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Eco-friendly self-compacting cement pastes incorporating wood waste as cement replacement: A feasibility study

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A B S T R A C T

This experimental study explores the feasibility of the development of eco-friendly self-compacting cementitious systems, utilizing wood waste sawdust (SD), for sustainable building construction. Two different gradations of SD viz-a-viz, coarse SD (CSD) and fine SD (FSD) were used in modifying neat Portland cement paste system as partial replacement of cement, in various weight fractions of 2%, 5%, and 7%. The fresh and hardened state properties of SD modified paste were determined. The results indicated that despite the strength reduction with SD addition in cement paste (strength decrease of 11%–34% was observed with SD addition), the resulting shrinkage strain is greatly reduced owing to the higher water absorption of SD particles thus increasing the water demand, to maintain self-compactibility, as well. The reduction in shrinkage of SD modified pastes was significant, with a reduction range of 45%–80%, as compared to control sample. Density and unit weight of the developed pastes were also reduced. The ability of SD to absorb water and releasing it later, thus providing moisture for cement hydration, suggests that SD has the potential to serve as an internal curing agent in self-compacting cementitious systems. Utilizing SD in cementitious binders may, then, not only promote sustainable development, but also lead to more durable infrastructures.

1. Introduction

Persistently increasing amounts of industrial wastes due to rapid urbanization and industrialization is a critical issue. Managing such wastes effectively and efficiently is an ever-growing research area. Depleting natural resources in creating built environments has further raised serious concerns from the sustainability point of view (Hanif et al., 2011; Shi et al., 2015). Cement alone constitutes 5% of the total global carbon dioxide emissions (Hanif, 2017; Lee et al., 2018; Naik and Moriconi, 2005), one way to target both the fore mentioned issues is the use of suitable industrial wastes as supplementary cementing material (SCM). By doing so, some percentage of cement can be replaced with any of these suitable material which will lead to reduced cement consumption, thereby generating lower greenhouse emissions, great savings on costs further strengthening the economy, and reducing the dumping loads for landfills. These benefits collectively contribute towards societal acceptance, economic viability, and environmental bearing; the three pillars of "sustainable development". It's no surprise that preventive measures to matters of resource reduction and global pollution are the prime aspects, if not the main objective of most of the research programs being carried out in any field (Ijigah et al., 2013). The construction industry is no exception to that. Having a direct major impact on environment and its localities, the need is more than ever for an environmental friendly material which utilizes raw/waste materials to not only benefit the environment, but also keeping the material quality and its standard intact (Shakir et al., 2013).

1.1. State − of − the − art

Wood is one of the major construction and accommodating material. Hence, generation of continuous large piles of wood waste in sawmills and farms is inevitable. Therefore, wood waste,

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especially of sawdust (SD) is amassed all over the world raising serious environmental concerns and health issues (Corinaldesi et al., 2016; Morales-Conde et al., 2016; Pedreño-Rojas et al., 2017). The storage of SD in large piles and their consequent rapid decomposition rate could also aggravate the greenhouse effect (Wihersaari, 2005).

Concrete is the second most widely used material on earth, and great resources are consumed in its production. One way to reduce the aforementioned environmental impact is the efficient utilization of waste materials in concrete. Several waste materials have been used earlier e.g. fly ash (Hu, 2014; Kumar et al., 2014), silica fume (Collepardi et al., 2004; Hu and Li, 2015; Razak and Wong, 2005) ground granulated blast furnace slag (GGBFS) (Gholampour and Ozbakkaloglu, 2017; Hu et al., 2014; Kim et al., 2018; Patra and Mukharjee, 2017), waste glass powder (Castro and Brito, 2011; Lee et al., 2018), and wood waste (Novais et al., 2015; Pedreño-Rojas et al., 2017). One special type of concrete is self-compacting or self-consolidating which flows and encapsulates the form work without any use of compacting effort due to its own weight and workability (Sonebi et al., 2007). Despite the interesting features that self-compacting cementitious system offers, there are some major issues that still need improvement. One of the major problem associated with self-compacting cementitious system is its early shrinkage and cracking (Han et al., 2014). To cater for this, internal curing is suggested to be a better solution, and a lot of research work is going on the use of super absorbent polymers (SAP) as an internal curing agent (Craeye et al., 2011). The results also corroborate the improvements being made by using an internal curing agent to alleviate the effects of shrinkage and heat in the cement system (Hasholt et al., 2012).

