Journal of Cleaner Production xxx (2014) 1–10

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Bio-based versus traditional polymer composites. A life cycle assessment perspective

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A R T I C L E I N F O

Article history:
Received 15 August 2013
Received in revised form
3 March 2014
Accepted 7 March 2014
Available online xxx

Keywords:
Eco-sandwich
Granulated cork
Hemp mat
Bio-based epoxy resin
Life cycle assessment (LCA)

A B S T R A C T

A comparative LCA between an eco-sandwich made of bio-based epoxy resin (SuperSap 100/1000) and natural fibers against a traditional sandwich made of epoxy/glass-fibers was carried out. The main purpose and contribution of this study is the exploration of the eco-efficiency of this new material which featured applications span from naval to automotive and building sectors. To a minor degree, it is also a contribution in the sense that it provides life cycle inventory data on composites, which as yet are scarce in the LCA community. Life cycle assessments of bio-based polymers have shown favourable results in terms of environmental impacts and energy use compared to petroleum-based products. However, calculation of these impacts always depends on the system and boundary conditions considered during the study.

1. Introduction

Sandwich panels are widely used in composite structures because of their ideal combination of high flexural stiffness and low weight. Structural sandwich applications normally rely on the use of honeycombs made of aramid paper or aluminum as core materials while, for semi-structural applications, PVC and balsa wood cores are the preferred choice. The skin materials can vary from glass to carbon fiber/polymer composites. Glass and carbon fibers may both negatively affect the environment in terms of the energy and resources consumption needed for their production. Natural fibers are perceived as green materials that can be produced starting from renewable materials and with production techniques that consume lower energy relative to synthetic fiber production techniques (Corbière-Nicollier et al., 2001).

LCA has been applied to a large range of natural fiber composites for assessing the environmental aspects and potential impacts associated with the products (e.g. Riedel and Nickel, 2003). Results demonstrate that natural fiber composites offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components (Joshi et al., 2004; Dornburg et al., 2004; Mohanty et al., 2002). However, Dissanayake et al. (2009a, 2009b) have presented data that suggest that flax fibres may require equivalent or higher energy consumption due to heavy reliance on agrochemicals (when all burdens are assigned to the primary product as recommended by Ekvall and Finnveden, 2001). Le Duigou et al. (2011) use alternative apportionments to generate lower energy input values with their Table 2 stressing the differences between the respective independent analyses which return comparable data.

The objective of the present study is to evaluate the environmental impacts associated to the production of a sandwich composite where the core is made of granulated (see §2.3.2.2 below) cork panel and the external skins are made of bio-derived epoxy resin reinforced with hemp fibers (Fig.1). The future goal will be to understand if the use of eco-materials in the sandwich formulation is able to considerably reduce the environmental burdens without compromising the mechanical performance. An LCA of the cork panels used, produced by Syfar s.r.l (Messina in Sicily) was also carried out. Cork is a product of great ecological value (Rives et al.,

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http://dx.doi.org/10.1016/j.jclepro.2014.03.017
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Table 1
Thermal insulation properties of cork and polyurethane.

Core materials	Thermal properties		
	Thermal conductivity, λ (W/mK)	Thickness (m)	Thermal resistance (m^2K/W)
Cork	0.05	0.02	0.4
Polyurethane	0.022	0.01	0.45

2012a, 2012b), with many features that make it very interesting from a sustainability perspective. In addition to its low emissions and the great potential for capturing CO_2, it generates economic revenues, provides jobs and development in rural areas, and allows many environmental services such as forest preservation, biodiversity conservation and wildfire prevention (Pereira, 2007; Pereira and Tomé, 2004).

2. Methodology

2.1. Goal and scope definition as used in ISO 14040

The present work is a cradle-to-manufacture study in order to evaluate the main environmental impacts related to the production of an eco-sandwich panel containing cork, hemp and bio-based epoxy resin as natural materials. A comparison with a traditional sandwich composite made of glass fiber, petroleum based epoxy resin and polyurethane, was carried out. The Life Cycle Assessment study was developed according to the ISO 14040 and 14044 methodology (ISO 14040, 2006; ISO 14044, 2006) and used the Simapro 7.2 software (SimaPro 7.2, 2012).

