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Double Lap Shear and Peel Properties of Rigid Foam Core Glass/Epoxy Skin Sandwich Composites with Different Foam Densities

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Abstract **-The focus of current investigation is on adhesively bonded joints of glass/epoxy skin- rigid unfilled thermoset foam core material sandwich composite structures to study their shear failure properties. Rigid foam cores of Polyurethane (PUF) or Polyisocyanurate (PIR) of four different densities – 64,125,250 and 500 kg/m^3 were used with uniform thicknesses. Plain weave glass fabric and a room temperature epoxy GY 257 withA140 hardener were used for the skin design. The lap shear and peel test specimens were prepared by vacuum bagging technique. The double lap shear properties were compared with the single lap shear properties evaluated earlier and a detailed comparative analysis was made on the influence of different foam densities and their adhesion to the skin on the failure behaviour of otherwise identical sandwich composite samples. The peel properties of the skin were also evaluated in Mode I cantilever set up against foams of different densities. The highlight of this work is in the comparison of porosity levels of foams, their influence on adhesive and cohesive fracture, failure mode property correlation and the usefulness of the obtained data in the design of sandwich joints.**

Keywords: Sandwich composites, Double lap shear test, Peel test, PUF, PIR, Failure analysis

I. Introduction

A structural sandwich composite is a form of laminated composite comprising a combination of different materials bonded to each other. They are widely used in aerospace, automotive and marine industries because of high stiffness and strength at a lower weight ratio. In this investigation glass/epoxy skin and two rigid foam materials –polyurethane and polyisocyanurate with different densities were used to fabricate the sandwich specimens by vacuum bagging technique.

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Studying shear failures by mode I - by opening and, mode II - by sliding is the main aim of the current investigation, as the evaluation of accurate shear properties of core is important in determination of the overall sandwich behaviour[1]. Double lap shear and peel tests were performed on the adhesively bonded joints of composite structures in order to evaluate the shear properties in mode-I and mode-II loading conditions. There are various types of failures modes occurring in the lap shear joints like adhesive, cohesive, thin layer cohesive, stock break failure, light fibre tear failure, adhesive to adhesion promoter, adhesion promoter to substrate etc. [2].Significant shear deformations and core shear stiffness influence the interaction between constituent components as most of the load is carried by the lighter weight core[3].

II. Experiment

A. *Fabrication*

Plain weave glass fabric, PUF and PIR foams, Epoxy resin and hardener were used to fabricate the sandwich specimens for two different test configurations, double lap shear test and peel test.

Double Lap Shear Specimen Fabrication- The glass/epoxy laminate skin, polyurethane and polyisocyanurate foam materials with 10mm thickness and 64,125,250 and 500 kg/m^{3}densities were used as the core materials. The fabrication process for double lap shear specimens was carried out in two steps. Firstly, the four layers of glass/epoxy skin laminate was prepared by the vacuum bagging technique. This technique will help maintain atmospheric pressure on the glass/epoxy laminate panel evenly and allow the resin to impregnate into the glass fabric. The volume fraction of the glass fabric (V_f) was maintained at 0.3. In the second step of the process, a groove of about 1mm thickness was made in the foam material, in order to fit the laminate tab. A coat of mixture of epoxy resin and hardener were applied on the tab and sides of the groove to which the former was inserted and cured at room temperature, atmospheric pressure. The double lap shear specimens had four layered glass/epoxy skins on either side of the core as shown in Figure.1, initially for all densities with a laminate thickness of 1.2mm. The numbers of layers were increased later for higher densities, due to laminate failures in the first stage of testing. According to Banea & Lucas [4] , thick adherends reduce, but do not eliminate peel stresses . EW Godwin, in the edited book by Hodgkin son [5] has also thrown light on specimen preparation.

