Study on Flatwise Compression Behaviour of Open- Cell Polymer Foam Sandwich Structure

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***Abstract*— Due to their high strength to weight ratios, composite sandwich structures have proven their usefulness in a large number of applications in various technical fields, especially in aeronautics and civil engineering. One of the main drawbacks of sandwich structures is loss of load carrying capacity due to low density core. The purpose of this work is the evaluation of the response of open cell foam core sandwich structure under compression. Experimental tests were performed by using Instron universal testing machine under displacement control at cross-head speed of 1 mm/min. The test specimens were manufactured by using open cell foam slab stock method with a thickness of 12mm and a glass fiber face sheets with 2mm. The load-displacements response under loading was recorded. The results show the polymer-polymer cored-polymer(PPP) sandwich has maximum deformation and epoxy based core sandwich bears high compressive stress then polyester based foams .Failure mechanisms of the fractures specimen were studied through scanning electron microscopy, which reveals that delamination starts at interface between core and skin of the sandwich structure though initiated at the middle of the polymer core when observed between the tensile and compressive regions. It is observed that the stress decreases by about 10-20% after reaching a peak value that denotes the point of crack origination in the specimens. After this decrease, the stress becomes nearly constant for further deformation. The polymer sandwiches failed predominantly due to face-core de-bonding with a large scatter at a measured peak load and crosshead deflection. The compression data is very useful for designing sandwich beams with lightweight and multifunctional applications.**

Keywords—Opencell polymer foams; compression test;Sandwich composite structue; Debonding;

I. INTRODUCTION

Sandwich structures have become increasingly popular for structural design purpose over the last 30-40 years due to the possibility of obtaining very high stiffness to weight and strength ratios. Sandwich constructions may successfully be used in a variety of vehicle applications, including components in space craft, train and truck structures, containers , tanks and car body parts. The core material in a sandwich may be either honeycomb, cellular foams or polymer foams. When a sandwich structure is subject buckling or bending loads the core material is mainly loaded in shear. However, hollow foam composites or syntactic foams have recently gained a lot of attention as they provide the same strength characteristics and much lower density than that of the solid foam. However, several studies have been focused on the fabrication of polymer foam. But, only a few researchers have worked on the performance of low cost open cell polymer foam based sandwich structures. The objective of this research was to fabricate open cell polymer foam, sandwich structure using the same foam and their characterization on compression strength .

By sandwiching a low density core between stiff face sheets effectively provide a lightweight, stiffer and stronger sandwich structure. The face sheets are basically unidirectional fiber- reinforced laminated composites, while the core is a thick layer of low-density material like foam or a honeycomb material [1] The core materials were traditionally manufactured using stochastic metal or polymer foams [2,3], corrugated [4], honeycomb [5,6] and truss materials [7,8]. These combinations of properties are very important in the development of many contemporary vehicles and structures. Sandwich structures generally allow an additional weight reduction without jeopardizing the strength and performance of the structure by using fiber -reinforced composites in it. Hence sandwich structures made of fibre reinforced composites are attractive for building ultra-light and high-strength components, specially for the aerospace industry and fight structures [9]. Larger-sized, mass-produced sandwich panels have many potential applications in building large-scale structures. In addition they are energy absorbent [10].

