LOW VELOCITY IMPACT RESPONSE OF GLASS FIBER REINFORCED ALUMINIUM FOAM SANDWICH

E. Kara[1]*, V. Crupi[2], G. Epasto[2], E. Guglielmino[2], H. Aykul[1]

[1] *Department of Mechanical Engineering, Hitit University, Faculty of Engineering Çorum 19030, Turkey*
[2] *Department of Industrial Chemistry and Material Engineering, University of Messina, C/da di Dio, Messina 98166, Italy*
**emrekara@hitit.edu.tr*

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Abstract

The aim of this study was the analysis of the bending and the low - velocity impact response of aluminium foam sandwich reinforced by the outer skins made of glass fiber reinforced epoxy matrix and the results were compared with those obtained for aluminium foam sandwiches without glass fiber skins. Static bending tests were carried on panels with the same nominal size at different support span distances in order to analyze the collapse modes and their capacity of absorbing energy, while the energy amount absorbed under dynamic loading was evaluated by means of impact tests. The experimental investigation has particular importance for applications which require lightweight structures with a high capacity of energy dissipation, such as transport industries.

1 Introduction

Sandwich structures, consisting of glass fiber reinforced plastic (*GFRP*) skins bonded onto low density cores, offer great potential for use in various high performance composite structures which are nowadays widely used in aerospace, marine, automobile, windmills, transport, shipbuilding, defense because of their high specific stiffnesses and strengths, excellent thermal insulation, acoustic damping, fire retardancy, ease of machining and forming among others. It is important to choose high-quality core material in the optimal design of sandwich. Most current sandwich structures are based on polymeric foams (such as *PVC*, *PUR*) and aluminium honeycomb bonded to *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, acting as a structural component in a sandwich composite but also as an acoustic damper, fire retardant or heat exchanger [1]. As a new multi-function engineering material, aluminium 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. [2, 3]. This fact opens a wide range of potential applications for sandwich structures with aluminium-foam core. Aluminium foam sandwiches (*AFS*) [4, 5], obtained by combining metal face sheets with a lightweight metal foam core, are suitable for applications in automotive industry and ship construction

[6], as they allow a speed increase with good passenger comfort, thanks to their specific weight and high damping capacity.

In a previous research paper of some of the authors [7], the structural response of *AFS* under static and impact loading was compared with that of the *PVC* foam sandwiches. The failure mode and the damaged structure of the impacted panels have been also investigated by a Computed Tomography system [8]. An extensive series of experimental tests has been carried out by the same authors for analyzing the mechanical behaviour and collapse failure of the aluminium honeycomb sandwiches under static bending and low velocity impact loading, comparing the energy absorbing capacity with the one of the *AFS* [9]. Static and dynamic bending tests have been performed on *AFS* panels with the skins bonded by acrylate adhesive and no strain rate sensitivity was found by Yu et al. [10]. The main weakness of sandwich structures is the poor rigidity in the transverse direction. These structures are especially susceptible to low-velocity impact damage, which reduces the structural stiffness and strength. Therefore, the behavior of sandwich structures depends on the properties of core material, especially under impact loading [11]. A theoretical approach, based on the energy balance model, has been applied by some of the authors to investigate the impact behavior of *AFS* [12] and honeycomb panels [9]. The model parameters were obtained directly from the measurements carried out on the tomographic images of the impacted sandwiches and not from the results of static tests, as it is usually done in literature.

The aim of the present research was the investigation of the bending and low velocity impact response of glass fiber reinforced aluminium foam sandwiches (*GFR-AFS*) and the comparison with the *AFS* panels without *GFRP* outer skins in terms of absorbed energy. The glass fiber reinforced skins can be easily bonded to the sandwich and it is possible to design the best configuration (base materials, fiber angle orientation, number of layers) for a specific application. Hand lay-up method was used to produce the outer skins, made of glass fiber reinforced epoxy matrix, and the skins were bonded onto the aluminium faces of *AFS* using *SikaFlex-265* commercial adhesive. Preliminarily, some impact tests were performed on *GFR-AFS* panels, made in laboratory, in order to check the best configuration for the skin-*AFS* adhesion. Then, bending static tests were carried out on *GFR-AFS* specimens at different values of support span in order to investigate the collapse modes, as it was already done for honeycomb panels [9]. Moreover, low velocity impact tests were carried out on *GFR-AFS* specimens by a drop test machine with different values of impact velocity in order to analyze its influence.

The obtained results have 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.

