# Effect of Treated Oil Sands Drill Cuttings Waste on Micropiles Grout Properties

Moustafa Aboutabikh and M. Hesham El Naggar
*Department of Civil and Environmental Engineering – University of Western, London, Ontario, Canada*

Ahmed Soliman
*Department of Civil and Environmental Engineering – University of Western, London, Ontario, Canada (on Leave of Ain Shams University, Cairo, Egypt)*

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ABSTRACT
A micropile is constructed by drilling a hole, placing a steel reinforcing element, grouting it using neat cement. However, cement production consumes energy and generates carbon dioxide. To develop sustainable and environmentally benign micropile construction, a feasibility study was performed on using treated oil sands drill cuttings waste (TOSW) as a partially replacement of cement in micropiles. Results show that TOSW did not affect the flowability for grout mixtures. Increasing TOSW replacement level reduced the 28-day grout compressive strength slightly, while strength gain rate had increased at later ages. Moreover, the achieved strength was still higher than the required strength by different standards. Results suggest that TOSW can be used in micropiles leading to environmental and economic benefits.

RÉSUMÉ
Un micropieu est construit en perçant un trou, en plaçant un élément de renforcement d'acier et en utilisant un coulis de ciment pour étanchéifier celui-ci. Toutefois, la production de ciment consomme de l'énergie et génère du dioxyde de carbone. Pour développer la construction des micropieux d'une façon durable et favorable pour l'environnement, une étude de faisabilité a été exécutée sur l'utilisation des déchets des sables bitumineux traités (TOSW) comme remplaçant partiel du ciment dans les micropieux. Les résultats montrent que les TOSW n'ont pas affecté la fluidité des mélanges de coulis. L'augmentation du taux de remplacement des TOSW réduit légèrement la résistance en compression des coulis après 28 jours, tandis que le taux de résistance gagné augmente par la suite. De plus, la résistance en compression atteinte était toujours plus grande que la résistance requise par les différentes normes. Les résultats proposent que les TOSW puissent être utilisés dans les micropieux, menant à des avantages économiques et environnementaux.

## 1. INTRODUCTION

Micropiles are small diameter (less than 300 mm), drilled and grouted piles that can be used to provide foundation support for structures and soil improvement. Typically the construction of micropiles involves the usage of grout in order to achieve a high strength grout-ground bond. The method of grouting has a major impact on the capacity of micropiles and a part of micropiles classification refers to methods of grouting.

Grout are designed to transfer loads between the reinforcement and surrounding ground, it can be a part of the load-bearing cross section of the pile and, it increases the corrosion resistance of steel reinforcement. Therefore, the grout must have suitable properties of fluidity, strength and stability.

A great challenge now for civil and environmental engineers is to divert industrial waste towards useful construction purposes. In the last few years, oil sands industry became an increasingly major driver behind the economic activity. While contributing to the economic, oil sands industry is one of the top waste production industries in western Canada. Oil sands drilling cuttings waste represents one of the most difficult challenges for the oil sands mining sector.

Different technologies had been applied as a pre-treatment process to convert these oil sands drilling cuttings waste to a reusable product. Recently, an innovative technology (so called Thermo-mechanical Cuttings Cleaner (TCC)) for treating oil sands drilling cuttings while recovering hydrocarbons was proposed. In the TCC, the waste is heated to a temperature just high enough to evaporate oil and water. The oil and water will be brought back to a liquid phase in separate condensers. The remaining solids (i.e. by-products) of TCC is a very fine quartzes powder with a high surface enrichment of Aluminum/Silica which increases its potential as a filler material for constructional applications.

On the other hand, cement is one of the major contributors to the climate change. Just one ton of Portland cement produced emits approximately one ton of carbon dioxide ($CO_2$) into the atmosphere (Meyer, 2009). In addition, it consumes substantial natural resources and energy. In order to achieve green concrete, cement can be partially replaced by inert materials, or by supplementary cementitious materials (SCM's) such as fly ash, silica fume, and ground granulated blast furnace slag (Sato, 2006). To add a new material as a replacement of cement it should have proper properties in order to be used as an efficient material in construction applications. These materials should present a performance that satisfies the specifications determined by its applications. In addition, the effect of these materials on the environment should be controlled to achieve a non-harmful, environment friendly performance (Remond *et al.,* 2002).

Therefore, in this study, the effect of incorporating TCC by-products (i.e. TOSW) on the development of cementitious material properties will be examined. This would pave the way for the implementation of TOSW in micropiles application leading to economically and sustainably transform of oil sands drill cuttings wastes to a high-value product.

## 2. EXPERIMENTAL PROGRAM

### 2.1. Tests and samples preparation

Fresh and hardened properties for typical grout mixtures for micropiles application, incorporating different percentages of TOSW, were evaluated. Grout mixtures were prepared according to ASTM C305 (Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency).

