Journal of Building Engineering 5 (2016) 194–210

Contents lists available at ScienceDirect

Journal of Building Engineering

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

Experimental characterisation of cork agglomerate core sandwich panels for wall assemblies in buildings

Ricardo Ferreira*, Diogo Pereira, António Gago, Jorge Proença

CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

A R T I C L E I N F O

Article history:
Received 3 April 2015
Received in revised form
7 January 2016
Accepted 7 January 2016
Available online 11 January 2016

Keywords:
Sandwich panel
Cork agglomerate core (CA)
Glass fibre reinforced polymer (GFRP) facing
Mechanical properties
Fire resistance

A B S T R A C T

In recent times, the construction market has seen a very significant increase in the demand of pre-fabricated solutions of nonstructural elements, such as sandwich panels for buildings walls. Due to the inherent low weight, good mechanical behaviour, ease of assembly and cost-effectiveness, these types of wall assemblies are especially competitive in construction of single-family houses or one unit dwelling structures.

However, the low fire resistance of many of these solutions, such as sandwich panels with expanded polystyrene core or polyethylene terephthalate foam core, precludes their use in buildings with more than one floor. The substandard fire resistance is generally due to the fact that the constituent materials are combustible or, at least, their properties are extremely sensible when subjected to high temperatures or flame.

Given the isolation properties, good mechanical damping and fire resistance, cork agglomerate can be used as the core material for sandwich panels. However, this material is heavier than the other materials commonly used as core for sandwich panels. In order to deal with this drawback, it is necessary to choose a material for the panel facings that could fulfil the mechanical requirements and the condition not excessively increase the panel weight. The use of a glass fibre reinforced polymer seemed a suitable solution for the facing component. Therefore, the proposed wall assembly solution consists in a sandwich panel with cork agglomerate core and glass fibre reinforced polymer facings.

The scope of this work was the assessment of the feasibility of a new configuration of vertical (wall) sandwich panels that could, not only be a cost effective solution for prefabricated construction, but also provide good mechanical performance and fire resistance. This sandwich wall panel configuration was tested for characterisation of its mechanical behaviour, resistance to impact and to fire. The results of the experimental campaign carried out are presented in this manuscript along with some conclusions about the suitability of this solution as sandwich wall panel for buildings façades.

1. Introduction

The use of composite materials has seen a significant increase over the last few decades, especially in the transport and aerospace industries, mainly due to the search for structures that are both lighter and. In the last ten years, the construction industry has been no stranger to such development, particularly in developing repair and strengthening solutions for old structures and composite structures for partition and external walls.

In some cases, the traditional brick construction for partition and external non-structural walls in buildings has successfully been replaced by updated pre-fabricated composite wall solutions such as sandwich wall panels, especially in situations where low weight is needed. In the context of building construction, sandwich wall panels of polyurethane or expanded polystyrene cores and glass fibre reinforced polymer facings are the most popular solutions [1–4]. Among the advantages of these wall panels are their low weight, adaptability to uncommon shapes (e.g., non-orthogonal or non-rectangular), and their thermal and acoustic properties. In recent years, several materials and configurations have been studied for potential use for sandwich panel.

However, the poor fire resistance of the materials widely used in sandwich panels, such as resins, polystyrene and polyurethane, precludes their use in many situations. Furthermore, sustainable development requisites and ecological concerns regarding energy consumption have to be taken into consideration.

Extensive studies have also been carried out to assess the fire resistance of composite panels [5–9] and [10]. It is therefore desirable to address this problem by using ecological, sustainable, core materials with high fire resistance and that do not unduly

* Corresponding author.
E-mail address: ricardosousaalvesferreira@gmail.com (R. Ferreira).

http://dx.doi.org/10.1016/j.jobe.2016.01.003
2352-7102/

sacrifice the mechanical requisites for walls. Given these premises, this research aims to evaluate the potential use of cork agglomerate as core material for sandwich panels to be used as partition or external walls.

Cork is the natural bark produced by the cork oak (*Quercus suber* L.). It is a natural lightweight material that has interesting properties, including elasticity, low permeability to gases and liquids, good thermal insulation and high damping capacity and durability [11].

According to [11], cork has an alveolar cellular structure similar to that of a honeycomb and its cells are mostly formed by suberin, lignin and cellulose. This composition has a strong influence on the mechanical properties of cork-based materials

Cork agglomerates (CA) are produced from cork waste and residues through an industrial process. This waste (in granules) is autoclaved at high temperature and pressure without the use of an additional adhesive. This industrial process induces the thermochemical degradation of the cork cell wall, through prior expansion of the granules.

The temperature and pressure applied cause all the granules to be covered by suberin and waxes that can diffuse and deposit on the cork granule surfaces. The result is a corkboard that can be used for multiple purposes. CA retains some of the advantages provided by natural cork such as good thermal insulation, low water and acoustic absorption, good vibration damping and chemical resistance. In addition, CA is an economically and environmentally sustainable material.

