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Experimental Study on Quasi-Static Response of Multi-layer Sandwich Composite Structures

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Abstract**—**In this paper the effects of adding an extra layer within a sandwich panel and core- types in top and bottom cores on quasi- static loading are studied experimentally. The panel includes polymer composite laminated sheets for faces and the internal laminated sheet called extra layer sheet, and two types of crushable foams are selected as the core material. Quasi- static tests were done by ZWICK testing machine on fully backed specimens with two foam cores, Poly Urethane Rigid (PUR) and Poly Vinyl Chloride (PVC). It was found that the core material type has made significant role on improving the sandwich panel's behavior compared with the effect of extra layer location.

Keywords**—**Multi-layer sandwich structures, Internal sheet, Crushable foam, Top core, Bottom core.

I. INTRODUCTION

SANDWICH structures is with composite laminated face sheets and lightweight core material are being used in several parts of aircraft, aerospace and marine structures. Generally these structures are subjected to impacts such as tool drops, hail, bird strikes and runway debris. Since metal sheets have more beneficial in resistance and continuity against transverse loads rather than fiber reinforced plastics, however, they are sensitive to form of large regions of internal damage whenever subjected to impact loads and more vulnerable to humid effects [1]. The impact loadings generally cause different modes of damage in the face sheets, in the core, or in the interface between the face sheets and the core, or even in all of them. As a result of these kinds of damage, the mechanical properties of the sandwich structures will be degraded considerably. The critical failure modes are: (a) core buckling; (b) delamination in the impact face sheet; (c) core cracking; (d) matrix cracking and (e) fiber breakage in the facings [2], [3]. There are few studies on the mechanical response of the multi- layer sandwich panels in literature so far. Stickney et al. [4] introduced a small deflection theory for the flexure of multi-layer circular sandwich plates by extremizing the complementary energy with the use of Lagrange multipliers and examined the effects of shear and the degree of orthotropy on the deflection for several symmetrical and non- symmetrical cases. Thomsen [5] proposed a general theory for the analysis of multiple layer plate assemblies consisting of interchanging high density, high stiffness layers and low density, low stiffness/ compliant interface layers and predicted the complete deformation and stress fields in a 7- layer cantilever sandwich plate composed of 4 solid laminates interfaced by 3 compliant interface layers. Suvorov and Dvorak [6] introduced and investigated a modified design that protected the foam core by inserting a ductile foam as an interlayer under the external face sheet under low velocity impact. They observed that inserting interlayer foam reduced overall and local deflections of the face sheet, local compression of the foam core and residual stresses. Jiang and Shu [7] investigated the effects of internal sheet inserted into the honeycomb core in different locations under low-velocity impact and concluded that local displacement of the core along the direction of the impact was decreased significantly by introducing the internal sheet into a traditional single sandwich structure. Bahei- El- Din and Dvorak [8] compared the behavior of conventional and modified sandwich plate designs under blast loads. The modified plate included a thin ductile interlayer as a hyperelastic PUR that was inserted between the top face sheet and the foam core. The results showed that utilizing an interlayer causes a much reduced core compression, face sheet vibration and overall deflection compared to the conventional design. Dongmei [9] studied the compressive behavior of multi-layer corrugated sandwich structures experimentally and concluded that compressive resistances were similar for the same type of corrugated sandwich structures with different layers; the energy absorption of the multi-layer corrugated sandwich structures was significantly greater than the monolayer one and had compression resistance capability for repetitious shock. Namalis et al. [10] used metal sheets at the outer surfaces and introduced a new concept called hybrid sandwich structure to maximize rigidity while introducing in between lightweight cores adhesively bonded to keep the whole structure together. There are some limitations on panel thickness in structures such as in aerospace panels. A suitable way to increase the panel resistance under local loads and to decrease local deformation is to insert an internal sheet within the soft cores. In all previous studies on multi- layer sandwich panels the effects of either using two different foams in top and bottom cores or inserting internal composite laminated face sheet in various locations through the thickness of core were investigated. The aim of this study is to consider both parameters on local displacement of top core, contact force and deflection of sandwich panels under static and low-velocity impact loads for two types of boundary conditions. In this research, by inserting an additional sheet called the internal sheet, to

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separate top and bottom core, a multi- layer sandwich structures is created. The material of each top and bottom cores could also be different. Some quasi-static perforations were applied by ZWICK testing machine for fully backed sandwich panels. The Polyvinyl chloride (PVC) and Poly Urthane Rigid (PUR) foams are selected as the top and bottom cores of specimens.

