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The use of waste materials in wood-plastic composites and their impact on the profitability of the product

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ABSTRACT

The profitability of using different waste materials and side fractions as a part of wood-plastic composites is studied. The increased efficiency of waste recycling creates more materials for re-use. The purpose of this study is to find out whether there would be economical reasons to use raw materials as a part of wood-plastic composites. Six different waste- based composites from previous studies were selected and they were compared with a composite manufactured from virgin materials. The costs of the manufactured composites were divided into manufacturing and material costs. The manufacturing costs did not change remarkably between the composites. The material costs decreased most when recycled plastic was used instead of virgin material. Other recycled materials did not affect the material costs significantly.

1. Introduction

The wood-plastic composite (WPC) manufacturing sector has grown rapidly in recent years. North America and China are the two largest producers, Europe being the third. The largest categories in this sector are decking, automotive industry, siding, and fencing. The market development has been great in recent years, and especially in China the pace of market development has been frenetic, with the production of WPC having tripled from 2010 to 2012 (Carus et al. 2014).

The European Union (EU) encourages more efficient waste management to save natural resources. In 2010, 2.5 billion tons of waste was produced in the European Union (EU) area. 16 tons of material per person is used per year, of which 6 tons ends up as waste. It has been estimated that 0.6 billion tons of these could have been recycled or reused. Circular economy has become the topic of today. There are plans to improve circular economy in the EU (European commission, 2018).

One possibility to improve circular economy is to use different waste materials and side fractions as a part of wood-plastic composites. A wide range of different wastes and by-products are produced in different sectors. Depending on the sector and location, a lot of these wastes are underutilized. In the EU 28-area, most of the wastes (34.7%) come from the construction and demolition industry, with mining and quarrying coming second with a 28.2% share, before manufacturing (10%) (Eurostat, 2014).

According to the waste hierarchy, re-using of waste material is the second desirable option in waste management after the prevention of waste (European Commission, 2008). Using these wastes in WPCs is a considerable option. Utilizing wood fibers as a part of plastic is usually done in order to replace the more expensive plastic (Schwarzkopf and Burnard, 2016). The advantage of using recycled materials is not only the lower price, but it is also more eco-effective to recycle materials instead of disposing them. There is already a wide range and large number of different kinds of products made from WPC (Partanen and Carus, 2016). Using recycled materials as a part of WPC offers more options for the composition of composites.

Interest in the environmental impact of products and processes is gaining popularity (Schwarzkopf and Burnard, 2016). Research about wood-plastic composites has been carried out in recent years. Material study has had the largest share, but also research on other perspectives has been done. One of the approaches is life cycle analysis, which has been the topic of several studies (Sommerhuber et al., 2017; Väntsi & Kärki, 2015).

Different types of industries produce diverse materials, some of which have been already studied as a part of a composite. The range of the materials is huge, and there is a wide variety of different areas of waste producers. For example, there have been studies about veneer polishing dust and carton cellulose fiber (Viksne et al., 2010). In a study of lignocellulosic fibers (cotton stalk, rice straw, bagasse and banana plant waste) from the agro-industry, these natural fibers were found beneficial in strengthening polymer matrices. These waste materials are difficult to dispose of, while the production numbers are huge (Habibi et al., 2008). One example is using printed circuit boards as a part of a WPC (Guo et al., 2010).

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Table 1
Material composition of manufactured WPCs.

Composite	Fiber source	Plastic	Filler
MCW	Virgin wood fiber	Virgin	Burned construction waste
CCW	Recycled carton waste	Virgin	None
LW	Virgin wood fiber	Virgin	Limestone waste
PB-MW	Virgin wood fiber	Virgin	Recycled plaster board and mineral wool
PW	Virgin wood fiber	Recycled	None
Ref	Virgin wood fiber	Virgin	None

Studies related to WPCs focus usually on the material properties. The commercialization of wood-plastic composites and their potential in the market are discussed in two studies (Roos et al. 2014; Fowler et al. 2006), but the price of the composites is not processed in detail. The purpose of this study is to bring up the less studied economical side in WPC manufacturing. Some calculations and valuing of different recycled materials as a part of WPCs are made. The evaluation of economic benefits offers a new insight when considering the utilization of recycled materials.