The study on buckling properties is very important in design of lightweight sandwich beams. There is much literature is available pertaining to buckling behaviour of sandwich beams with various kinds of cores. Allen HG (1969) presented analysis and design of structural sandwich panels with square honeycomb cores[11]. Aiello MA et al.(1997) conducted buckling tests in order to reveal the mechanical property and the failure mechanism of sandwich panels made with laminated faces[12]. Hyukbong kwon et al. (2006) reported a buckling and debond growth in adhesively bonded composite splice joint[13]. S Rivailant et al. (2006) presented the experimental and numerical study of dynamic local buckling of skin on foam core[14]. Dai Okumura et al. (2008) have investigated the buckling modes and stresses of elastic Kelvin open-cell foams subjected to uniaxial compression[15].Typically shows that non-uniformity of cross- sectional areas is an important factor for the buckling behaviour of the open-cell foams. Ji Hoon Jeon et al., (2004). has reported that the structural rigidity and buckling behaviour was calculated from theorital model and was compared with experimental results[16]. Frosting Y et al., (1993). High order buckling analysis of sandwich beams with transversely flexible core[17]. Daowu Zhou et al., (2005). Mechanical properties of fibrous core sandwich panels [18]. Narayan Pokharel et al., (2003). Experimental investigation and design of sandwich panels subjected to local buckling effects[19]. Davies JM . (2002). Sandwich panels [20]. To date, however, there is no research work on the bending behaviour of sandwich beam with open cell polymer foam as core material , since this innovative core architecture appeared recently for designing lightweight and multifunctional sandwich structure. The properties of the parent material are listed in Tabel 1. In the present paper, the buckling properties and the failure mechanism of glass fiber composite sandwich beam with open cell polymer foam cores have been researched using experimental tests. the PPP possess as higher value of critical load and maximum deflections compared to five specimens. EPE possess lower value of critical load and sandwich beam deflection compared to other sandwich specimen.

2. EXPERIMENTAL

2.1.Fabrication of specimens

The material used for this experiment and their properties are given in Table 1. Polymer open cell core was fabricated by placing water dissolvable balls inside the mould filled with epoxy/polyester resin mixed with accelerator and catalyst and curing for 24 hours. The polymer foam was placed in hot water for 15 minutes. GFRPs using polyester and epoxy resins and glass reinforcement were used as skins for the sandwich structures fabricated by wet hand lay-up technique. Six types of specimens such as EEE (Epoxy/glass front face-Epoxy core- Epoxy/glass back sheet), PPP (polyester/glass front face- polyester core-polyester/glass back sheet), EPE (Epoxy/glass front face-polyester core-Epoxy/glass back sheet), PEP (polyester/glass front face-Epoxy core- polyester/glass back sheet), PEE (polyester/glass front face- Epoxy core- Epoxy/glass back sheet) and PPE (polyester/glass front face- polyester core- Epoxy/glass back sheet).As per calculation, six numbers of fiber mats of area 150 mm x 150mm were prepared for face sheet. 18 g of polyester resin /epoxy resin, hardener 2% of accelerator (methyl ethyl ketone peroxide) and 2% of catalyst (diethyl acetamide) for polyester resin and 10% amine based hardener for epoxy resin were used. Resin and hardener were stirred for five minutes for uniform mixing. Mixture of resin-hardener was applied to the Mylar sheet using a spreader on ceramic tile. The glass mats are placed on the Mylar sheet and

Fig 1 Sandwich structure

Apply mixture on the ply until the entire ply gets uniformly wetted. This procedure continues until to get 1 mm thickness of the face sheet. Finally, the Mylar sheet is covered with the FRP laminates and finally ceramic tile was placed over this Mylar sheet and the specimen was allowed to cure for 24hrs. Placed prepared polyester / epoxy open cell foam on the epoxy / polyester face sheet during preparation. Apply calculated amount of polyester/ epoxy resin (5g) (resin + hardener) mixture resin is spread on a face sheet and foam material using spreader. Then face sheet is placed on a top and bottom of the foam material and covered with two tile blocks for 24 hrs.

Table 1. Material used and their properties

Material	Density (g/cm^3)	Volume fraction (%)	E (Gpa)
Epoxy	1.4	0.35	3
E-glass fibre (0/90)	2	0.65	2.5
Polyester	1.2	0.35	2.8

2.2 . Flat-wise Compression test

Flat wise compressive strength and modulus are fundamental mechanical properties of sandwich cores that are used in designing sandwich panels. Deformation data can be obtained, and from a complete force versus deformation curve, it is possible to compute the compressive stress at any applied force (such as compressive stress at proportional limit force or compressive strength at the maximum force) and to compute the effective modulus of the core.

This test method provides a standard method of obtaining the flatwise compressive strength and modulus for sandwich core structural design properties, material specifications, research and development applications, and quality assurance.

In order to prevent local crushing at the edges of some honeycomb cores, it is often desirable to stabilize the edges with a suitable material, such as a thin layer of resin or thin facings. Flatwise compressive strength data may be generated using either stabilized specimens (reported as stabilized compression strength) or non-stabilized specimens (reported as bare compression strength). It is customary aerospace industry practice to determine compression modulus only when using stabilized specimens.