II. Experimental Procedure

A. Specimens and Material Properties

The material properties of the top face sheet, bottom face sheet and internal face sheet are E-glass fiber reinforced epoxy resin matrix composite laminate. The mechanical properties of composite laminated sheets are determined using ASTM1[1] D638M, see Table I. A description of ply sequences and dimensions of laminates are explained in Table II. The ply sequences and thickness of the top and bottom face sheets are the same but differ from the internal sheet. At first, fibrous composite were made by hand lay- up with various layer arrangements and then bonded to foam cores by same epoxy resin as it was applied for laminating. Hand lay-up method pursued by curing process includes pressurizing to reduce voids and removal of excess resin. Also, the mechanical properties of foams which were used in quasi- static and low velocity impact tests are shown in Table III.

TABLE I
PROPERTIES OF COMPOSITE LAMINATED SHEET

Materials	Density (kg/ $\mathbf{m^3}$)	Young's modulus (Gpa)	Shear modulus (Gpa)	Poisson's ratio
Laminatese	1100	E_x=50,	G_{xy}=5.43,	υ_{xy}=0.163
		E_y=50,	G_{yz}=3.26,	υ_{yz}=0.0458
		E_z=9.5	G_{xz}=5.43	υ_{xz}=0.0263

TABLE II
GEOMETRICAL PROPERTIES OF COMPOSITE LAMINATED SHEET

Sheet	Top	Internal	Bottom
Ply sequence	$[0/45/90/-45/0]_s$	$[0/90/90/0]_s$	$[0/45/90/-45/0]_s$
Thickness (mm)	1.25	1	1.25
Dimensions of the target in x-y plane (mm)		76.4×76.4	

TABLE III
PROPERTIES OF CRUSHABLE FOAMS

Core materials	Density (kg/m3)	Young's modulus (Gpa)	Shear modulus (Gpa)	Poisson's ratio
PUR	76	0.0011	0.00042	0.3
PVC	140	0.0040	0.00140	0.3

The specimens of PVC and PUR foams selected according to ASTM, D1621/94 code [11], were tested under quasi-static loading in two rates (3 and 100mm/min) and the stress-strain data of them are shown in Fig. 1. According to the results these kinds of foams are not considerably sensitive to strain rate. The stress-strain curves include overall three regions of stress- strain curves of crushable foams including: linear elastic, plateau and densification.

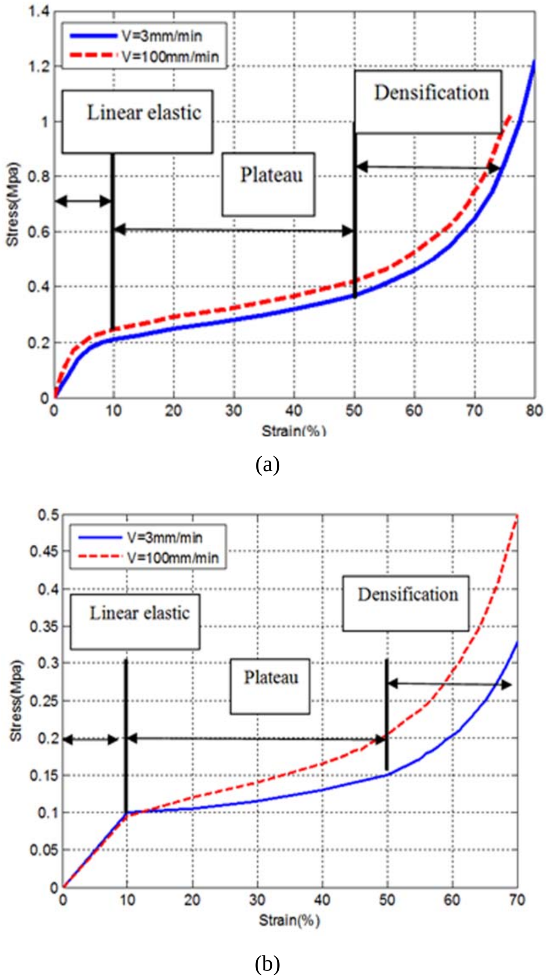

Fig. 1 Stress- strain curves of crushable foams under quasi- static loadings in two rates: (a) PVC (b) PUR

III. Quasi- Static Perforations

The multi layer fully backed sandwich panels with two foam cores, PUR and PVC, were tested under quasi-static loading, see Fig. 2. The loading rate was 5mm/min and experiments were applied by ZWICK testing machine, see Fig. 3. Two effects are examined in quasi- static tests on fully backed specimens. At first, the influence of material type of the core is studied on deformation of the top face sheet until its failure and second, the effect of location of the internal sheet through the thickness of the multi layer sandwich panel is investigated. To investigate the location effects of internal sheet on load-deflection behaviors and failure of top and internal sheets, four locations of the internal sheet were considered for two types of sandwich panel with PUR and PVC foams. They are so-called Su1, Su2, Su3, Su4, Su5 and Su6 are related to specimens with PUR core andSv1, Sv2, Sv3, Sv4, Sv5 and Sv6 are referred to sandwich panel with PVC foam core, see Table IV.

