Numerical study of the influence of variation skin's properties of a stitched sandwich structure under three-point bending test

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Abstract

Although the innovation of sandwich panels in structures is an old technology, it has given great performance by improving the resistance of structures by assembling two metal skins attached to a foam core on either side. In recent decades, sandwiches with composite skins have appeared. This new technology has been reinforced by the development of structural features that, while ensuring a solid link between the two skins, also give the structure resistance to the compressive force that stresses the skins during bending. Our research team is quite intrigued by this particularity, so we are focusing through this investigation on the study of the influence of the modification of the properties of the skin on the static behavior of a stitched sandwich structure. To do this, the study undertaken concerns the numerical analysis of a stitched sandwich structure composed of two equal woven fiberglass/epoxy faces, foam core reinforced with latex wicks under a three-point bending test. Three types of beam samples were studied with material variation of the two skins through a numerical model developed using finite element (FE) analysis software was used to achieve our goal. The results obtained show a significant increase of about three times the stresses and consequently a reduction in the displacements of the global structure.

Keywords: Composite materials; stitched sandwich; three-point bending; Finite elements analysis

1.Introduction:

A sandwich structure typically consists of two skins that are joined by an adhesive to a core; each part affects the behaviour and resistance of these structures, in the goal to increase the mechanical properties, such as its rigidity in flexion, while lowering the associated bulk [1,2,12] the researchers want to validate the function of each component through experimental and numerical studies like Lascoup,B (2004,2005,2006) [8-10], in the year of (2013) like. Sadighi, M [13], Shigang, A [15], Wang, P[16],Ai, S[17], and Tumino, D (2014)[3], (2019) Araújo, H.[4],Cucinotta, F[5] and Mocian, O[7] , recently Zangana, S (2020)[14],and in (2021) Ai,S[19],Drake,D[20,21],Hu, Y[22],Eyvazian, A[23] and Zhao, X [28], finally in (2022) Munafò, P [6],Hayta, N[11],and Sun, Y[25], Balıkoğlu, F [29],Neale, G [30],Jiang, H [31], Chaalani, A [32] ,Youcef, S. A [33].

Lascoup,B focused in their experimental studies on sandwich structure with foam core with transverse reinforcement technology (stitches) by modifying difference parameters as: stitching and their structural parameters , and improve the efficient of stitching on static and dynamic behaviour[8-10].
In the same rang Sadighi, M was validated a FE model studying the mechanical behavior of three-dimensional woven glass-fiber sandwich composites. [13]
The effect of stitching angle on mechanical properties of stitched sandwich panels was investigated by Shigang, A [15].

Wang, P. examined an experimental and numerical analysis of six types of beams under a test of 3-point bending in order to evaluate the flexural properties of stitched foam core sandwich structure.[16]
In thermodynamic Ai, S was studied the effect of the stitching step of thermal protection structures on its capability and the induced thermal stress by codes of Abaqus[17]
Another types of sandwich structures were carried out :
The behaviour of sandwich structures with corrugated cores was illustrated in the work of D. Tumino who validated an FE model replacing an elementary cell with an analytical model of these complex structures [3]. Modifying the geometry of the core by additive manufacturing can be an alternative to traditional shapes [4]. A numerical model had been used to explore and validate the research of the effect of material type, fibre orientation, and other degrees of freedom on sandwich structures [5].

Zangana, S was investigated a new model of structures by modifying the composition of the fiber of a Trapezoidal corrugated core introducing 25% of high resistance fiber (Zylon et Kevlar) to improve the dynamic impact performance.)[14],

Recently Ai,S with an experimental work analysed the effect of stitching density, stitching yarn twist, and strands on the mechanical performances of novel stitched sandwich panel structure composed by two Al_2O_3/Al_2O_3 woven composite face sheets, an aerogel heat-insulation core, and several mullite zpin fiber yarns[19].

D Drake in a review and experimental investigation, was examined the effect of stitch parameters (stitch density, linear thread density, and facesheet thickness) on fracture energy of sandwich composites with carbon/epoxy facesheets and a foam core [20,21].

Hu, Y. used an automatic reinforcement stitching machine that was specially constructed to show how the effect of sandwich beam stitching spacing on the crack propagation process may be improved.[22]

Using composite sandwich panels with a polyvinyl chloride core and glass/epoxy face sheets, Eyvazian, A. examined the impacts of reinforcing parameters by resin pins under quasi-static indentation and three-point bending test.[23]

The insertion of nylon 6 fabric in the adhesive layer shows their applicability by improving their mechanical performance and adhesion [6].

Sun, Y. examined the mechanical characteristics of a ceramic-fiber-reinforced SiO_2 aerogel composite layer core and a stitched sandwich thermal protection structure and compared them under various experimental tests. The results improved the effectiveness of the sandwich thermal protection structure.[25]

The experimental study of low velocity impact behavior of foam core sandwich panels with composite face sheets reinforced with aluminum and glass fibers has concluded that each normalized parameter gives specific information on the sandwich response and, therefore, the information obtained from each of them must be corroborated. [7]. A Special attention to foam core sandwich structures through the innovation of transverse reinforcement technology by seams these structures finally increase the mechanical properties in the direction of the thickness and present a gain in mechanical performance comparing a sewn structure with a structure not stitched [2,8,9,10,11].

