Construction and Building Materials 55 (2014) 220–226

Contents lists available at ScienceDirect

Construction and Building Materials

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

Utilization of recycled mineral wool as filler in wood–polypropylene composites

Olli Väntsi *, Timo Kärki [1]

Lappeenranta University of Technology, Department of Mechanical Engineering, Fiber Composite Laboratory, P.O. Box 20, 53851 Lappeenranta, Finland

HIGHLIGHTS

- A new recycling method for underutilized waste fraction is presented.
- Properties of the composites utilizing recycled mineral wool as filler are presented.
- Recycled mineral wool improved the moisture resistance properties of the composites.

ARTICLE INFO

Article history:
Received 5 April 2013
Received in revised form 9 January 2014
Accepted 11 January 2014
Available online 8 February 2014

Keywords:
Construction and demolition waste
Recycling
Mineral wool
Wood plastic composites
Mechanical properties
Moisture resistance properties

ABSTRACT

The construction and demolition (C&D) industry is a major source of waste. Environmental regulations and laws have been implemented in many countries to improve and encourage the recycling of C&D waste. To meet tightened regulations, new C&D waste recycling methods must be developed. Mineral wool is a waste fraction that is currently considered un-recyclable. In this study, the mechanical and moisture resistance properties of wood plastic composites utilizing recycled mineral wool as filler are presented. According to the findings, the addition of recycled mineral wool improved the moisture resistance properties of the composites noticeably, but a decrease in some mechanical properties was observed.

1. Introduction

The construction and demolition (C&D) industry has been identified as a major source of waste, varying between 13% and 40% of the total solid waste generated, depending on the country [1,2]. Only fragmented information is available about the recycling rates of C&D waste. It has been estimated that about 46% of C&D waste generated in the EU27 countries is recycled [3]. In the US, the recycling rate is estimated to be 20–30% [2]. Environmental regulations and laws concerning the recycling of C&D waste have been implemented in many countries [4], and the European Union has set an binding legislation, according to which 70% of non-hazardous C&D waste has to be prepared for re-use, recycled or recovered by 2020 [5].

Increasing the rate of recycling C&D waste has multiple benefits. A direct effect of increased re-use would be a reduced amount of waste being disposed to legal and illegal landfill sites. The shortage of land for waste disposal and the rising landfilling costs increase the attractiveness of re-using materials instead of disposing them to landfills. There are environment benefits when leachates from landfilled C&D waste decrease. Natural resources are conserved when C&D waste materials are used to replace virgin raw materials [6,7].

The utilization of mineral wool waste could play an important role in improving the recycling percentage of C&D waste. Mineral wool is a general term covering a variety of inorganic insulation materials. Rock wool, glass wool and slag wool, all manufactured from different raw materials, fall under the general term mineral wool [8,9]. Mineral wool is typically used in construction industry for heat insulation, cold and fire protection, and noise insulation [8]. It accounts for about 60% of the total insulation product market [10].

Current solutions for the recycling of mineral wool waste include for example the utilization of mineral wool waste in cement-based composites [11], composite ceramics [12] or wood fiber composites [13].

A new solution for the recycling of mineral wool waste could be utilization of the waste as filler in wood polymer composites. The

* Corresponding author. Tel.: +358 400 367 322.
E-mail addresses: olli.vantsi@lut.fi (O. Väntsi), timo.karki@lut.fi (T. Kärki).
[1] Tel.: +358 40 770 8791.

http://dx.doi.org/10.1016/j.conbuildmat.2014.01.050
0950-0618/

demand for wood polymer composites (WPC) is growing continuously. Typically, wood polymer composites consist of polymer, wood fiber and additives [14]. Coupling agents, lubricants, colorants, flame retardants and different inorganic filler materials are the most typical additives in wood polymer composites [15–18]. Wood polymer composites have a wide range of applications, including decking products, automotive parts and construction products [19–21].

Previously researched inorganic fillers for wood polymer composites include for example calcium carbonate, wollastonite, soapstone, talc, nanoclay, silica, and glass fiber [18,22–24]. These inorganic fillers have shown potential in improving the mechanical, fire retardant and thermal properties of WPC. Inorganic fillers are also cheaper than polymers, and therefore the raw material costs of WPC can decrease when polymers are replaced with inorganic fillers [25].

The chemical composition of mineral wool can vary depending on whether it is glass wool or rock wool. The main component in both rock and glass wool is SiO_2 [8]. Glass wool has a slightly higher SiO_2 content, while rock wool contains more Fe_2O_3, giving it a darker color and higher heat resistance [26]. As can be seen in Table 1, the chemical compositions of mineral wool are rather close to that of glass fibers which are used as filler in composites. Pure SiO_2, the main component in mineral wool, is also used as filler in composites [24].

The diameter of mineral wool fibers can vary, usually between 0.2 μm and 20 μm [27]. Glass fibers used as filler in composites have diameters around 16 μm [23,26]. It has also been noted that rock fibers with a small diameter (<9 μm) have better diameter-strength relationship than fibers with a larger diameter [26]. The fiber diameter, thermal conductivity or density of mineral wool does not change notably during its service life (30–50 years) [28].

In this study, the effects of mineral wool waste on the mechanical and moisture resistant properties of WPC are investigated. Three different volumes: 20%, 30% and 40% of mineral wool waste have been added to wood/polypropylene composites. The above mentioned properties are investigated and compared to a wood/polypropylene composite containing no mineral wool waste, and the results are discussed below.