Factors that influence the flatwise compressive strength and shall therefore be reported include the following: core material, methods of material fabrication, core geometry (cell size), core density, specimen geometry, specimen preparation, specimen conditioning, environment of testing, specimen alignment, loading procedure, and speed of testing.

This test method covers the determination of compressive strength and modulus of sandwich cores. These properties are usually determined for design purposes in a direction normal to the plane of facings as the core would be placed in a structural sandwich construction. The test procedures pertain to compression in this direction in particular, but also can be applied with possible minor variations to determining compressive properties in other directions. Permissible core material forms include those with continuous bonding surfaces (such as balsa wood and foams) as well as those with discontinuous bonding surfaces (such as honeycomb)

The compressive properties and crushing behavior of the sandwich specimens were experimentally investigated by applying compressive load in a standard 10 ton capacity UTM machine compressive testing of the sandwich panels was performed in accordance with the requirements of ASTM standard C365-94. For this purpose, test specimens with two different combinations of face sheet and core were used. The composite sandwich dimensions was 25mm 25mm 12mm and tests were performed. The compressive load was applied at a cross speed of 1mm/min [11].

The flat-wise compressive strength (σ) values were calculated using the following equation;

$$\sigma = P/A \tag{1}$$

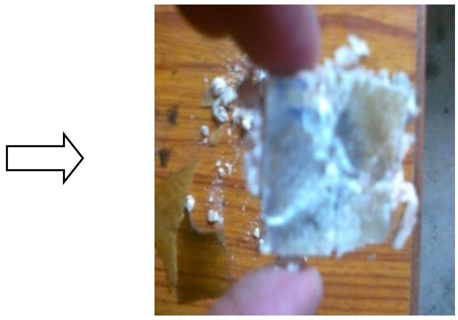
Where P is the ultimate load and A is the cross-sectional area of the specimen

Tests were interrupt Flat-wise compressive testing of the sandwich panels of size 25 x 25 x 12.4 mm were performed in accordance with the requirements of the ASTM C365-94 standard test procedure. By applying in –plane compressive load in the flat-wise direction along the face of the panels shown in Fig a), in a standard 10 ton capacity tensile testing machine. The compressive load was applied at a cross head speed of 1mm/min.

Tests were interrupted at total displacement corresponding to half the original thickness of the sandwich panels.

a

b



c

Figure 2 -core failures after test

3. RESULTS AND DISCUSSION

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Figure 3 shows stress –strain curves obtained by the compressive tests of the sandwich specimens are depicted in the diagrams grouped per type of faceplate laminate, i.e. curves of sandwich specimens of different foam core material i.e. epoxy foam core and polyester foam core but same type of face plate laminate.. Results of compression tests of both types are also compared here to develop a better understanding of deformation and fracture pattern of polymer foams. This comparison also helps in highlighting the effect of specimen aspect ratio on the compressive strength. The polymer material system used as matrix in the epoxy/polyester foam is also tested for compressive properties as per both selected standards. It is observed that the stress decreases by about 10-20% after reaching a peak value that denotes the point of crack origination in the specimens. After this decrease, the stress becomes nearly constant for further deformation. This constant load region is referred as densification stage. Characteristic close-up pictures of the crushed form of these sandwich panels taken

