Composites Part A 109 (2018) 10–19

Contents lists available at ScienceDirect

Composites Part A

journal homepage: www.elsevier.com/locate/compositesa

Experimental investigation of impact behavior of wood-based sandwich structures

John Susainathan, Florent Eyma, Emmanuel De Luycker, Arthur Cantarel, Bruno Castanie*

Institut Clément Ader (ICA), Université de Toulouse, CNRS UMR 5312-INSA-ISAE-Mines Albi-UPS, Toulouse, France

ARTICLE INFO

Keywords:
Wood
Impact
Sandwich
Damage

ABSTRACT

Low carbon emission and sustainable development are shared goals throughout the transportation industry. One way to meet such expectations is to introduce lightweight materials based on renewable sources. Sandwich panels with plywood core and fiber reinforced composite skins appear to be good candidates. Additional properties of wood such as fire resistance or thermal and acoustic insulation are also essential for many applications and could lead to a new interest for this old material. In this paper, Sandwich panels with two different types of plywood and four different skins (aluminum and glass, CFRP, or flax reinforced polymer) are tested under low-velocity/low energy impacts and their behavior is discussed.

1. Introduction

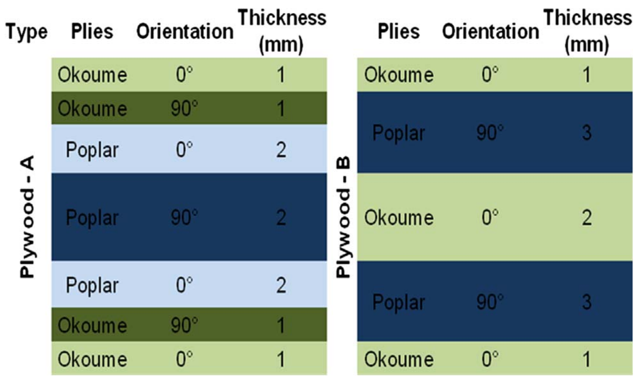
Sandwich structures are lightweight composite structures that have been widely used in numerous sectors, such as the automotive, aerospace, marine and energy industries, due to their several advantages: high specific bending strength and stiffness, excellent damping, and thermal insulation [1,2]. Low carbon emission and sustainable development are shared goals in the transportation industry and one way of achieving them is to implement lightweight materials based on renewable materials. Sandwich panels with plywood core and fiber reinforced composite skins appear to be good candidates, particularly as certain additional properties of wood such as fire resistance or thermal and acoustic insulation are also essential for many applications. Plywood is still used in the construction of homemade airplanes and, until the 1990s was employed in the design of acrobatic aircraft like the Mudry CAP10. It is perhaps less well known that, in the 1960s, a car designed for the “Le Mans” race by the famous English engineer Frank Costin had a plywood structure for a total mass of only 450 kg. So, a combination of plywood and other materials seems to be relevant and was first investigated statically by the authors [3,4]. Wood based sandwich structures with high specific properties, low costs and good energy dissipation capability are promising candidates for impact and crash applications in the transportation sector [4–7]. The buckling of tracheid cells in wood at micro scale is similar to the structural buckling of honeycomb cell walls at macro scale and enables maximum energy dissipation [8,9]. Hence, the implementation of new sandwich structures requires significant efforts to understand their behavior. In particular, sandwich structures are vulnerable to various impact loads and may be exposed to different impacts during their service life [4]. These impacts may result in significant damage, such as local cell wall buckling or core crushing, and debonding between skin and core, so damage in the skin can intensively compromise the integrity of the structure [5–10] and especially the compression after impact strength [6,11]. So the analysis of plywood based sandwich structures under impact is a priority.

Impact tests are generally classified as low (< 10 m/s), medium (10–50 m/s) or high velocity (50–1000 m/s) impacts [12]. In this paper, we will focus on low energy/low velocity impact, which corresponds to common uses of structures and may be sensitive for innovative structures. Much research has focused on low velocity impacts on conventional composite and sandwich structures [5,10–19] while wood-based sandwich structures have been little investigated. Toson et al. [20] pointed out that balsa wood presents significant interest as a core material in sandwich panels because of its transversely isotropic behavior, i.e., it is stiffer and stronger in the fiber direction (axial) than in the radial and tangential directions. Atas [21] compared the impact responses of composite skinned sandwich structures with balsa wood – HD (high density) or PVC foam cores, and revealed that sandwich structures with balsa wood gave better results in terms of energy absorption capability and impact induced damage than sandwich structures with conventional polymeric foam cores. In similar way, Shin et al. [7] analyzed impact responses of composite skinned sandwich structures with various cores, such as HD balsa wood and aluminum honeycomb, and claimed that the energy absorption of wood based sandwich structures was comparable with that of aluminum honeycomb sandwich structure. Hachemane et al. [22] performed an

---

* Corresponding author.
E-mail address: bruno.castanie@insa-toulouse.fr (B. Castanie).

https://doi.org/10.1016/j.compositesa.2018.02.029
Received 22 November 2017; Received in revised form 17 January 2018; Accepted 19 February 2018



Type	Plies	Orientation	Thickness (mm)
Plywood - A	Okoume	0°	1
	Okoume	90°	1
	Poplar	0°	2
	Poplar	90°	2
	Poplar	0°	2
	Okoume	90°	1
	Okoume	0°	1