In this article we aim to study the influence of changes in the materials of the skins on the behaviour of the sandwich structures sewn digitally using an FE model. The validation of the FE model had already been approved in the previous studies of Mr.TAB [2].

2. FINITE ELEMENT MODELLING:

2.1. *Material constitutive models*

The sewn sandwich specimen consists of two balanced woven fiberglass skins, a foam core and the seams connecting the two skins through the core creating a criss-cross pattern.

As shown in the following statement, the constitutive equation in anisotropy for the two layered skins, regarded as laminated plates, gives the stress vector as a function of the vector of deformations [B.Lorrain and Co,2000]

$$\begin{Bmatrix} \sigma1 \\ \sigma2 \\ \sigma3 \\ \sigma4 \\ \sigma5 \\ \sigma6 \end{Bmatrix} = \begin{bmatrix} \varrho11 & \varrho12 & \varrho13 & 0 & 0 & 0 \\ \varrho12 & \varrho22 & \varrho23 & 0 & 0 & 0 \\ \varrho13 & \varrho32 & \varrho33 & 0 & 0 & 0 \\ 0 & 0 & 0 & \varrho44 & 0 & 0 \\ 0 & 0 & 0 & 0 & \varrho55 & 0 \\ 0 & 0 & 0 & 0 & 0 & \varrho66 \end{bmatrix} \begin{Bmatrix} \varepsilon1 \\ \varepsilon2 \\ \varepsilon3 \\ \varepsilon4 \\ \varepsilon5 \\ \varepsilon6 \end{Bmatrix}$$

σi: main stress

ε_i: deformations

ϱ_{ij}: are the elastic coefficients which are determined by the following expressions:

$$\varrho11 = E_1.\frac{1-\nu23.\nu32}{\Delta}$$

$$\varrho11 = E_1.\frac{\nu21-\nu31.\nu23}{\Delta} = E_2.\frac{\nu12-\nu32.\nu13}{\Delta} = \varrho21$$

$$\varrho13 = E_1.\frac{\nu31-\nu21.\nu32}{\Delta} = E_3.\frac{\nu23-\nu21.\nu13}{\Delta} = \varrho31$$

$$\varrho22 = E_2.\frac{1-\nu13.\nu31}{\Delta}$$

$$\varrho23 = E_1.\frac{\nu32-\nu12.\nu31}{\Delta} = E_3.\frac{\nu23-\nu21.\nu13}{\Delta} = \varrho32$$

$$\varrho33 = E_3.\frac{1-\nu12.\nu21}{\Delta}$$

With

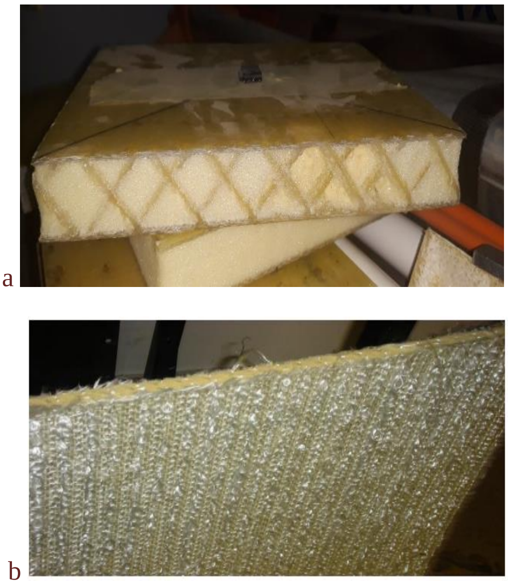
$$\Delta = 1 - \nu12.\nu21 - \nu23.\nu32 - \nu31.\nu13 - 2\nu21.\nu32.\nu13$$

The properties of each component derive from work [Bertrant, 2005]:

This basic sandwich beam will be considered as the reference for this study.

Figure 1 show the configuration (**a.** the studied sewn sandwich sample. **b.**view of a skin)

Table 1 lists the material composition of the studied sample



a b

Figure 1: Stitched sandwich structure

Component	Material	Note
face	Woven Fiber-glass	Thickness: 1.5mm
core	Foam	Thickness: 20mm
stitches	Latex	Diameter: 2mm

Table 1: General characteristic of the structure

To study the effect of skin materials on the behaviour of the studied structure; three types of specimens are used:

1- woven fiberglass/Epoxy,
2- E-glass SMC/UP
3- E-glass MAT/UP

2.2. Geometry and mesh

Figure 2 illustrates the 3D finite element model of the sample used in the bending simulations. The model size is 23x630x92 mm^3 and the stitching step is 20mm with 45°angle . Three specimens with different skin materials were constructed to study the effect of skin materials on the bending response of these structures.

Figure 2: 3D Stitching sandwich structure

2.3.Loading and boundary conditions:

Three points bending:

The numerical modeling of the three-point bending test on the stitched sandwich structure has been built using commercial finite element (FE) code ABAQUS.A linear static analysis has been taken into account; A concentrated force has been applied by rigid cylinder to the center of the upper face of the beam in the punch reference point (RP). The supports which radius is R = 20 mm while the lower support is blocked.