2. Materials and methods

2.1. Materials

The thermoplastic matrix in the composites was commercially available recyclable polypropylene supplied by Ineos Polyolefins (Eltex P HY001P). The melt flow index of the polypropylene was 45 g/10 min (230 °C), the melting point was 161 °C and the density 910 kg m^{-3}. Maleated polypropylene (MAPP; OREVAC® CA 100; Arkema) was used as the coupling agent (MFI 10 g/10 min/190 °C, melting point 167 °C). The Orevac CA 100 polymer has low functionality (1%) and a high molar mass (25 kg mol^{-1}). Struktol TPW 113 was used as the lubricating agent.

Table 1
The chemical compositions of rock wool, glass wool and glass fiber.

	Rock wool [8]	Rock wool [9]	Glass wool [8]	Glass fiber [26]
SiO_2	46.43	40–52	56.89	58.25
Al_2O_3	11.42	8–13	3.47	11.86
TiO_2	1.47	1.5–2.7	0.12	0.41
Fe_2O_3	4.41	5.5–6.5	0.57	0.30
FeO	4.72	NR	0.18	NR
MnO	0.23	0.1–0.3	0.56	NR
CaO	17.89	10–12	12.61	21.09
MgO	9.24	8–15	3.61	0.54
BaO	0.11	NR	1.49	NR
Na_2O	3.07	0.8–3.3	12.86	0.30
K_2O	1.01	0.8–2.0	1.36	0.43
B_2O_3	0	NR	6	NR

NR = not reported.

The wood fiber used in the study was conifer with specific gravity of 158 g dm^{-3} in the recipes containing 20% and 30% of mineral wool waste, and conifer with specific gravity of 180 g dm^{-3} in the recipe containing 40% of mineral wool. The wood chips with specific gravity of 158 g dm^{-3} were prepared from sawn timber with a combined chipper/hammer mill apparatus, and the wood chips with 180 g dm^{-3} were prepared with separated crusher and hammer mill apparatuses. The length distribution of the wood chips was analysed using a microscope camera, and ImageJ software was used to measure the lengths of the fibers in the microscope camera photos. The length distribution for both types of chips is shown in Fig. 1.

The mineral wool waste was rock wool waste from a rock wool manufacturing process, and it was obtained from the landfill of a rock wool plant. It was processed with crusher and hammer mill apparatuses before the composite manufacturing stage. The fiber diameter distribution of recycled mineral wool fibers was measured from scanning electron microscope (SEM) pictures taken with Jeol JSM-5800 LV scanning microscope operating at 20 kV. IrfanView version 4.35 graphics software was used to measure the fiber diameters from the pictures. The measured fiber diameter distribution is presented in Fig. 2.

2.2. Manufacturing of wood–polymer composites

The amount of polypropylene, coupling agent and lubricant agent were kept constant in all the recipes, at 30%, 3% and 3% by weight, respectively. The amount of wood fiber and recycled mineral wool were as presented in Table 2.

All the materials were agglomerated together prior to extruding with agglomeration apparatus consisting of a PLASMEC TRL100/FV/W turbomixer and PLASMEC RFV-200 cooler. Hollow-shape decking boards were then produced with a counter-rotating twin-screw extruder, Weber CE7.2. The die temperature was maintained at approximately 185 °C. The screw speed was maintained at 13 rpm and the screw had the L/D ratio of 17. The pressure at the die varied between 3 MPa and 4 MPa, depending on the material blend. The material output varied between 20 kg/h and 28 kg/h, also depending on the material blend.

2.3. Scanning electron microscopy

Scanning electron microscopy (SEM) was performed with a Jeol JSM-5800 LV scanning microscope operating at 20 kV. Prior to the analysis, the fracture surfaces were covered with a layer of gold using a sputter coater.

2.4. Mechanical analysis

The bending test, flexural impact/Charpy and tensile properties were determined according to standards SFS-EN 310 [29], SFS-EN ISO 179-1 [30] and SFS-EN ISO 527-1 [31], respectively. Brinell-hardness was measured from 75 × 75 mm samples according to standard SFS-EN 1534 [32]. Moisture resistance under cyclic test conditions was determined according to standard SFS-EN 321 [33], and three-point tests were carried out according to SFS-EN 310 [29] standard after 3 weeks of soak/freeze/dry cycles. The size of the specimens for the bending tests and for moisture resistance under the cyclic test conditions was 450 × 50 mm. For the flexural impact tests, the size of the specimens was 80 × 10 × 5 mm. For measuring the tensile properties, the thickness of the dumbbell-shaped samples were 5 mm, and the width of the narrow part in the samples was 10 mm. For the mechanical measurements, the average of 20 measurements was calculated, except for the tensile property (9–20 accepted measurements) and cyclic three-point tests (10 measurements). The mechanical properties were tested with a Zwick Roell (Z020) apparatus.

3. Results and discussion

3.1. Scanning electron microscopy analysis

Fig. 3 shows scanning electron microscope pictures taken from the bending fracture surfaces of selected composites, as well as a picture of recycled mineral wool fibers. A good compatibility between the polymer matrix and the recycled mineral wool fibers can be observed in Fig. 3b–e. Both polypropylene and mineral wool fibers are hydrophobic materials, and thus good mechanical adhesion between the materials is expected. Fig. 3a shows micropores in the polymer matrix on the facture surface of composite MW0. It seems that there are less such pores visible in the composites containing recycled mineral wool fibers, although it can be sometimes hard to distinguish a pore from a hole caused by a recycled mineral wool fiber pulled out of the matrix during breakage of the composite. It can also be seen that some fibers pulled out of the polymer matrix. In Fig. 3d and e, holes where recycled mineral