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COMPOSITE SANDWICH STRUCTURES – AN OVERVIEW

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Abstract: *This paper gives a brief overview of composite Sandwich structures and some of their application fields. Sandwich composite structures combine laminated faces, also known as skins, with a light core in-between, thus combining the mechanical properties of the core and skins. High rigidity with a small addition to mass is obtained. The focus points of the paper are on structures used in automotive and aerospace applications. Specific constituent materials and architectures are studied. Mechanical properties of GFRP (Glass Fiber Reinforced Polymer) and CFRP (Carbon Fiber Reinforced Polymer) skins are studied, along with architectures and specific materials of the Sandwich core. Properties of different core types are evaluated (balsa wood cores, polyurethane foam cores and Nomex honeycomb type cores). The last part of the paper focuses on the manufacturing specifics of composite Sandwich structures and specific applications in the aerospace industry.*

Key words: *Composite Sandwich Structure, Fiber Reinforced Polymer*

1. INTRODUCTION

Composite materials consist of macroscopic combinations of two or more distinct materials (fazes) having an interface separating them. [1]

The specific feature of the Sandwich composite construction is the use of a multilayer skin consisting of one or more high-strength outer layers and one or more low-density inner layers (the core of the structure). Great numbers of combinations of materials and architectures are possible today, both for the core and the skins. [2] Due to their high stiffness and low mass, composite Sandwich structures are perfect candidates for aerospace applications.

2. GENERAL CLASSIFICATION

Composite Sandwich structures can be basically split into two general categories:

- Symmetrical structures
- Asymmetrical structures

The assembly is considered to be symmetrical if it has the exact same type of skin on both sides of the core. Sometimes, in specific applications the faces may differ in thickness, materials, or fiber orientation. This is caused by the fact that in practice, one face is an external face while the other is an internal face; the former sandwich is regarded as a mid-plane symmetric sandwich, the latter a mid-plane asymmetric sandwich. This is called an asymmetrical structure.[1]

2.1 Symmetrical structures

Symmetrical composite Sandwich structures have a good bucking response and are suitable for membrane structures. [4] In the figure below (Fig. 1), A represents the skins and B represents the structural core.

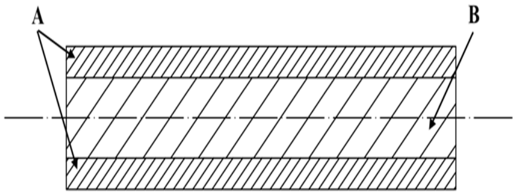
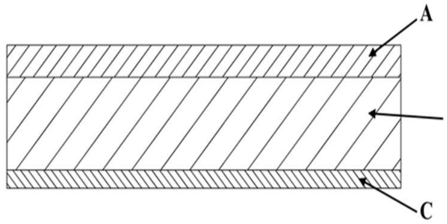


Fig. 1. Symmetrical Sandwich structure.

2.2 Asymmetrical structures

Asymmetrical composite Sandwich structures (Fig. 2) are usually used in non-pressurized applications. [2]



A- outer sin
B- core
C- inner skin

Fig. 2. Asymmetrical Sandwich structure.

3. GENERAL MATERIALS USED IN COMPOSITE SANDWICH STRUCTURES

When evaluating the age of a composite Sandwich structure, fatigue is a very important aspect to be considered. For example, in aerostructures, Sandwich technologies bring great benefits regarding fatigue resistance. Another great advantage of composite Sandwich structures is the high thermal stability. Mechanical properties of the composite Sandwich structure can be determined by evaluating the mechanical properties of each constituent (skin and core). Several parameters can be defined:

- Mass percentage of fibers M_f, as the ratio between the mass of the fibers contained into a defined volume and total mass of the same volume
- Mass percentage of the matrix (1):

$$M_m = 1 - M_f \quad (1)$$

- Volumetric percentage of the fibers, V_f, as the ratio between the volume of the fibers and contained into a defined volume and that volume;

- Volumetric percentage of the matrix (2):

$$V_m = 1 - V_F \quad (2)$$

- Mass of the fibers on the surface unit (3):

$$m_{0f}\ [kg/m^2] \quad (3)\ [14]$$

3.1 Skin materials

Aerospace and advanced applications require very specific mechanical properties for both skins and core.

Regarding skins, carbon fibers (unidirectional, biaxial, or woven cloth) are often used, together with an epoxy matrix, resulting a CFRP (Carbon Fiber Reinforced Polymer) type of skin. Usual values of tensile strength of the filament are: σ= 2,5-3,5 GPa. [6] Another popular type of skin material consists of unidirectional or woven aramid filaments with tensile strength values between: σ = 1,8- 3GPa. [7] [8] Glass fiber filaments, (biaxial, or woven), with tensile strength values: σ = 1,8 - 3.5GPa, are also popular for skin applications in Sandwich composite structures. [9]

Some novel type of skins consists of basalt fibers with a tensile strength of: σ= 3,1GPa and vegetal types like flax fibers with tensile strength values around: σ= 1,8GPa. [10] [11] [12] [13] All the above-depicted types of fibers are used together with an epoxy matrix, in order to form a composite skin.

