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Cement type composite panels manufactured using paper mill sludge as filler

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HIGHLIGHTS

- Black sludge added wood cement board meets requirement the relevant standard.
- Anaerobic sludge is suitable additive for WCB production compared to aerobic sludge.
- PMS depending on sludge type could be used up to 20% wt in wood cement board.

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ABSTRACT

The aim of this study was to evaluate some physical and mechanical properties of the paper mill (PMS) and spruce planer shaving added cement boards. Also the effect of sludge type in consequence of waste water treatment technique on properties of wood-cement boards (WCB) was investigated. The wood/cement ratios were used as 1/3, based on the oven dry weight for the WCB manufacture. PMS was used up to 20% wt of total composite based on organic (wood) and inorganic (cement) amounts. Black sludge has shown more improvement than grey sludge on properties of WCBs, which indicates the anaerobic waste treatment technique is more effective for additive in WCB. The modulus of rupture and elasticity values of the WCBs with 5% of grey sludge, 5% and 10% of mixture of grey and black sludge were acceptable limits according to EN 634-2 standard. The mechanical strengths of all WCBs with black sludge were found above the specified EN standard. This suggests that PMS depending on sludge type may be used up to 20% wt of total composite weight for the commercial production of WCBs, which could expand the raw material base for this panel product.

1. Introduction

Wood cement boards (WCB) were commonly used in external cladding surfaces, siding panels, roof shakes, a wall lining in public buildings, protective elements for fireproofing to present a good resistance to fire, specialized flooring, thermal as well as acoustic insulation purposes, renovation work of the buildings, decorative applications, and sound insulation [1–5]. WCBs have drawn a great attention in industrial fields in recent years due to lack of source of wood particles, increasing use of wastes from wood and industrial processing, and changing forest management regimes [5,6]. The main advantages of WCB are highly resistant to absorbing moisture and can be used where energy efficiency is required [7].

Lignocellulosic wastes obtain from different sources such as wheat straw, coconut fiber, rice husk, saw dust, hazelnut husk, peanut hull, sugar cane, bagasse, coconut fiber, tea residues, bark of various wood species, oil palm residues, planer shaving produced from machining dry wood. Despite the wastes create various environmental problems during manufacturing timber, furniture, and medium density fiberboard; they have been used as filler in WCBs [8–11].

When small particles are used in manufacturing of wood based panel the adhesive consumption increases due to the enlargement of the surface and this causes an increase in the product price due to the high cost of Petroleum based synthetic binders. Therefore, using mineral binder such as Portland cement became popular in worldwide [5]. In comparison with wood and conventional wood products, WCBs are produced from wood particles, Portland cement, and water under pressure [6,12]. WCBs are pressed to

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consolidate for several hours because the hydration of the cement is a slow process. The compatibility between wood and cement is related to the degree of cement setting [13]. The presence of starch, sugar, lignin, hemicellulose, and extractive in wood affects the cement curing, setting time, and final strength of WCBs [14–16]. During interaction of cement, wood, and water to produce the cement based board, hydration reactions happened [1]. It is well known that hydrogen bonding and hydroxyl bridges have significant effect on the bonding of cement based composite [5]. If wood is incompatible with cement, calcium chloride, ferric chloride, magnesium chloride, sodium silicate, calcium hydroxide, and aluminum sulphate can be used to accelerate the curing of cement. Calcium chloride decreases the hydration time of WCBs and the inhibitory effects of wood on the setting of Portland cement [1]. It also improves crystalline formation in cement binder and increases mechanical interlocking between the cement and wood particles [14].

Pulp and paper industry (PPI) is one of the most water and energy intensive sectors in the world. PPI is also one of the largest producers of wastewater. The waste water treatment process is very important due to increasing environmental constraints for PPI. Between 2012 and 2020, it is expected to increase 60% in the global waste and waste water treatment market. PPI has been used some techniques such as aerobic, anaerobic and combined aerobic-anaerobic treatments for waste water treatment [17]. After waste water treatment, pulp and paper mill sludge is generated, which consists of small cellulose fibers, high concentration of heavy metals, a cocktail of the inks, mineral fillers, inorganic materials such as kaolin, clay, and calcium carbonate etc., organic compounds, and water [18–20]. Paper mill sludge (PMS) has the following advantages: (1) no requirement for high temperature chemical and mechanical pretreatment, (2) no additional unit operations, (3) negative feedstock cost, and (4) potential integration of process into a preexisting industrial infrastructure [21]. Based on these advantages, it is an alternative fuel in the production of Portland cement [22].

Evaluation of pulp and paper mill sludge in cement matrix has been studied by some researches [18,22] but there is no comparison with techniques of waste water treatment in these studies. The aim of this study was to investigate the effects of the paper mill sludge on some physical including water absorption and thickness swelling and mechanical properties, which are modulus of rupture and modulus of elasticity, of WCBs made from spruce planer shaving. Also the effect of sludge type in consequence of waste water treatment technique on properties of WCBs was investigated.

