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Application of Treated Oil Sands Drill Cuttings Waste in Micropiles Construction

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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. Implementing waste materials in construction applications represents a sustainable solution for many waste management problems. On the other hand, oil sands drill cuttings waste represents one of the most difficult challenges for the oil sands mining sector. Reducing the amount of oil sands drill cutting waste sent to landfill offers one of the best solutions for waste management. This thesis presents an innovative solution for application of treated oil sands waste (TOSW) in grout mixtures used for micropiles construction. In this study, the physical, chemical and mineralogical characteristics of the treated oil sands drill cuttings waste were investigated. Fresh and hardened properties for micropiles grouts incorporating the treated solid drill cuttings waste were evaluated. Moreover, the effects of employing these grout mixtures on micropiles cross-section, surface interface properties and axial behaviour were investigated. The results showed 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. On the other hand, 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. In addition, it was noticed an enhancement in the grout body diameter for micropiles installed using the developed grout, while maintaining the micropile surface properties. Moreover, micropiles installed using grout incorporating a high percentage of the TOSW (up to 30%) exhibited the same axial behaviour as that of micropile installed using conventional grout. Therefore, incorporating TOSW in micropile applications has high potential for producing cost efficient micropiles along with providing a green oil sands waste management solution.

Keywords: Micropiles; Grout; Sustainability; Oil Sands, Drill Cuttings Waste.

Co-Authorship Statement

This thesis has been prepared in accordance with the regulation of integrated-article format stipulated by the Faculty of Graduate Studies at The University of Western Ontario. Substantial parts of this thesis were either published in or submitted for publication to peer-reviewed technical journals and an international conference. All experimental work, data analysis, modeling process and writing of initial versions of all publications listed below were carried out by the candidate himself. The contribution of his research advisor and any other co-author, if applicable, consisted of either providing advice, and/or helping in the development of the final versions of publications:

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To: *My Father Ahmed*

My Mother Wafaa

My Sister Marwa, My Brother Salah, Liala and Noura

My Sister Farah

My Beloved Fiancée Hadil

My Brother DR. Ahmed Soliman

My Brother Mahmoud Kassem

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LIST OF SYMBOLS

A_g	Area of the grout
A_s	Area of the steel pile
A_p	Cross sectional area of micropile
d_{bar}	Hollow bar diameter
d_{bit}	Drill bit diameter
D	Diameter of pile
D_r	Relative density
E	Young's modulus
E_g	Modulus of elasticity of grout
E_p	Modulus of elasticity of pile
E_s	Moadulus of elasticity of steel
e_{max}	Maximum voids ratio
e_{min}	Minimum voids ratio
f_a	Axial applied stress
F_a	Allowable axial stress
f'_c	Compressive strength of grout
f_y	Specific yield of steel
G_s	Specific gravity
ID	Inner diameter
L	Pile length
$P_{c\text{-}Allowable}$	Allowable structural axial compression load

P_p	Applied load at the pile head
$P_{T\text{-}Allowable}$	Allowable structural axial tension load
P_{ult}	Ultimate capacity of micropiles in tension or compression
R_a	Average roughness
R_t	Total roughness
wc	Water content
ε	Total strain measurement
$\phi°$	Effective friction angle
$\delta°$	Interface angle

CHAPTER ONE

INTRODUCTION

1.1. OVERVIEW

Micropiles are a small diameter drilled and grouted piles (less than 300 mm). The construction of micropiles consists of drilling a borehole, placing a steel reinforcement and placing or injecting grout in the borehole. The grout is placed by gravity, under pressure or using both methods (post grouting). Micropiles are typically reinforced by a solid or hollow steel bar. Micropiles can carry axial and lateral loads, which make them a possible alternative for the conventional piling systems, which includes driven piles or drilled shafts. Micropiles are mainly used for underpinning existing foundations, soil reinforcement, seismic retrofitting and they can also be used as foundations for new constructions.

Micropiles have several advantages including the possibility of installation in most soil types and rocks. In addition, due to the small size of the installation equipment, micropiles can be installed in limited head room causing minimal vibration, and disturbance to adjacent structures.

Due to the new drilling and grouting techniques, high strength grout to ground bond is achieved. The grout has several purposes in micropiles construction, including; load transfer between the reinforcement and the surrounding ground, forming a part of the load-bearing cross section of the micropile, and acting as a protective layer for the steel reinforcement from corrosion. The grout to ground bond strength achieved is mainly dependant on the soil type and the grouting method. Due to the small cross-section of micropiles, the end bearing contribution in the capacity of micropiles is generally neglected (FHWI NHI, 2005).

Grout mixtures usually consist of cement and water; and in certain cases additives are added in order to enhance the grout properties. However, cement industry is a major contributor to the CO_2 emissions around the world. On the other hand, one of the great challenges now for civil and environmental engineers is to divert industrial waste towards useful construction purposes. In the last few years, oil sands industry has become one of the major waste sources in western Canada. Oil sands drilling cuttings are considered a difficult challenge for the oil sands mining sector. Different treatment methods for the oil sands waste were applied in order to convert these wastes to a product that can be safely disposed or can have the potential to be recycled in other applications. One of the recent technologies for oil sands waste treatment (so called Thermo-mechanical Cutting Cleaner (TCC)) was proposed. In the TCC, the waste is heated to a temperature high enough to evaporate oil and water. The oil and water are brought back to a liquid phase in separate condensers. The remaining by-product of TOSW is very fine quartzes powder with an acceptable disposal limit of hydrocarbons (less than 1%), and having the potential to be used as filler material in constructional applications (Haliburton thermomechanical cuttings cleaner, 2014, Thermtech AS, 2010). Many researches have reported the implementation of filler materials in cementitious materials. The addition of filler material can affect the physical and chemical properties of cementitious materials. It also should not increase the water demand when used in cementitious materials.

Therefore, this study presents an innovative solution for treated oil sand wastes (TOSW) disposal in micropiles grout. This would expand TOSW recycling in several construction applications, leading to a better and more sustainable environment.

1.1.1. Micropiles Background

Micropiles were presented first in Italy in 1952, when Dr. Fernando Lizzi used them in the application of underpinning historic buildings damaged during World War II (Bruce, 1988). The first generation of micropiles were small diameter (less than 100 mm), drilled, cast-in-place, lightly reinforced, grouted piles that are designed to carry loads less than 100 kN. Since then, micropiles construction has been expanding rapidly all over the world, and micropiles were upgraded to larger diameters (up to 300 mm).

The second generation of micropiles was presented in the 1970s, which were installed by using either an open or cased hole drilling method with a central reinforcement bar filled with grout. This generation was known with different names including; mini piles, needle piles, and GEWI-Pile. The name of micropiles was approved by the Federal Highway Administration (FHWA) in 1993, and was used as the common name for this type of piles.

A third generation was presented by Ernst Ischebeck in 1983; and named the Titan Injection Bore (IBO) micropile (CON-TECH SYSTEM, 2011). This type is a continuously all threaded hollow steel bar, which is used as the drill steel, allowing drilling and grouting to proceed simultaneously without the need for a casing. To drill this type of micropiles, a sacrificial bit containing openings that allow for pressure grouting of the surrounding soil is threaded onto the end of the hollow bar. This system has been known as “self-drilling anchoring” because the installation is done in a single operation as the hollow bar serves as both the drill string and the grouted anchor (William Form–Ground Anchor system 2010).

The use of hollow bars for micropiles construction has increased over the past 10 years. Hollow bars became preferred by many contractors because it is characterized by easy and fast installation with a high degree of ground improvement.

1.1.2. Oil Sands in Canada

The exploration of oil sands in Canada started in the 1940s when the Alberta government partnered with a company called Oil Sands Limited to build a pilot oil sands extraction plant at Bitumount (Woynillowicz, *et al.*, 2005). However, the construction of the plant and the extraction costs of oil were doubled in the following years which made Oil Sands Limited to pull out. Commercial development started in 1967 when the Great Canadian Oil Sands Company commissioned the first open pit surface mine. Later, Syncrude started its oil sands extraction in 1978 carrying the oil from their plant to Edmonton through a pipeline system owned by Syncrude (Ritts, 2010). However, for several years the oil sands industry faced numerous challenges such as breakdowns, freeze ups, fires and high production costs.

Several technologies were invented in order to enhance oil sands production and reduce its extraction costs. By 1986, the cost of producing synthetic crude oil was reduced from Cdn$35 to Cdn$13 per barrel. Until the mid-1990s, oil sands production was still considered risky and unprofitable. In 1995, the government of Canada introduced new strategy to double or triple the production of oil sands by 2020, reaching between 800,000 and 1.2 million barrels per day (National Task Force, 1995). By 2012, Alberta was able to produce 1.9 million barrels per day of crude bitumen, a huge increase to the anticipated amount and timeline introduced by the government (Alberta Oil Sands Industry, 2013). The scale of this new development exceeded the expectations greatly. Also, the strong growth in demand for transportation fuels and growth in industry was always a major potential for the huge increase in oil sands production.

1.1.3. Oil Sands Wastes

Due to the growth in oil sands industry, managing the environmental impacts arising from this industry must be addressed. The goal of bitumen production has increased to five million barrels per day by 2030. This has resulted in Alberta being the worst offender in Canada for industrial air pollutants due to the oil sands industry. In addition, oil sands are the single largest contributor to greenhouse gas emissions growth in Canada (Woynillowicz *et al.*, 2005).

As a result to oil sands production, millions of tons of oil-contaminated tailings and drill cuttings are produced every year. These types of wastes are slurries of bitumen, water, sand, silt and fine clay particles that are pumped to tailing ponds and landfills. Tailing ponds are considered to be the largest human-made structures in the world, covering an area of land greater than 50 square kilometers. One of the major risks caused by oil sands waste is the migration of pollutants into the groundwater system and leakage into the surrounding soil and surface water (Canada's Oil Sands, 2006). Also, the water in tailings ponds is toxic to aquatic life and will affect the migratory birds that might land in these huge parts (Rogers *et al.*, 2002).