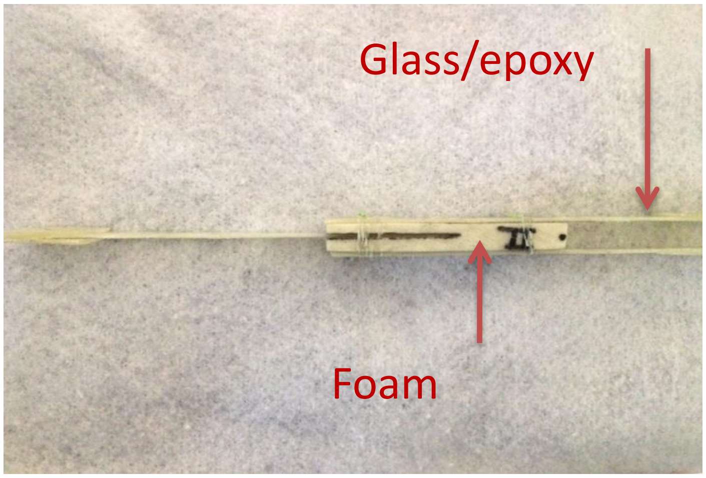


Figure 1: Double lap shear test specimen

Peel Test Specimen Fabrication- The sandwich composite panels for the peel test [3] were fabricated using the vacuum bagging technique for rigid foam densities of 64, 125, 250 and 500 kg/m^3 ,separately. The sandwich specimens had four layers glass fabric 260 GSM skin on either side. The volume fraction of the glass fabric (V_f) was maintained at 0.3 for all the test panels. Specimens were machine cut and bonded with latch type hinges on one end. The opposite side was bonded with a 3M VHB tape and, to a treated metal strip, which in turn was bolted to a fixture– Figure.2. This would help constrain the specimens in the required manner and show the peel failure progression in the foam or laminate. There were no crack initiating agents introduced during the fabrication.

B. Testing

Mode II Shear Testing–As the mode II shear failure involves the failure of the material by sliding, double lap shear test was carried out to calculate the shear stress,shear strain and shear modulus of the adhesively bonded laminates with PUF and PIR core materials [6].The adhesive and cohesive failures in the tests add to our understanding of the foam behavior and fracture in mode 2 failure. Tests for the all the specimens were carried out on anINSTRON universal testing machine. A crosshead velocityof 2 mm/min was maintained for all the specimens. A grip pressure of 5-10 bars was maintained initially for all the densities. Laminate failure and slippage was observed in case of higher densities, so laminate tabs of increased thickness were prepared with a thickness of about 3.6mm. A grip pressure in the range of 30-60 bars was maintained for specimens of 250 kg/m^{3}and 500 kg/m^3.An average of 3 specimen samples was tested for mode II shear test.The lap area was maintained at 40x 26mm in phase-1 and 40x36 mm in phase-2 of the testing, where the grip pressure was increased.The effect of geometry is clearly mentioned by GS Giare et al [7].

Mode I Shear Testing-The peel test was carried out to evaluate the mechanical properties of the foam from mode I failure and compare it with the properties obtained in the double lap shear test. The experimental setup is as shown in Figure.2.Grove et al. [8] has explained the influence of processing parameters on peel strength of sandwich composites.Cantwell et al [9] has explained the adhesion characteristics and test geometry influences in mode 1 failure. Mixed mode failure is more visible in single lap shear [10].

Figure 2. Peel Test Setup Test

C. Observations:

In case of double lap shear, it is observed that the lower density foams of 64kg/m^3& 125kg/m^{3}show cohesive failure [Figure 3(b)] in both foams while there is a combination of adhesive and cohesive failures in 250 and 500 kg/m^3- Figures 3(a), 4(a) of foams.

(a)  **(b)** 

Figure.3. (a) PIR 500 Adhesive Laminate Failure;
(b)Cohesive Failure of the PIR 64

