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Mechanical behavior of multilayered sandwich panels of wood veneer and a core of cork agglomerates

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ABSTRACT

Sandwich panels were produced using wood veneer of Aleppo pine as face sheets and cork agglomerate as core, including multilayered designs, for use in construction. The mechanical behavior of the panels was tested for perpendicular compression and tensile, longitudinal compression, three and four point bending, and shear. The load–displacement curves, patterns and cracking fractures were analyzed.

The cork agglomerate provided a high performance under perpendicular compression, while the wood layers protected the core material and increased mechanical strength under tensile loads. Failure occurred mostly by fracture between cork granules. Multilayered sandwich panels showed higher strength and an increased number of layers improved the mechanical performance of the composite structure.

The results suggested that these sandwich panels may be used as construction materials for paneling or partition walls in interior applications with the advantage of environmental friendliness and cost effectiveness.

1. Introduction

Sandwich structures have increasingly become structural and non-structural components in construction. Sandwich structures are usually based on two thin face sheets with high stiffness and strength, and a compliant and light-weight core that maintains the distance between the faces and sustains deformation, often with insulation properties. By varying the material and thickness of core and face sheets, it is possible to obtain sandwich structures with different properties and performance [1–3].

The properties of interest for core materials include, among others, low density and good thermal and acoustic insulation characteristics [3,4]. Commonly used core materials are honeycombs, foams and balsa wood, but other alternatives of cellular core structures are being proposed.

Cork is a natural cellular material with a set of properties that largely fulfils the requirements for sandwich cores: it has an alveolar structure similar to a honeycomb, with closed cells, low density and excellent insulation properties [5–7]. It is also a renewable raw material from a sustainable production system, therefore contributing to the present intent of increasing the "greenness" of construction.

Cork agglomerates are cork-based products that are marketed for several applications, mainly for surfacing, flooring and insulation purposes. The so-called composition corks are made with cork granules of variable dimensions that are joined together by using adhesives (e.g. polyurethane, melamine) [8]. Although the composition cork agglomerates retain most of the properties of the cork material, as summarized in [5], the mechanical strength of a specific composite cork product is also related to the properties of the adhesive.

The mechanical behavior of agglomerated cork was characterized for compression [9,10], tensile [9], shear [11], three-point bending [11–13], creep in compression [14], as well as for dynamic compression [11,15] and vibrations [9].

A few studies already considered cork agglomerates as core materials in sandwich panels. Static bending and shear tests on carbon/epoxy–cork sandwich samples showed that the cork performance depends mainly on density and grain size, with the maximum force, shear strength and modulus increasing with grain size [11]. A comparison between the mechanical behavior during impact of sandwich plates with foam core and cork core showed a larger maximum impact force for the cork core panels with a higher capacity to absorb the impact energy with low depth damage [16].

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Micro-agglomerated cork materials were incorporated as cores in sandwich structures with aluminum alloy face sheets and tested under compression and high pulse wave, showing that the impulse transmitted to the structure decreased with the core thickness with a threshold core thickness separating sandwich and plate behavior [17].

This study focused on the development of sandwich panels with face sheets of veneer wood of Aleppo pine and agglomerated cork as core, including multilayered designs. Four types of sandwich panels were produced and tested under compression, tension, bending and shear. The influence of the number of layers on the mechanical behavior of the sandwich panels was analyzed.

The underlying objective is to use natural materials with a favorable ecological footprint in the production of sandwich panels that are light and good insulation performers, yet low cost, for use in construction as interior partitioning or separation walls.

2. Materials and methods

2.1. Materials

The materials used for the production of the multilayer sandwich panels were the following:

(i) composite cork agglomerates as boards with 10 mm, 15 mm, 20 mm and 40 mm thickness to be used as core material in the sandwich panels;
(ii) wood veneer with 1.5 mm thickness obtained by peeling of Aleppo pine logs, to be used as a skin in sandwich panels.

The raw cork was obtained from the Jijel forest (Skikda, Algeria) and was processed into the cork agglomerates at the industrial mill "Taleza cork" at Skikda, Algeria. The cork agglomerates were produced with cork granules with granulometric fractions of 1–2 mm, 2–3 mm and 3–5 mm, using as adhesive a food-grade polyurethane resin, and cut as rectangular boards with a length and width of respectively 1000 mm and 500 mm The cork agglomerates had a density of 280 kg m^{-3} and a thermal conductivity (λ) of 0.0375 W m^{-2} K^{-1}.