3.2 Core materials

Different types of core materials are used, depending on the technical demands of the application. Nomex honeycomb is a popular core type used in lightweight composite Sandwich structures. Also, a great selection of closed cell foams can be used (Airex, RohaCell, AeroCell). Thin structures are designed with wooden fibers (balsa wood, abbachi), having an especially good buckling behavior. Closed foam cores cand be used in advanced geometry structures. This capacity is given by the ease of machining of this specific types of materials. A popular type of metallic core is the aluminum honeycomb. This type of core uses lightweight aluminum or lightweight alloys with a honeycomb architecture.

Popular architectures for the Sandwich core are:

- Foam core
- Corrugated core
- Honeycomb
- Hybrid core
- Folded core
- Stimulus responsive core

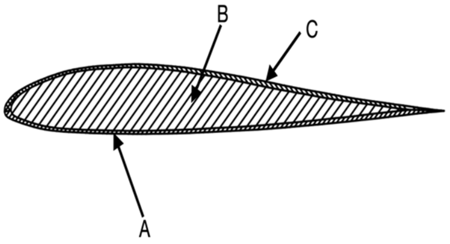
Corrugated sandwich structures are widely used in aeronautics and automotive fields. The corrugated core between the structure's skins has various geometric designs. The geometry can be rectangular, trapezoidal, triangular, or sinusoidal.

Honeycomb cored structures, as depicted earlier, are in the vast majority closed-cell prismatic structures. The properties of the honeycomb core can be improved if different material insertions are imbedded, forming a hybrid core.

The folded cores are based on the origami folding techniques and offer a performant low density core structure. Experiments revealed that the height of the folded core has effects on the radar absorbing characteristics of the Sandwich structure, making the structure suitable for various aerospace applications.

Stimulus responsive cores can be seen as a category in the smart materials family. The stimulus responsive cores can be self-folding or shape programable. Piezoelectric elements, electrorheological elements, or magnetorheological materials are used to form a stimulus responsive core. In this way, a morphing structure can be obtained. [5] [17]

A particular type of structure is the profiled core Sandwich structure. In Fig. 3, a section of an aircraft wing made with a profiled core Sandwich structure. This architecture is often seen in the wing's structure of light UAS (Unmanned Aerial Systems). The core consists of a milled geometry made of closed cell foam. The structure can be both symmetrical or asymmetrical in this case. Using a mold, the constituents are pressed together. Mobile control surfaces can be cut after demolding, or they can be created in the molding process if the mold has special features in this way. Usually, this type of structures with mobile control surfaces, use live hinges made of aramid.



A- inner skin
B- profiled core
C- outer skin

Fig. 3. Special profile core.

3. APPLICATIONS

Sandwich structures were used primarily in aircraft manufacturing since the 1940's. Beech Starship was the first all composite Sandwich aircraft built. It uses Sandwich structure with Nomex honeycomb core and CFRP skins. Some structural elements also have Sandwich structure with Nomex honeycomb and aramid reinforced polymer skins. In Table. 1, the use of Sandwich construction in Boeing aircraft is depicted. [4]

Table 1

Use of Sandwich construction in Boeing aircraft

Boeing Aircraft type	Percent of Sandwich structural elements
707	8
727	18
737	26
747	36
757	46
767	46

Symmetrical composite structures made of Nomex honeycomb and CFRP skins are often used for pressurized fuselages. Asymmetrical structures are used more and more often for UAS (Unmanned Aerial System) structures. One of the most common structures of this kind is a CFRP outer shell, Rohacell core and aramid reinforced polymer inner shell. Also, for good radio penetration, structures made of an aramid reinforced polymer outer shell, Airex core and GFRP (inner shell is used, thus obtaining an asymmetrical construction with high weight to stiffness ratio and good radio penetration.

4. ADVANTAGES

Considering an isotropic Sandwich structure and a thin-walled structure (monocoque) of the same weight, an interesting comparison can be made between these two. Let's consider a symmetrical composite Sandwich structure, with t_f, the thickness of the skin and h_c, the core's depth. Now let us consider a monocoque structure, a flat sheet with the thickness $2t_f$. We consider the second structure as being at the same weight as the composite sandwich structure. Thus, the extensional stiffness/ unit width, K, can be written:

$$K = \frac{2E_f t_f}{1-v_f^2} \qquad (4)$$

The relation (4) is applicable for both types of composite structures, where E_f is the elastic modulus. It can be observed that the two types of structures have similar in-plane stiffness when tensile and compressive loads are applied.