1.1.4. Treated Oil Sands Waste

These challenges related to oil sands wastes have motivated researchers to find different mitigation methods in order to treat or reduce the amount of waste. One of the recent technologies for treating oil sands drill cuttings, called Thermo-mechanical Cutting Cleaner (TCC), is currently employed for treating oil sands drill cuttings while recovering hydrocarbons. TCC is specially designed for the processing of oil contaminated drilling waste. Its mechanism consists of applying friction to drill cuttings via screws that cause a high temperature above the boiling points of water and oil. Once these temperatures are reached, hydrocarbons are removed from the solids to an acceptable disposal limit (less than 1% oil on cuttings). The oil and water vapors are brought back to their liquid state in separate condensers in the form of heavy oil, recovered light oil, and recovered water. The remaining clean solids are discharged from a valve at the bottom of the unit, while new tailings are pumped in. After cooling, these treated solids discharged from the TCC are referred to treated oil sands wastes (TOSW). TOSW are very fine quartzes powder, which has the potential to be used as a filler material in different construction applications.

1.2. RESEARCH OBJECTIVES AND METHODOLOGY

During the installation of hollow bar micropiles, grout is injected through the drilling bit forming the grout body of this type of micropiles. Grout is one of the main factors that contribute to the capacity of micropiles as it transfers load from the pile to ground through the skin friction of micropiles. Due to the small cross-section of micropiles, end bearing capacity is usually neglected which underscores the importance of the shaft properties, responsible for load transfer through friction and governing the capacity of micropiles. On the other hand, due to the challenges faced by the oil sands industry and their harmful effect on the environment, different technologies have been applied for recycling or reusing oil sands waste in construction applications. Treated oil sands waste are final treated product from oil sands drill cuttings with very low hydrocarbons levels acceptable to disposal limits (less than 1% oil per cuttings), which are characterized by their very fine particles and having the potential to be used as fillers in cementitious materials. Therefore, the specific objects of the study were to:

- Investigate the physical, chemical and mineralogical characteristics of treated oil sand wastes (TOSW).
- Study the effect of treated oil sand wastes (TOSW) addition on fresh properties of grout used in the installation of hollow bar micropiles.
- Examine the incorporation effect of treated oil sand wastes on the hardened properties of grout used in the construction of hollow bar micropiles.
- Investigate the effect of the treated waste on the percentage of heavy materials leached from the tested grout mixtures.
- Study the filler effect of treated oil sand wastes mixed with grout on the particle size distribution.
- Examine the axial compression behaviour of hollow bar micropiles installed using grout incorporating treated oil cement waste with percentages up to 30%.

- Investigate the load transfer mechanism of hollow bar micropiles under axial compression load, and asses load distribution of micropiles due to axial load.
- Study the effect of treated oil sand wastes on the diameter change and cross section of hollow bar micropiles.
- Examine the interface properties between the grout body of hollow bar micropiles and the surrounded soil, and asses the effect of treated oil sand waste on the surface properties of hollow bar micropiles.

To achieve the stated objectives, different grout mixtures were tested to investigate the effects of adding treated oil sand waste (TOSW) on the cementitious materials performance. Also, four hollow bar micropiles were installed using the treated waste, and axial load tests were performed to assess their performance. The testing program involved two different phases.

1. **In phase 1**, 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%. The water-to-powder ratio was maintained constant at 0.42. The water of the grout mixtures mixed with and without TOSW was evaluated performing water consistency and flowability tests. In addition, the effect of TOSW addition on cement reactivity was monitored through measuring the heat of hydration of different mixtures. Also, the drying

shrinkage and compressive strength of the investigated mixtures were examined. On the other hand, heavy metals leached from new grout mixed with treated oil sands wastes were investigated, using coupled plasma mass spectrometry (ICP-MS). Finally, the effect of TOSW on the pore size distribution was monitored using a Micromeritics AutoPore IV 9500 porosimeter.

2. **The second phase** comprised four hollow bar micropiles installed using the treated oil sand wastes with percentages up to 30% partial replacement of cement. First, axial compression tests were conducted on the installed micropiles in order to determine the effect of TOSW on the axial capacity of hollow bar micropiles. In addition, the effect of TOSW addition on micropiles grout body properties including diameter change and cross-section were investigated. Finally, the effect of TOSW on interface properties of hollow bar micropiles were studied using direct shear tests and roughness evaluation was performed in this study.

The original contributions of this study are:

- Evaluate the effect of TOSW addition on the properties of grout used in the installation of micropiles.
- Investigate the performance of hollow bar micropiles installed using grout mixed with treated oil sand wastes.

1.3. THESIS ORGANIZATION

This thesis has been produced in accordance with the guidelines of the School of Graduate and Postdoctoral Studies. Parts of this thesis have been submitted and others will be submitted at international conferences and for publication in journals.

This thesis consists of 5 chapters. ***Chapter 1*** includes an introduction that highlights the advantages of micropiles, introduces a historical background on micropiles, provides a highlight on oil sand industry and present a description the treated oil sands waste produced from this industry.

Chapter 2 provides a review of the state of practice including classification system and design consideration for different types of micropiles, followed by a review on the oil sand industry, methods of waste treatment and the potential of waste materials usage in construction applications.

Chapter 3 presents investigation on the physical, chemical and mineralogical characteristics of the treated solid drill cuttings waste were investigated. Fresh and hardened properties for micropiles grouts incorporating the treated solid drill cuttings waste were also evaluated.

Chapter 4 documents the effect of application of treated oil sands waste in grout used for micropiles construction. Also, the effects of incorporating grout with different percentages of treated oil sands waste on micropiles cross-section, surface interface and axial behaviour were investigated

Chapter 5 includes the summary and conclusions together with recommendations for future research.

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CHAPTER TWO

LITERATURE REVIEW*

2.1. INTRODUCTION

Micropiles are a cost effective deep foundation system that is gaining popularity in North America. It was first used in Italy in 1952 for underpinning historic buildings that were damaged during World War II (Bruce, 1988). Micropiles are constructed by drilling a borehole, placing a steel reinforcing element into the borehole and grouting the borehole (**Fig. 2.1**). They are typically reinforced by solid central bar that occupies about one-third of the whole volume. The grout is placed by gravity, under pressure or by a combination of both (post grouting). Thus, micropiles can be considered as small drilled-shafts (Cadden *et al.*, 2004). Micropile typically derives its load resistance from the skin friction between the grout and surrounding soil. Consequently, its capacity varies depending on the size and subsurface profile of its grout body. This grout body is formed during micropile installation as a result of injecting grout with or without pressure (Juran *et al.*, 1999). Besides, this grout body increases the corrosion resistance of the steel reinforcement of micropiles (FHWA-NHI, 2005) (**Fig. 2.2**). Realizing the importance of grout, the Federal Highway Administration Guidelines for Micropiles Design and Construction had set a minimum required performance for grout used in micropile application (FHWA-NHI, 2005).

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*A part of this chapter has been submitted for the Annual Conference of the Canadian Society for Civil Engineering, London, Ontario, Canada.

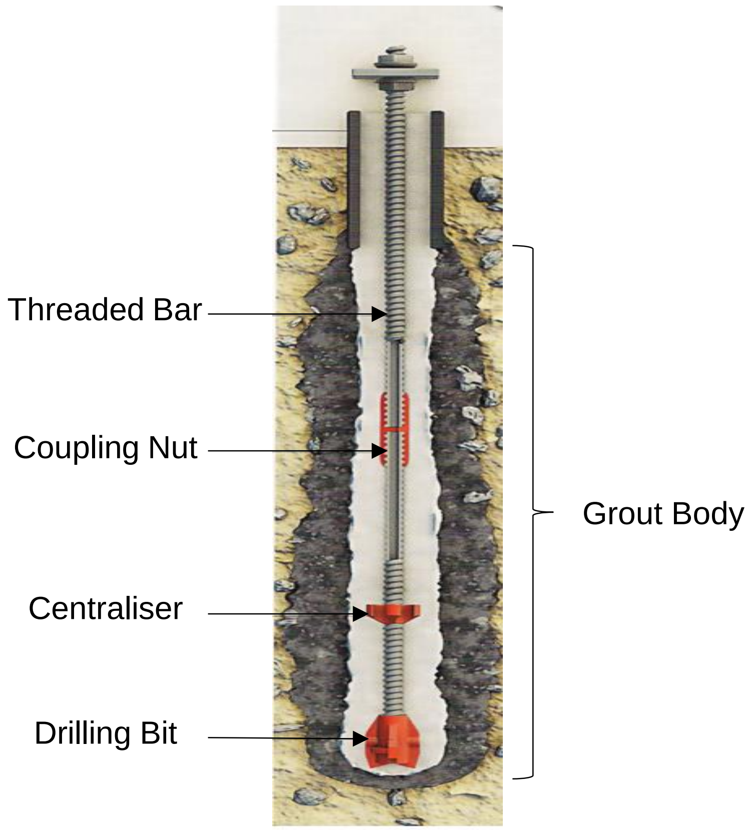

Figure 2.1: Micropiles system components (After micropiles brochures-TITAN Ltd.)

Figure 2.2: Typical Cross section for micropiles (After Con-Tec system Ltd., 2011)

On the other hand, cement, the main component of grout, is a major contributor to the climate change. Each ton of Portland cement production 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 construction, 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 satisfy the specifications determined by its application. 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).

The following section provides a brief description of the worldwide micropile classification systems and their design considerations. This will be followed by a review of the published research addressing the potential of implementing different industrial wastes in construction applications. Special attention is given to hollow bar micropiles and the use of treated oil sands drill cutting waste.

2.2. MICROPILES CLASSIFICATION

Micropiles have been used worldwide in many structural applications. These applications included seismic retrofitting applications, underpinning of existing foundations, foundation systems for abutments and piers, wind turbines, transmission and communication towers, and for slope stabilization applications. **Figure 2.3** shows a number of popular applications of micropiles. Various types of micropiles are employed in these different applications (Drbe, 2013). Therefore, the Federal Highway Administration (FHWA-NHI, 2005) introduced two classification criteria: i) based on the philosophy of behaviour (i.e. design classification) and ii) based on methods of grouting (i.e. construction classification). In the following subsection these types will be explained.