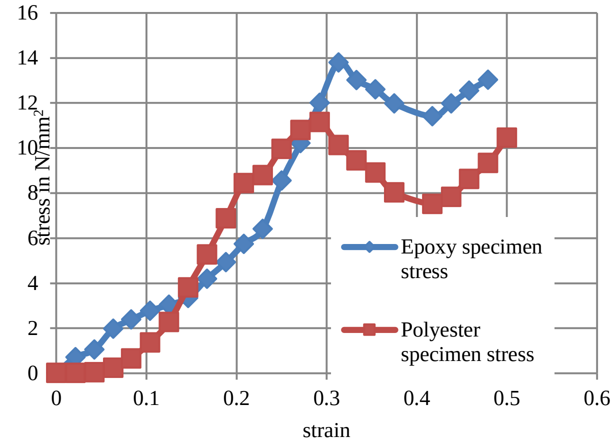

Figure 3- stress/ strain diagram epoxy/polymer based specimens

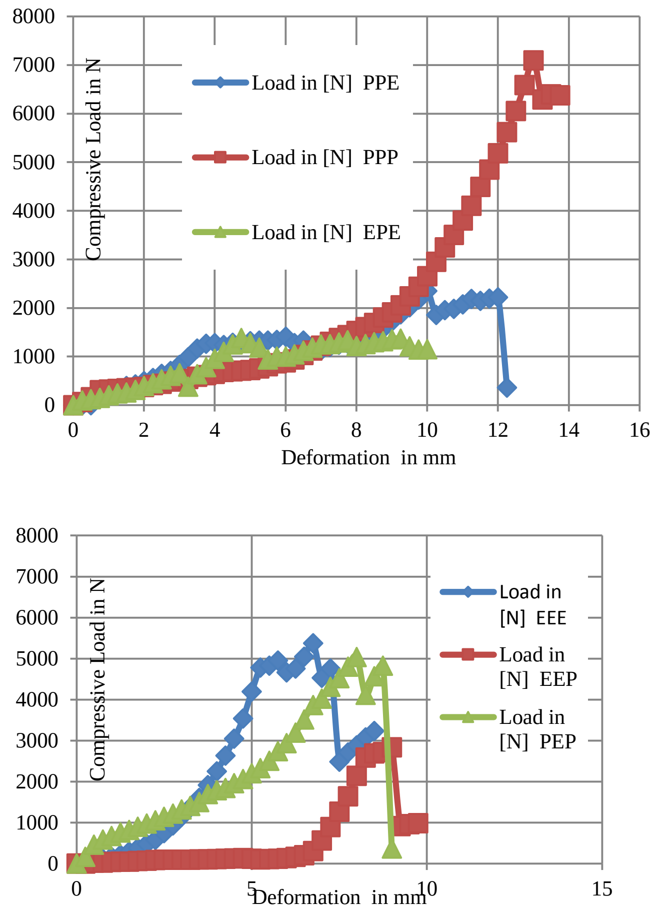

Figure 4- Load / Deformation plots

4. CONCLUSIONS

Glass fibre composite sandwich structures with open-cell polymer foam cores have been fabricated as per the ASTM standard using e-glass fibre / epoxy face sheet / e-glass/ polyester faces with epoxy / polyester based core. The compression and debond growth in adhesively bonded composite sandwich beam with open-cell polymer foam cores were experimentally investigated. The compression strength continuously increased with increasing compression deformation, reached peak then it fails in the form of a fracture and core shear deboning. In this study, the mechanical properties of composite sandwich structures fabricated with 0°/90° E-glass fiber/epoxy face sheet and polypropylene (PP) based honeycomb core were evaluated. The individual behavior of the PP based honeycomb core material and E-glass fiber/epoxy face sheets were also determined by performing related ASTM tests on these materials. Application of the flat wise compression tests to the open cell core material showed that core material compressive strength and modulus increased with the core thickness .For the sandwich structures, based on flat wise compression test, it was observed that composite sandwich structures with open cell core material deformed similarly with the core material itself. It was also observed that only the core material influences the flat wise compressive properties of sandwich panel. As the core thickness increased failure mechanism changed, a higher fraction of folding was observed with the thicker cores for the same deformation, therefore, energy absorption increased as well. Under the edgewise compression loading of sandwich structures, face sheets buckled and failure occurred at large deformation values, however buckling load was increased because of the coupling of the face sheets. In the edgewise compression test.

The six sandwich structures show different critical loads. The PPP shows maximum critical load and EPE shows lowest critical load. The sandwich deflection causes due to polymer foam crushing and the crack initiated between the foam. The polymer sandwiches failed predominantly due to face-core de-bonding with a large scatter at a measured peak load and crosshead deflection. Copression behaviour is an important factor in designing a sandwich structure . Other structural behaviour , such as three point bending behaviour , impact behaviour and fatigue load behaviour, should also be considered; these may constitute our future work. The results can be used in robust open cell polymer foam sandwich structure.

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