Journal of Cleaner Production xxx (2015) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Wood polymer composites and their contribution to cascading utilisation

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A R T I C L E   I N F O

Article history:
Received 30 July 2014
Received in revised form
2 March 2015
Accepted 5 April 2015
Available online xxx

Keywords:
Wood plastic composite
Green composite
Cascading utilisation
Resource efficiency
Environmental impact
Review

A B S T R A C T

Due to a shortage of resources and a growing competition of land use, sustainable and efficient resource utilisation becomes increasingly important. The application and multiple, cascading utilisation of renewable resources is aimed at to ensure an allocation and future availability of resources. Wood polymer composites (WPCs) are a group of innovative materials consisting of mainly renewable resources. By means of summarizing recent research, it is shown how WPC can potentially contribute to an enhanced cascading utilisation. For the production of WPC, waste materials and by-products from wood and agricultural industry, e.g. offcuts, sawdust, residues from board manufacturing, pulping sludge, can serve as a raw material. Furthermore, the cited literature presents the use of recycled polymers and biopolymers as a potential alternative for the polymer component of WPC. By using biodegradable polymers, a fully biodegradable composite can be formed. In addition to using recycled materials and potentially being biodegradable, it is pointed out that WPC furthermore offers the possibility of being recycled itself, therefore being considered as a "green composite". Although the influence of contaminated waste streams and mixed filler and polymer types on the properties of WPC made with such recyclates is yet not fully understood and no collection systems exist for post-consumer WPC, in-house recycling on the production sites is identified as a promising option as it reduces production costs and enhances resource efficiency and cascading utilisation. On the basis of cited life cycle assessments, the eco friendliness of WPC is assessed resulting in the conclusion that WPC cannot compete with solid wood with respect to environmental impact but is an environmentally friendly alternative to neat plastics in several applications.

1. Introduction

A continuously growing demand for resources makes a sustainable and efficient resource utilisation more and more important (Brown et al., 2011; Elliott, 2006). Many existing materials rely on fossil fuels with a prospectively limited availability, which leads to an increasing competition for the scarce resources (Birol, 2012). Therefore, an alternative raw material base and a more efficient production are required. As an alternative to materials which are based on fossil fuels, those materials made from renewable resources are promising. They help to ensure future resource allocation due to their renewable character. When comparing traditional, fossil fuel based materials with materials made from renewable resources, the latter show various environmental advantages. An increased usage of renewable resources can at least partially encounter diverse environmental problems humanity is faced with, e.g. climate change and biodiversity threats (Lenzen et al., 2012).

Nevertheless, efficient and sustainable resource utilisation is also required for renewable resources as a competition between

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[1] DFG Research Training Group 1703 "Resource Efficiency in Interorganizational Networks".

http://dx.doi.org/10.1016/j.jclepro.2015.04.009
0959-6526/

Please cite this article in press as: Teuber, L., et al., Wood polymer composites and their contribution to cascading utilisation, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.04.009

different forms of land usage has emerged in recent years, e.g. cultivation of food crops, bioenergy crops or crops for technical applications (Godfray et al., 2010). When considering the realisation of (multiple) material usage of raw materials including their by-products, the principle of cascading utilisation becomes crucial. Developing materials based on by-products is promising, as by-products are often directly converted into energy nowadays (Carus et al., 2008).The strategy of efficient and sustainable resource utilisation is also pursued by green chemistry, an industrial sector that aims at optimising raw material utilisation by minimising waste creation (Ashori, 2008). Dealing with waste is an important issue. Waste disposal laws, for example, force the wood processing industry to find applications for by-products and wastes (Migneault et al., 2014).

Wood polymer composites (WPCs) are a group of hybrid materials mainly consisting of renewable resources. They help to realise a more responsible and efficient method of resource utilisation as they contain wood waste materials and by-products and like this are in line with the principle of cascading utilisation and resource efficiency. WPC is a merger of different components including synthetic ones (e.g. plastics). Therefore it has to be considered that the natural and synthetic components together affect the environmental impact of WPC. Little research has been done yet to investigate how the conflictive combination affects WPC eco friendliness. Nonetheless, this question is crucial for evaluating WPC in light of environmental issues which are increasingly gaining in importance in political discourses, corporate policies and customer requirements. Therefore, the purpose of the present article is to review the possible contribution of WPC to cascading utilisation and to identify factors influencing its eco friendliness.