2.2. Functional unit

An eco-sandwich panel sized (0.400 × 0.400 × 0.02 m) is the functional unit for this study (Fig. 1). Assembling the granulated cork panel with hemp mats and epoxy resin produces the composite sandwich by means of resin infusion under flexible tooling (RIFT I) (Summerscales and Searle, 2005). For comparisons, a traditional sandwich made of polyurethane core and using glass fibre for resin reinforcement, was also studied. In order to provide a congruous comparison we prepared both sandwich panels with the same thermal insulation properties by varying the amount of insulating materials (cork and polyurethane). The thermal resistance was fixed, according to the Italian law for building applications, $U < 0.4\ m^2K/W$ as reported in Table 1. The thermal conductivity of cork was evaluated by means of a heat flow-meter HFM 436 Lambda (Netzsch). The thermal conductivity of polyurethane was found in literature (Mingheng et al., 2006).

Mechanical tests are being carried out and will be used for a future paper. A theoretical evaluation is included in the present work, in Table 2.

2.3. Boundaries and description of the system

2.3.1. System boundaries

A cradle (field) to manufacture (factory) study was carried out considering raw materials production (consisting of cork forestry and granulated cork panels production; hemp cropping and hemp mat production) and eco-sandwich manufacture as boundaries. Waste scenarios were also discussed and landfill was included in the LCA. Primary data were collected for the manufacturing process of the cork and the eco-sandwich; literature data were used for the hemp cultivation and production (González-García et al., 2010; La Rosa et al., 2013) and data from the Ecoinvent v2.2 database were used as a last resort (PRè-Product Ecology Consultants, 2012).

Table 2
Mechanical properties of an eco-sandwich and a traditional sandwich. Sandwich dimensions and weights are reported in Table 4.

Sandwich	Tensile strength (MPa)	Tensile modulus (MPa)	Compressive strength (MPa)	Compressive modulus (MPa)
Eco				
- Cork	[a]0.23	[a]32	[a]0.83	[a]1.22
- Hemp mat	552.6	28000		
- SuperSap resin	60.0	3074		
- Composite (hemp mat 25% + SuperSap resin 75%)	[c]94.58	[c]4820		
[d]**Flexural Stiffness**: $D = E \cdot I = 6995\ (N\ m^2)$				
Traditional				
- Polyurethane foam	[b]5.6	[b]172	[b]2.65	[b]130
- Glass fibre	2400	70000		
- Epoxy resin	69.0	3500		
- Composite (E-glass mat 25% + Epoxy resin 75%)	[c]271.3	[c]8990		
[d]**Flexural Stiffness** $D = E \cdot I = 4083\ (N\ m^2)$				

[a] Data provided by the Syfar company.
[b] Data source: http://www.matweb.com/search/QuickText.aspx?SearchText=polyurethane%20foam.
[c] Tensile modulus and tensile strength of reinforced resins were evaluated through the Madsen model (Madsen and Lilholt, 2003; Madsen et al., 2007) considering voids percentage value Vp = 0.88%.
[d] Flexural stiffness was evaluated through the following equation (Biron, 2007) where E_f and E_c are the moduli of elasticity of the faces (index f) and the core (index c).

$$D = E_f\frac{bt^3}{6} + E_f\frac{btd^2}{2} + E_c\frac{bc^3}{12}$$

2.3.2. Description of the manufacturing process

2.3.2.1. *Cork forestry: cork reproduction and extraction in a Sicilian forest.* Cork consists of the thick outer bark of the cork oak (Quercus suber). Harvesting cork is the operation of removing bark from the tree and is repeated every 9 years. It is always carried out between May and August (from 15 May to 15 August according to the regional law), by a team of workers. The flowchart in Fig. 2a reports the main steps of the extraction process. Typical Mediterranean wild plants create a deep barrier to working operations therefore clearing of the underwood area by means of a tractor is required as the first operation. A manual bark stripping operation, by expert workers using axes, takes place. The stripper makes long cuts in order to extract large pieces of cork. The raw cork material obtained is moved to the road (Rives et al., 2012a).

Fig. 1. Eco-sandwich with core in granulated cork and skins in hemp/bio-resin.