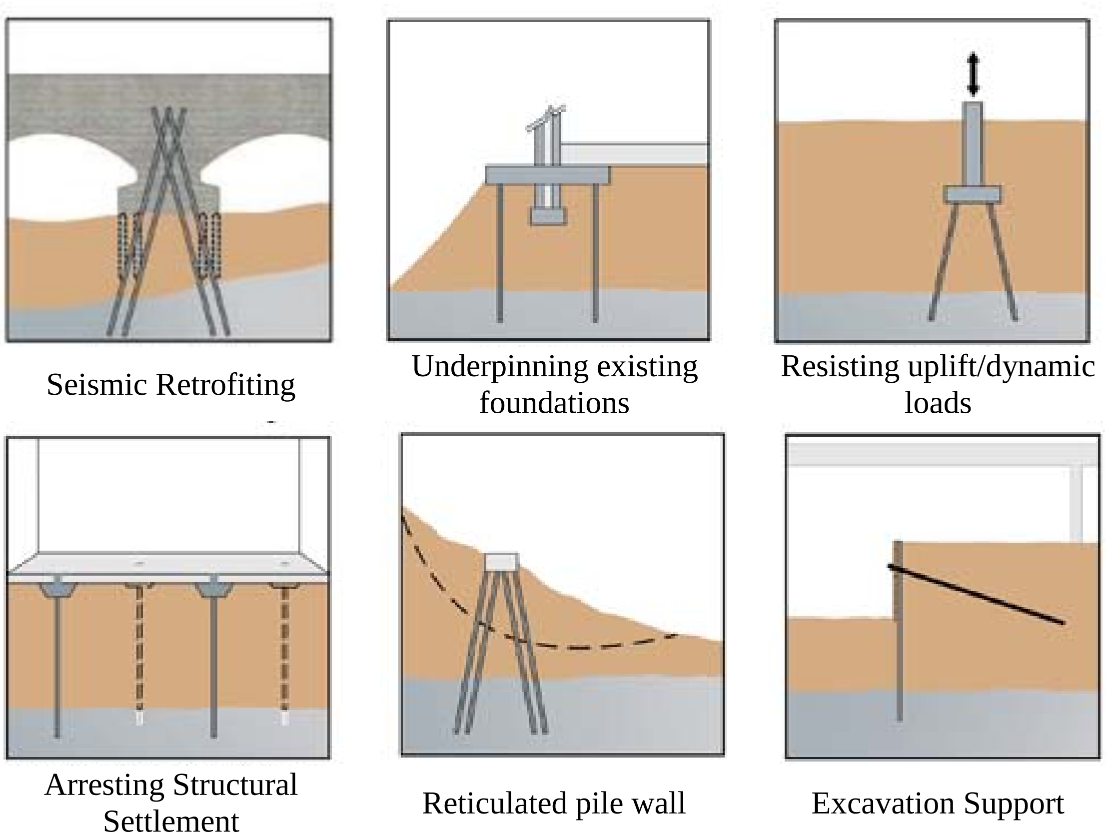

Figure 2.3: Different applications for micropiles (After Hayward Baker Inc. ,2015)

2.2.1. Design Classification of Micropiles

In accordance with the FHWA NHI (2005), micropiles are classified based on the philosophy of behaviour into two different case types:

<u>Case 1:</u> Micropiles are loaded directly. Loads are resisted structurally by the steel reinforcement and geotechnically by the grout/ground interaction and the end bearing resistance through the grouted section. This case of micropiles can be used as single or in groups (**Fig. 2.4)**.

<u>Case 2:</u> Micropiles are used in a reticulated arrangement such that they serve as reinforcing to the soil to create a composite mass system to resist the applied loads (**Fig. 2.5**).

Usually, micropiles are used as structural support which means they are categorized as Case 1 design philosophy.

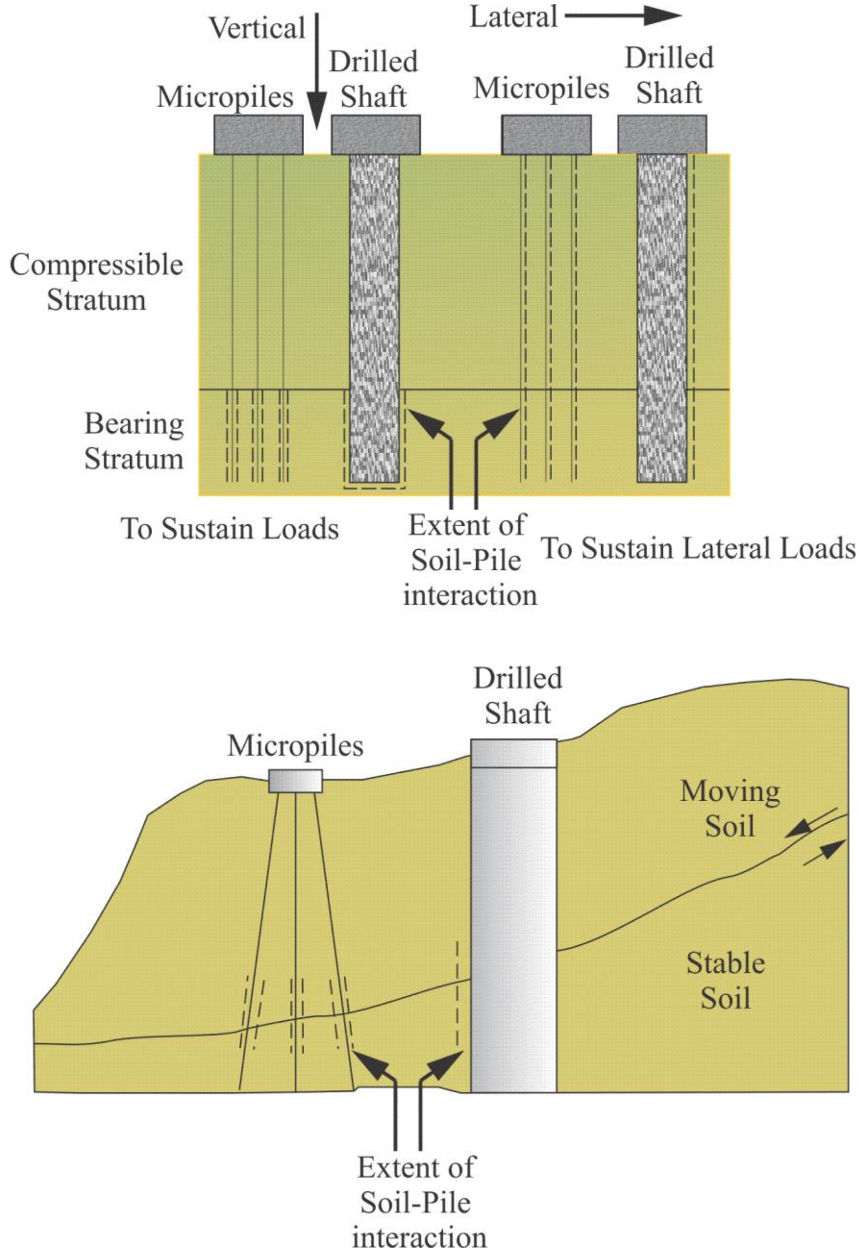

Figure 2.4: CASE 1 micropiles (After FHWA, 2005)

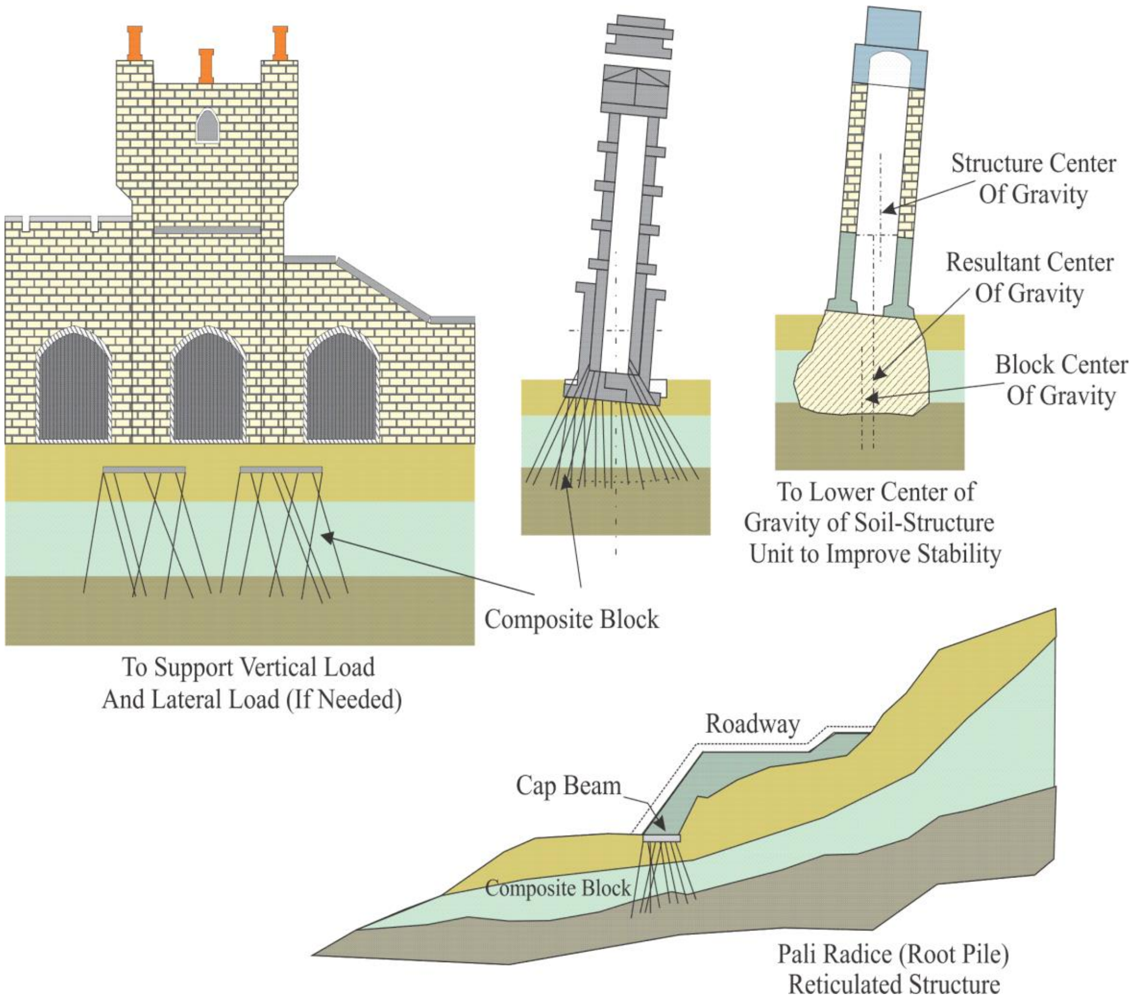

Figure 2.5: CASE 2 micropiles (After FHWA, 2005)

2.2.2. Construction Classification of Micropiles

Many factors in the construction of micropiles are affecting their performance. For instance, drilling method, which highly affects the bond between the grout and the soil, reinforcement type and grouting methods. However, grouting method is the most sensitive process that influences the grout/ground bond capacity (i.e. the skin friction) (Bruce *et al.*, 1997, Drbe, 2013). Therefore, construction classification based on the grouting methods was established as follows:

Type A: In this type, neat cement or sand-cement is used and placed under gravity pressure no extra pressure is applied in construction.