The paper describes the experimental work involved in the creation and physical validation of a CA core sandwich panel. It is part of a research project aiming to develop an innovative building construction system. In addition to the potential mechanical and fire behaviour benefits, this solution offers ecological and sustainability benefits [12]. This study focused on the mechanical and impact behaviour, as well as the fire resistance of sandwich panels with CA core. The assessment was conducted bearing in mind the recommendations of the relevant ISO and ASTM.

2. Previous studies and experimental investigation

A wide variety of materials and configurations have been developed and tested for potential use in sandwich panels, particularly in the transport and aerospace industry. Some relevant experimental studies conducted on sandwich panels for building construction and other purposes are briefly summarised next.

Smakosz and Tejchman [13] carried out a series of experiments to analyse the strength, deformability and failure mode of panels made from expanded polystyrene (EPS) foam core and glass–fibre facings reinforced with magnesium-cement. The aim was to describe the mechanical behaviour of such panels and their components under bending, compressive and tensile quasi-static monotonic loads. For this purpose, large- and small-scale specimens were tested. Impact and thermal behaviour were also addressed through experimental testing. Tests showed that the general behaviour of these panels under loading is initially linear, then slightly non-linear and finally brittle at failure. In the bending tests, failure was due to tensile failure of the bottom facing, whereas in compression failure was due to crushing of the facings (without local or overall buckling of the facing).

As for the impact behaviour of these panels, tests showed insignificant penetration and traces of damage on the panel surface and thus both the serviceability and safety requirements of panels against impacts were satisfied. Finally, the thermal results showed that the effect of the gradient temperature on the panel deformation was negligible.

Zinno et al. [1], reported the experimental characterisation of a different kind of panel that used an alternative material for the sandwich panel core. A phenolic-impregnated honeycomb core produced with Nomex (aramid paper/phenolic resin) was chosen. The scope of this study was to determine the efficiency of this material in terms of its structural and impact behaviour, with a view to using it in the transport industry. The same authors also assessed the environmental degradation of the component materials through accelerated ageing tests. The sandwich experiments involved both compressive and bending quasi-static tests to evaluate the compressive and shear mechanical properties of the core and to shed light on the bending behaviour effects in the stiffness and failure modes.

Average values estimated for the mechanical properties such as compressive modulus E, compressive strength σ and shear modulus G were derived from the quasi-static experimental tests. The structural performance of phenolic-based core sandwich structures subjected to environmental effects was also assessed experimentally by means of accelerated ageing. Finally, the experimental work also included ballistic impact tests to understand the response of the sandwich material and the damage mechanisms involved when a sandwich structure suffers an impact. The dynamic impact tests showed that the facings are mostly responsible for the overall behaviour and energy absorption.

Castro et al. [14], carried out an investigation to optimise the mechanical properties of cork-based agglomerates intended to be used as sandwich panel components for lightweight structures. Consequently, three new types of cork agglomerate consisting of cork granules and epoxy resin were produced and tested.

The experiments carried out by Castro et al. comprised three different types of behaviour characterisation tests: mechanical tests, impact tests and thermal conductivity tests. The tested sandwich panels consisted of carbon/epoxy facings and several different core materials, namely, Nomex, Rohacell 71 WF rigid foam, commercial cork agglomerates (of 3 different densities) and enhanced cork agglomerates. The enhanced cork agglomerates consisted of conventional cork agglomerate with epoxy resin added to the adhesion process of the cork granules.

Regarding the cork agglomerates' mechanical behaviour, test results showed that their performance essentially depends on the cork granule size, its density and the bonding procedure used for the granulates. The authors also concluded that the aforementioned parameters can be adjusted according to the final application intended for the sandwich panel.

The highest maximum core shear stress was recorded for the Nomex core sandwich specimens, followed by the cork-epoxy agglomerate cores (1–12% lower than Nomex, 38–56% higher than Rohacell rigid foam and four to seven times higher than the commercial cork agglomerates). Maximum stress at the facing and panel shear rigidity values were also found in Nomex/carbon and Rohacell/carbon sandwiches. Values of those stresses in the cork-epoxy core sandwich specimens were nearly three times higher than in the conventional cork agglomerates.

Concerning the impact test results, the authors concluded that the impact performance of cork-epoxy and conventional cork agglomerates had a similar behaviour, but slightly higher impact forces were obtained for cork-epoxy composites. The authors observed that cork agglomerates are characterised by their rapid response to transient loads, which, together with the elastic behaviour demonstrated in the bending tests, could be considered as a minimising factor with respect to the probability of extensive damage. The authors also reported the excellent recovery capacity exhibited by the cork-based sandwich panels' displacement curves, regardless of the type of cork agglomerate and fabrication method.

Finally, regarding the thermal behaviour tests, the authors concluded that cork agglomerates with lower densities had better