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Impact behaviour of a new Hemp/Carbon sandwich structure

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Abstract

This paper aims to present a new sandwich structure comprising of a grid hemp core and carbon skins. Two typology of hemp cores (7 and 8 mm in thickness) that mainly differ in the density values (0.36 and 0.63 g/cm^3) were produced by an ad hoc manufacturing process and adopted to produce the sandwich structures under investigation.
Aiming to extend the use of natural fibre composites (NFCs) for applications where high impact resistance is required and to replace common materials used as cores with more eco-friendly ones like the proposed hemp core, low velocity impact (LVI) tests and non-destructive (ND) tests were carried out.

Keywords: Hemp; Hemp Core; Hybrid sandwich strucure; Impact; Non destructive test

1. Introduction

Sandwich structures consisting of two relativity thin and high-performance face sheets, called skins, divided by a thick and low-density core are very popular in several application fields thanks to their excellent balance between rigidity/strength and lightness [1,2]. Indeed, their high stiffness/strength-to-weight ratio make these structures very appealing for advanced industries of aerospace, maritime, sports equipment, transportation, construction and defense [3,4].

The desired balance between mechanical properties of sandwich structures and their weight together with the increases of moment of inertia conferred by the thick core, can be obtained with any kind of materials, both isotropic and no-isotropic materials can be taken into account. However, as often occurred to maximize the specific mechanical properties, the use of high-performance composite materials represents an interesting opportunity. For this reason, it is very common to find sandwich structures consisting of carbon, Kevlar or glass composite skins. If on one hand these materials confer high strength and rigidity to the skins, on the others due to their thinness and sometime for their intrinsic properties, these elements do not offer any compression and impact resistance or thermal and acoustic isolation properties. These properties have to be conferred by the core usually either be of metallic, polymeric or natural materials.

In the last years, considering the increasing environmental awareness and the introduction of new rules and regulations to reduce the environmental impact and reach sustainability, the new products must minimize the environmental impact, so the interest and then use of eco-friendly materials is grooving more and more in different application fields [5–9]. This aspect is especially relevant in the composite manufacturing field, where petroleum polymers and synthetic fibres are still widely used. Therefore, in this context, it can be interesting to consider the use of NFCs as constitute material of a core for sandwich structures, indeed different research works on this topic are available in literature.

Li et al. [10] studied the compression strength of a lattice sandwich structure mainly consisting of jute fiber and resin epoxy. The density of the juta lattice structure was around 1.15

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g/cm^3 and the manufacturing process was not continuous because three main steps (i.e. forming of the juta laminates, cutting of the laminate in struts and their connection using epoxy resin) were required.

Cicala et al. [11] highlighted the interest in the use of natural fiber composites as core for sandwich studying the feasibility of using a hemp/epoxy biocomposite materials as base for an hexachiral auxetic truss-core made with RTM techniques.

From the literature review clearly appears the current interest for the use of NFCs as core for sandwiches but in the same time some gaps are evident. First of all, an extensive investigation on the impact behavior of sandwich structure consisting of lightweight NFC cores were not found. Secondly, most of the works available in literature, focused the attention on the use of jute or flax as fiber for the production of core composites for sandwich. However, another important vegetable fiber, like hemp, needs to be considered due to its attractive mechanical properties, low production cost and high cellulose content. In addition, the hemp plant is characterized by the ability of extracting heavy metals from the soil makes and the environmental conditions required from its cultivation allow the easy growth of this plant around the world. Last but not least, from the literature review appeared that natural fiber composite cores were made by using no-continuous process. Therefore, aiming to fill these gaps, to extend further the use of hemp fibers for primary structural applications, the focus of this work is to use hemp fibers to produce a core for sandwich structure by using an ad-hoc continuous manufacturing process. In detail, sandwich structures with hemp core with different density values and CFRPs skins were produced and the impact behavior was detailed studied.