The wood veneer was obtained by peeling Aleppo pine logs at the "Transbois Bejaia" wood processing mill at Darguina (Bejaia, Algeria). The Aleppo pine (*Pinus halepensis*) wood had the following properties: density 540 kg m^{-3}, shrinkage of 1.2%, 3.9% and 5.0% in longitudinal, radial and tangential directions respectively, MOE of 13047 MPa in 4-point bending and 5576 MPa in 3-point bending, and thermal conductivity of 0.19 W m^{-2} K^{-1}.

2.2. Panel production

Four types of multilayer sandwich panels were produced, as shown in Fig. 1:

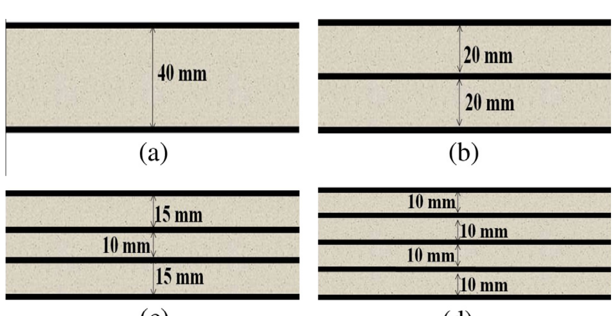

Fig. 1. Schematic representation of the sandwich panels assembly: (a) S40, (b) S20, (c) S15 and (d) S10.

– *S40:* a core of 40 mm thick cork agglomerate between two external layers of wood veneer.
– *S20:* a core of two layers of 20 mm thick cork agglomerate separated by a mid-layer of wood veneer, between two external layers of wood veneer.
– *S15:* a core of two layers of 15 mm thick cork agglomerate and one layer of 10 mm thick cork agglomerate in the middle, separated by two layers of wood veneer and with two external layers of wood veneer.
– *S10:* a core of four layers of 10 mm thick cork agglomerate separated by three layers of wood veneer and with two external layers of wood veneer.

The production of the sandwich panels was made using a hot-plate hydraulic press (SIMI). The temperature was set at 80 °C, the pressure at 40 bar and the pressing time at 10 min. The adhesive used for the bonding of the wood and the agglomerated cork layers was an urea-formaldehyde glue used in the plywood industry. The panels were stabilized in the open air under ambient conditions for 24 h.

The veneer layers of the face sheets were oriented in the sandwich panel with the grain parallel to the largest dimension, here called length. The internal layers of wood veneer were oriented with the grain perpendicular to the grain orientation of the adjacent wood veneer layer. Six sandwich panels of each type were prepared.

2.3. Mechanical properties

Mechanical testing of the sandwich panels was performed at the Research Unit Materials, Processes and Environment (UR-MPE1) of the University of Boumerdes, Algeria. The tests were carried out on a Zwick/Roell universal machine type 250, with computer-controlled acquisition testXpert V9.0 software, and with a 250 kN force sensor.

The following tests were made: compression [18] and tension [19] in the perpendicular direction, edgewise compression (in the longitudinal direction) with and without buckling [20], three-point and four-point bending [21] and shear [22], according to the French standards, respectively, NF T54-602 (1983) [18], NF T 54-603 (1983) [19], NF T54-604 (1986) [20], NF T54-606 (1987) [21] and NF T 54-605 (1983) [22]. Longitudinal direction means in this context parallel to the grain of the wood veneer face sheets (here called the length of the samples), and perpendicular direction means at 90° to the veneer layer. Fig. 2 schematically represents the different mechanical tests that were performed on the sandwich panels.

2.3.1. Compression in the perpendicular direction

The compression test in the perpendicular direction [18] was performed with samples of 50 × 50 mm^2 (length × width) at a constant crosshead speed of 4 mm min^{-1}. The modulus of elasticity was determined between 2.5% (ε_1) and 7.5% (ε_2) strains. The σ_{10} stress was also calculated corresponding to ε = 10%. The maximum stress (σ_{max}) reached during the test was about 1 MPa and the crushing value (Δh_{max}) for this load corresponded to a maximum deformation of approximately 70% (ε_{max}).

After testing, the samples were kept in the laboratorial environment during 14 days, after which the panel thickness was measured for calculation of the relaxation rate (η).

The following mechanical properties were calculated from the stress–strain curves:

$$\varepsilon_{max} = \frac{\Delta h_{max}}{h_0} \times 100 \quad (1)$$

$$E_a = \frac{F_2 - F_1}{\Delta h_2 - \Delta h_1} \times \frac{h_0}{S_0} \quad (2)$$