Flexural Performance of the Sandwich Structures Having Aluminum Foam Core with Different Thicknesses

Emre Kara, Ahmet F. Geylan, Kadir Koç, Şura Karakuzu, Metehan Demir, Halil Aykul

***Abstract*—**The structures obtained with the use of sandwich technologies combine low weight with high energy absorbing capacity and load carrying capacity. Hence, there is a growing and markedly interest in the use of sandwiches with aluminum foam core because of very good properties such as flexural rigidity and energy absorption capability. In the current investigation, the static three-point bending tests were carried out on the sandwiches with aluminum foam core and glass fiber reinforced polymer (GFRP) skins at different values of support span distances aiming the analyses of their flexural performance. The influence of the core thickness and the GFRP skin type was reported in terms of peak load and energy absorption capacity. For this purpose, the skins with two different types of fabrics which have same thickness value and the aluminum foam core with two different thicknesses were bonded with a commercial polyurethane based flexible adhesive in order to combine the composite sandwich panels. The main results of the bending tests are: force-displacement curves, peak force values, absorbed energy, collapse mechanisms and the effect of the support span length and core thickness. The results of the experimental study showed that the sandwich with the skins made of S-Glass Woven fabrics and with the thicker foam core presented higher mechanical values such as load carrying and energy absorption capacities. The increment of the support span distance generated the decrease of the mechanical values for each type of panels, as expected, because of the inverse proportion between the force and span length. The most common failure types of the sandwiches are debonding of the lower skin and the core shear. The obtained results have particular importance for applications that require lightweight structures with a high capacity of energy dissipation, such as the transport industry (automotive, aerospace, shipbuilding and marine industry), where the problems of collision and crash have increased in the last years.

***Keywords*—**Aluminum foam, Composite panel, Flexure, Transport application.

I. Introduction

SANDWICH structures produced with the combination of two thin but stiff skins having low density and a thick core present widely potential use particularly in transport industries such as automotive, aerospace and shipbuilding and other industrial applications. The most interesting benefits of using these structures are their high bending stiffness, high load carrying capacity and high strength to weight ratios [1]. With the use of these lightweight materials in transport industry, it is possible to increase payload, to reach higher speed and to obtain lower fuel consumption [2]. Most current sandwich structures are based on polymeric foams (such as *PVC*, *PUR*) bonded to glass fiber reinforced polymer (GFRP) skins. Recently a great number of metal foams have been developed to replace polymer foams in applications where multi-functionality is important. For instance, metal foams take part not only as a structural component in a sandwich composite but also as an acoustic damper, fire retardant or heat exchanger [3]. As a new multi-function engineering material, aluminum foams have many useful properties such as low density, high stiffness, good impact resistance, high energy absorption capacity, easy to manufacture into complex shape, good erosion resistance, etc. [4], [5]. This fact opens a wide range of potential applications for sandwich structures with aluminum foam core.

Sandwich structures can fail with different collapse mechanisms under static and dynamic loading conditions, depending on the physical and geometrical properties of their components [6], [7]. The failure model of a sandwich with metallic foam core has been established by some of the authors [7], [8] and they estimated the failure expected to result by several modes (i.e. face yield, core shear, indentation and face wrinkling) corresponding to the minimum collapse loads, depending on the deformation forms. Their model has been confirmed by multiple parallel studies [9]-[12]. Moreover, it has been investigated that the most of the sandwiches failed due to core shear during flexural loading [13], [14]. The results of these studies presented that the use thicker foam can affect the response of the whole sandwich structure.

The purpose of this investigation was the analysis of flexural performance of the sandwiches obtained by bonding of the glass fiber reinforced polymer (GFRP) skins to an aluminum alloy foam core with the use of polyurethane based flexible adhesive and the comparison of the results respect to the influence of the variety of the skin type and core thickness to the entire panel in terms of absorbed energy and peak force values. Vacuum Assisted Resin Transfer Molding (VARTM) method was used to produce the GFRP skins consisting of two different types of [0º/90º] cross-ply woven glass fabrics (E-Glass and S-Glass) and a Bisphenol A based epoxy resin. The bonding process was performed using a press machine in order to obtain uniform adhesion thickness throughout the panel and

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to remove the air inside the adhesive. The static three-point bending tests were performed on the sandwich panels by a universal testing machine with different values of support span distance (L = 55, 70, 80 and 125 mm) in order to determine its influence to the collapse modes.