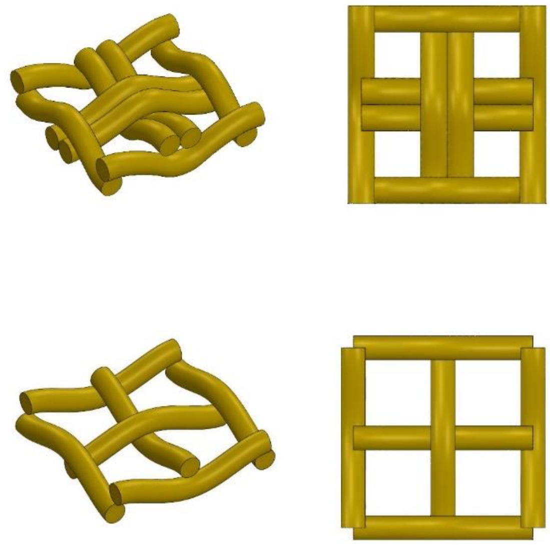
2. Materials and methods

2.1. Materials

Two main hemp core sample families that differ from the density value were studied in this experimental campaign. To produce the two sample typologies, two types of woven hemp fabrics (supplied by Fidia Srl) with an areal density of 380 and 190 g/m^2 were impregnated with an epoxy resin SX10 (supplied by Mates Srl). In Fig.1 is reported a schematisation of the elementary cell of the two hemp fabrics, the first one (Fig.1a) is characterised by the highest areal density (GMS = 380 g/m^2) and the second one (Fig.1b) by the lowest areal density (GMS = 190 g/m^2).

Based on this classification, the high-density hemp core was labelled ad HD, meanwhile the low density one was labelled ad LD.

A woven carbon fabric prepreg (supplied by Easy Composites) characterised by an areal density of 200 g/m^2 was used to produce thin skins and an epoxy adhesive film (supplied by Easy Composite) was used for the sandwich structure assembling.



a)

b)

Fig. 1. Schematisation of the elementary cell (a) HD; (b) LD hemp fabrics.

2.2. Sample manufacturing

According to other researchers methodologies [6,7,12], in order to improve the fibre-matrix adhesion, both the hemp fabric typologies were soaked in 2% NaOH solution at room temperature for 30 minutes before the impregnation phase.

After this chemical treatment, the hemp fabrics were washed to remove any traces of the chemical solution and then were treated with a 1% acetic acid solution.

Then, at the end of this treatment, both configurations were dried in an oven at 60° for 12 hours.

The hemp core samples were produced by using an ad-hoc continuous manufacturing process that is schematised in Fig.2 and characterised by the following steps:

- Impregnation
- Resin content reduction
- Resin absorption
- Cutting
- Polymerisation

A caterpillar system pulls and forces the hemp fibres into a resin bath where tension rolls squeeze the fabric in order to obtain a good impregnation.

Then, the resin content is regularised using an air jet that flows through the mesh of the impregnated fabric and a couple of rolls with renewable absorbent paper on their surfaces to absorb the excess of resin.

The fibre weight fraction content of each hemp core's layer was fixed at almost the 40%, then the ratio between the weight of the impregnated and unimpregnated layer was kept constant to 2,5.

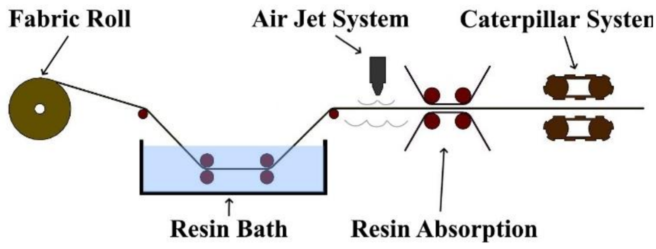


Fig. 2. Schematisation of the hemp core production system.

The impregnated fabrics are then cut in layers 100 x 150 mm^2 in dimension and a total number of 6 layers for each specimen were stacked one to the other in a close mould constituted by a steel plate and a polymeric bag to allow the use of vacuum. Then, the closed mould was placed in a hydraulic press to have the polymerisation of the hemp cores with a pressure of 1 bar at room temperature for 24 hours.

The carbon fibre skins were manufactured with a total number of 4 plies to obtain laminates 1 mm in thickness. The carbon fibre reinforced plastic (CFRP) laminates were cured in autoclave with a pressure of 8 bar at 120 °C for 8 hours then, at the end of the polymerisation, were cut in plates 100 x 150 mm^2 in dimension.