2. General composition and fields of application

Wood plastic composites are a group of materials mainly consisting of wood, thermoplastic polymers and, to a small amount, additives. The wood content of the material may vary up to more than 80% (Klyosov, 2007). Depending on the region of manufacture and on the availability, softwoods as well as hardwoods in the form of fibres, particles, or fine flour serve as raw material. The term wood fibre thereby generally corresponds to spindle-shaped wood cells with an aspect ratio (length to diameter ratio) of 10:1 to 25:1 (Klyosov, 2007) which are separated by different pulping methods. Wood particles are fibre bundles or, as in the case of fine flour, cell wall fragments with an aspect ratio of 1:1 to 5:1 (Clemons, 2008). The constitution of the wood component influences the physical and mechanical properties of the WPC (Clemons, 2008). While fibres, having a greater aspect ratio (length/width ratio), enhance the tensile strength (Chen et al., 2006; Klyosov, 2007; Stark, 1999), particles are easier to dose to the production process and easier to disperse in the polymeric matrix and therefore result in more homogeneous materials (Shahi et al., 2012; Yam et al., 1990). In addition, the properties mentioned beforehand as well as visual properties of the WPC depend on the intrinsic properties of the wood species used (Clemons, 2008).

As a thermoplastic matrix material polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP) are commonly used for most applications (Ashori, 2008; Carus et al., 2014). WPC combines the differing properties of wood and polymer. Wood is strongly hydrophilic and therefore prone to high moisture absorption and swelling rates resulting in decay and dimensional instability, which is disadvantageous especially for outdoor applications. By incorporating the wood into a hydrophobic polymer matrix, the moisture absorption and sensitivity to fungal decay and insect attack is reduced. Simultaneously, the wood enhances the stiffness, thermal stability and creep behaviour of the polymer (Michaud et al., 2009; Shahi et al., 2012). The properties of WPC strongly depend on the compatibility and interfacial adhesion between wood and polymer, which represents one of the main limitations as wood is strongly polar and most matrix polymers are nonpolar (Michaud et al., 2009). To overcome this drawback, particle/fibre surface modifications can be applied (Ashori, 2008; Vieira de Carvalho Neto et al., 2014) and additives like compatibilisers and coupling agents are used (Adhikary et al., 2008; Kuo et al., 2009). Other additives to tailor the WPC's properties to its destined application comprise, among others, blowing agents for the production of foamed WPC, biocides, pigments to dye the WPC, UV stabilizers, flame retardants, and lubricants as processing aid (Ashori, 2008; Satov, 2008).

WPCs show a thermoplastic behaviour enabling processing on the same machines and with the same equipment as their unfilled matrix. The main processing methods for the production of WPC products are extrusion and injection moulding, which are both highly productive and economically advantageous (Sykacek et al., 2009), as well as compression moulding and thermoforming. In 2012 the production of WPC amounted to 1,100,000 t in North America and 900,000 t in China. In the EU 260,000 t of WPC were produced, 67% of it in the field of deckings and 24% in the automotive industry, followed by siding and fencing, technical applications, furniture, and consumer goods (Table 1) (Carus et al., 2014). The application in automotive industry comprises trim parts – e.g. door panels, dashboard, and cabin linings – as well as thermo-acoustic insulations (Ashori, 2008). The production of WPC in the EU is expected to grow by approximately 10% per year, especially in the fields of furniture, technical parts, and consumer goods (Carus et al., 2014).

Initially, wood fibres or particles have been used as cheap fillers for polymers to reduce production costs (Selke and Wichman, 2004). Nowadays, in the light of continuously rising polymer prices and growing ecological awareness of consumers, WPCs with their good and adjustable properties offer an alternative to traditional materials in many fields of application (Carus et al., 2008). Comprising two different materials, namely wood and polymer, WPC opens up possibilities to contribute to a sustainable use of raw materials and an enhanced cascading utilisation.

3. Contribution to cascading utilisation

3.1. Wood component

As a variety of types of wood particles or fibres can serve as raw material for WPC (Table 2), this material offers an opportunity to enhance the sustainability of the wood processing industry in the form of added value by optimizing the material use and minimizing and recycling wood wastes (Eshun et al., 2012; Migneault et al., 2014). Wood waste can be divided into post-industrial and post-consumer wood waste. While post-consumer wood waste may comprise sources like old newspapers, wood pallets, and building and construction residues, post-industrial wood waste includes sawdust, shavings, chips, milling

Table 1
Production of WPC in the European Union 2012 in tonnes (Carus et al., 2014).

Wood-plastic composites	260,000
Decking	174,000
Automotive	60,000
Siding and Fencing	16,000
Technical Applications	5000
Furniture	2500
Consumer	2500

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