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Review

Mechanical, durability and environmental aspects of magnesium oxychloride cement boards incorporating waste wood

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ABSTRACT

Waste timber formwork from construction sites was used as fibre to prepare wood-magnesium oxychloride cement (MOC) board. The effect of wood fibre content, pulverized fly ash (PFA) and incinerated sewage sludge ash (ISSA) on the mechanical and durability properties of wood-MOC board was investigated. Greenhouse gases (GHGs) emission, one of the representative and most globally concerned environmental impacts, for the production of different types of composite boards was assessed and compared by using lifecycle assessment (LCA) technique. The 'cradle-to-gate' system boundary with 1 kg of board production was considered as the functional unit in this assessment. The result showed that the wood-MOC composites prepared with a higher content of wood fibre had a lower thermal conductivity, higher flexural strength, higher residual flexural strength after exposure to high temperatures and water immersion, and better noise reduction effect. Even though the water absorption was increased with the increase of wood fibre content, it can still be considered to be low. The wood -MOC composites incorporating ISSA showed higher flexural strength, better high temperature resistance and better water resistance than other composites. In addition, the production of the wood MOC board induces lower GHGs emission than plywood and lower human toxicity than conventional resin-based particleboard.

Contents

1. Introduction

The construction industry has been blamed for the generation of massive amounts of construction and demolition wastes. The Hong

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Kong Environment Protection Department (HK EPD) estimated that approximately 24.4 million tonnes of construction waste were generated in 2016 (Hong Kong, 2017). Among the construction waste, inert wastes (e.g. soil, rock and concrete rubbles) are deposited at public filling areas or recycled (Rao et al., 2007). While the remaining non-inert wastes (about 7% of all construction waste), timber/wood, bamboo, plastics, paper and packaging materials, have to be disposed of at municipal solid waste landfills as they are often mixed and contaminated (Poon et al., 2001). Because of the shortages of landfilling space, it is necessary to develop new ways of recycling non-inert wastes.

It was reported that timber formwork, accounting for 30% of all identified non-inert construction waste in HK (Poon et al., 2004), can be used to produce wood-cement boards which performed better than neat cement based products with higher flexural strengths (Soroushian et al., 1994), and when compared to wood products only, the wood-cement board had a high resistance to harmful effects of sunlight, rain and insects (Lee, 1986). It has been suggested that the bonding between the wood fibre and the cement matrix included physical bonds and chemical bonds. Physical bonds developed during the hydration process when the hydration products formed and interlocked with each other. Chemically, the metal hydroxyl groups in the cement matrix could react with the carboxylic groups in the wood fibre (Coutts and Kightly, 1984). It was found that many parameters affected the strength of the bond between wood fibre and cement matrix, including matrix composition, fibre geometry, and fibre type etc (Bentur and Mindess, 2014). The fibre content affected the flexural strength of wood-cement composites (Coutts and Kightly, 1984; Coutts and Warden, 1985). The strengthening effect of the fibre was evident, and the maximum improvement was achieved when the optimum fibre content was used. The decrease of flexural strength at high fibre content was explained on the basis of inefficient compaction and the lower density of the wood fibre-cement composite. In terms of fibre length, the wood fibre-cement composite prepared with the longer fibre had a higher flexural strength. This was related to the crack bridging function of wood fibre. The wood-fibre reinforced composites failed by cracking when loaded in flexure. The short fibre limited the width of crack that can be bridged and would slip from the paste matrix. The wood-cement composites prepared with the shorter fibre and the longer fibre failed by fibre pull-out and fibre fracture respectively (Coutts and Kightly, 1982).