Finally, the hybrid sandwich structures were assembled placing the epoxy resin film between the bio-based core and the carbon skins and cured in autoclave under vacuum with a pressure of 8 bar at 120 °C for 8 hours. Fig. 3 shows a schematisation of the assembling process (Fig.3a) and the cured sample (Fig.3b). Therefore, in this experimental campaign, two main sample typologies that differ in the core density value were manufactured. Table 1 resumes the main physical properties of all samples under inspection.

Table 1. Main properties of the sample families.

Label	Number of core plies	Weight [g]	Sandwich thickness [mm]	Core density [g/cm^3]
HD_6P	6	131,2	9,93	0,63
LD_6P	6	88,9	8,76	0,37

2.3. Experimental procedure

In this experimental campaign low velocity impact test (LVI) at 25 J and 45 J were carried out according to the ASTM D7136 standard, to study the impact behaviour of the hybrid sandwich structures. The internal damage extension was measured with the Computed Tomography Scan (CT-Scan) according to the ASTM E1672 standard.

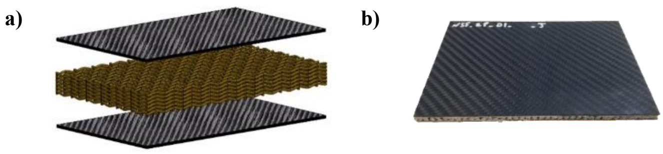


Fig. 3. Schematisation of assembling process(a) and cured sample (b).

The impact tests campaign was performed using a homemade falling drop weight machine, the apparatus is composed by a 9 kg falling shuttle moving on low friction guides and a hemispherical impactor tip 15 mm in diameter.

The impactor rig is also equipped with an anti-rebound system to avoid multiple impact events on the tested specimen. The impact tests were carried out according to the ASTM standard, therefore rectangular specimens with 100 x 150 mm^2 in dimension were tested.

All data acquired were processed by a MatLab routine obtaining as output impact curves such as force-displacement; velocity-time and displacement-time, but in this experimental campaign the attention will be focused on the force-displacement curves because are the most representative of an impact event.

The internal damage was detected using CT-Scan. This non-destructive test method overcome some issues related with the sandwich structures, that limit the use of the most traditional non-destructive testing techniques such as Phased array and Thermography.

In detail, these issues are related with the presence of multiple interfaces and voids that characterise the sandwich panel and the core structure respectively.

This method gives as output 3D images of internal areas with details of the internal damaged volume allowing to the evaluation of the damage extension.

Furthermore, additional inspection of the longitudinal cross section path of the impacted specimen, permits a detailed description of the failure mechanisms that occur during an impact event.

Fig. 4 shows a schematic representation of the hybrid sandwich structure and the longitudinal cross section path.

3. Results and discussion

In Fig. 5 the impact force-displacement curves of both the HD and LD samples impacted at the same energy level of 25 J are reported.

Comparing these two sandwich typologies it is possible to note that the HD sample shows a stiffer behaviour in comparison with the LD one, it is expected since the HD typology is characterised by a denser core with a double number of fibres per unit of area if compared to the LD sample.

Focusing the attention on the 25 J impact curve, it is possible to observe from the HD and LD samples comparison, that the LD one is characterised by a different response, showing a reduced peak force of almost 36% if compared to the HD sample.

Fig. 4. Schematisation of the longitudinal cross section used for the CT-Scan inspection.