II. Materials and Methods

The sandwich specimens used in this study were consisted of bonding of two GFRP skins to aluminum alloy foam core (Alulight® International GmbH) with the use of an polyurethane based flexible commercial adhesive (Sikaflex-265) under press machine with the pressure of 0.01 bar without crushing the core in order to obtain uniform adhesion thickness throughout the panel and to remove the air inside the adhesive.

The skins made of two different [0º/90º] cross-ply woven glass fabrics (E-Glass and S-Glass with the areal density of 500 g/m^2 and 190 g/m^2, respectively) with the thickness of about 1.5 mm for each type of fabrics and a Bisphenol A based epoxy resin (Araldite® LY 1564) with a hardener (Aradur® 3486) in a mixture ratio by weight of 100/34 were produced via VARTM which is also known as Vacuum Infusion. For the curing of resin, aluminum lay-up surface was heated up 100 ºC during two hours.

In the bonding process, firstly, one skin material was bonded to one of the surface of aluminum foam core under press machine using a steel alignment plate with the thickness containing the sum of one skin (about 1.5), core (10 mm or 15 mm) and one adhesive (about 0.5 mm) thicknesses. For the curing of first adhesion, it has been waited for about three hours. Then, another skin was bonded to another surface of the core under same pressure value using a secondary steel alignment plate produced respect to the total thicknesses of the whole panels. For the curing of second adhesion, the press machine was held under same pressure value about three hours.

In order to identify the sandwich typologies used in the current study, some of the abbreviations were done representing the base materials of a panel as shown in Fig. 1.

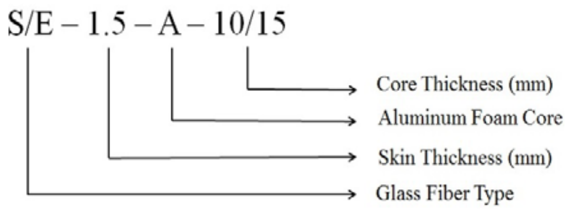

Fig. 1 Identification of sandwich typologies used in the present work respect to the base materials

The physical and geometrical properties of the investigated panels and their base materials are reported in Table 1.

TABLE I
PHYSICAL AND GEOMETRICAL PROPERTIES OF SANDWICH PANELS

Sandwich Typology	Skin			Core			Adhesive		
	Material	Density [kg/m^3]	Thickness [mm]	Material	Density [kg/m^3]	Thickness [mm]	Material	Density [kg/m^3]	Thickness [mm]
E1.5A10	E-Glass Woven Fiber/Epoxy Resin	1480	1.5	AlSi10	530±60	10	SikaFlex-265	1200	0.5
E1.5A15	E-Glass Woven Fiber/Epoxy Resin	1480	1.5	AlSi10	530±60	15	SikaFlex-265	1200	0.5
S1.5A10	S-Glass Woven Fiber/Epoxy Resin	1580	1.5	AlSi10	530±60	10	SikaFlex-265	1200	0.5
S1.5A15	S-Glass Woven Fiber/Epoxy Resin	1580	1.5	AlSi10	530±60	15	SikaFlex-265	1200	0.5

The static three point bending tests were performed on the sandwich specimens with the sizes of 150 x 50 x 14 mm and 150 x 50 x 19 mm using a servo-hydraulic universal load machine. All the tests were performed on the panels after one week of the production of the whole panels in order to get the best performance of the adhesive. The failure mode of the panels under bending load applied at different values of support span distances and the damage of the specimens have been also investigated as reported by [7], [15]-[17].

