	Young modulus, GPa [17]	Fracture toughness K_{IC}, $(MPa\sqrt{m})$	Surface release energy G_{IC}, kJ/m^2.
1 Layer	35	244.6	228.54	213
2 Layers	37.8	293.5	244.86	204
4 Layers	42.66	438.9	272.63	168
6 Layers	65.47	531	427.5	344
8 Layers	92.38	682	603.22	533.34

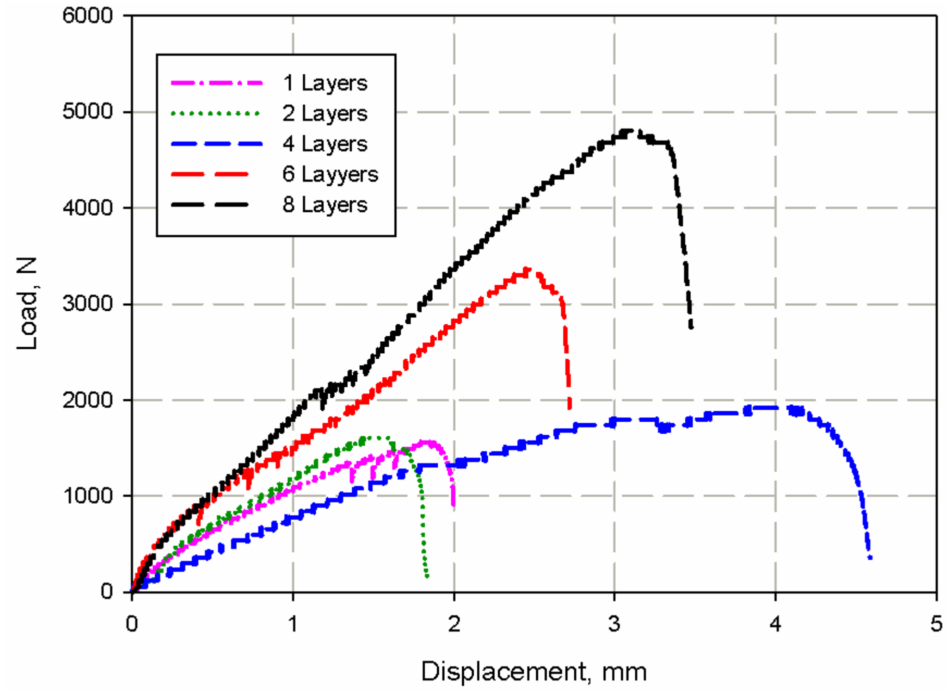

Fig. 4. Load Vs. Displacement in DENB specimen

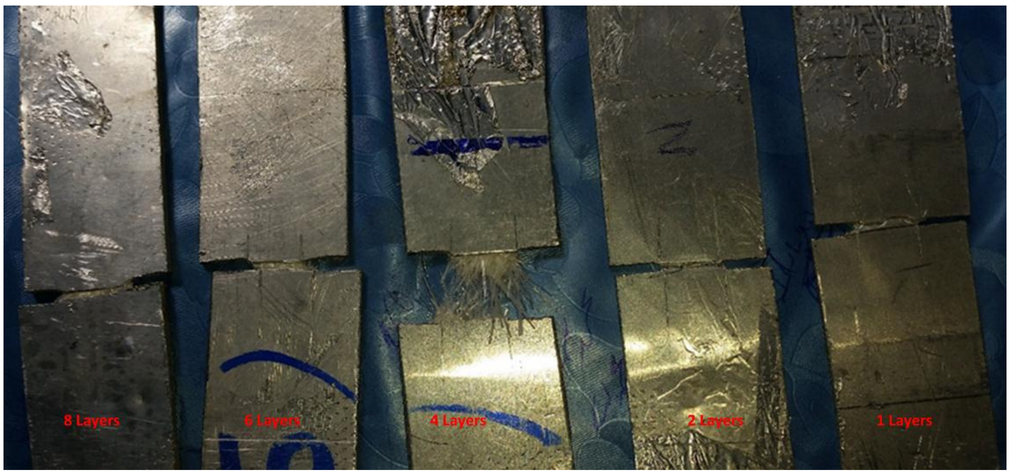

Fig. 5. Mode of failure in DENB specimen

Delamination resistant (through thickness strength)

Double cantilever beam

Experimental testing was performed for Mode I (delaminar) testing using three specimens where they measure the load and deflection of a specimen to determine the fracture toughness (G_{IC}) of a composite, according to ASTM D5528 [22]:

$$G_{IC} = \frac{3p\delta}{2ba} \quad (4)$$

Where (b) is the specimen width, (P) is the applied load, (δ) is the displacement of the load-point, and (a) is the crack length. The applied load is measured using load displacement curve which is shown in Fig. 6. It is clear the knee at the beginning of bond failure at (38N), after maximum load crack propagates through softening profile. The failure mode I is shown in Fig. 7. The surface release energy measured is nearly 2 kJ/m^2. It is clear that the delamination is at interfaces between one of aluminum plates or between glasses, fibers reinforced layers and the two aluminum plates interfaces.

