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Properties of cementitious material incorporating treated oil sands drill cuttings waste

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HIGHLIGHTS

- Proposed an innovative reuse of treated oil sands waste (TOSW) in grout manufacture.
- Investigated the physical, chemical and mineralogical characteristics of the TOSW.
- Evaluated fresh and hardened properties for grouts incorporating TOSW.
- Replace up to 20% of cement by TOSW will not adversely affect the grout properties.
- Tested mixtures released less heavy metals with respect to raw waste.

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ABSTRACT

Oil sands drill cuttings waste represents one of the most difficult challenges for the oil sands mining sector. Reducing the amount oil sands drill cutting waste sent to landfill offers one of the best solutions for waste management. The present work offers an innovative solution for the recycle and reuse of treated oil sands drill cuttings waste (TOSW) in grout manufacture. In this study, the physical, chemical and mineralogical characteristics of the treated oil sands drill cuttings waste were investigated. Fresh and hardened properties for grouts incorporating the treated solid drill cuttings waste were evaluated. The results show that incorporating up to 20% of the treated solid drill cuttings waste as a partially replacement of cement will not adversely affect the properties of the grout. Leaching tests evidenced the reduction in the release of heavy metals from the tested mixtures compared to that of the raw waste indicating successful stabilization/solidification of such waste in the grout.

1. Introduction

Implementing industrial waste in cementitious material manufacture may represent a satisfactory solution to many problems posed by waste management [25,33]. Different industrial wastes can be used in cementitious materials as components of binder, as a portion of aggregate, or as additives, which can alter their fresh and hardened properties [2,18,13,37,1,43]. Successful use of any industrial waste in cementitious materials depends on the required properties of the end product. For any new material to be usable as a construction material, it should have the adequate performance, in terms of workability, mechanical strength and durability, to satisfy the specifications determined by its applications. In addition, it should not have any harmful effect on health or environment [33].

In the last decade, oil sands industry became an increasingly major driver behind the economic activity in Canada [11]. While contributing to the economy, oil sands industry produces significant amounts of waste. Oil sands drill cuttings waste represents one of the most difficult challenges for the oil sands mining sector [17,38]. Different technologies had been applied as a pre-treatment process to convert this oil sands drilling cuttings waste to a reusable product [20,24,10]. Recently, an innovative technology (so called Thermo-mechanical Cuttings Cleaner (TCC)) was developed for treating oil sands drilling cuttings and recovering hydrocarbons [29]. In the TCC, waste is heated to a temperature just high enough to evaporate oil and water, which are then brought back to a liquid phase in separate condensers. The remaining solids (i.e. by-product) of TCC is a very fine quartzes powder, which can potentially be used as a filler material in manufacture of cementitious materials.

Fine materials can affect the properties of cementitious materials through modifying the hydration kinetics of cement chemically,

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physically or both [22]. Their chemical effect will depend on their composition and solubility, i.e., they may modify the chemical equilibrium of ionic species in pore solutions leading to acceleration or retardation of the hydration reactions. Physical effect of fine materials on cement hydration can be through cement dilution, modification of the particle size distribution and heterogeneous nucleation. The dilution effect increases as the replacement rate of cement by the fine materials increases. Naturally, less cement implies less hydrated cement. The effect of the particle size distribution depends on the fineness and the amount of added fines as it will modify the initial porosity of the mixture. Heterogeneous nucleation is a physical process leading to a chemical activation for the hydration of cement. It is related to the nucleation of hydrates on foreign mineral particles. The fine material does not have to be reactive itself since its principal function is to provide nucleation sites for hydrates.

Therefore, this study investigates the effect of incorporating TOSW on the development of cementitious material properties. This would pave the way for the implementation of TOSW in several construction applications, which leads to transforming oil sands drill cuttings waste into to a high-value product.

2. Experimental program

2.1. Materials and mixture proportions

Ordinary Portland cement (OPC) Type 10 with a Blaine fineness of 360 m^2/kg and specific gravity of 3.15 was used as a binder material. It contains 61% Tricalcium Silicate (C_3S), 11% Dicalcium Silicate (C_2S), 9% Tricalcium Aluminate (C_3A), 7% Tetracalcium Aluminoferrite (C_4AF), 0.82% equivalent alkalis and 5% limestone. The TOSW material used is a silicate-based material with a Blaine fineness of 1440 m^2/kg and specific gravity of 2.23. Fig. 1 shows a scanning electron microscopy photograph and an energy dispersive X-ray analysis (SEM/EDX) for the TOSW. Chemical compositions for OPC and TOSW obtained through X-ray diffraction are provided in Table 1. The grain size distribution curves for OPC and TOSW are shown in Fig. 2.