[1] American Standard Test Method

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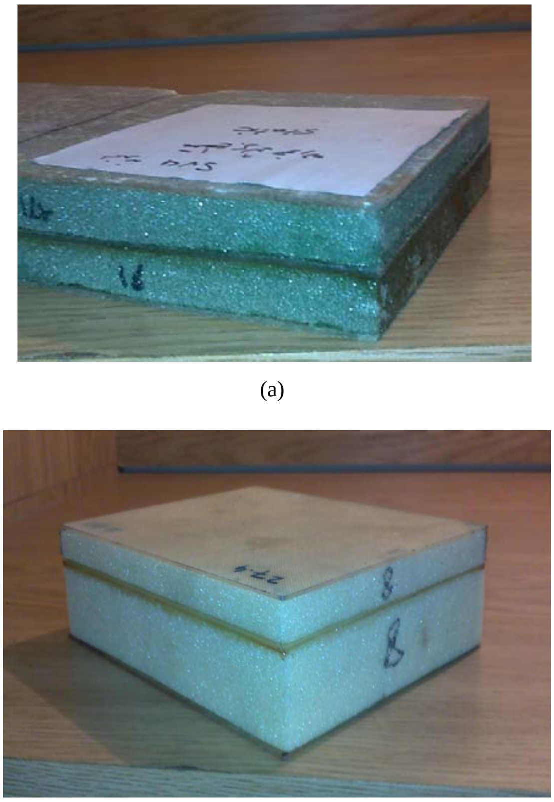


(a)

(b)

Fig. 2 The multi layer sandwich specimens with two foam cores, (a) PVC (b) PUR

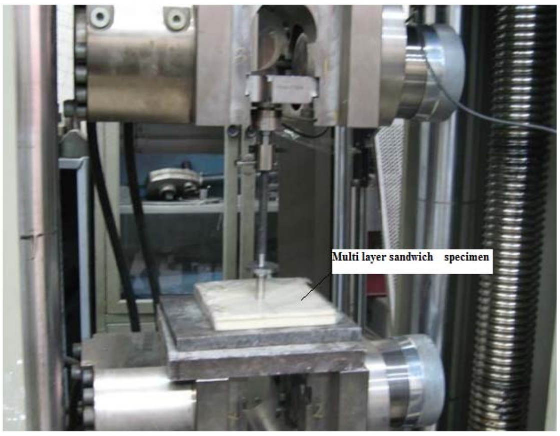


Fig. 3 ZWICK testing machine for quasi- static tests

TABLE IV
GEOMETRICAL PROPERTIES OF MULTI LAYER SANDWICH SPECIMENS IN QUASI- STATIC TESTS

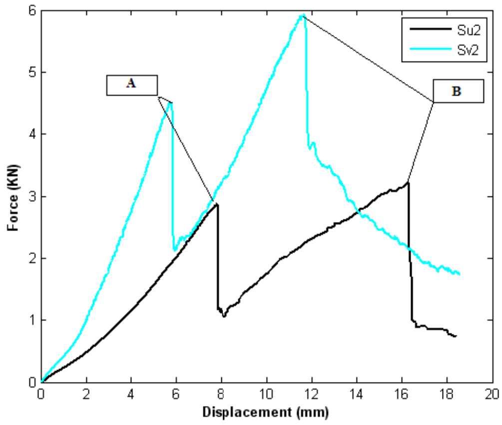
Target No.	Top core		Bottom core	
	Foam	Thickness(mm)	Foam	Thickness (mm)
Su1(Sv1)		5		15
Su2(Sv2)		5		15
Su3(Sv3)	PUR (PVC)	5	PUR (PVC)	15
Su4(Sv4)		10		10
Su5(Sv5)		15		5
Su6(Sv6)		20 (Single core)		0