2 Materials

The specimens were realized bonding two *GFRP* skins to *AFS* panels using a commercial adhesive (Fig. 1).

Figure 1. *GFR-AFS* panel.

Two different commercial aluminum alloy foam sandwiches have been investigated: the first one (*Schunk-Honsel Entwicklungsgemeinschaft*) with faces obtained by extrusion (integral skins), the second one (*Alulight® International GmbH*) with faces bonded to the core by an epoxy adhesive. The physical and geometrical properties of the *AFS* panels are reported in Table 1.

	AFS Alulight		***AFS Schunk***	
	Skin	**Core**	**Skin**	**Core**
material	Al (99.5%)	AlSi10	AlMn1	AlSi7
density (kg/m^3)	2730	530±60	2730	450±40
thickness (mm)	1	9	1	9
total density of *AFS* panel (kg/m^3)	950±50		870±40	
total thickness of *AFS* panel (mm)	11		11	

Table 1. Physical and geometrical properties of the *AFS* panels.

The adhesive and the *GFRP* parameters (orientation angle, resin type, number of layers, thickness) were chosen after preliminary impact tests in order to check the adhesion and to obtain the best configuration for sandwich construction.
The mechanical properties of commercial adhesive *(SikaFlex-265),* chosen for the sandwich construction, are reported in Table 2. The thickness of the adhesive is about 1.5 mm.

Type	**Shear modulus (MPa)**	**Shear Strength (MPa)**	**Shear Strain (%)**
Polyurethane	0.7	4.5	450

Table 2. Mechanical properties of the adhesive *SikaFlex-265*.

The properties of the *GFRP* composites, used for the sandwich construction, are reported in Table 3.

Orientation angle	**Number of layers**	**Layer thickness (mm)**	**Resin type**	**Resin density (kg/m^3)**
[0^o/90^o/Mat]	2	1.5	Epoxy	1180

Table 3. Properties of materials used.

Hand lay-up method was used to produce the *GFRP* outer skins in this investigation because of its easy feasibility. Primarily the type and the number of the layers of the fibers were considered according to the dimensions of *AFS* samples and the epoxy resin was prepared according to the mixture ratio given by the company. Then, a release agent was applied to the lay-up surface and finally glass fibers were laid up and impregnated with epoxy resin. It has been waited for about forty eight hours for curing of *GFRP*. After curing, *GFRP* outer skins were bonded onto aluminium faces of *AFS* using *SikaFlex-265* commercial adhesive in order to produce *GFR-AFS* test specimens. For curing of adhesive, it has been waited for about forty eight hours, too.

The presence of the outer skins produces an increment of the sandwich weight and thickness of about 2 and 1.7 times, respectively.

3 Experimental investigation

3.1 Static bending tests

Static three-point bending tests were performed on *GFR-AFS Alulight* and *GFR-AFS Schunk* panels using a servo-hydraulic load machine. The load was applied at a constant rate of 2 mm/min and with a preload of 10 N. The tests were performed on *GFR-AFS* specimens with the same nominal dimensions (150 x 50 x 18 mm) at different values of the support span distances (L = 55, 125 mm). Figs. 2 and 3 show the load-deflection curves obtained from bending tests carried out at L = 55 and 125 mm.

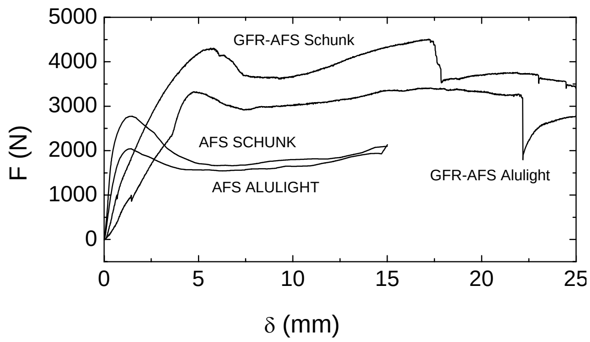

Figure 2. Load - deflection curves measured under static three-point bending (L = 55 mm).

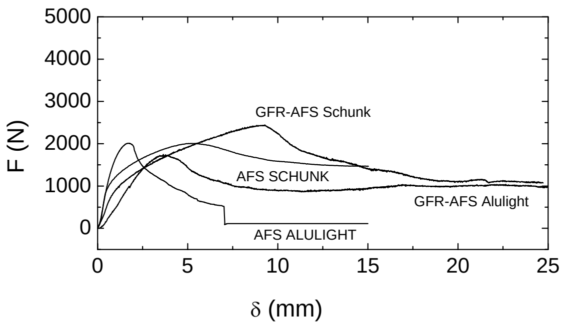

Figure 3. Load - deflection curves measured under static three-point bending (L = 125 mm).