An important difference in the flex-stiffness per unit width, D, can be observed in the next part. We can write the relation of flex-stiffness for the monocoque structure as in (5):

$$D_m = \frac{2E_f t_f^3}{3\left(1-v_f^2\right)} \qquad (5)$$

The same relation for the composite isotropic Sandwich structure cand be written as in (6):

$$D_s = \frac{E_f t_f h_c^2}{2\left(1-v_f^2\right)} \qquad (6)$$

It is important to mention that the assumption that the core does not have an important influence upon the flex-stiffness ($t_f/h_c<1$). Thus, in (7) we can observe the flex-stiffness ratio of the two types of structures, at the same weight, using same skin materials:

$$\frac{D_s}{D_m} = \frac{3}{4}\left(\frac{h_c}{t_f}\right)^2 \qquad (7)\ [2],\ [4]$$

Thus, we can observe that for the composite Sandwich structure we can obtain lower lateral deflexions and higher capable bucking loads, when compared to the monocoque structure, at the same gross weight.

5. DAMAGE DETECTION

Due to the specific mechanical behavior of composite Sandwich structures, structural damage detection and monitoring can be made using several techniques.

Structural damage implies changes in the local and global dynamic properties of the composite Sandwich structure. Thus, damage can be evaluated by analyzing the dynamic response of the structure. A structure made of CFRP skins and Nomex core will be used as an example. Let us consider a structure that has an isolated delamination zone with both skins separated from the Nomex core. Experimental modal analysis shows the connection between the natural frequency shift and the size of the delamination zone.

Another technique for damage detection is the wave propagation study. Lamb waves (two-dimensional acoustic waves) are generated in the thin skins. Lamb waves stimulate the structure in its entire volume so they can be used for inspection of the thin skins. There is an important difference in impedance between the skins and the core. Thus, the amplitude of the direct wave packet is related to the global wave leakage in the structural core, so this can be the parameter to expose delamination between the skins and the core.

Another way of structural monitoring and damage assessment can be made by embedding optical fiber sensors in the composite Sandwich structure. The sensor network is implemented in the structure in the manufacturing stage. Two main systems can be integrated into the structures: ODTR (optical time domain reflectometry) and FBG sensors (fiber Bragg grating). In the ODTR case, light backscattering launched into the optical filament is used. When the fiber bends along with the structure, the ODTR signal is described by a gradual decrease in the bent portion. When a critical bend with small radius of the optical element's curvature is produced, a reflection peak appears in the ODTR signal.

For strain measurement, FBG technique can be used. When broadband light propagates into the sensor, a narrow band of light is reflected. The wavelength will change proportional to the strain and temperature applied to the structure imbedded sensor. The FBG technique can also be used to measure the flexural stiffness of the structure. [15]

5. CONCLUSIONS

In the paper, aspects regarding types of composite Sandwich structures, constituent materials and damage detection techniques are depicted.

Both symmetrical and asymmetrical composite Sandwich structures have a wide range of applications in aerospace and automotive industries. By customizing the composite Sandwich structure for a specific application, a more favorable weight to strength ratio is obtained. Stimulus responsive structures can be obtained, enhancing the overall performance of the composite Sandwich structure.

By implementing a smart systems for damage detection and monitoring of the composite Sandwich structures, an age estimation can be made, obtaining safer operation of the structure.

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STRUCTURI SANDWICH COMPOZITE - PREZENTARE GENERALĂ

Rezumat: Acest articol oferă o scurtă prezentare a structurilor sandwich compozite și a câtorva dintre domeniile lor de aplicare. Structurile sandwich compozite combină fețele laminate, cunoscute și sub numele de plăci, cu un miez ușor aflat între ele, combinând astfel proprietățile mecanice ale miezului și ale plăcilor. Se obține o rigiditate ridicată cu o mică creștere a masei. Punctele de focalizare ale articolului se referă la structurile utilizate în aplicațiile din industria auto și aeronautică. Materialele și arhitecturile constitutive specifice sunt studiate. Se analizează proprietățile mecanice ale plăcilor din GFRP (Polimer Armat cu Fibre de Sticlă) și CFRP (Polimer Armat cu Fibre de Carbon), împreună cu arhitecturile și materialele specifice ale miezului sandwich. Proprietățile diferitelor tipuri de miez sunt evaluate (miezuri din lemn de balsa, miezuri din spumă de poliuretan și miezuri de tip fagure de miere Nomex). Ultima parte a articolului se concentrează asupra aspectelor specifice de fabricație ale structurilor sandwich compozite și asupra aplicațiilor specifice în industria aeronautică.

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