Type B: A pressure ranging from 0.5 MPa to 1 MPa is applied to inject the neat cement grout during construction while a temporary drill casing is placed.

Type C: In this type of micropiles two steps process are applied, first neat cement grout is placed under gravity pressure in the drilled hole same concept of type A. Before the primary grout harden same grout mixture is place under a minimum pressure of 1 MPa via a preplaced sleeved grout pipe.

Type D: Another two steps process method; first the neat cement grout is placed under gravity pressure only, as in type A. After several hours when the initial grout hardens, additional grout is injected through a sleeved grout pipe under high pressure ranging from 2 MPa to 8 MPa. A packer can be used in order to enable a specific horizon to be treated several times. The four presented types (A to D) are shown in **Fig. 2.6**.

Type E: This type is an addition to the original types presented by the (FHWA-NHI, 2005) (A to D). This type consists of a threaded hollow bar connected to a drilling bit, the hollow bar is drilled and advanced through the soil using air, water, or grout. The gourd is injected under a pressure up to 1.4 MPa through the hollow bar passing the nozzles in the drilling bit to the hole while the system is rotated, type E is shown in

Fig. 2.7. This type will be the focus of this research, hence, a detailed explanation is provided in the following section.

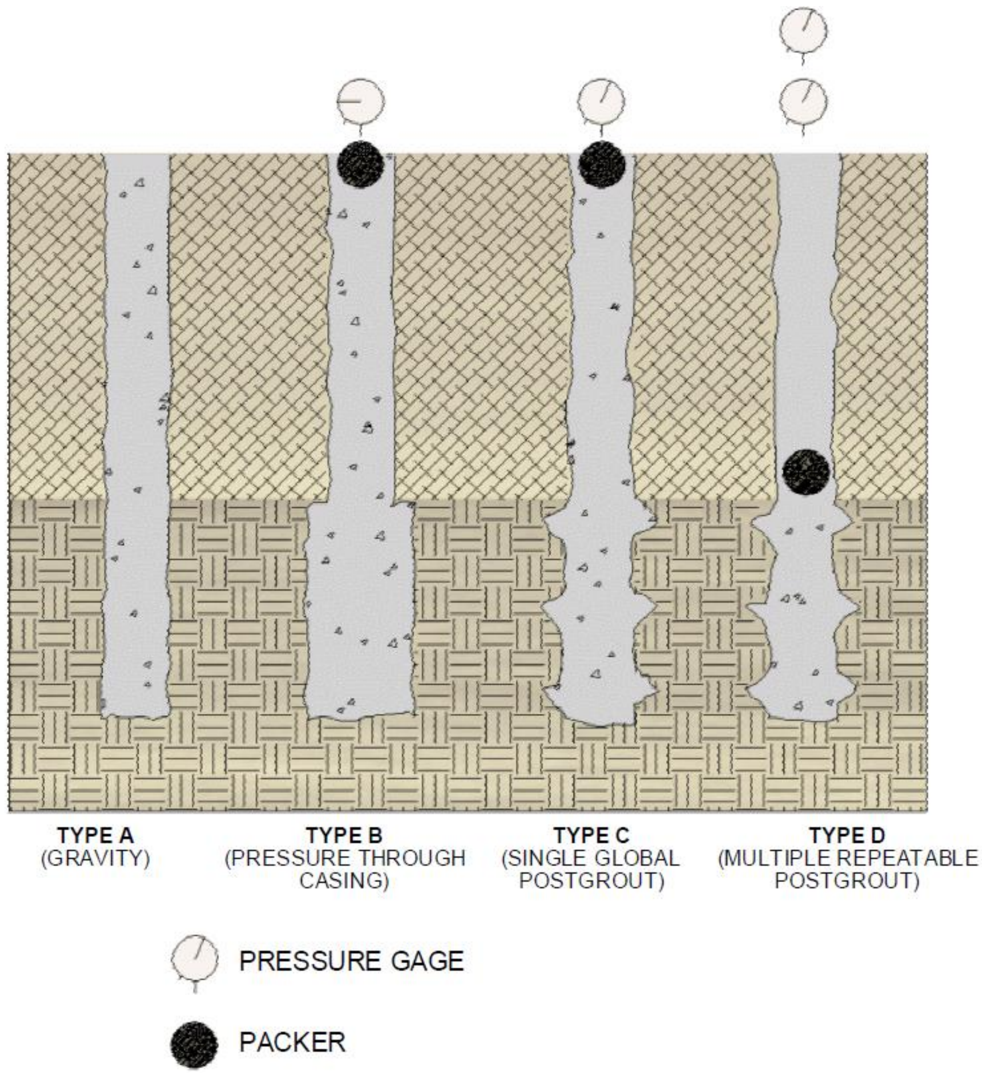

Figure 2.6: Micropile classification system based on method of grouting (After FHWA, 2000)

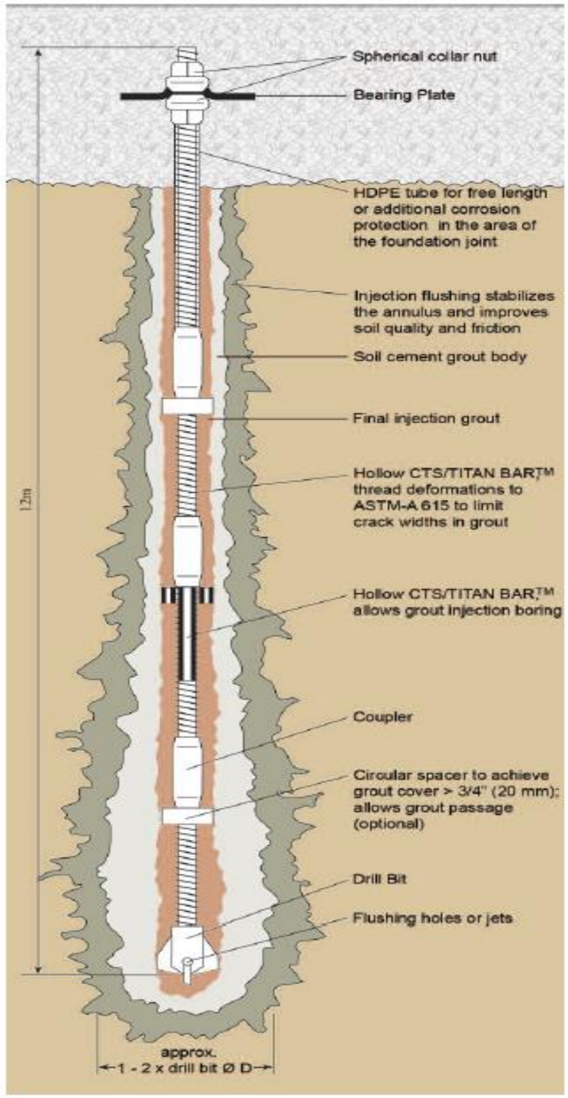

Figure 2.7: Type E hollow bar micropile (After Con-Tec system Ltd., 2011)

2.3. HOLLOW BAR MICROPILE (TYPE E)

In Type E micropile, a threaded hollow bar is replacing the solid central mono bar used in Types from A to D (**Fig. 2.8**). One of the main advantages of Type E micropiles is the fast installation process. The process for placing Type A to D requires a number of steps, from drilling the hole, installing a casing, installing the steel reinforcement, and finally placing the grout (Abd Elaziz and El Naggar, 2012). On the other hand, hollow bar micropiles act as a drilling rod and reinforcement component at the same time, then the grout is injected to the hollow bar and passing to the soil through the nozzles found in the drilling bit (Drbe, 2013).

Type E micropiles is composed of three main components as shown in **Fig. 2.9** a) a threaded hollow steel bar, b) a sacrificial drilling bit that has two or more nozzles, and c) couplers to attach the hollow bars in order to reach the desired depth during installation. To install Type E micropile, the hollow bar is drilled into the soil using the drilling bit with air and/or water and/or grout flushing technique. The grout is usually injected at a pressure up to 1.4 MPa.

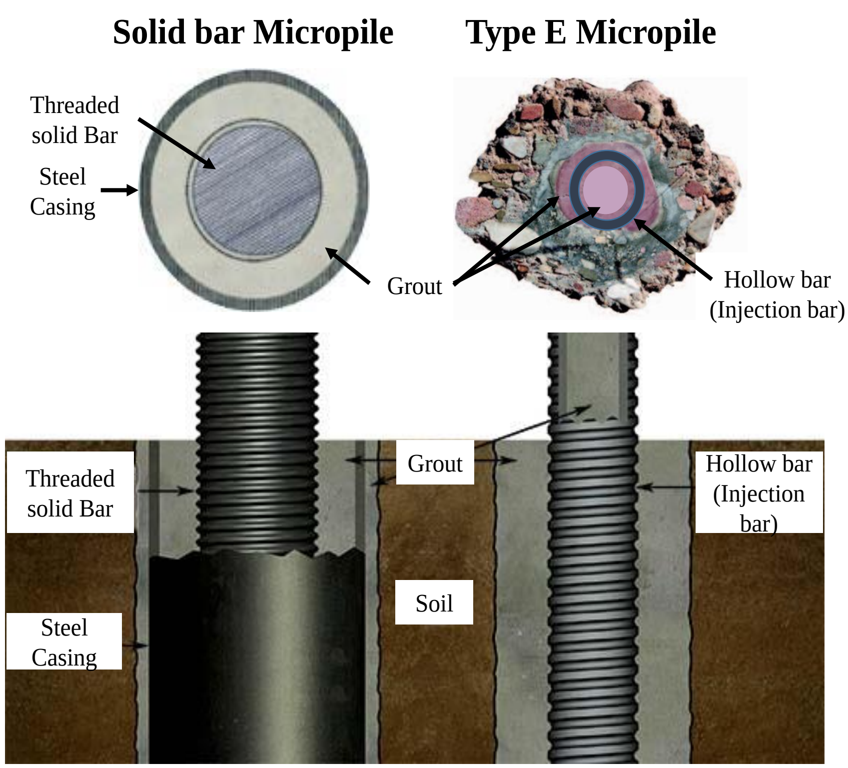

Figure 2.8: Solid bar micropile with casing and hollow bar micropile (modified after Williams Form Engineering Corp., 2011)