III. Results and Discussion

Static three-point bending tests were performed on the sandwich panels using a servo-hydraulic load machine. The load was applied at a constant rate of 2 mm/min and with a preload of 20 N. The tests were performed on the specimens at different values of the support span distances (L = 55, 70, 80, 125 mm). Figs. 2-5 show the load-deflection curves obtained from bending tests carried out on all the sandwich typologies with different types of GFRP skin and different thicknesses of aluminum foam core.

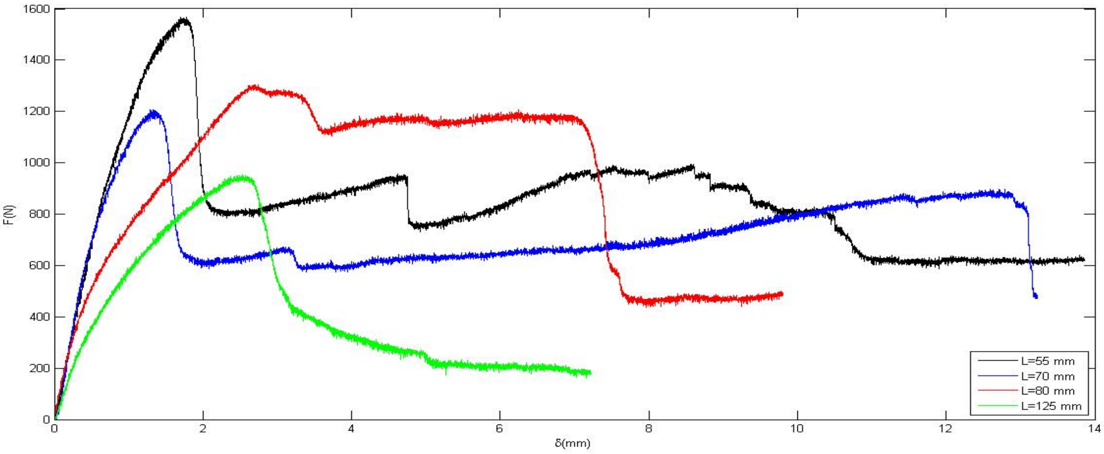

Fig. 2 Load - deflection curves measured under static three-point bending for the sandwiches named E1.5A10

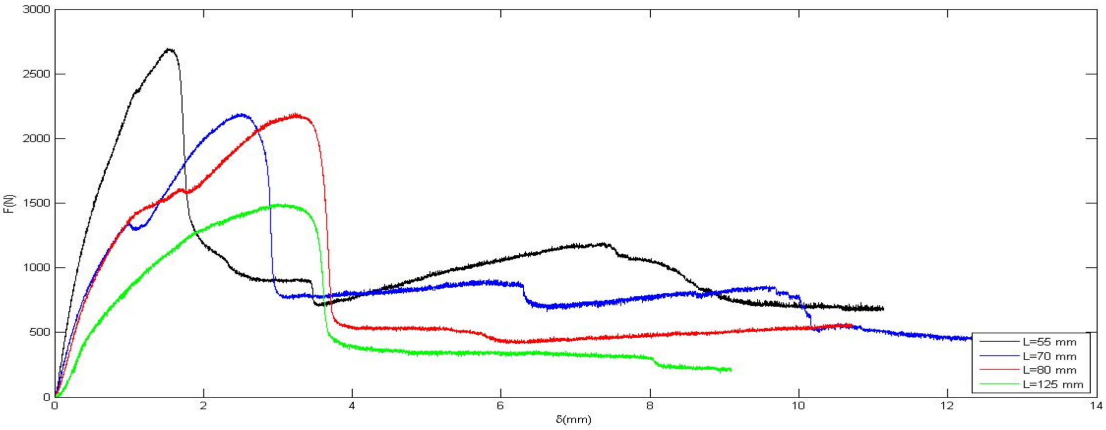

Fig. 3 Load - deflection curves measured under static three-point bending for the sandwiches named E1.5A15