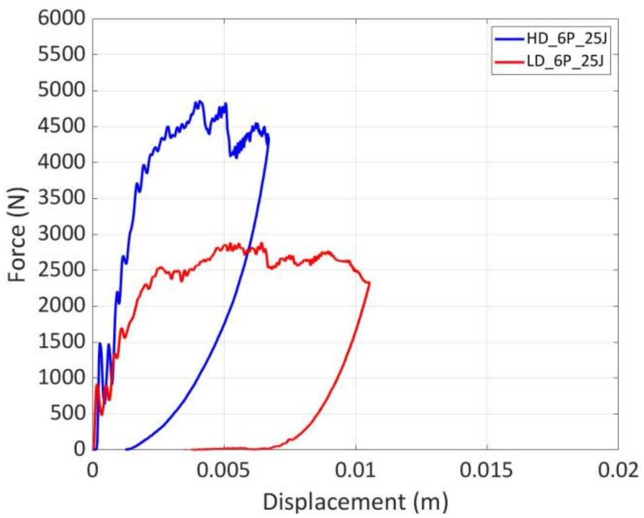


Fig. 5. Force-displacement impact curves at the same impact energy level of 25J for both HD and LD sample type.

It is also clear for both the sample typologies, a remarkable load drop in the first section of the loading portion of the impact curve pointing out cracks and damage of the outer skin of the sandwich structure.

The same conclusions can be drawn at the end of impact tests performed at 45 J for both the sample typologies. In Fig. 6 are shown the force-displacement curves of HD and LD samples impacted at the same impact energy of 45 J.

As well as for the impact tests carried out at 25 J, the HD typology shows a stiffer behaviour in comparison with the LD one. This aspect is further confirmed by the peak force and the maximum displacement registered during the impact event, the LD configuration shows a peak force reduction of almost 20% and an improvement of the maximum displacement around 50% if compared to the HD sample.

Therefore, it is possible to appreciate that the HD sample is not affected by severe internal damage, it shows a load drop in correspondence of the top skin failure and then the rebound, meanwhile the LD configuration shows a clear load drop that indicate the failure at penetration but no perforation occur.

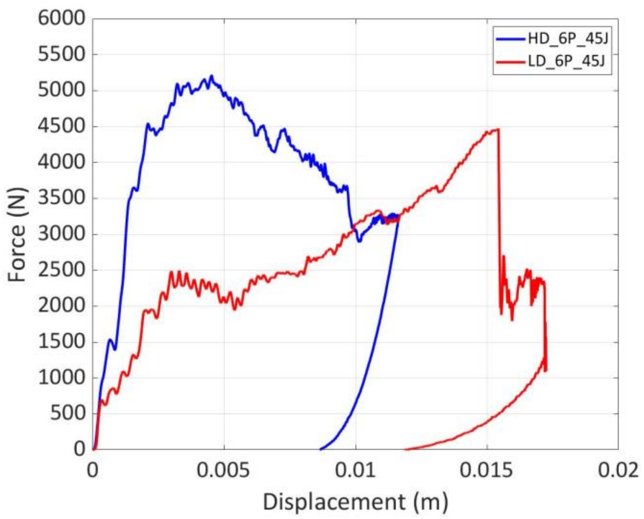


Fig. 6. Force-displacement impact curves at the same impact energy level 45J (a) HD sample; (b) LD sample; (c) HD and LD comparison.

From the low velocity impact experimental campaign, the stiffer behaviour of the HD sample is revealed, but the energy absorption capability of the LD configuration is highlighted, indeed both impact test revealed an improvement of the absorbed energy of almost 23% and 11% respectively at 25 and 45 Joules.

Even if the LD sample shows a higher capability in energy absorption if compared to the HD typology, to compare the impact behaviour of both configurations, the specific absorbed energy was evaluated by the ratio between the absorbed energy and the sample's weigh.

In Fig.7 are resumed the 25 J and 45 J force-displacement impact curves of both the sample typologies (Fig.7a) and the absorbed energy per unit of weight graph (Fig.7b).