In these experiments, TOSW was used as a replacement of cement by volume at different replacement rates. The effect of TOSW addition on micropile grout mixture flowability were evaluated according to ASTM C939 (Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)). Moreover, compressive strength tests were conducted according ASTM C109 (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)). In addition, the effect of TOSW addition on cement reactivity was monitored through measuring the heat of hydration for each grout mixture.

### 2.2. Materials:

An ordinary Portland cement containing 61% tricalcium silicate ($C_3S$), 11% dicalcium silicate ($C_2S$), 9% tricalcium aluminate ($C_3A$), 7% tetracalcium aluminoferrite ($C_4FA$), 0.82% equivalent alkalis and 5% limestone was used as the binder material. Treated oil sand waste used in this study is a silicate-based material with an average particle size of 2.7 µm and surface area of 4.85 $m^2/g$, was added at different rates as a partially replacement of cement. A polycarboxylate-based high-range water-reducing admixture (HRWRA) was added at to adjust flowability. Water from used admixture was included in the specified water-to-cement ratio (w/c). Table 1 shows compositions for the tested grout mixtures.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Particle size distribution

Table 2 summarizes the particle size distribution results for TOSW and cement Type 10 as a reference material. The surface area moment mean of TOSW is around one-third of that of the cement. This indicates that TOSW has a greater percentage of fine particulates in the size

Table 1. Grout mixtures compositions

| Mixture | Cement ($kg/m^3$) | Water ($kg/m^3$) | OSW ($kg/m^3$) |
|---|---|---|---|
| C100 | 1300 | | 0 |
| C90 | 1170 | 569 | 92 |
| C80 | 1040 | | 185 |
| C70 | 910 | | 276 |

distribution. The volume moment mean, which reflects the size of those particles which constitute the bulk of the sample volume, for the TOSW is about 77% lower than that of the cement. Figure 1 shows the particle size distribution. By monitoring these three parameters, it is clear that the variation in the mean particle size for TOSW is lower than that of the cement. For instance, the variation in size for about 80% of the particles was around 9.055 µm and 35.252 µm for TOSW and cement, respectively. This indicate the high uniformity of TOSW with respect to that of the cement.

Table 2. Particle size distribution for Cement type 10 and TOSW

| | Cement Type 10 | TOSW |
|---|---|---|
| Surface area moment mean (µm) | 6.467 | 2.009 |
| Volume moment mean (µm) | 18.402 | 4.187 |
| Dv10 (µm) | 3.369 | 0.905 |
| Dv90 (µm) | 38.621 | 9.960 |
| Uniformity (%) | 72.10 | 99.10 |

Dv10 and Dv90 the maximum particle diameter below which 10% and 90% of the sample volume exists, respectively.

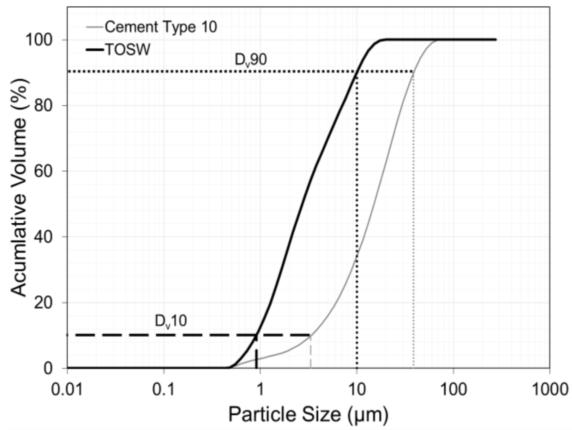


Figure 1. Particle size distribution

3.2. Flowability of grout mixture

In this investigation, flow cone test was used to determine the effect of TOSW on the efflux time of the cement grout. Typical times for grout can vary up to 2 minutes (Warner, 2004). The shorter the efflux time, the higher the flowability of grout mixture. As shown in Table 3, addition of TOSW will decrease the efflux time for cement grout which confirms the previous water demand for normal consistency results. The effect of TOSW addition can be considered as a resultant for two compensating effects induced by TOSW: TOSW is a very fine material, hence, it increases the surface area in the mixture leading to a higher water demand. Simultaneously, OSW small particles size allows it to penetrate between cement particles filling the space between cement particles and freeing entrapped water and making it available (Khaleel and Razak, 2012).