The *GFR-AFS* specimens collapsed after the bending tests at L = 55 and 125 mm are shown in Figs. 4 -7.

Figure 4. *GFR-AFS Alulight* panel collapsed after bending test (L = 55 mm).

Figure 5. *GFR-AFS Alulight* panel collapsed after bending test (L = 125 mm).

Figure 6. *GFR-AFS Schunk* panel collapsed after bending test (L = 55 mm).

Figure 7. *GFR-AFS Schunk* panel collapsed after bending test (L = 125 mm).

From the Figs. 2 and 3, it is clear that all the sandwiches exhibit an initial linear-elastic behaviour, which is followed by an elasto-plastic phase, due to the permanent plastic deformation of the aluminium foam core, until a load peak value is reached. Afterward the load decreases, initially markedly and then it remains almost constant. The partial debonding of one aluminium skin, that produces an abrupt load loss, is clearly observable in the load -

deflection curve obtained from the bending test carried out on the *AFS Alulight* panel at *L* = 125 mm and on the *GFR-AFS Alulight* panel at *L* = 55 mm, while the load loss observable in the load - deflection curve of the *GFR-AFS Schunk* panel at *L* = 55 mm is due to the failure of the lower *GFRP* skin (Fig. 6). The failed *GFR-AFS* 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 Reyes [14] on sandwich panels based on aluminium foam core and different types 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 various authors [4, 13, 15] 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 collapse modes, observed during bending tests on *AFS* and honeycomb panels [9] at different support spans, differ somewhat from the mechanism already reported in literature; therefore new collapse models, called *Mode I* and *Mode II*, were introduced to explain the observed experimental behavior and to predict the limit loads. For that concerns the *AFS Alulight*, an asymmetric failure mechanism (*Mode II*), due to core shear, was observed in all the bending tests [9]. This collapse mode is similar to the core shear failure mode *AB*, intermediate between core shear modes *A* and *B* [15]. For *AFS Schunk*, the collapse modes differ depending on support span *L*: under bending loads, they always collapsed by *Mode I* for *L*>90 mm and by *Mode II* for *L*<80 mm [9].
The collapse mechanism, called *Mode II*, occurred also for the *GFR-AFS* panels, investigated in this study, under bending tests at *L* = 55 mm and at *L* = 125 mm.
The amount of the energy absorption was evaluated integrating the load - deflection curves, obtained by the bending tests. The values of dissipated energy up to $\theta = 17°$ were considered in order to compare the bending tests at different support spans *L*. The angle θ was defined as the ratio between the impactor displacement and half the support span. The average values corresponding to the *GFR-AFS* sandwiches are reported in Table 4 and compared to the values obtained for *AFS*. The experimental results confirm the higher ability to absorb energy of the investigated *GFR-AFS* sandwiches.

	L [mm]	Collapse mode	E [J]
AFS Alulight	55<L<125	Mode II	11
GFR-AFS Alulight	55<L<125	Mode II	19
AFS Schunk	L<80	Mode II	18
AFS Schunk	L>90	Mode I	27
GFR-AFS Schunk	55, 125	Mode II	29

Table 4. Energy dissipated at $\theta = 17°$.

3.2 Low velocity impact tests

The low-velocity impact tests were carried out by means of a drop test machine (Fig. 8), able to eliminate multiple impacts. The mass of the impactor and the drop height are variable, allowing for a wide range of impact energies. Dynamic impact tests were performed on specimens of *GFR-AFS Alulight* with an impactor mass of about 7 kg and different values of impact velocity ranging from 3 to 9 ms^{-1}. The impact energy values range from 32 to 285 J.

The impactor, having a hemispherical tip with diameter of 20 mm, is instrumented by means of strain gauge, which allows the measurement of a force value until 40 kN. The *GFR-AFS Alulight* specimens (75x50x17.5 mm) were fully fixed by a rigid metallic plate with a diameter of 40 mm without crushing the sample.
The load – displacement curves at different impact velocities are given in Figs 9 and 10 for *AFS Alulight* [7, 12] and *GFR-AFS Alulight* sandwiches. Fig. 10 reveals that the impact load tends to a plateau pattern, due to the global deformation, for high values of impact velocity ($v>7ms^{-1}$).