Type	Plies	Orientation	Thickness (mm)
Plywood - B	Okoume	0°	1
	Poplar	90°	3
	Okoume	0°	2
	Poplar	90°	3
	Okoume	0°	1

Fig. 1. Plywood A and B stacking. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

experimental characterization of a jute/epoxy–cork sandwich structure exposed to impact and indentation. Petit et al. [23] used cork as a thermal shield and analyzed the impact behavior of Sandwich panels and laminates. It was shown that the thermal shield significantly modified the failure patterns and created an effect of shift in damage creation. Mezeix et al. [24] tested inserts in sandwich structures using a drop-weight device and analyzed the impact response and failure patterns. The residual strength after impact was very high in comparison to the large reductions habitually observed after impact tests. Abdalasam [25] compared the low velocity impact response between end and regular grain balsa wood core sandwich with glass epoxy skin and found that a sandwich offered better energy absorption when it had a regular rather than an end grain balsa core. However, end grain balsa core can withstand higher impact loads than regular balsa core thanks to its higher stiffness. Energy absorption, impact load and failure modes are strongly dependent on the orientation of the wood core grain [25]. Wang et al. [26] analyzed the medium velocity impact response of sandwich structures with different cores such as cores of balsa wood, cork, polypropylene honeycomb and polystyrene foam. He claimed that, among the five panels, the sandwich panel with the HD balsa core yielded the best results in terms of specific energy absorption because of its lower density compared to the other core materials. In summary, a review of the results regarding the impact response of sandwich structures confirms that structures with plywood core have been little studied. Therefore, the Sandwich panels with plywood cores that were manufactured and tested statically in [3] are analyzed under low energy impacts here. Considering the results mentioned above, the precise aim of our work was to compare the materials currently used for cargo bay floors, namely aramid honeycomb having carbon and glass composite skins, with wooden sandwich structures developed in the laboratory. A 10 mm plywood core was used in order to be able to compare the effects on the impact behavior of skins made out of aluminum alloy, and composites reinforced with glass, carbon or flax fibers. These materials were impacted at energy levels of 5 J, 10 J, and 15 J using a drop-weight impact test, and a comparison based on the force–displacement response and failure modes of the panels is presented. The damage resistance and failure modes of wood based sandwich structures under low energy impact will be described on the basis of post impact tomography analysis [27–30].

2. Materials and methods

2.1. Specimens

The manufacturing method and the specimens are described in [3] and are briefly recalled here. The core materials were plywood structures, named plywood A and plywood B. Both plywood structures were made up of poplar and okoume plies bonded together using Melamine Urea Formaldehyde (MUF) glue. The stacking sequences and thicknesses of plywood A & B are shown in Fig. 1. The two cores had the same thickness (about 10 mm) in order to minimize the effects of the geometry on the bending stiffness of the sandwich, and make comparisons easier.

Skins were made of aluminum sheet (1xxx) or fiber reinforced polymer composite, containing carbon, glass or flax. The skin materials were chosen as representative of the different types of face sheets used in sandwich construction. Eight different configurations of wood based sandwich structures were manufactured according to Table 1. A reference material, Nomex honeycomb sandwiched between carbon or glass reinforced skins, which is currently used in cargo-bay floors in some AIRBUS aircraft, was also considered for qualitative comparison with the above eight configurations. Large plates $500 \times 500\,\text{mm}^2$ were manufactured and then cut into $150 \times 100\,\text{mm}^2$ squares for impact testing as per AIRBUS standard AITM 1-0010.

2.2. Impact testing

Impact tests were performed using a drop weight apparatus (Fig. 2) followed by tomography analysis. The principle of the falling weight is to drop an instrumented mass, guided in a tube, onto a sample plate held by a clamping window. In our test, the main components were:

- A mass of 2.08 kg. This value was set so as to achieve the desired impact energy with speeds of up to 5 m/s;
- A load sensor located under the mass, to measure the force between the impactor and the specimen during the impact;
- A hemispherical impactor 16 mm in diameter;
- An optical sensor measuring the speed of the impactor immediately before impact;
- A support window, of internal dimensions $125 \times 75\,\text{mm}^2$, on which the specimen was positioned (standard specimen dimensions: $100 \times 150\,\text{mm}^2$). These dimensions were determined based on Airbus standards AITM 1-0010;
- A clamping window having inner dimensions identical to those of the lower window ($125 \times 75\,\text{mm}^2$) to hold the specimen during the impact;
- A kickback system to prevent multiple shocks on the specimen (same as in [24]).

Table 1
Specimens manufactured.

Core	Skin	Process	Density	Thickness (mm)	Process specification
Plywood A	–	–	0.461	10	–
Plywood B	–	–	0.433	10	–
Plywood A	Aluminum	–	0.678	11	–
Plywood A	Glass	Vacuum bag molding - Prepreg	0.638	12	At 160 °C for 3 h
	Carbon		0.569		At 90 °C for 30 min then at 125 °C for 1 h
Plywood B	Flax	Thermo-compression - Prepreg	0.488	12	At 120 °C with pressure of 4 bar for 1 h
	Carbon		0.614		At 90 °C for 30 min then at 120 °C for 1 h, all with pressure of 4 bar
	Glass		0.609		At 160 °C with pressure of 4 bar for 3 h
Aramid honeycomb	Carbon & Glass	–	0.233	10	–