Table 3. Grout mixtures results

| Mixture | Flow Cone (sec) | Compressive strength (MPa) | |
|---|---|---|---|
| | | 7 D | 28 D |
| C100 | 12.5 | 44.5 | 52 |
| C90 | 11.9 | 36.5 | 48.5 |
| C80 | 11.3 | 33 | 46.5 |
| C70 | 11.1 | 28 | 39 |

3.3. Compressive strength

According to the Federal Highway Administration (FHWA), a minimum design compressive strength of 28 MPa is recommended to be used in the gout injection of micropiles. Table 3 shows the compressive strengths for grout mixtures with and without TOSW. The results show that compressive strength for grout mixtures decreases as the proportion of TOSW increases. The higher the replacement of cement by the TOSW is, the lower the compressive strength of grout is. For instance, at age 7 days, grout mixtures incorporating 10%, 20% and 30% exhibited about 17%, 23% and 37% lower compressive strength than that of the control grout mixture, respectively (Fig. 2). However, at later age (i.e. 28 days) grout mixtures incorporating 10%, 20% and 30% exhibited only 5.3%, 11.1% and 27.0% lower compressive strength than that of the control grout mixture, respectively. All these results agree with the FHWA requirements for 28 days compressive strength of grout as shown in (Fig. 2).

This can be explain as follow: it is known that there is a relationship between the hydration of cementatious materials and its hardened properties. In other words, compressive strength of grout is generally gained from the hydration reaction between the cement and water. Also, it was reported that the rate of hydration is affected

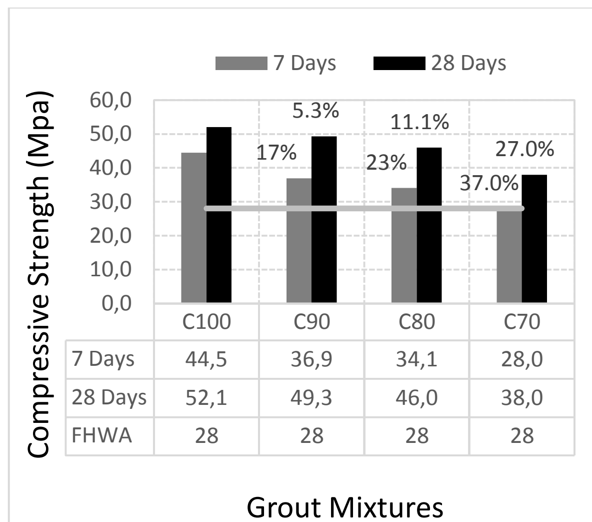


Figure 2. Compressive strength development for grout mixtures incorporating TOSW.

by many factors such as fineness and cement content (Amen, 2011) Therefore, replacing cement by filler materials will probably will affect the development and strength gaining rate for cementitious materials. This was confirmed by following the heat of hydration for grout mixtures with and without TOSW as shown in Figure 3. Calorimetric curves, depicting heat flow versus time, show three main peaks through the first 40 hours of hydration for tested grout mixtures (Fig. 3). Control grout (C100), as the most hydraulic active constituent contributes to heat release to a great extent. The influence of TOSW on the heat flow peak of hydration is illustrated by (Fig. 3). It is clear that with increasing OSW content decreases heat flow peak intensity indicating reduction in reactivity. Addition of inert filler materials decrease the hydration heat due to cement replacement and dilution effect.

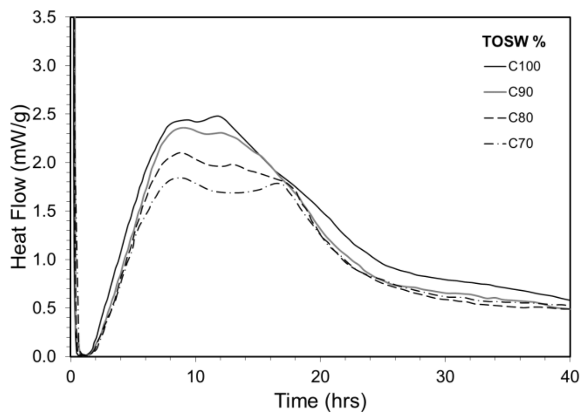


Figure 3. Heat flow for grout mixtures incorporating different percentages of TOSW

At later ages, filler addition can improve compressive strength as a result of acting as a filler material filling voids and reducing the required volume to be filled by hydration product of cement making cement grout more homogenous and denser (Jaturapitakkul *et al.*, 2011).

## 4. CONCLUSIONS

The incorporation of waste materials in the construction application can be an effective solution for waste management challenges. The effect of TOSW addition on cementitious materials was studied. TOSW is a very fine powder which has smaller size grading than that of typical cement, its surface is rich of aluminum/silica which can have the potential of being used as a filler material in construction application. A series of experiments were conducted in order to study the effect of TOSW on the fresh and hardened properties of grout. The flowability of grout containing different percentages of waste were tested. The addition of TOSW did not significantly affect the flowability for micropile grout. The effect of the replacement of cement with TOSW on the compressive strength was evaluated, the addition of TOSW decreases the compressive strength of cement grout, mainly the gain of strength is a result of the hydration reaction between water and cement, replacing cement by a filler will reduce the hydration reactions, reducing the compressive strength of grout. On the other hand, a gain of strength in the grout containing OSW was noticed after 28 days which can be resulted from the filler effect caused by the incorporation of OSW in grout.

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