A total of 5 mixtures were tested to assess the effect of TOSW addition on the cementitious materials performance. The different mixtures were achieved by varying TOSW contents in the tested mixtures from 0%, 10%, 20%, 30% to 50% as a partially replacement of cement (i.e. by volume as TOSW is typically less dense than cement). Table 2 provides a summary for tested mixtures composition.

2.2. Tests and specimens preparation

All tested cement paste mixtures were prepared according to ASTM C305 [4] (Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency). For each cement paste mixture, specimens for different tests were prepared from the same batch. After casting, specimens were maintained at ambient temperature (i.e. 23 ± 1 °C) and covered with polyethylene sheets until demolding to avoid any moisture loss. Immediately after demolding, specimens were moved to a moist curing room (Temperature = 23 ± 1 °C and relative humidity = 98%) until the testing age.

The effect of TOSW addition on water demand for normal consistency was evaluated according to ASTM C187 [6] (Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste). In addition, the effect of TOSW addition on cement reactivity was monitored through measuring the heat of hydration for each cement paste mixture and setting time according to ASTM C191 [5] (Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle). Cubic specimens (50 × 50 × 50 mm) were used to determine the compressive strength at ages 7, 28 and 90 days according to ASTM C109 [3] (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars [Using 2-in. or (50-mm) Cube Specimens)]. Prismatic specimens (25 × 25 × 280 mm) were used for evaluating drying shrinkage following ASTM Method C490 [7] (Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete). Identical size specimens were used to measure the mass loss in order to dispel the effect of the specimen size on the results. Thermo-gravimetric analysis was also conducted on selected cement paste samples to assess the development of their microstructure. Cubic specimens of size 50 × 50 × 50 mm were prepared for leaching test following the same procedure in previous study by [15]. Collected leachate samples were analyzed every 3 days up to 18 days using inductively coupled plasma mass spectrometry (ICP-MS). Cement paste fragments were taken from tested specimens and immediately plunged in an isopropanol solvent to stop hydration and subsequently dried inside a desiccator until a constant mass was achieved. The pore size distribution for each specimen was determined automatically using a Micromeritics AutoPore IV 9500 Series porosimeter.

3. Results and discussion

3.1. Water of consistency

Fig. 3 shows the water of consistency, which represents the amount of water required to achieve a normal consistency for all tested cement paste mixtures incorporating different percentages of TOSW. Results reveal that the water of consistency for tested cement paste mixtures slightly decreases as the percentage of TOSW increases. However, increasing the TOSW dosage higher than 20% results in a lower reduction in the water of consistency. For instance, paste mixtures incorporating 20% and 30% of TOSW had exhibited a reduction in the water demand for normal consistency with about 6.7% and 4.3% than that of the pure OPC paste mixture. This can be attributed to two compensating effects induced by TOSW: TOSW is a very fine material, hence, addition of such fine particles will increase the specific surface area of the powder, leading to a higher water demand to achieve a given consistency. Simultaneously, TOSW small particles size enhances the packing density of powder and reduce the interstitial void, thus decreasing entrapped water between cement particles and making it available leading to a lower flow resistance [42]. Therefore, the controlling factor for which one of the compensating effects will dominate the behaviour mainly depends on the particle size of the used fine material. In this study, the addition of 20% TOSW can be considered as the threshold value and is highly dependent on its particle size. At TOSW addition rate below 20%, the increase in water demand is compensated by the reduction in flow resistance leading to a lower water of consistency. Conversely, as the TOSW addition rate exceeds 20%, the increase in water demand dominates the behaviour leading to a higher water of consistency. Also, higher free water is expected in mixtures incorporating TOSW, as TOSW addition was found to enhance formation of monocarboaluminate hydrate that needs less water than that of ettringite as will be discussed later [16].

3.2. Heat of hydration

Fig. 4 illustrates the effect of TOSW addition of cement hydration through monitoring the heat liberation for pure cement paste and paste mixtures incorporating different percentages of TOSW as a partial replacement of cement. It is clear that adding TOSW as a partial replacement of cement reduces the hydration heat. The higher the replacement rate of cement by TOSW, the greater the reduction in the main hydration peak. This can be attributed to the dilution effect [30]. Generally, once water and cement come in contact, cement wetting and hydration of free lime cause initial rapid heat liberation, resulting in a peak within the first 1–2 min. The second peak of hydration curve, the so-called "silicate peak" is related to the rapid hydration of tricalcium silicate (C_3S) and the precipitation of portlandite (CH) [27]. A third hydration peak can occur as a result of calcium carboaluminates formation from the reaction between limestone and aluminates from C_3A existing in the OPC [19,40].

In order to characterize the differences between the control paste mixture and other pastes, an adapted reference curve was plotted. This curve is obtained by multiplying the curve values of the control paste by 100% minus the respective incorporation rate of TOSW of the composition under consideration. Hence, the effect of cement substitution with an inert material (i.e. TOSW) is simulated. Theoretically, the substitution of cement with an inert material decreases the hydration heat since it is normalised with