IV. Results and Discussion

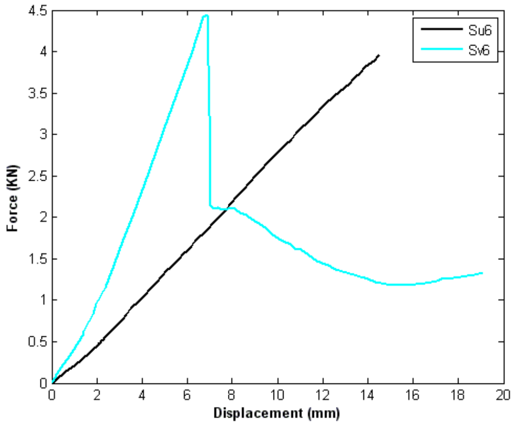
A. Effects of Core Material Type

In order to study the foam core material effect on deformation of the top face sheet, two foam cores, PUR and PVC, are considered. The comparative results are depicted for the two cases, with and without the internal sheet, in Fig. 4. Since the PVC is stiffer than the PUR, it could be observed that the slope of load in the specimen with PVC core is much more than the PUR one. In other word, with increasing the load the compressive resistance of the foam core is increased. As the PVC compressive strength is more than the PUR, the compressibility of the PVC is lower than the PUR at the same level of load. So the deformation of the top face sheet in the Sv2 specimen due to bending is more restricted than the Su2 and as a result of this, the main portion of the load is contributed to compressive stress in the top face sheet of the Sv2. Since the compressive strength of composite laminated sheet is much lower than the bending strength, the top face sheet in the Sv2 is broke at a smaller deformation than the Su2 (point A). After failure of the top face sheet, with increasing the load, elevation of compressive resistance of the top core is continued. Similar to the above description about failure of the top face sheet, the major part of the load is transformed to compressive stress rather than bending stress in the internal sheet. Therefore, the internal sheet in the Sv2 is broken in smaller deformation than the Su2 (point B).

In the cases without internal sheet, Su6 and Sv6, the same result is concluded. Since the compressive stiffness of PUR foam is much lower than the PVC, the failure of the top face sheet in the Su6 occurred at large deflection of the sandwich panel. Also, the cross section of multi layer specimen after quasi-static perforation with PVC foams in both top and bottom cores (Sv4) is shown in Fig. 5.



(a)



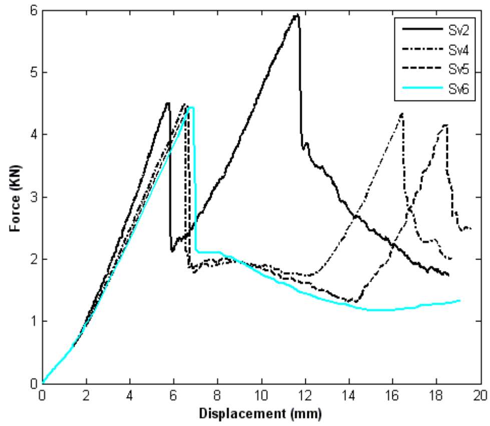
(b)

Fig. 4 Load versus deflection of the multi layer sandwich panel under static loading (a) with internal sheet (b) without internal sheet

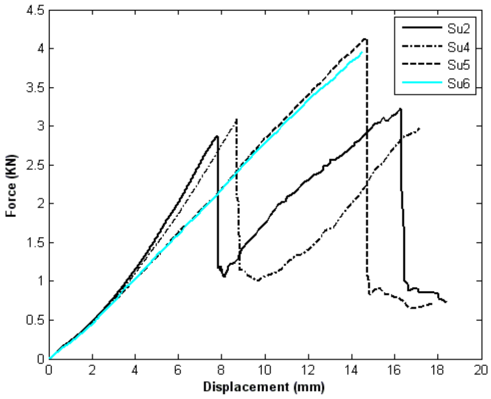
Fig. 5 Cross- section of multi layer sandwich specimen (Sv4) after quasi- static perforation

B. Location of the Internal Sheet

Inserting the internal sheet at different locations increases the compressive stiffness of the multi layer sandwich panel and as a result of this, in comparison with conventional panels (single core), the failure of the top face sheet occurs in the smaller deformation. On the other hand, according to the Fig. 6, by decreasing the thickness of top core in both types of foams, its compressive resistance is elevated. So load slope is increased by decreasing of the top core thickness at the identical level of top face sheet deformation. Also, by decreasing the compressibility of top core, the bending deflection of the top face sheet is limited. As a result of this, the main part of the load is contributed to compressive stress in the top face sheet and leads to premature failure of it.



(a)



(b)

Fig. 6 Load versus deflection of the multi layer sandwich panel under static loading in different location of the internal sheet (a) with PVC core (b) with PUR core

V. Conclusion

According to quasi- static tests since the PVC foam is stiffer than the PUR, it could be concluded that the failure of the top and internal face sheet in the multi layer sandwich with PVC foam (Sv2) in comparison with specimen with PUR core (Su2) occurred at the smaller deformation. On the other hand, whenever the thickness of the top core decreased, in both types of the foam core, the stiffness increased and the top and internal face sheet broke at the lower level of deformation.

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