2. Materials and methods

WPCs manufactured from different waste materials are used as an example in this study. Different composites were selected from previous studies written by the authors. Details from these WPCs can be found in the following articles: Keskisaari et al., 2016; Keskisaari and Kärki, 2018; Turku et al., 2017. The materials came from different sectors. Some of the materials were recycled from waste, and some were side fractions from manufacturing processes. The materials are presented in Table 1 below.

The amount of recycled materials in the composite was raised as high as production-related issues allowed. The proportions of materials in the composites differed slightly from each other. The composition of the composites can be seen in Table 2.

The materials in this study were made in pilot scale. The prices were determined according to the general price level. In the case of carton cutting waste (CCW), its value was evaluated by the price of combustion energy. It must be remembered, however, that the materials and prices used in this study are examples. They are not valid in every situation. The purpose of this study is to give an example of the costs. The study does not take account of different fixed costs, taxes, investment costs, salaries, or equipment costs.

Sensitivity analysis was done to evaluate the influence of any variable changes. The variables for sensitivity analysis were selected according to previously obtained results.

2.1. Materials

In wood-plastic composites, the two main materials are strengthening fibers and plastic as the matrix (Schwarzkopf and Burnard, 2016).

Table 2
Composition of the composite materials.

Composite	Fiber material (%)	Plastic (%)	Lubricant (%)	Coupling agent (%)	Filler (%)
MCW	44	30	3	3	20
CCW	64	30	3	3	0
LW	44	30	3	3	20
PB-MW	24	30	3	3	40
PW	54	40*	3	3	0
Ref	64	30	3	3	0

* Recycled.

Table 3
Unit price of materials in tons.

Material	€/ton
Wood fiber	100
Virgin plastic	1500
Recycled plastic	500
Lubricant	2500
Coupling agent	2500
Limestone waste	100
Mineral wool	−100
Plasterboard	−100
Burned C&D waste	−100
Carton cutting waste	80

In addition to these, also different kinds of fillers and additives are used in composites. In this research, there are examples of replacing both the fiber and the matrix, and also several examples of adding recycled materials as fillers in the composites.

All the materials used in this study were manufactured with extrusion. The materials were then tested with different mechanical tests, and the test results were presented in previous studies (Keskisaari et al., 2016; Keskisaari and Kärki, 2018; Turku et al., 2017).

For some of the materials, some preparations had to be done before extrusion. All the composites were agglomerated before extrusion. Some of them had to be crushed before agglomeration, and one material was burned. Table 2 shows the composition of the composites used in this article. All composites had the same fiber material (wood fiber) except for CCW, where the fiber material was carton cutting waste. In the PW composite the plastic was recycled, in all the other cases the plastic was virgin polypropylene (PP).

2.2. Price of the composites

The unit prices of the different raw materials used in the composites are presented in Table 3.

In Table 4, the prices of the products have been calculated as percentages of unit prices.

Table 4 presents the prices of different composites. As can be seen in the table, virgin plastic is the biggest expense. The most expensive composite are the limestone waste composite and the reference, and the least expensive one is the plastic waste composite. A negative value means that the material has a negative value to its producer.

Table 5 presents the costs of different manufacturing processes.

Table 6 presents the manufacturing costs separately for each composite.

Agglomeration was more expensive for the LW composite because there was more moisture in the limestone waste, which had to be removed during the agglomeration.

3. Results and discussion

3.1. Production costs

Fig. 1 shows the same information as Table 6. As can be seen, extrusion is the biggest cost element in WPC production. In the case of the

Table 4
Price of the materials.

	Wood	Plastic	Lubricant	Coupling agent	Fillers	Total price
MCW	44	450	75	75	−20	624
CCW	51.2	450	75	75		651.2
LW	44	450	75	75	20	664
PB-MW	24	450	75	75	−40	584
PW	54	200	75	75		404
Ref	64	450	75	75		664