Fi Figure.4 (a)Cohesive- Adhesive failure in PUF 500

(b)SEM of Double Lap Shear Cohesive Failure - PUF 125

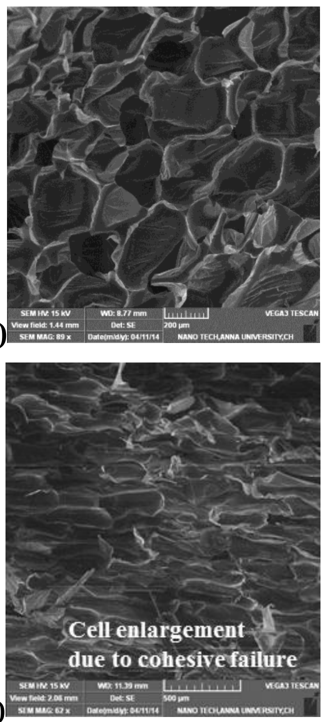


Figure.5(a) SEM of Double Lap Shear Cohesive Failure PIR 64

(b) PUF Cell Enlarge Ment Due To Cell Failure

Figure 4(b) gives a clear microscopic image of the shear fracture at the edge of the foam on taking a load beyond 3500N. The 500 kg/m^3 foams managed a load upto 14kN before failing.Table-1 gives clear details on failure modes between the densities in double lap shear. While the adhesive failures were mainly visible in the foams of 500kg/m^3, the shear strength is clearly better in PUF and the shear moduli of PIR foams seem to be better.

The Peel test done for the various specimens did not see the light of valid results as the hinges or tape debonded in most of the cases after taking a load of about 130N- Figure.5.

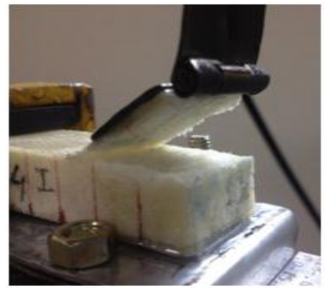


Figure.5: Peel Failure on top laminate

Figure.6: Peel failure on bottm laminate

III. Results and Discussion:

The double lap shear test, unlike the single lap shear test which shows mixed mode failures under tensile load, is seen to exhibit certain trends in shear strength properties.

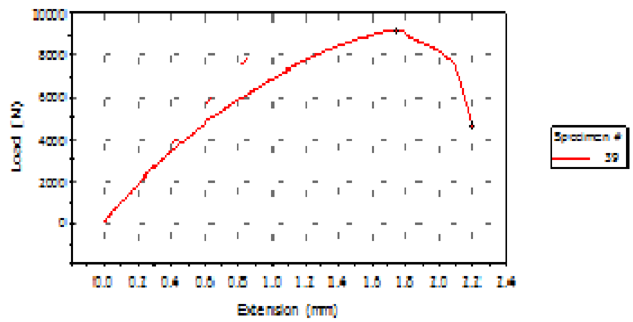


Figure.7.Double Lap Shear-Load deflection plot for PUF - 250

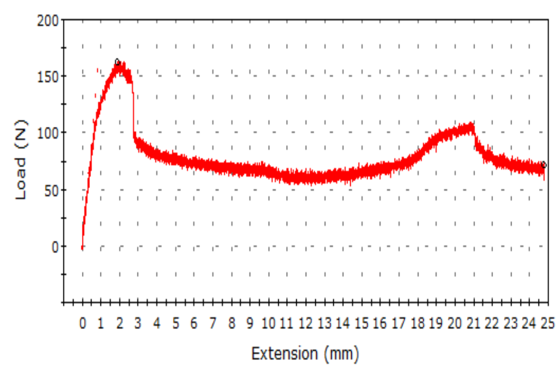


Figure.8.Peel Test-Load deflection plot for PUF - 64

Table - 1. Double Lap Shear Specimens properties

Type of foam	Density kg/m^3	Shear stress N/mm^2 MAX-MIN [AVG]	Shear Strain MAX-MIN [AVG]	Shear modulus N/mm^2 MAX-MIN [AVG]	Type of Failure
PUF	64	1.77-1.97 [1.88]	0.034-0.039 [0.03]	44.29-62.54 49.86	C.F

PUF	125	1.40-2.10 [1.78]	0.042-0.043 [0.042]	33.36-42.94 [41.7]	C.F
PUF	250	5.12-5.91 [5.53]	0.042-0.55 [0.047]	91.67-140.23 [115.82]	C.F
PUF	500	8.7-10.59 [9.75]	0.03-0.044 [0.039]	238.08-258.22 [244.41]	A.F center tab
PIR	64	0.76-1.46 [1.06]	0.012-0.033 [0.021]	44.29-62.54 [50.92]	C.F
PIR	125	1.35-1.76 [1.58]	0.034-0.036 [0.0345]	40.37-52.02 [46.01]	C.F
PIR	250	3.6-5.8 [4.4]	0.020-0.033 [0.0253]	176.48-178 [177.24]	C.F (thin layer)
PIR	500	5.5-6.4 [5.9]	0.029-0.034 [0.0322]	162.67-201.41 [186.56]	C.FCe nter tab

