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Experimental investigation of mechanical and microstructural properties of cemented paste backfill containing maple-wood filler

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ABSTRACT

This experimental study investigates the influence of maple-wood sawdust addition on the mechanical and microstructural properties of cemented paste backfill (CPB). Mechanical properties of CPB were determined by uniaxial compressive strength (UCS) tests and microstructural changes were evaluated by mercury intrusion porosimetry (MIP) and scanning electron microscopy (SEM) analysis. Results indicate that the addition of 12.5% maple-wood sawdust (by dry mass of binder) improves the strength development of CPB specimens at later hydration age (91 curing days). However, at a higher maple-wood sawdust content of 14.5%, the UCS showed lower improvement. Moreover, MIP and SEM analysis results revealed that the 12.5% wood filler addition made the CPB material less porous and more compact by increasing the mineral content formed by cement hydration. The positive influence of maple-wood sawdust on CPB was associated with higher binder content ($\geqslant$5%) and mid- to long-term curing times ($\geqslant$56 days).

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1. Introduction

The use of cemented paste backfill (CPB) is an innovative mine tailings management method that can reduce the tailings stream from surface storage to extracted underground mine stopes by up to 50%. Furthermore, CPB can also be used as secondary ground support [1,2]. CPB is made of mill tailings (68–77%) generated by the mineral processing plant, water (15–30%), and a binding agent (2–8%) such as Portland cement or blends of cement and mineral additives such as lime, pulverized fly ash, ground granulated blast furnace slag, or silica fume [1,3]. The binding agent provides the CPB with undrained cohesive strength, which is commonly evaluated by the uniaxial compressive strength (UCS 0.2–4 MPa) [4–7]. The prepared CPB mixture should have appropriate flowability for delivery to mine stopes, either by gravity or pumping. Generally, a slump height equal to or greater than 180 mm ($\geqslant$7 in.) provides adequate fluidity [8]. In this case, the available water content in the CPB largely exceeds what is required for binder (e.g., Portland cement) hydration (water-to-binder ratio $\geqslant$ 3) [4,9–11].

Wood fillers usually consist of cellulose (40–50%), hemicellulose (15–25%), lignin (15–30%), pectin, and waxes [12–14]. They are generally obtained from two sources: residues from round wood (debarked wood, logging residues after thinning) and from industrial wood (sawdust, shavings, offcuts, and slabs) [15,16]. Whereas cellulose is insoluble in water, organic solvents, and alkaline solutions, hemicellulose is soluble in alkaline condition, and even in water. Lignin, the most complex naturally occurring polymer, remains stable under the influence of various organic solvents, alkaline solutions, and water. Extractives, on the other hand, are the non-polymeric components of wood that are dissolvable in organic solvents and water [13,14,17]. It has been reported that sugar concentrations (originating from hemicellulose), even at low amounts (0.03–0.15 wt.%), retard the initial setting time and strength of cementitious materials [18]. In fact, tricalcium aluminate (C_3A), being the fastest reacting cement component, is responsible for the initial setting time of hydration, but the presence of organic compounds alters the C_3A reaction. In addition, extractives contained in wood fillers may be adsorbed on the calcium hydroxide nuclei, thereby retarding the hydration of tricalcium silicate (C_3S) [19,20]. In cement-based materials, wood fillers act through different mechanisms, including chemical interaction with hydration processes, adsorption on cement particle surfaces, alteration of the surface tension of water (affecting the rheology of the mixture), and addition of specific chemicals to the mixture [2,21–23]. The main advantages of wood filler addition to cementitious materials and composites are that they are inexpensive, abundant, environmentally friendly, and easy to process [24,25]. In addition,

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they reduce the setting time of cement hydration [26,27] and improve the mechanical properties, including flexural strength, toughness, impact resistance [28,29], and compressive and tensile strength [30,31]. However, they come with certain disadvantages, including low modulus of elasticity, deterioration and mineralization in alkaline conditions [24,32,33], dimensional instability, high variability of physical and mechanical properties [12,34], and inconsistent reinforcement [35]. Although some authors have proposed various treatments for natural and wood fillers to reduce potential problems within cementitious materials [36–39], these treatments are not feasible for paste backfill due to the additional waste management cost. Furthermore, the incompatibility of some wood species with cementitious materials means that the compatibility of each wood species must be assessed individually [40].

In cement-based materials, the use of blended binders (e.g., a blend of general use Portland cement – GU and ground granulated blast furnace slag – GBFS) can reduce the potential negative influence of wood filler. The effectiveness of slag cement binder in cementitious materials, especially at later hydration ages, has been reported in several studies [1,4,41,42]. In addition, the use of slag in cementitious materials containing wood filler can prevent the retarding influence of sugars (from hemicellulose) and extractives. In fact, because slag has a higher specific surface area compared to that of cement [43,44], it adsorbs primarily the extractives and water-soluble sugars released from the wood filler [13]. Furthermore, the combination of Portland cement and slag can decrease the pore size distribution in CPB specimens [45–47].