While SD ash has been widely used as a powdered material in self-compacting concrete system (Elinwa and Mahmood, 2002; Elinwa and Mamuda, 2014), there aren't much findings in the literature where wood SD in dry form has been used as an internal curing agent in self-compacting cementitious system. Previously, wood SD is being used in conventional concrete mainly as a filler material (Saini et al., 2016). Morales-Conde et al. (2016) investigated the physical and mechanical behavior of wood-gypsum composites by using wood waste as an additive. Pedreño-Rojas et al. (2017) suggested that better acoustic and thermal properties were achieved with false ceiling plates when wood sawdust shaving were used in the mix as opposed to conventional plaster mixes. It was observed that the incorporation of wood in the system lowered the hardness and thermal conductivity of the composites, whereas the compressive strengths were also reduced of the composites. Coatanlem et al. (2006) used wood chippings in the concrete system and studied its durability; it was suggested that better results were achieved due to an improved bonding between chippings and cement paste when wood chippings were saturated with sodium silicate solution prior to its use. Similarly, in conventional concrete system wood SD has also been used as lightweight aggregate and reduction in compressive strength was prominent (Belhadj et al., 2014). Corinaldesi et al., (2016) showed the effect of wood SD in mortar and suggested a better performance of mortar with fine SD rather than using coarse size. It has also been shown that better properties are achieved when wood waste used in cement and clay mix (Bouguerra et al., 2002). Similarly, Adebakin and Adeyemi (2012) demonstrated that at 10% SD replacement of sand in mortar, the overall cost and weight can be reduced by 3% and 10%, respectively.

1.2. Research significance

The use of wood waste in mortar and concrete has been evaluated earlier, by various researchers. Mechanical and thermal insulation properties have been primarily addressed in the reported studies. The effects of SD on the properties of self-compacting cementitious pastes is still unknown. Current study has been conducted to fill these research gaps and focuses on the properties of SD incorporated self-compacting pastes with special reference to internal curing due to SD addition. The resulting fresh and hardened state properties (density, flow, air-content, setting time, strength, shrinkage strain, and hydration attributes) have been investigated. The present study provides useful insight for development and application of sustainable SCC binders.

2. Materials characterization and experimental methods

2.1. Materials characterization

Cement: Ordinary Portland cement (OPC) type I, (grade 52.5), meeting the requirements of ASTM C150-04 (ASTM C150-04, 2004) was used. For chemical composition X-ray fluorescence spectroscopy (XRF) was done, using Axios Advanced WD XRF PANalytical, by pellet method. Particle size distribution (PSD) and BET-specific surface area were determined by Laser granulometry and Coulter SA3100, respectively. The D_{50} value calculated from PSD curve is 16.2 μm and a BET value of 1.1 m^2/g suggesting a fine cement particle size. The loss on ignition was found as 3.85% suggesting a well burnt material. The results of physical and chemical characterization of cement are given in Table 1.

Super-plasticizer: Melflux 2651F, a third generation polycarboxylate ether (PCE) based super plasticizer imported from Germany BASF industries, was used to prepare paste specimens. Melflux, being from PCE powdered Family, helps reducing the water demand effectively and preventing segregation and bleeding. The recommended dosage as per manufacturer is 0.05–1.00%.

Saw-dust (SD): Two different sizes of dry SD were used, coarse saw-dust (CSD) and fine saw-dust (FSD), as shown in Fig. 1. The particle size distribution was assessed using Master-sizer Malvern

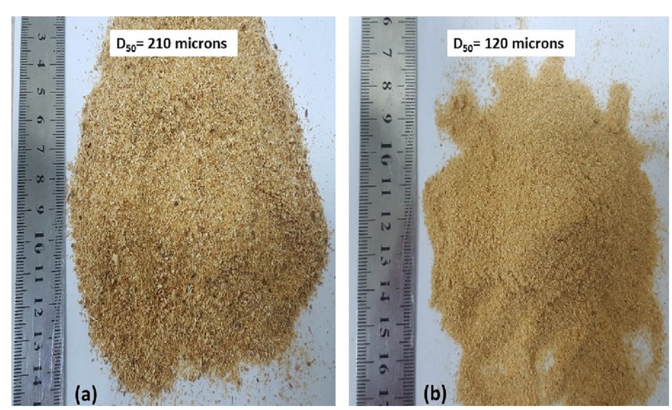

Fig. 1. Sawdust used in the study; (a) coarse sawdust (CSD), and (b) fine sawdust (FSD).

Table 1
Chemical and Physical analysis of ordinary Portland cement.

Sample	Al_2O_3 (%)	MnO (%)	MgO (%)	SiO_2 (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	TiO_2 (%)	Fe_2O_3 (%)	LOI (%)	BET m^2/g
OPC	4.96	0.04	2.23	19.17	65.11	0.57	0.51	0.07	0.28	3.21	3.85	1.1