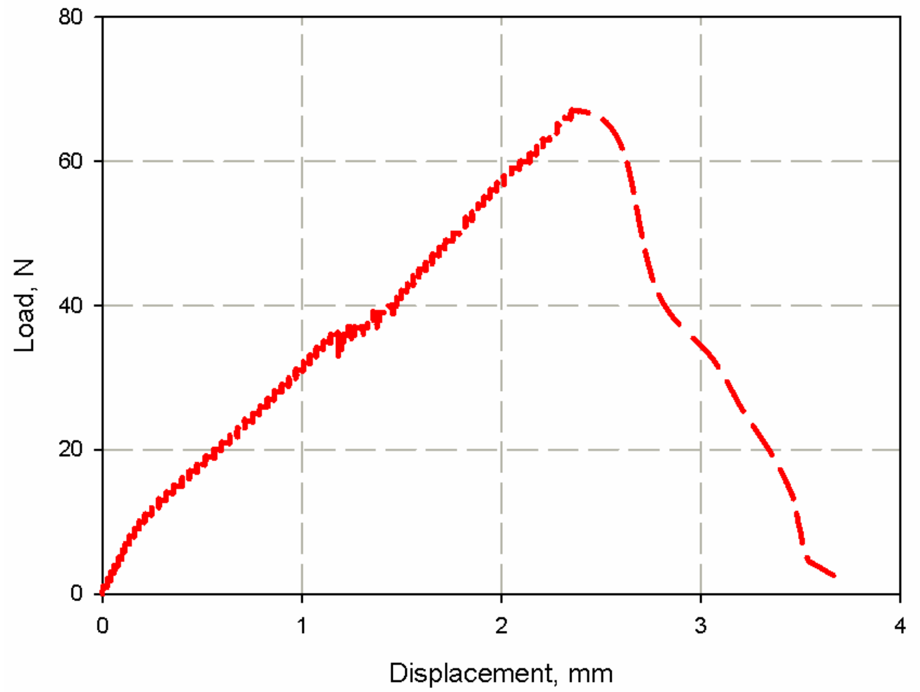

Fig. 6. Force displacement curve

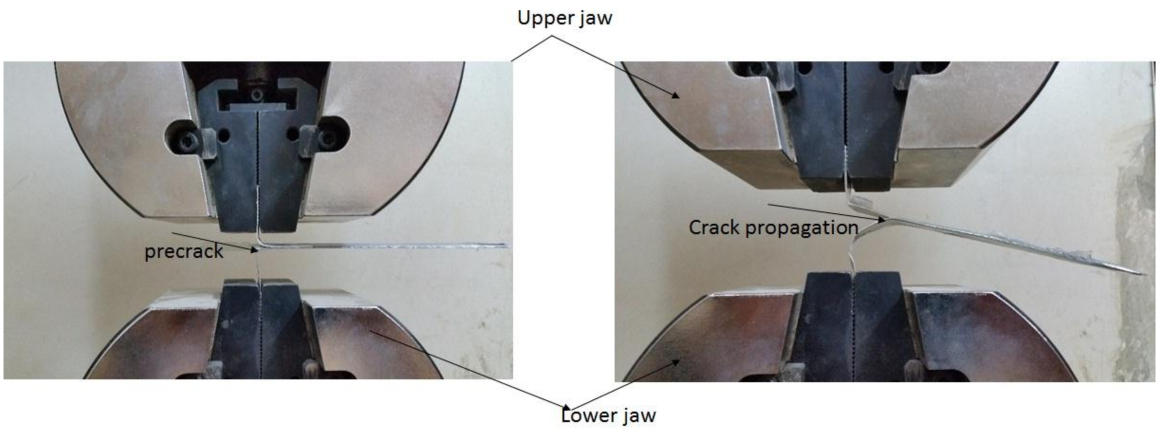

Fig. 7. image of crack propagation

CONCLUSION

Mainly important fracture parameters are measured in the present paper. It is achieved that Longitudinal fracture toughness through a general stander test specimen is increasing with increasing number of insert layers of glass fiber between aluminum plates for GLARE material but this with keep thickness small as possible to avoid delamination. However, the surface release energy of the through thickness is investigated through stander double cantilever beam specimen is established that bonding between glass fiber composite layers at interfaces is relatively weak and need extra works to get stronger in the through thickness strength.

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