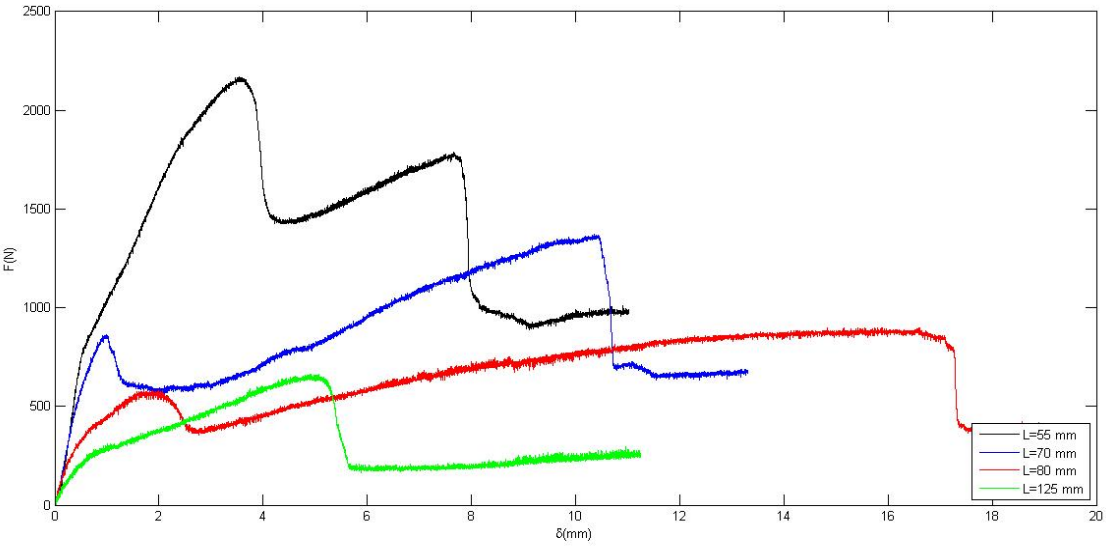

Fig. 4 Load - deflection curves measured under static three-point bending for the sandwiches named S1.5A10

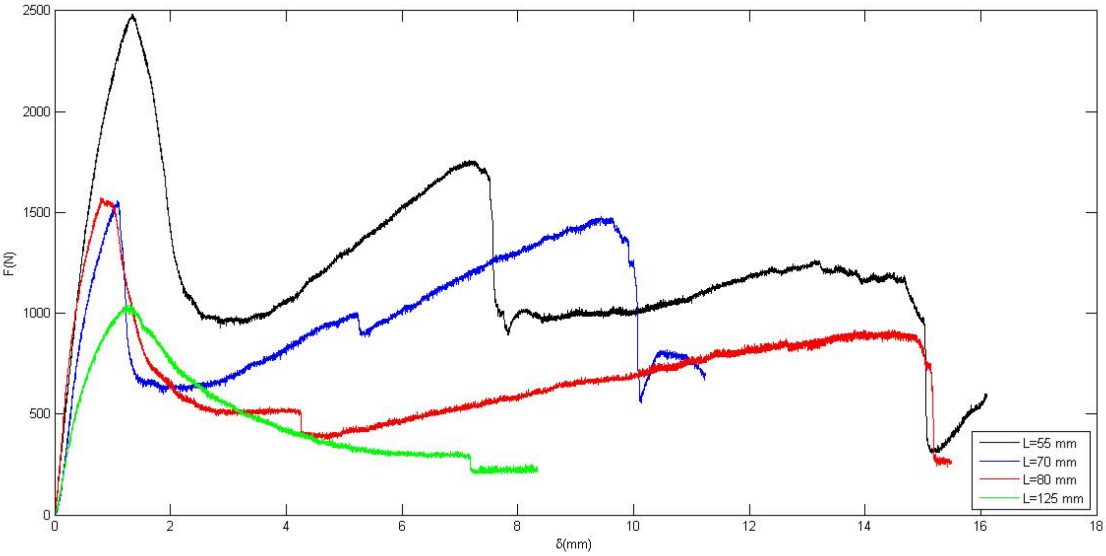

Fig. 5 Load - deflection curves measured under static three-point bending for the sandwiches named S1.5A15

All the sandwich specimens collapsed after the bending tests are presented in Figs. 6-9.