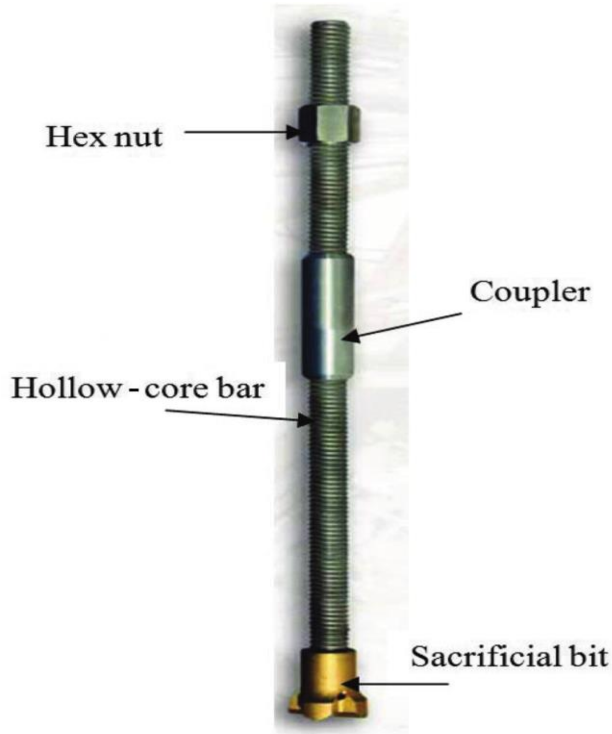

Figure 2.9: Hollow-bar micropile parts (modified after Williams Form Engineering Corp., 2011)

2.4. LOAD TRANSFER MECHANISMS OF MICROPILES

Previous study, conducted by (Bruce and Yeung, 1984) based on 5 m pile with a diameter of 20 cm, showed that skin friction is the main contributor to the geotechnical capacity of micropiles. It was reported that a settlement of 10% to 20% of the micropile diameter is needed to mobilize its bearing capacity, compared with only 0.5% to 1% to mobilize the maximum skin resistance. Therefore, Juran *et al.* (1999) proposed that micropile should be designed considering load transference through the shaft resistance only. Lately, (FHWA-NHI, 2005) stated that the maximum applied compression and tension loads must be resisted through grout to ground bond over the area of contact with the grout denoted as the bond length of the micropile. Therefore, in most cases, micropiles attain their load carrying capacity mainly through skin friction rather than end bearing. This was confirmed by a field study conducted by (Drbe and El Naggar, 2013) on four hollow bar micropiles in a firm to stiff clay.

2.5. DESIGN PHILOSOPHY

Micropiles should be designed for both structural and geotechnical capacities in order to sustain the anticipated loading conditions at tolerable stress levels following the accepted displacement levels. The following section will illustrate different methods for evaluating the structural and geotechnical capacities of micropiles.

2.5.1. Structural Design of Micropiles

Each part of the micropiles contributes to loads transference to a deeper and stronger stratum. Structural loads are mainly resisted through the reinforcement component, and the geotechnical capacity of the grout/ground bond zone. A number of equations can be utilized for calculating the micropiles capacities under compression and tension:

- Under compression, according to FHWA (**Eq. 2.1**):

$$P_{c\text{-allowable}} = 0.4\, f'_c\, A_g + 0.47\, f_y\, A_s \qquad \text{(Eq. 2.1)}$$

- Under compression, according to IBC (International Building Code) (**Eq. 2.2**):

$$P_{c\text{-allowable}} = 0.33\, f_c\, A_g + 0.40\, f_y\, A_s \qquad \text{(Eq. 2.2)}$$

- Under tension, according to FHWA (**Eq. 2.3**):

$$P_{t\text{-}allowable} = 0.55\ f_y\ A_s \qquad \text{(Eq. 2.3)}$$

- Under tension, according to IBC (International Building Code) (**Eq. 2.4**):

$$P_{t\text{-}allowable} = 0.60\ f_y\ A_s \qquad \text{(Eq. 2.4)}$$

Where: $P_{c\text{-}allowable}$ is the allowable structural axial compression load of the micropile, $P_{t\text{-}allowable}$ is the allowable structural axial tension load, $f_{c'}$ is the compressive strength of the grout (typically after 28-days), f_y is the yield stress of steel, A_g is the area of the grout in micropile section, and A_s is the steel area in the micropile section (bar + casing).

2.5.2. Geotechnical Design Capacity of Micropiles

Micropiles are generally considered as friction piles (FHWA-NHI, 2005). The large contact area along its length results in a significantly higher skin friction contribution than end bearing. Moreover, in Type E, the innovative technique in grouting during installation leads to a higher grout/ground bond capacity resulting in a negligible end bearing effect. Hence, the geotechnical capacity of micropiles is evaluated through the uncased length only. This length is described as the bond length of micropiles. Geotechnical capacity of micropiles can be estimated using the following equation (**Eq. 2.5**) provided by (FHWA-NHI, 2005):

$$P_{ult} = \alpha_{bond} \times \pi \times D_{bond} \times (\text{bond length}) \qquad \text{(Eq. 2.5)}$$

Where: α_{bond} is the grout to ground bond estimated by (FHWA-NHI, 2005), D_b is the diameter of the drilled hole, and L_b is the bond length between the soil and the uncased section of micropile. **Table 2.1** provides the suggested values by (FHWA-NHI, 2005) for $\alpha_{bond.}$ These values depend on the ground conditions and installation techniques during the construction of micropiles. It is clear that the contribution of end bearing resistance in the geotechnical capacity of micropiles is neglected due to the small diameter of micropiles (FHWA-NHI, 2005).

Table 2.1: Grout-to-ground bond values

Soil/Rock Description	Grout/Ground Bond Ultimate Strengths Typical Ranges (kPa)			
	Type A	Type B	Type C	Type D
Silt & Clay (Some Sand)(Soft, Medium Plastic)	35-70	35-95	50-120	50-145
Silt & Clay (Some Sand) (stiff, dense to very dense)	50-120	70-190	95-190	95-190
Sand (Some Silt) (Fine, Loose to Medium Dense) (stiff, dense to very dense)	70-145	70-190	95-190	95-240
Sand (Some Silt, Gravel) (Fine-Coarse, Medium to Very Dense)	95-215	120-360	145-360	145-385
Gravel (Some sand) (Medium to Very Dense)	95-265	120-360	145-360	145-385
Glacial Till (silt, Sand, Gravel) (Medium to Very Dense, Cemented)	95-190	95-310	120-310	120-335
Soft Shales (Fresh to Moderate Fracturing, Little to no Weathering)	205-550	N/A	N/A	N/A
Slates and Hard Shales (Fresh to Moderate Fracturing, Little to no Weathering)	515-1380	N/A	N/A	N/A
Limestone (Fresh to Moderate Fracturing, Little to no Weathering)	1035-2070	N/A	N/A	N/A
Sandstone (Fresh to Moderate Fracturing, Little to no Weathering	520-1720	N/A	N/A	N/A
Granite and Basalt (Fresh to Moderate Fracturing, Little to no Weathering)	1380-4200	N/A	N/A	N/A

2.6. REVIEW OF PREVIOUS STUDIES

Many field and laboratory investigations had been performed in order to evaluate the actual performance of micropiles. In parallel with field tests, several numerical studies were conducted considering different types of micropiles. Moreover, the load transfer mechanisms had attracted the attention of many researchers and many theories were proposed. A review of the available literature on micropiles is presented in the following section.

2.6.1. Case Studies for Micropiles

In three case histories reported by Traylor *et al.* (2002), micropiles Type A were used in a karst ground to provide structural support and act as a foundation system. The micropiles working load ranged between 600 to 1000 kN in compression. The average ultimate bond values of used micropile in massive hard rock were more than 17.5 MPa. They argued that for anchors in rock, bond lengths greater than about 3m rarely produce much increase in capacity.

A comparison between the calculated allowable capacity based on different codes guidelines and loading test results for micropiles with outer diameter of 178 mm installed into a 203 mm drill hole were summarized by Cadden *et al.* (2004). It was found that the allowable structural capacity based on the codes ranged from about 800 to 2100 kN, while load tested micropiles exhibited about double these values without displaying any sign of failure. These findings demonstrated that most codes underestimate the capacity of micropiles.

Jeon (2004) examined the load-displacement behaviour of Type B, C and D micropiles constructed in cohesive soils and sand under axial compression tests. The capacity of the micropiles was compared with the design values for drilled shafts. The results showed that micropiles possess higher unit skin friction compared to larger-diameter drilled shafts (i.e. around 1.5 to 2.5 the values for drilled shafts). This increase was attributed to the different grouting methods applied during micropile installation.

Holman and Tuozzolo (2006) analyzed three micropile load tests from two case histories. Two of the three micropiles were tested to plunging failure and one to impending failure. They found that the load distribution in the bond zone of the tested micropiles was generally non-uniform, indicating that the mobilized unit bond stress was not constant.

2.6.2. Case Studies for Hollow Bar Micropiles

Hollow bar micropiles were presented recently in the industry. Therefore, research done to evaluate the performance of this type of micropiles is not intensive.

The performance of hollow bar micropiles in five different projects was studied by Bishop *et al.* (2006). The hollow bar micropiles were installed in different soil types. A high skin friction was noticed in the performed tests, which allows carrying moderate to moderately high loads. They also determined the capacity of a pile group by calculating the sum of the individual micropiles.

In another study performed by Gómez *et al*, (2007), the performance of 260 hollow bar micropiles was investigated. In this investigation, a grout flushing technique was used in the installation of micropiles. They reported that hollow bar micropiles have an advantage of fast installation over the other types of micropiles. They have also found a greater values of grout-to-ground bond for the provided values in accordance with type B micropiles.