To our knowledge, no studies to date have addressed the influence of wood fillers on the properties of CPB. Hence the motivation for this study. Because CPB has substantial water content, and because wood fillers can absorb large amounts of water (compared to their initial weight) [48,49], the authors believe that wood filler addition to CPB materials can improve the hydration process by reducing the water-to-binder ratio. In addition, water drainage due to self-weight consolidation in CPB-filled stopes can be reduced by wood filler addition [50]. However, it should be mentioned that the addition of powdered wood filler would increase the water absorption and decrease the water uptake time [2,51]. Moreover, when the shape and size of wood filler grains are similar to those of the tailings grains, the wood filler dispersion within the CPB matrix would be more homogeneous. Consequently, when the CPB is under load, forces could be transferred throughout the material more uniformly [52]. Therefore, powdered wood fillers (sawdust) were used in this study. The influence of wood fillers on different properties of CPB are assessed and discussed in terms of UCS, slump height, mercury intrusion porosimetry (MIP), and scanning electron microscopy (SEM) results.

2. Materials and methods

2.1. Mine tailings and maple-wood sawdust

The Casa Berardi mine (Hecla Mining Company gold mine), located in the Northwest region of Québec (Canada), provided all the tailings for this study. Tailings were collected from the ore processing plant and stored in barrels. After transfer to the lab, the tailings barrels were homogenized. Different tailings samples were then taken for X-ray diffractometry (XRD) analysis (mineralogy), grain size distribution determination, and inductively coupled plasma-atomic emission spectrometer (ICP-AES) analysis (chemical composition), as explained elsewhere [3,53]. The specific gravity of tailings G_s was determined to be 2.715 using a helium pycnometer (AccuPyc 1330, Micrometrics). Fig. 1 shows the grain size distribution and Table 1 presents the chemical and mineralogical compositions (ICP-AES and XRD analyses) of the mine tailings.

Maple is a hardwood species. The maple-wood sawdust used in this study was purchased from P.W.I. Industries. The average specific gravity of the cell walls of wood filler made from maple wood is approximately 1.5 [54], with a specific surface area of 1.1 m^2/g. The particle size distribution of maple-wood sawdust is shown in Fig. 1. The chemical and elemental compositions of maple-wood sawdust are presented in Tables 2 and 3 [55].

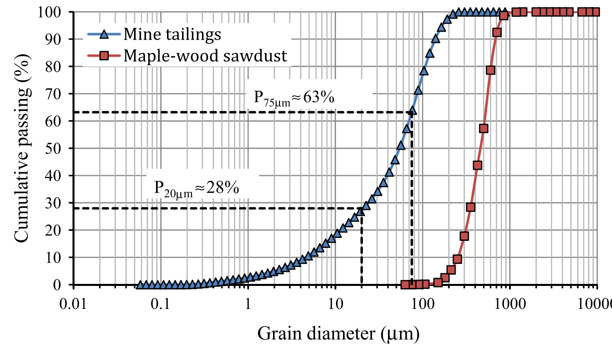

Fig. 1. Cumulative grain and particle size distribution curves for the Casa Berardi mine tailings and maple-wood sawdust (fillers).

Table 1
ICP-AES analysis and XRD quantification of the Casa Berardi mine tailings.

ICP-AES analysis (%)		XRD quantification (%)	
Element	Tailings	Minerals	Tailings
Al	1.7	Quartz	86.6
As	0.21	Muscovite	4.49
Ca	0.75	Albite	5.41
Fe	1.8	Pyrite	1.04
K	0.56	Ankerite	2.46
Na	0.34		
S	0.84		

Table 2
Chemical composition of maple-wood sawdust [55].

Cellulose (%)	Lignin (%)	Pectin (%)	Ash (%)	Hemicellulose (%)	Methoxyl (%)	Acetyl (%)
42–47	23.3	1.9	0.2–0.5	30.4	7.25	3.2–3.8

The addition of 12% natural filler (by dry mass of cement) has been proposed in different studies as an effective amount to improve various properties of cementitious materials [26]. Hence, in this study, 12.5% and 14.5% maple-wood sawdust filler in CPB (by dry mass of binder) are examined.

2.2. Binder types and mixing water

As mentioned above, the use of a blended binder is preferable in cementitious materials containing wood filler. Hence, a binder consisting of a blend of 20% general use Portland cement (GU) and 80% ground granulated blast furnace slag (Slag) was prepared for use in this study (GU/Slag@20/80). The mineralogical composition and the relevant physical properties of the binder (GU and Slag) are presented in Tables 4 and 5. The effective grain size (D_{10}) and the mean grain size (D_{50}) of the GU and Slag are presented in Table 5. Potable municipal water (tap water) was used to prepare all mixtures.

2.3. Preparation of cemented paste backfill

To prepare the CPB specimens, three different binder contents (B_w = mass of binder/mass of dry tailings) of 2, 4.5, and 7% were tested with three formulations: a control CPB (without wood filler) and CPB containing 12.5% and 14.5% maple-wood sawdust by dry mass of binder (CWF specimens). Table 6 presents the mix proportioning for all prepared CPB specimens. CPB specimens were prepared by adding the prepared binder–wood filler mixture to the tailings in a Hobart mixer while tap water was slowly added to obtain a target slump height of ~180 mm (7 in.). A total of nine mixtures and 108 triplicate specimens were prepared and poured into cylindrical plastic moulds of 50.8 mm diameter and 101.6 mm height (2 in. diameter and 4 in. height), capped, and left in a humidity chamber at 23 °C and ⩾90% relative humidity for four curing times (14, 28, 56, and 91 days).

2.4. Experimental methods

The consistency of the CPB mixtures was determined by slump height measurement using a standard slump cone. To determine the influence of maple-wood sawdust on CPB consistency, a control mixture (without wood filler) was prepared at approximately 180 mm slump height, corresponding to 74.1% solid mass

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