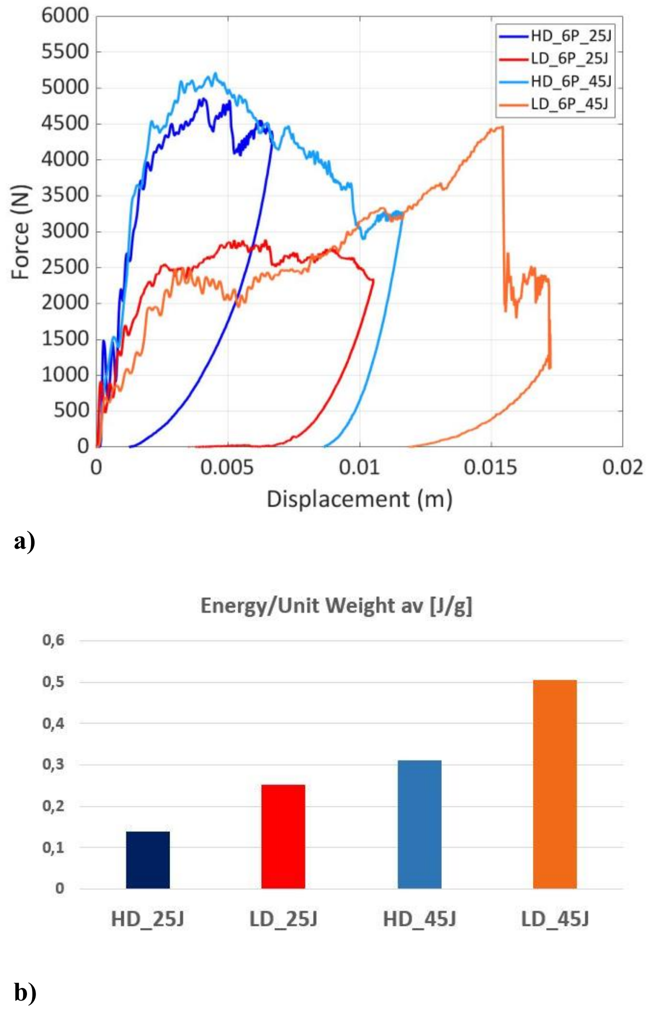


Fig. 7. Force-displacement impact curves at 25 J and 45 J impact energy level of HD and LD samples (a) and absorbed energy per unit of weight (b).

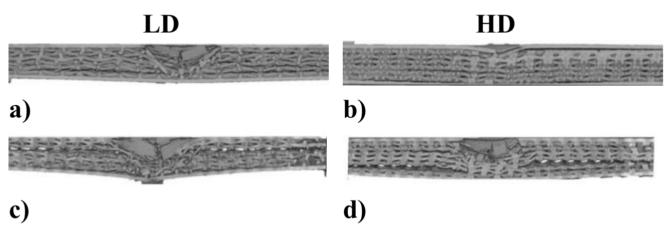


Fig. 8. CT-Scan results for (a) LD sample at 25 J; (b) HD sample at 25 J; (c) LD sample at 45 J; (d) HD sample at 45 J.

In Fig. 7b are shown the average valued of the absorbed energy per unit of weight at 25 J and 45 J for each sample typology. When the sample's weight is taken into account, it is possible to observe that increasing the impact energy, the specific absorbed energy increases. Furthermore, both at 25 J and 45 J, the LD configuration reveals a specific absorbed energy that is respectively almost 82% and 73% higher if compared to the HD one.

Therefore, the low velocity impact tests demonstrate that the LD sample is able to absorb more impact energy per unit of area in comparison with the HD typology.

The effect of the impact event on the tested samples have been examined by the CT-Scan test, what observed in this non-destructive test is in good accordance with the results of the impact experimental campaign.

In Fig. 8 the CT-Scan results of HD and LD samples impacted at 25 J and 45 J are reported. If the attention is focused on the 25 J impacted samples, it is possible to observe that the LD typology is affected by intra-core delamination meanwhile the HD one does not show appreciable sign of delamination, but core crushing and top skin damage.

The different impact behaviour of the two samples is determined by the different stiffness that characterises them, the HD typology is characterised by more contact points between fibre tows in warp and weft direction making this configuration stiffer than the LD one.

The same conclusion can be drown when the impact energy rises up, the LD sample reveals clear sign of bottom skin failure, core crushing and severe intra-core delamination, on the other hand, the HD one starts to show clear sign of intra-core delamination and severe core crushing.

Furthermore, an additional impact energy absorption mechanism that characterises the HD sample at 45 J, is a remarkable debonding phenomenon between the hemp core and the bottom skin.

Therefore, it is possible to affirm that thanks to the high flexibility that characterises the LD configuration, it is able to deflect more than the HD configuration, dissipating the impact energy through intra-core delamination when the critical threshold limit is reached.