A surface-to-surface contact interaction has been used between the rigid body and the faces of the structure.

In addition, a general hard contact with penetration was defined for the simulation with a penalty/coefficient of friction of 0.15. The skin parts were meshed with masonry elements with 8 linear hexagonal dominance nodes (C38DR) with an element size of 30.5 mm. The stitching were meshed with 3D lattice elements with 2 linear nodes (T3D2) And the cylinders were meshed by a rigid bilinear 3D quadrilateral with 4 nodes (R3D4).

The model consists of approximately 2094 elements and 2457 nodes.

Figure (3) illustrate the boundary conditions and the adopted mesh of the structure designed as three dimensions (3D) model.

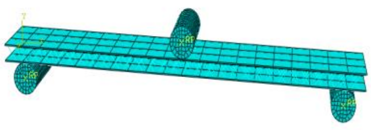


Figure 3: Mesh and boundary conditions

3. RESULTS AND DISCUSSION:

Static bending simulations were carried out: a force concentrated on the upper cylinder has been applied while the other end of the specimen is clamped at the level of the two cylinders. The Mises contour and the displacement contour of the sample with different materials of the skins is shown in Figure. 4.

According to the results of the simulation, we observe a concentration of the stresses and displacements at the level of the application of the load then of the minimum values towards the two lower supports. Table 2 summarizes the maximum values of the stresses and displacements for the three types of structures: We note a significant increase in the Mises compressive stresses and a reduction in the displacements of the skins: the organization of the reinforcements influences the overall behavior of the structure-sewn sandwiches. The two histograms summarize the values described in table 2.

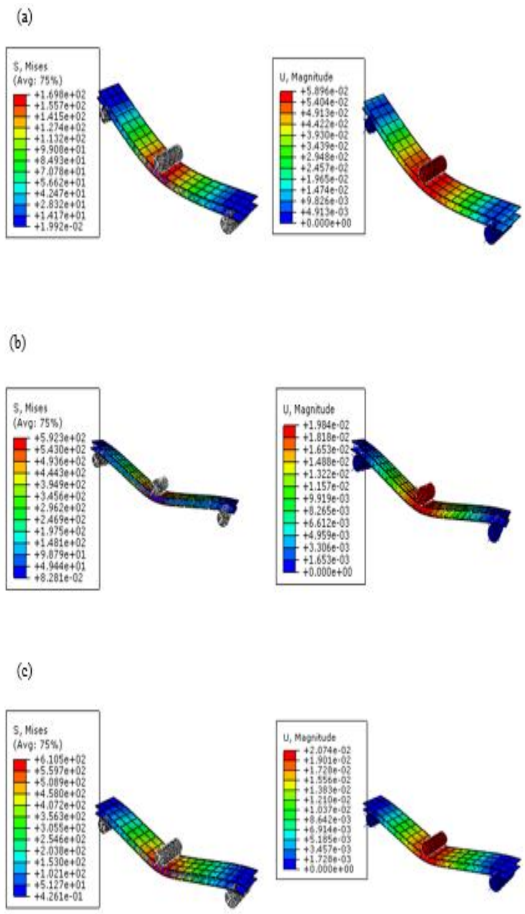


Figure 4: Mises stress and displacements, (a) faces with woven fiberglass/epoxy, (b) faces E-glass SMC/UP, (c) E-glass MAT/UP

Materials	E-glass/Epoxy	E-glass SMC/UP	E-glass MAT/UP
Stress max (S Mises) $\times 10^2$ [KN/m²]	1.698	5.923	6.105
Displacements $\times 10^{-2}$ [m]	5.896	1.984	2.074

Table 2: Max values of Mises stress and displacements

Figure5.Stress and displacement histograms for skins materials

5.Conclusions:

This paper investigated numerically the behavior under the bending test of stitched foam core sandwich beams. The displacements as well as the stresses put on these sandwich panels have been deduced. Based on the results and discussions, the following conclusions can be drawn:

- The analysis carried out using the computer tool used was very interesting insofar as it allowed us to compare the results: in general and in the three cases: The beams showed a very regular behavior against the three-point bending stress.
- The shape of the arrows of the beams is normal, because it presented a strong concentration of tractions of lower skins stretched in the middle and at the supports this concentration is indicated for the upper faces.
- The type of material E-glass SMC/UP presents min displacements whereas E-glass MAT/UP presents max stresses.

As a future development, the FE model could be leveraged in a topology optimization tool to obtain the best layouts for thickness, materials, fiber orientation, and core size for specific applications in static and dynamic analysis.

6.Future scope:

This work is part of a research axis of the "Analysis and Modeling" team of the laboratory to which it belongs. This axis consists in carrying out a broad popularization campaign of the so-called subject structure of the present study. The aim of this campaign is to innovate this structural material thus designed in the field of mechanical, civil and public works engineering. To do this, two application projects are in perspective. The first proposes the use of these panels as covering for aeronautical floors, while the second aims to use them as road guardrails.

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