Fig. 6 Collapsed sandwiches named E1.5A10 after the bending tests at different support span values (top to bottom: L = 55, 70, 80 and 125 mm)

Fig. 7 Collapsed sandwiches named E1.5A15 after the bending tests at different support span values (top to bottom: L = 55, 70, 80 and 125 mm)

Fig. 8 Collapsed sandwiches named S1.5A10 after the bending tests at different support span values (top to bottom: L = 55, 70, 80 and 125 mm)

Fig. 9 Collapsed sandwiches named S1.5A15 after the bending tests at different support span values (top to bottom: L = 55, 70, 80 and 125 mm)

From Figs. 2-5, it is clear that all the sandwiches exhibit initial linear-elastic behavior which is followed by an elasto-plastic phase, due to the permanent plastic deformation of the aluminum alloy foam core up to maximum load value. Afterward, the load decreases initially markedly, then it remains almost constant up to the second abrupt load loss because of local debonding of the lower skin (Figs. 6-9) for all the sandwich typologies.

The failed sandwich specimens exhibit a significant permanent global deformation of the panel and core shear failure away from the loading points. Three point bending tests carried out by [15] on sandwich panels based on aluminum foam core and different types of composite skins revealed that the panels failed by different mechanisms and this suggests that a proper selection of the composite skin significantly influences the overall failure mode of the sandwiches and high capacity of absorbing energy.

Some theoretical models were developed by several authors [7], [16] to predict the failure mechanism of sandwiches. These authors have been particularly concerned with foam core sandwiches. Assuming a perfect bond between the faces and the core and eliminating the possibility of delamination, sandwich beams can fail by several modes in bending tests: core shear, face yield, indentation and face wrinkling.

The observed collapse mechanism of the sandwiches analyzed in the study which wasn't affected by the support span length, the types of the skin and core thickness occurred as core shear for all the sandwich typologies, as seen from Figs. 6-9.

The amount of the energy absorption E_{abs} was evaluated integrating the load - deflection curves obtained by the bending tests. The average values of the bending test results corresponding to the sandwich typologies are reported in Table II.

TABLE II
RESULTS OF BENDING TESTS

Sandwich Typology	L = 55 mm		L = 70 mm		L = 80 mm		L = 125 mm	
	F_{max} [N]	E_{abs} [J]	F_{max} [N]	E_{abs} [J]	F_{max} [N]	E_{abs} [J]	F_{max} [N]	E_{abs} [J]
E1.5A10	1566	12	1206	10	1303	9	953	3
E1.5A15	2697	12	2194	11	2197	9	1497	6
S1.5A10	2169	15	1372	11	900	12	663	4
S1.5A15	2481	19	1556	11	1572	11	1037	4

The experimental results confirm that the ability to absorb energy of the sandwiches with aluminum alloy foam core is obviously affected by the type of skin, the thickness of core and the support span value. The best response in terms of absorbed energy, as reported in Table II, was obtained for the sandwich typologies having thicker core, subjected to bending loads with support span value of L = 55 mm. It is due to the peak force value which was influenced by the skin type and core thickness and hence the higher rigidity of the whole panel that was affected by the support span length.

IV. CONCLUSIONS

The flexural performances of the sandwich composites with different thicknesses of aluminum alloy foam core and GFRP skin types with the same thickness were investigated and the results were compared respect to the variety of the GFRP skin type and thickness and also support span values in terms of peak load and absorbed energy.

The experimental investigation has demonstrated that the light-weight sandwiches with aluminum foam core and GFRP skins are efficient energy absorbers and that the amount of energy absorption under bending tests can be improved using different fiber type and thicker core, which can be designed according to the application of the sandwich. From the results of the analyses, the sandwiches having thicker foam core and S-Glass skins absorb greater amount of energy while the panels consisting of E-Glass skins present the highest value of peak load at the lowest support span distance. The support span distance can also affect peak load and energy absorption values and also the behavior of the entire panel.

This experimental work has particular importance for applications that require lightweight structures with a high capacity of energy dissipation, such as the transport industry, where problems of collision and crash have increased in the last years.

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