Verification compression and tension loading tests were conducted on hollow bar micropiles by (Telford *et al.,* 2009). The tested micropiles were installed in cohesionless soil to a depth of 9.8 m. The results of the verification tests confirmed that micropiles can support high compression load greater than 1300 KN with small movement of the pile head. They also considered in their investigation an enlarged pile diameter of 1.5 times the drill bit diameter. The calculated grout-to-ground bond strength values were close to values proposed by (FHWA-NHI, 2005).

Four pairs of micropiles installed in a layer of soft clay/sandy clay/very loose to loose clayey sands, were tested by Bennet and Hotherm (2010). The tested piles had depths of 7 m, 8.5 m, 10 m, and 11.5 m. The axial capacity of the shortest pile was 480 kN and 460 kN for the 150 mm clay bit and the 115 mm cross bit, respectively.

Five hollow bar micropiles were examined by Abd Elaziz and El Naggar (2010, 2011, and 2012). All micropiles were installed in cohesive soils. All micropiles had a constant outer diameter of 76 mm, and connected to a 178 mm carbide drill bit. The results showed that considering hollow bar micropiles as type B underestimates the grout-to-ground bond strength.

Four hollow bar micropiles installed in a firm to stiff clay were tested by (Drbe and El Naggar, 2013). The installed hollow bar micropiles had a diameter of 178 mm, and were constructed using two different carbide drill bit of 178 mm and 228 mm. The installation process was performed using air-water flushing technique. They have noted an increase of micropiles diameter of 10% to 20% for the different types of drill bit. They also have indicated higher values of grout-to-ground bond strength, than the values presented by (FHWA-NHI, 2005).

2.6.3. Analytical and Theoretical Analyses

Misra *et al.* (2004) proposed analytical relationships to describe pullout load-displacement behaviour for micropile–soil interaction. Micropile was considered as partially bonded with a top debonded zone and a bottom bond zone. Moreover, it was assumed that the micropile–soil interface has elastic-perfectly plastic behaviour and homogeneous, hence, the effects of soil layering and grout inhomogeneity were averaged. Their model provided good predictions for field measured load-displacement curves of different case studies.

The effect of buckling on the capacity of micropiles was considered by Cadden and Gomez (2002). They produced a graphical chart based on the Euler buckling equation which can be used as a useful tool to check buckling of a given micropile section. However, they neglected the grout effect on the buckling behaviour. These graphs were reproduced by the FHWA NHI (2005).

2.6.4. Numerical Analysis

Ousta and Shahrour (2001) investigated the seismic behaviour of micropiles used for the reinforcement of saturated soils. The fluid-soil coupling and a cyclic elasto-plastic constitutive relation were used to describe the soil behaviour in three-dimensional finite element analysis. They showed that micropiles have slight effect on earthquake-induced pore-pressure. Micropiles installed in loose to medium sand increase the pore-pressure under seismic loading leading. Moreover, Sadek and Shahrour (2004) analyzed the influence of micropiles inclination on their response to seismic loading using three-dimensional finite element modeling. Their results showed that the micropile inclination improved the seismic performance compared to vertical micropiles. The inclination allowed a better mobilization of the axial stiffness of micropiles leading to lower shearing forces and bending moment induced by seismic loading. Additionally, Sadek and Shahrour (2006) investigated the influence of the head and tip condition on the seismic performance of micropiles installed in linear elastic soil. They showed that the pinned connection between the micropiles and their cap reduced the axial force and bending moment in micropiles. In addition, embedment of the micropiles tip in a stiff layer resulted in a significant increase in the induced internal forces by seismic loading.

2.7. IMPLEMENTATION OF INDUSTRIAL WASTE IN CONSTRUCTIONAL APPLICATIONS

The objective of this section is to investigate the potential use of different wastes in construction applications. This part is based on the comprehensive review of available literature on use of waste in construction materials. Usually, the production of different construction materials impacts the environment adversely. Besides, the disposal of industrial wastes has become a major concern for industry due to environmental controls that have been tightened by regulatory authorities (Carignan, 2005).

On the other hand, reusing industrial waste in construction applications represents an environmentally sustainable practice (Carignan *et al.*, 2007). Many researchers investigated different options for the reuse of wastes in construction applications. Different industrial wastes can be implemented in cementitious materials as components of binder, as a replacement aggregate, or as additives, which can modify their fresh and hardened properties (Helmuth, 1987; Cheng-yi and Feldman, 1985; Singh and Garg, 1999; Aggarwal and Siddique, 2014). However, to utilize a new material it should satisfy the specifications determined by its applications. Also, it should have no harmful effect on health or environment (Remond *et al.*, 2002).

2.7.1. Case studies for Reusing of Waste Materials in Constructional Applications

Tuncan *et al.* (2000) investigated the petroleum-contaminated drilling wastes, to be used as sub-base material for road construction. In this study, the petroleum waste was stabilized by mixing pozzolanic fly ash, lime and cement. The physical, mechanical, and chemical properties of the new material were studied. They noted an improvement in the properties of the stabilized specimens in comparison with the un-stabilized ones. They also proposed an optimum mixture proportions.

The reuse of water based mud drilling wastes (WBM) in construction applications was presented by Page *et al.* (2003). They studied the potential of using the waste material in four different applications; cement manufacture, road pavements, bitumen and ready mix. They have concluded that the WBM drilling wastes have the potential to be implemented in concrete and asphalt. However, they indicated that further treatment for the drill cuttings was required, which included; washing (to remove sulphate, chloride and soluble metals) and oil removal.

The effect of waste material addition in geo-grid applications was investigated by Sivakumar and Glyn (2004). They have studied the effect of quarried basalt, quarry waste, building debris and crushed concrete on the performance of geo-grids. Tests performed included direct shear tests in wet and dry conditions and crushability tests. Results showed a satisfactory performance for the geo-grid with the waste material. However, it was noticed a weakness in the crushability of the tested materials when subjected to repeated loading rates.

Hassan *et al.* (2004) have studied the potential uses of petroleum contaminated soil in highway construction. Their investigation included the stabilization of the tested soil with cement, crushed stone aggregate and using it as a fine aggregate replacement in hot mix asphalt concrete. They also have performed a toxicity characteristic leaching procedure (TCLP) on the tested specimens. TCLP test results showed that the investigated soil was non-hazardous. The unconfined compressive strength of the cement-stabilized contaminated soil at a percentage up to 5%, and remained relatively constant with the increase of cement content. They also noticed an adverse effect on the cement hydration caused by the addition of the waste. However, the tested waste still showed a good potential to be used in road construction.

The use of mine tailings in the construction applications was studied by Mahmood and Mulligan (2007). They studied the potential of using tailing wastes as a base material for the unpaved roads. Physical characteristic tests and unconfined compressive tests were performed on different types of tailing brought from several mines in eastern Canada. The results showed that all tested tailings have exceeded the minimum strength requirements for filling underground stopes. Moreover, a decrease in strength as the water cement ratio increases for all tailings was noticed. They suggested that tailing wastes can be used as a base material for the building of unpaved temporary access roads.

Another study performed by Chen *et al.* (2007) on the recycling of drill cutting wastes from three different locations, in construction applications. In this experimental study, mechanical properties of permeable brick and concrete manufactured with the waste material were evaluated. A decrease in the compressive strength of the brick produced using drill cutting waste in comparison to the pure cement bricks was reported.

Hassan *et al.* (2007) have investigated permeability and leaching of hot mix asphalt in concrete containing oil-contaminated soils (OCS). The OCS was added as a replacement of fine aggregate in the asphalt concrete mixtures with percentages up to 40% by weight. A significant reduction in the tested asphalt permeability as the percentage of OCS increased up to 30% was noticed. The results also showed satisfactory limits for heavy metals leaching.

Guney *et al.* (2010) have investigated the reuse of waste foundry sand in the production of high-strength concrete. The natural fine sand in concrete was partially replaced with foundry waste at rates of 0%, 5%, 10%, and 15%. Fresh and hardened properties of the tested materials were examined. A decrease in the compressive and tensile strengths of the tested materials in comparison with the control specimens was reported.

They also reported a reduction in freezing and thawing cycles, however, all the measured propertied were still within the acceptance limits of the ACI code.

Misra *et al.* (2011) investigated using the oil drill cuttings in construction of roads. They concluded that drill cuttings waste has a high potential to be used in the road construction as it can present a stable and strong sub-grade for roads with minimal amount of heavy/toxic metals, which means that the waste can be safely used in road construction.

Mohammed and Cheeseman (2011) investigated the use of waste oil drill cuttings treated by thermal desorption in sandcrete blocks. Their results showed that replacing sand with the treated waste up to 50% had enhanced the density and thermal conductivity of the tested materials. Compressive strength of different specimens was comparable to that of the control specimen. They concluded that the treated waste had the potential to be used in the production of sandcrete blocks.

Kamei *et al.* (2012) investigated the reuse of recycled bassanite produced from gypsum waste in conjunction with coal ash as a stabiliser material to enhance the strength of very soft clay soil. They also investigated the effect of bassanite addition on the durability of soft clay. In this study, the waste was added with percentages varying from 0% to 20%. Results showed that the use of recycled gypsum waste with coal ash has increased the strength and improved the durability of the investigated soil. They also noticed a decrease in the mechanical properties of the tested samples when the coal ash is added without bassanite. On the other hand, their results showed that the incorporation of bassinite with coal ash had decreased the durability and strength of the stabilized soil when subjected to wet-dry cycles.

Ahmed (2013) studied utilizing recycled bassanite produced from gypsum waste to enhance the mechanical properties of weak subgrade clay soils used in roads construction. The recycled bassanite was mixed with furnace slag cement with a ratio of 1:1 to prevent the solubility of bassanite. The results showed that the addition of bassanite had enhanced the stability of weak roadway subgrades clay soils. It was also noticed an increase in the mechanical properties of the tested soils when the amount of bassanite increased. It was concluded that the use of bassanite enhanced the performance of the tested soil, which would extend roads service life leading to environmental and economic benefits.

Irali *et al.* (2013) investigated the effect of recycled concrete aggregate in the construction of concrete pavements. They studied the behaviour of four pavement test sections constructed using the recycled concrete aggregate for a period of five years. The effect of environmental factors such as temperature and moisture gradients on long term performance of pavement was studied. Their results showed comparable performance of the investigated pavements and the control pavement. They suggested that the use of waste concrete content is feasible in the construction in concrete pavements.