However, the incompatibility between wood and Portland cement, which is caused by the inhibitory effect of extractable contents in wood on cement hydration, need to be addressed (Fan et al., 2012; Quiroga et al., 2016). Compared with wood Portland cement composites, wood-magnesium oxychloride cement (MOC) composites showed less incompatibility (Simatupang and Geimer, 1990). It was found that the extractives in wood retard the hydration of Portland cement and the typical cement-hardening inhibitory components can be classified into two groups. One group is comprised of carbohydrates of sucrose in beech and arabinogalactan in larch, and the other are phenolic compounds with a catechol unit of plicatic acid in western red cedar, teracacidin in acacia mangium, and sequirin C in sugi (Na et al., 2014). Simatupang and Geimer compared the relative hydration time of magnesia cement and Portland cement and found the value of wood-Portland cement was much longer than that of wood-magnesia cement for most wood species (Simatupang and Geimer, 1990). So MOC could significantly reduce this problem and be used to produce building components such as door panels and partition walls (Zhou and Li, 2012). Besides, MOC has high fire resistance, abrasion resistance (Misra and Mathur, 2007) and flexural strength and its hardening is achieved without the need of steam curing, which can reduce production costs (Simatupang and Geimer, 1990). Nevertheless, the poor water resistance of MOC paste has limited the application of wood-MOC boards (Deng, 2003). Previous studies showed that the incorporation supplementary cementitious materials (SCMs) such as pulverized fly ash (PFA) and incinerated sewage sludge ash (ISSA) could significantly improve the water resistance of MOC as the amorphous phase produced due to the reaction between PFA/ISSA with MOC was stable in water and protected the MOC hydration products from decomposing (He et al., 2017a, 2017b, 2017c). Thus, the MOC paste is a potential binding material to recycle waste wood. But few research has been done to study the effect of wood fibre contents and SCMs on the properties of wood-MOC paste. Thus, the main objective of this research is to investigate the mechanical properties, durability and environment aspects of waste timber-MOC boards incorporating different percentages of wood fibre and PFA or ISSA.

2. Experimental program

2.1. Materials and sample preparation

Construction waste timber (masson pine) formwork was collected from a construction site in Hong Kong, cut to wood block, crushed to wood fibre by a wood crusher, and sieved to fibre with a length less than 5 mm as shown in Fig. 1 The density and water absorption is 0.45 g/cm^3 and 0.55 g/g respectively. Commercially available magnesium oxide (MgO) (Liaoning province, China) and hexahydrate magnesium chloride ($MgCl_2 \bullet 6H_2O$) (Qinghai province, China) were employed to prepare the MOC paste. PFA was obtained from a local power plant in Hong Kong, and ISSA was provided by the sewage sludge incineration plant - T park, HK. The chemical compositions of MgO, PFA and ISSA are shown in Table 1.

The wood-MOC board was prepared with the proportion shown in Table 2. PFA and ISSA were used as the replacement of MgO. So the molar ratio of MgO/$MgCl_2$ was varied. CO_2 curing was adopted to obtain high water resistance according to our previous studies (He et al., 2017a, 2017c). The water resistance of ISSA-blended MOC paste was high already (about 80% strength retention), so the specimens incorporating ISSA was not subjected to CO_2 curing (He et al., 2017c). The prepared composites after mixing thoroughly using a mechanical mixer were transferred into steel moulds (160 × 160 × 20 mm) and covered with polyethylene sheets.

After 24 h of hardening, the wood-MOC board was demoulded and placed into a curing chamber at 25 ± 1 °C with a controlled humidity of 50% ± 5% for air curing. After 13 days of air curing, some samples were placed into a steel chamber for further CO_2 curing for 1 day. The chamber was vacuumed to −0.5 bar before the CO_2 injection. CO_2 used for CO_2 curing was at >99% purity and the pressure was 0.1 MPa. After 14 days of air curing or 13 day of air curing +1 day of CO_2 curing, some specimens were immersed in water for the water resistance test. It was reported that the development of compressive strength of MOC was rapid at the early curing age and reached stable after only two weeks (Xu et al., 2016a). So the curing period of the MOC board was limited to 14 days.

2.2. Test methods

Flexural strength, water absorption and thickness swelling were conducted according to ASTM C1185, 2008 (ASTM, 2008) and ASTM D 1037, 2012 (ASTM, 2012) respectively. The high temperature resistance of wood-MOC board was evaluated based on the residual flexural strength after heating for 2 h in an electric high temperature furnace at a temperature of 200 °C, 300 °C and 400 °C. There is no standard test for assessing the high temperature resistance of wood cement boards. But according to a previous study, at a