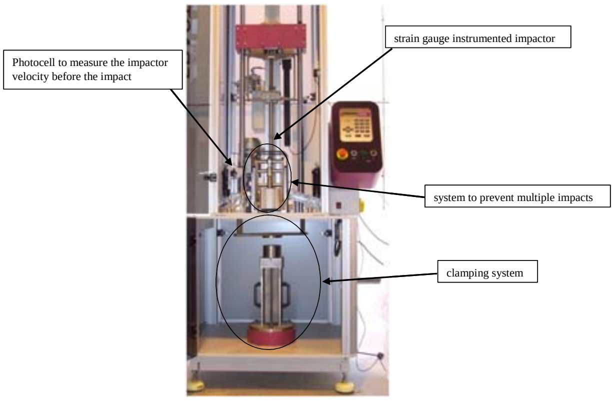

Figure 8. Drop-weight impact test machine.

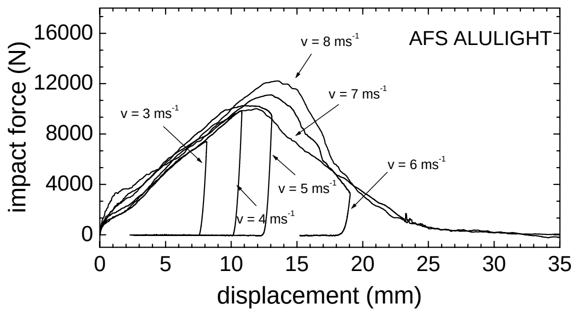

Figure 9. Impact force - displacement curves measured under impact loading (*AFS Alulight*).

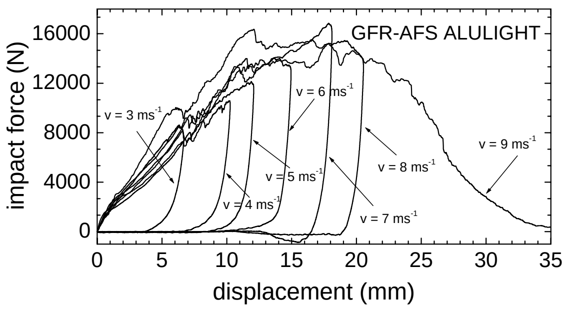

Figure 10. Impact force - displacement curves measured under impact loading (*GFR-AFS Alulight*).

Table 5 reports the results of the experimental tests in terms of absorbed energy and contact force peak for *AFS Alulight* [7, 12] and *GFR-AFS Alulight* sandwiches.

	AFS		***GFR-AFS Alulight***	
v [m/s]	**F_{max} [N]**	**E [J]**	**F_{max} [N]**	**E [J]**
3	7398	31	8615	31
4	9822	56	10580	56
5	10257	88	12140	88
6	11112	127	14033	127
7	10010	139	16848	173
8	11010	144	16360	225
9	-	-	15225	285

Table 5. Results of all the impact tests.

The energy amount, required to produce the complete failure of the sandwiches, was evaluated equal to: 142 J for *AFS Alulight* [7, 12] and 285 J for *GFR – AFS Alulight*. The experimental results confirm that, as expected, the *GFR - AFS* sandwiches are able to absorb greater amounts of energy and that the chosen adhesive produced a good skin-core adhesion; the debonding occurs generally for aluminium skin as demonstrated by Figure 11, which shows the *GFR-AFS Alulight* panels after the impact tests at different velocities.

Figure 11. Damaged *GFR-AFS* panels after impact tests**.**

The sandwiches collapsed for the foam crushing and their capacity of absorbing energy depends on the mechanical properties of the composite skin and foam core materials.

4 Conclusions

The static and impact responses of *AFS* reinforced by *GFRP* outer skins were investigated and compared with those of *AFS* without outer skins.

The experimental tests have demonstrated that the light weight aluminium sandwiches are efficient energy absorbers and that the amount of energy absorption under bending and impact tests can be improved of about 2 times reinforcing them by means of *GFRP* outer skins, which can be designed according to the application of the sandwich.

The study presented in this paper is part of a larger project aimed at the introduction of lightweight structures, made of aluminium sandwiches, in the transportation industry (automotive, aerospace, shipbuilding industry). The use of these sandwich structures, on the basis of preliminary information obtained from the experimental tests, can lead to a weight reduction, providing an adequate structural strength under operating conditions.

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