2.7.2. Treated Oil Sands Drill Cuttings Waste

Oil sands located in northern Alberta is considered the second largest oil reserve in the world after Saudi Arabia **Fig. 2.10** (ERCB, 2010). It can cover more than 170 billion barrels of bitumen (Alberta oil sands industry quarterly update, 2014). Generally, oil sands extend to a depth from 30 to 90 meters below the ground surface. Oil sands are composed of 8 to 14% (by weight) bitumen and 3 to 5% (by weight) water, the rest are mineral solids (sand, silt and clay) as shown in **Fig. 2.11** (Gosselin *et al.*, 2010).

Figure 2.10: Alberta's oil sands areas (ERCB, 2010)

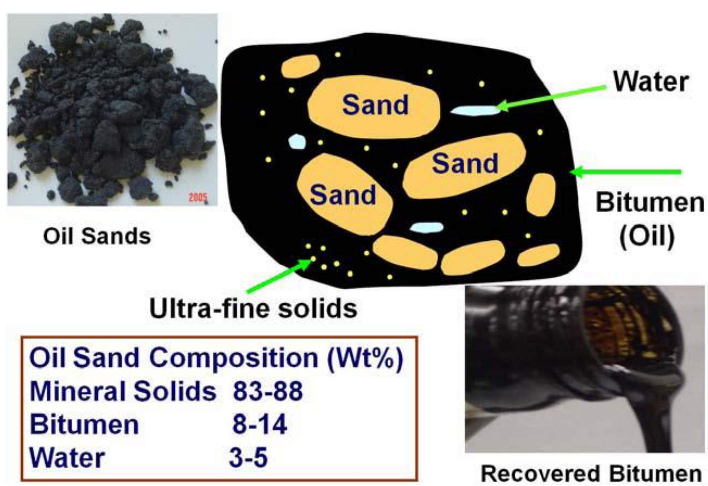

Figure 2.11: Characteristics of oil sands (Gosselin *et al.*, 2010)

The bitumen is extracted from the sand by one of two methods. The first method is in-situ mining, which is suitable for bitumen lying deeper than 70 m under the ground surface **Fig. 2.12**. In this process, bitumen is treated thermally to a temperature above 250°C to reduce its high viscosity and then pumped easily to the ground.

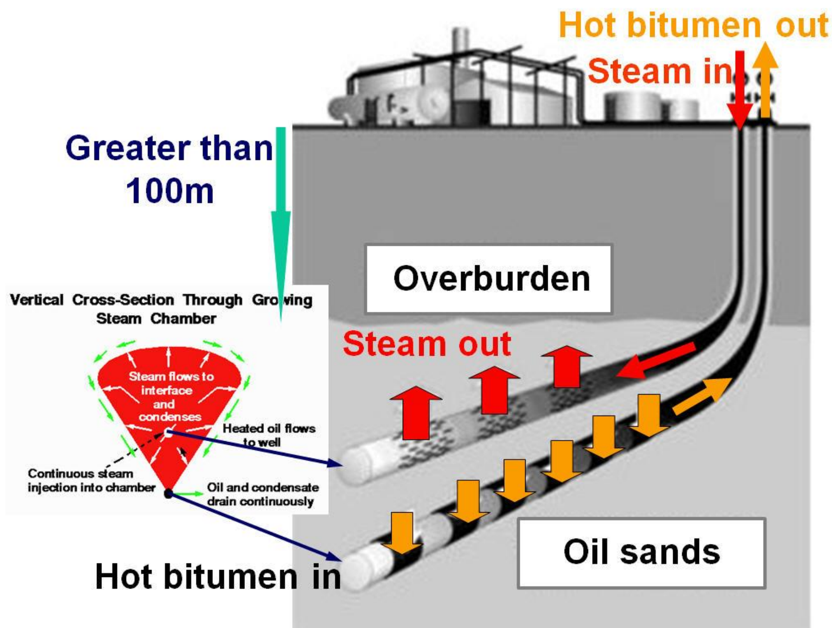

Figure 2.12: In-situ mining (Gosselin *et al.*, 2010)

The second process is open pit mining, also known as hot water process, is suitable for oil sands with depth up to 70 m. In this process, oil sands are excavated, crushed and transported into hot water in a temperature between 45 °C and 60 °C to make slurry. Then, air bubbles are pumped carrying the bitumen droplets to the surface, while the solids settle to the bottom and separated into large ponds (**Fig. 2.13)** (Gosselin *et al.*, 2010).

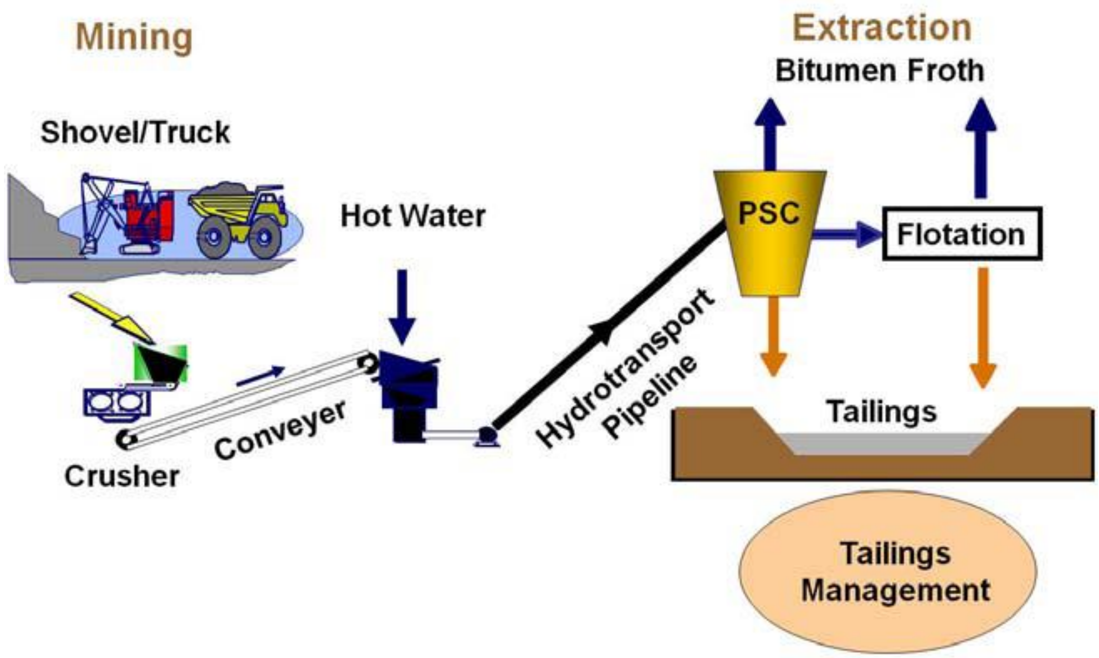

Figure 2.13: Open pit mining (Gosselin *et al.*, 2010)

The resulting products from this process are bitumen and tailings (warm aqueous suspension of sands, silt clay and residual bitumen). The tailings are pumped into large tailing ponds, then the coarse sand settles, while the residual bitumen are carried as slurry. A critical part in this process is the disposal of sands tailing. The current volume of tailing is more than 720 million m^3 and this number keeps increasing with the extraction of oil sands. Also, a study done by Mackinon *et al*. (2005) showed that the contaminated tailing water reached the ground water level. All these issues have led to an urgent need to find new innovative methods for disposing the oil sands tailing.

One of the recent technologies for the oil sands waste treatment is the Theremo-mechanical Cuttings Cleaner (TCC) for treating oil sands drilling cuttings (**Fig. 2.14)**.

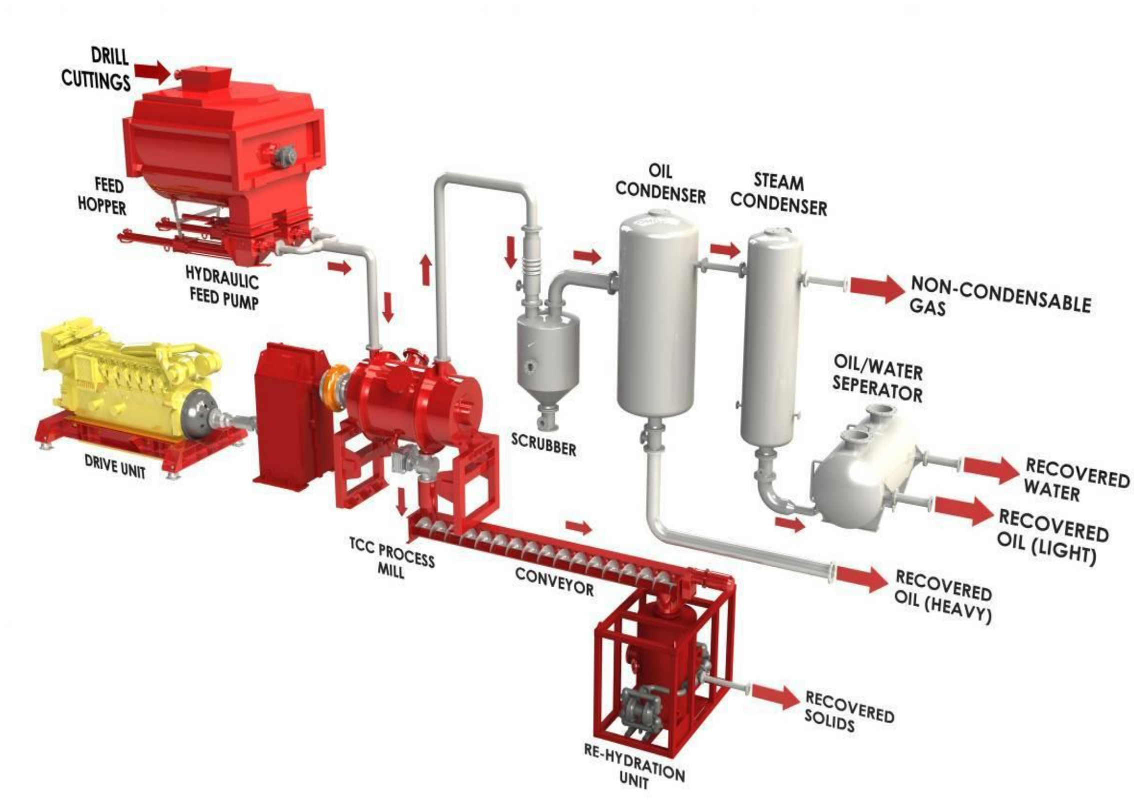

Figure 2.14: Thermo-mechanical Cuttings Cleaner (TCC) (After TCC brochure Halliburton)

The mechanism of TCC operation consists of heating the drill cuttings to a temperature high enough to evaporate oil and water. This high temperature is induced from the friction between waste particles and TCC. The evaporated oil and water are brought back to the liquid state using spate condensers. The remaining soil from this operation (i.e. by-products) of TCC is a very fine quartzes powder, with a hydrocarbons content less than 1% by weight and has a high surface enrichment of Aluminum/Silica which increases its potential as a filler material for constructional applications (Haliburton thermomechanical cuttings cleaner, 2014, Thermtech AS, 2010).