C.F = Cohesive failure, A.F = Adhesive failure

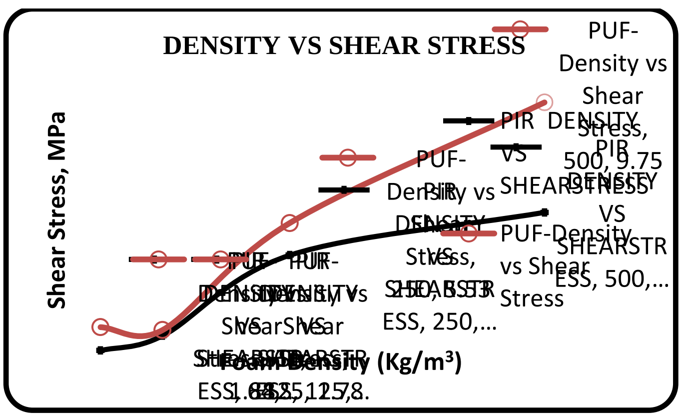


Figure.9. Density vs. Shear Stress

The plot in Figure.7 gives the typical trendline in the double lap shear test Figure.8 shows the failure in peel. From figures 9, 10 and 11, we observe a clear increase in the shear strength characteristics of the foams from 64 to 500 kg/m^3. The shear strain increases upto 250 kg/m^3 and decreases for 500kg/m^3 in case of PUF. Some studies on single lap shear were performed and the shear strength for PUF and PIR,for all the four densities was observed in the range of0.25 and 0.38N/mm^2.

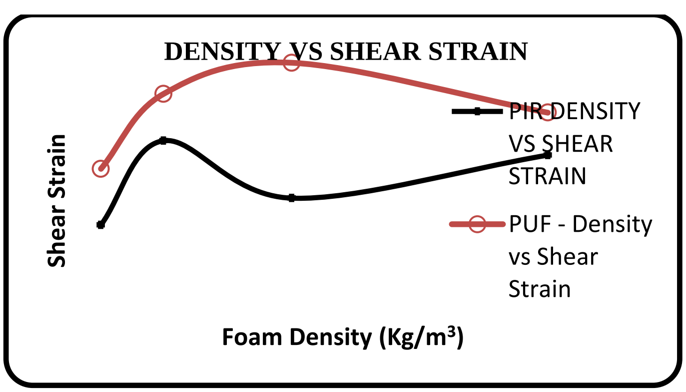
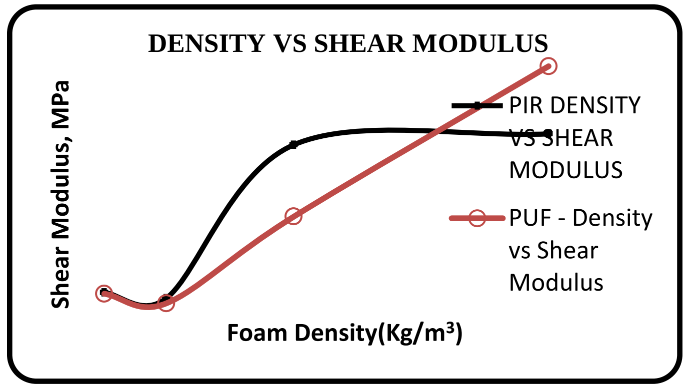


Figure.10 Density vs. Shear strain

Figure.11. Density vs. Shear Modulus



IV. Conclusion

The shear properties for the four rigid foam density sandwich composites were calculated and obtained from the double lap shear test in a UTM. The test results show that for an increase in the foam density, parameters like shear stress and shear moduli increased. The experiments show gradual cohesive failure for low density foams and interfacial debonding/ adhesive failure in higher density foam materials. Peel test was conducted for various densities and due to failure of adhesives; interpretation with the available data is difficult. Work is further to be carried out in order to complete the scenario. Itwas also however noted that the foams had taken about 120N before the adhesives failed in mode I.

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