4. Conclusions

New lightweight hemp composite structures were manufactured by means of an ad-hoc continuous impregnation process. The new grid structures have a very low apparent density in the range of 0.36–0.63 g/cm^3 (depending on the type of fabric used) and were successfully used as core for sandwiches.

Despite the main drawbacks of the hemp fibres (non-uniform surface, variability of properties, low resistance to water absorption and thermal decay), this work proved that their application can be increased, for example to produce core for high performances sandwiches.

The results of the entire experimental campaign highlight the interesting impact behavior of the grid structures under investigation with energy adsorption mechanisms that depend on the core density.

Both at 25 J and 45 J, the low density (LD) configuration reveals a specific absorbed energy that is respectively almost 82% and 73% higher if compared to the high density (HD) one. This because the LD typology is affected by intra-core delamination meanwhile the HD one does not show appreciable sign of delamination, but core crushing and top skin damage.

References

[1] Zaid NZM, Rejab MRM, Mohamed NAN. Sandwich Structure Based on Corrugated-Core: A Review. MATEC Web Conf 2016;74. https://doi.org/10.1051/matecconf/20167400029.

[2] Yin S, Chen H, Wu Y, Li Y, Xu J. Introducing composite lattice core sandwich structure as an alternative proposal for engine hood. Compos Struct 2018;201:131–40. https://doi.org/10.1016/j.compstruct.2018.06.038.

[3] Norouzi H, Rostamiyan Y. Experimental and numerical study of flatwise compression behavior of carbon fiber composite sandwich panels with new lattice cores. Constr Build Mater 2015;100:22–30. https://doi.org/10.1016/j.conbuildmat.2015.09.046.

[4] Fan HL, Meng FH, Yang W. Sandwich panels with Kagome lattice cores reinforced by carbon fibers. Compos Struct 2007;81:533–9. https://doi.org/10.1016/j.compstruct.2006.09.011.

[5] Boccarusso L, Durante M, Langella A, Minutolo FMC. FE Analysis of Low Density Hemp/Epoxy Composites Produced by a New Continuous Process. Procedia CIRP 2018;67:428–33. https://doi.org/10.1016/j.procir.2017.12.237.

[6] Boccarusso L, Carrino L, Durante M, Formisano A, Langella A, Memola Capece Minutolo F. Hemp fabric/epoxy composites manufactured by infusion process: Improvement of fire properties promoted by ammonium polyphosphate. Compos Part B Eng 2016;89. https://doi.org/10.1016/j.compositesb.2015.10.045.

[7] Boccarusso L, Durante M, Langella A. Lightweight hemp/bio-epoxy grid structure manufactured by a new continuous process. Compos Part B Eng 2018;146:165–75. https://doi.org/10.1016/j.compositesb.2018.04.009.

[8] Pinto F, Boccarusso L, De Fazio D, Cuomo S, Durante M, Meo M. Carbon/hemp bio-hybrid composites: Effects of the stacking sequence on flexural, damping and impact properties. Compos Struct 2020;242. https://doi.org/10.1016/j.compstruct.2020.112148.

[9] De Fazio D, Cuomo S, Boccarusso L, Pinto F, Durante M, Meo M. Design and characterization of hybrid hemp/carbon laminates with improved impact resistance. Mater Today Proc 2020. https://doi.org/10.1016/j.matpr.2020.02.732.

[10] Li S, Hu R, Cheng J, Hu Y. Compressive effect of jute fiber corrugated lattice sandwich structure. J Reinf Plast Compos 2020;39:209–18. https://doi.org/10.1177/0731684419881785.

[11] Cicala G, Recca G, Oliveri L, Perikleous Y, Scarpa F, Lira C, et al. Hexachiral truss-core with twisted hemp yarns: Out-of-plane shear properties. Compos Struct 2012;94:3556–62. https://doi.org/10.1016/j.compstruct.2012.05.020.

[12] Sepe R, Bollino F, Boccarusso L, Caputo F. Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites. Compos Part B Eng 2018;133. https://doi.org/10.1016/j.compositesb.2017.09.030.