2. Experimental

2.1. Materials

Portland cement, CEM II B-M (P-LL) 32.5 R type, produced by Askale Cement Co. in Turkey, was used in this work. Two types of sludge were used for experiment and supplied by Halkalı Kağıt Co. in Turkey. Calcium chloride ($CaCl_2$), which used as 5 wt% based on weight of cement, was obtained from Tetra Chemicals Europe AB, Sweden as an accelerator for process. Spruce planer shaving was obtained from a small size wood manufacturer shop in Artvin, Turkey. The spruce planer shaving was screened into different fractions with 1.5 and 3 mm by using a classifying screen and those on the 1.5 mm screen was used for WCB production.

2.2. Precipitation of paper mill waste water

The mill, supplied the sludge, uses waste paper and cardboard to manufacture paper for packaging purposes. To generate paper mill sludge, two methods were applied as aerobic and anaerobic. First method: Grey sludge -biological sludge- was occurred after biological treatment which is utilization bacteria in combination with reactant treatment (chemical method precipitated) using FeCl3. Reactant treatment in other words conditioning is needed to ensure better water repulsion of sludge. Second method: Black Sludge –anaerobic sludge– was precipitated fiber carried by under sieve water and deposited in the decantation of the system pollution without the use of chemicals in paper mill waste water. Two type of sludge were dried at 103 °C for 24 h. and then granulated before manufacturing.

2.3. Elemental analysis of paper mill sludge

The sample preparation from paper mill sludge was performed according to US-EPA Method 3051A with 10 ml HNO_3 in Berghof Speedwave two microwave digestion systems. The Cr, Cu, Mn, Ni, Pb, Y and Zn contents of microwave digested mill sludge measured with a Perkin Elmer ICP-OES Optima 8000 spectrometer (Perkin Elmer, Waltham, USA).

2.4. Manufacture of composite panels

The wood/cement ratios were used as 1/3, based on the oven dry weight for the board manufacture. The planer shaving, distilled water, cement, and $CaCl_2$were-blended until the cement paste completely hydrated. The amount of distilled water was adjusted according to the formula founded in Simatumpang et al. [23]. The formula was also used by some researchers [9,13,24–26].

$$Water(liter) = 0.35C + (0.30 - MC)W$$

where C is the cement weight (kg), MC is wood strands moisture content (oven dry basis), and W is oven dry wood strand weight (kg). These boards were produced at a target density of 1200 kg/m^3 and dimensions of 400 mm × 400 mm × 10 mm (length × width × thickness).

To calculate PMSs amount in manufacture, ash test was performed according to TAPPI T 413 standards. Inorganic and organic content in PMSs were determined with the ash test, PMSs were used up to 20% wt of total composite based on organic (wood) and inorganic (cement) amounts. According to the ash test results, organic/inorganic contents of black sludge and grey sludge were found as 54.7/45.3% and 39.11/60.89%, respectively. The experimental design for the manufacture of wood-cement boards with spruce plane shaving and paper mill sludge is shown in Table 1.

2.5. Determination of physical and mechanical properties of WCBs

The boards were conditioned at 20 °C and 65% relative humidity for 4 weeks before the mechanical and physical tests. The modulus of rupture (MOR) and modulus of elasticity (MOE) in bending of WCB panels were determined in accordance with EN 310 and EN 319 standards, respectively. The thickness swelling (TS) and water absorption (WA) values of the WCB panels were also measured after 24-h soaking in water in accordance with the EN 317 standard. All tests were performed on ten samples for each type of composite. The analysis of variance test general linear model (GLM) and Duncan's mean separation tests were carried out with SPSS 21.0 statistical package software to determine homogeneity groups of all the WCBs.

2.6. Scanning electron microscope (SEM)

The test samples for SEM observation were performed by cutting small sections from the fractured surfaces of the bending test samples. The small samples were inserted on sample stubs and then coated with gold for examination in EVO LS 10, ZEISS.

3. Results and discussion

3.1. Mechanical properties of the WCB samples

The results of modulus of rupture values of WCB are given in Fig. 1. The highest MOR values of WCB were obtained from control samples and the board samples containing 10% black sludge. Black sludge has shown more improvement than grey sludge on MOR of wood cement boards. This can be explained that black sludge has higher fiber content compared to grey sludge. It is reported by some researchers that geometry of lignocellulosic material affects mechanical and physical properties of wood-cement boards and wood particles with higher slenderness ratios provides more strength properties of the boards [27–29].

According to ICP analyze results in Table 2, different quantities and types of heavy metals were found in black sludge and grey sludge. Grey sludge has more heavy metal content than black sludge except for Zn and Mn. Pandey et al. [30] indicated that high heavy metal content caused to reduce mechanical properties of cement based products. However, these heavy metal contents for both are also under limit values for cement products using