Fabrication of Flooring Panels Using Recycled Paper De-inking Solid Waste

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1. Introduction

Large volume of sludges generated in pulp and paper industry causes environmental concerns and due to limited space and new legislations, their disposal options become more limited and uneconomical. Pulp and paper mill sludges, especially deinked paper sludge contains fundamentally non-hazardous solid materials such as lignocellulosic fibers, ink and significant amount of papermaking fillers such as kaolin, clay, CaCO₃, talc and silica [1]. As an eco-friendly and clean alternative to land fill, paper mill sludge can be used for the fabrication of lightweight fiber-cement panels in which mineral compounds of sludge behave like the ingredients of cement and sludge fibers work as effective reinforcing agents [2]. In order to reduce the disposal problem of papermaking sludge and enhance the properties of flooring panels, concrete, in this study an attempt has been made to examine the effect of deinked paper sludge on some physical and mechanical properties of the flooring panel.

2. Methodology

2.1. Experimental study

In this study, paper sludge (PS) originating from Latif Papermaking Co, Karaj, Iran was used. We had previously reported its chemical and morphological properties [1]. The binding agent employed was commercial grade of Portland cement, Type II and Calcium chloride (CaCl₂) was used as cement setting accelerator. It was an analytical grade from Merk Co, Germany. To improve the adhesion of cement and PS, a concrete bonding adhesive from CEDEX, Iran, with trade name of CRB was used as binding agent. Flooring panels with the dimensions of 350 × 270 × 12 mm³ were formed using PS contents of 40, 50, and 60 wt%, adhesive dosages of 0, 10, and 15 wt%, and 0 and 5 wt% of calcium chloride as an accelerator. At least three replications were fabricated for each treatment, and some mechanical and physical properties of the boards were evaluated. Control samples contained neat cement and water.

2.2. Physico-mechanical testing

Prior testing, all the boards were conditioned in a controlled room for 15 days at 25 °C and 65% RH to reach the equilibrium moisture content of 12%. Conditioned boards were sawn into test samples to determine the modulus of
rupture (MOR), modulus of elasticity (MOE, DIN EN 610), hardness (HS, DIN EN 897), and screw withdrawal perpendicular to the surface (SW, DIN EN 320), internal bond strength (IB, DIN EN 319) and fire resistance according to BS-476: Part 12 in the dry condition. Three-point flexural testing was carried out using an Instron Universal Testing Machine 4486, with a span of 180 mm and cross-head, the bearer diameter of 25 mm and the loading speed of 10 mm/min. The dimensions of test samples for MOR and MOE were 310 × 50 mm² and for other tests were 50 × 50 mm² with nine replications for each treatment. Physical properties, namely water absorption (WA) and thickness swelling (TS) were evaluated based on DIN EN 317. At least three specimens of every board were tested to obtain a reliable average and standard deviation.

3. Results and discussion

The density of boards varied from 0.77 to 0.99 g/cm³. The average measured values of bending modules of rupture and elasticity are plotted against the PS content in Fig. 1a. It can be observed that MOR and MOE properties were enhanced with increasing PS content from 40 to 60%. A further increase in PS content (60%) showed a reduction in the bending strength. After analyzing the broken pieces of the specimens, it was observed that some parts of the PS could not distribute uniformly in the matrix, and a portion of these PSs was clamped and placed in some points of the specimen containing 60% PS. The internal bond strength of the panels was found to be a maximum when PS content was 40% and further addition of PS increased the volume of fibers and reduced the volume of matrix causing lower bond strength (Fig. 1b). Moreover, the panels produced using 60% PS exhibited the highest water absorption (Fig. 1c), presumably due to the low density producing more permeable voids so that more water can be absorbed [3]. The samples exhibited satisfactory SW resistance of 22.7 kPa to make an acceptable connection loads for use as lightweight board materials. The boards also showed the addition of CaCl₂ and cement adhesive could not considerably improve SW resistance (Fig. 1d). Increasing the PS content showed negative influence on fire resistance and increased weight loss due to wire. Like SW resistance, the addition of CaCl₂ and cement adhesive reduced the fire resistance of panels.

![Fig. 1. Effect of formulations of the PS/cement in flooring boards on physico-mechanical properties: (a) MOR and MOE, (b) hardness and internal band, (c) water absorption and thickness swelling and, (d) screw withdrawal and fire resistance](www.SID.ir)
4. Conclusions

Results showed that the bending and internal strengths of the specimens were decreased with an increase in the PS content, and the maximum values were obtained at PS loading of 40 wt%. The negative influence of PS content on the mechanical properties can be explained by the reduced bonding ability of PS compared to cement. Screw withdrawal values were up to 22.7 kPa. Water absorption and the thickness swelling of fabricated panels were considerably increased with increased content of PS. In general, all properties of the boards were improved when the adhesive and calcium chloride contents were increased. The results showed that an increase in board density improved the mechanical and physical properties. In general, the fabricated panels with 40% PDS, 10% concrete adhesive and 5% CaCl$_2$ with a density of around 0.8 g/cm$^3$ had the best properties taking into account the bending modulus, internal bonding, hardness and thickness swelling which were considerably better than those of commercially available gypsum boards. Compared to the commercial gypsum boards, the fabricated panels had lower thickness swelling, comparable water adsorption and higher fire resistance.

5. References