2.8. SUMMARY

This literature review provides a brief description on different types of micropiles and their design philosophy and classifications. It also discusses previous research in the area of hollow bar micropiles. In addition, an overview on previous researches on the integration of waste materials in construction application is provided. Finally, a discussion is provided on oil sand waste production in Canada and the latest treatment methods for this type of waste and its potential to be used in construction applications.

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CHAPTER THREE

PROPERTIES OF CEMENTITIOUS MATERIAL INCORPORATING TREATED OIL SANDS DRILL CUTTINGS WASTE*

3.1. INTRODUCTION

Implementing industrial waste in cementitious material manufacture may represent a satisfactory solution to many problems posed by waste management (Remond *et al.*, 2002). 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 (Helmuth, 1987; Cheng-yi and Feldman, 1985; Singh and Garg, 1999; Aggarwal and Siddique, 2014, Yang *et al.*, 2015). 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 (Remond *et al.*, 2002).

In the last decade, oil sands industry became an increasingly major driver behind the economic activity in Canada (Carson, 2011). While contributing to the economy, oil

*A version of this chapter has been accepted in Construction and Building Materials Journal. Some parts of this chapter were also published in The Proceeding of the 68th Canadian Geotechnical Conference, Quebec City, Quebec, Canada 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 (Söderbergh *et al.*, 2007). Different technologies had been applied as a pre-treatment process to convert this oil sands drilling cuttings waste to a reusable product (Huang *et al.*, 2015, Loganathan *et al.*, 2015, Boudens *et al.*, 2016). Recently, an innovative technology (so called Thermo-mechanical Cuttings Cleaner (TCC)) was developed for treating oil sands drilling cuttings and recovering hydrocarbons (Ormeloh, 2014). 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.

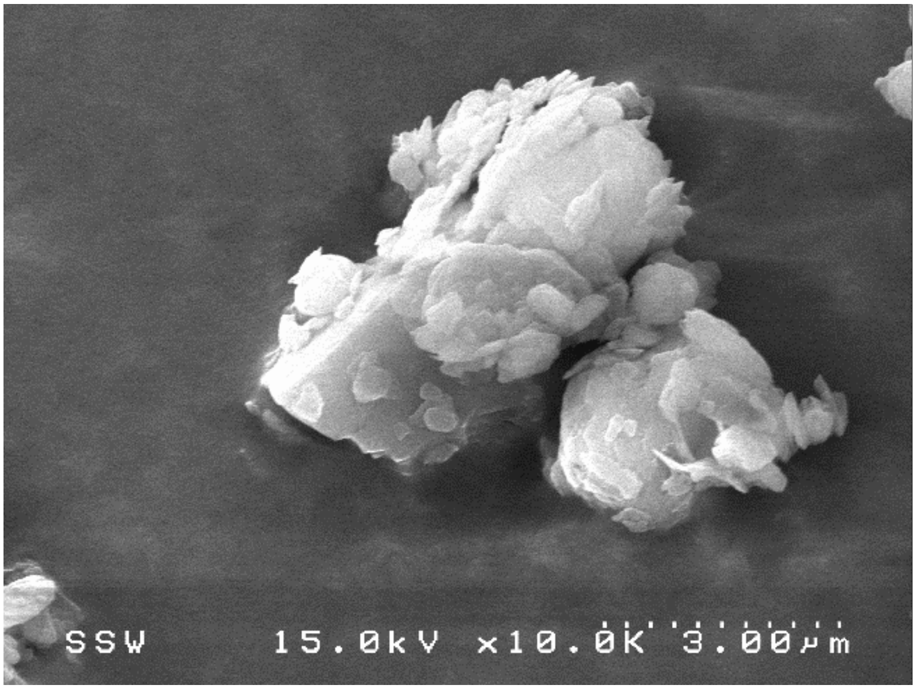
Fine materials can affect the properties of cementitious materials through modifying the hydration kinetics of cement chemically, physically or both (Lawrence *et al.*, 2003). Their chemical effect will depend on their composition and solubility, i.e., they may modify the chemical equilibrium of ionic 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.

3.2. EXPERIMENTAL PROGRAM

3.2.1. 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 2.54. **Figure 3.1** 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 3.1**. The grain size distribution curves for OPC and TOSW are shown in **Fig. 3.2** a)



b)

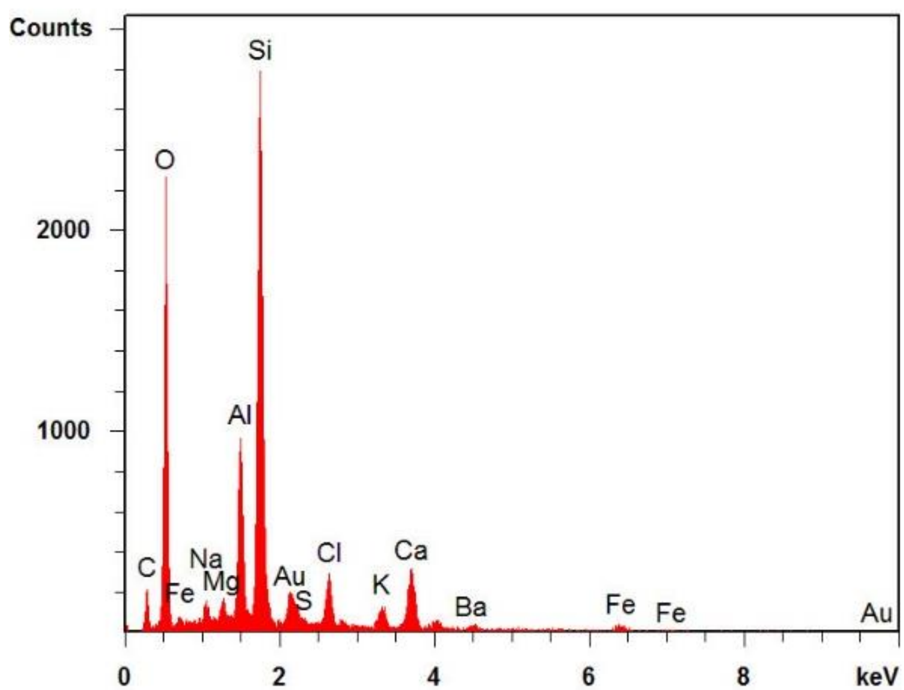


Figure 3.1: a) SEM image and b) EDX for TOSW

Table 3.1: Chemical composition and physical properties of cementitious materials

Chemical Analysis	Material	
	OPC	TOSW
SiO_2	21.60	61.24
Al_2O_3	6.00	8.73
Fe_2O_3	3.10	3.00
CaO	61.41	5.55
MgO	3.40	0.92

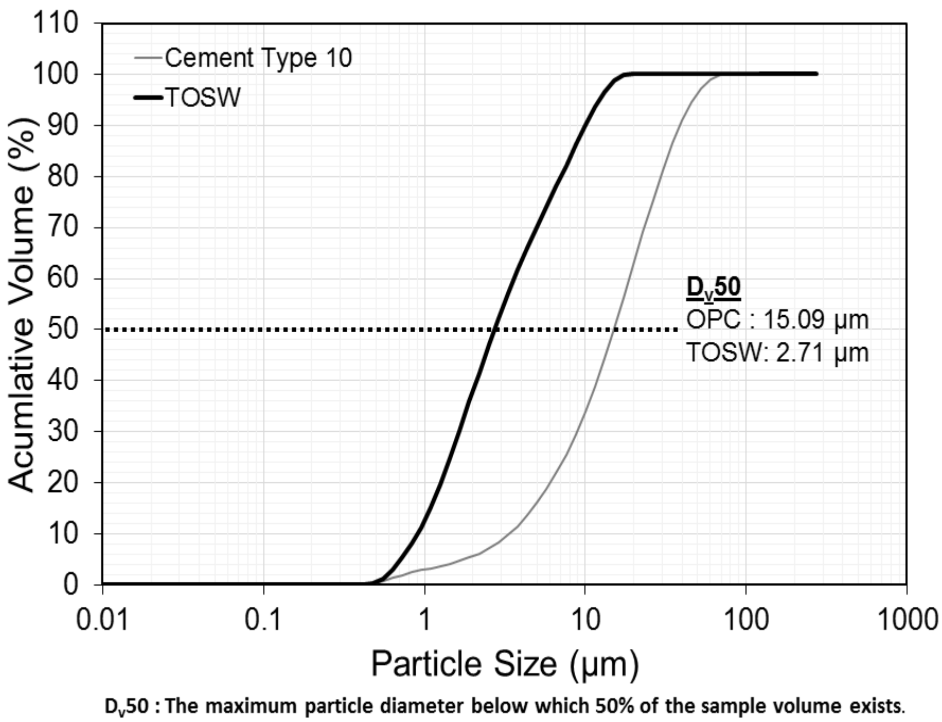


Figure 3.2: Particle size distribution using Laser diffraction for OPC and TOSW

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%, 9%, 18%, 27% to 45% as a partially replacement of cement by volume. For simplicity, mixtures will be denoted as 10%, 20%. 30% and 50%. **Table 3.2** provides a summary for tested mixtures composition.

Table 3.2:Composition for tested mixtures

Materials	TOSW %				
	0%	10%	20%	30%	50%
Cement	400 g	360 g	320 g	280 g	200 g
TOSW	----	28 g	57 g	85 g	142 g
TOSW (%) by volume	0.00	9.00	18.00	27.00	45.00
Water	168 g	167.81 g	168.21 g	168.03 g	168.24 g

3.2.2. Tests and Specimens Preparation

All tested cement paste mixtures were prepared according to ASTM C305 (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 (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 (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 (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 (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 (Dransfield, 2004). 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.

3.3. RESULTS AND DISCUSSION

3.3.1. Water of Consistency

Figure 3.3 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.

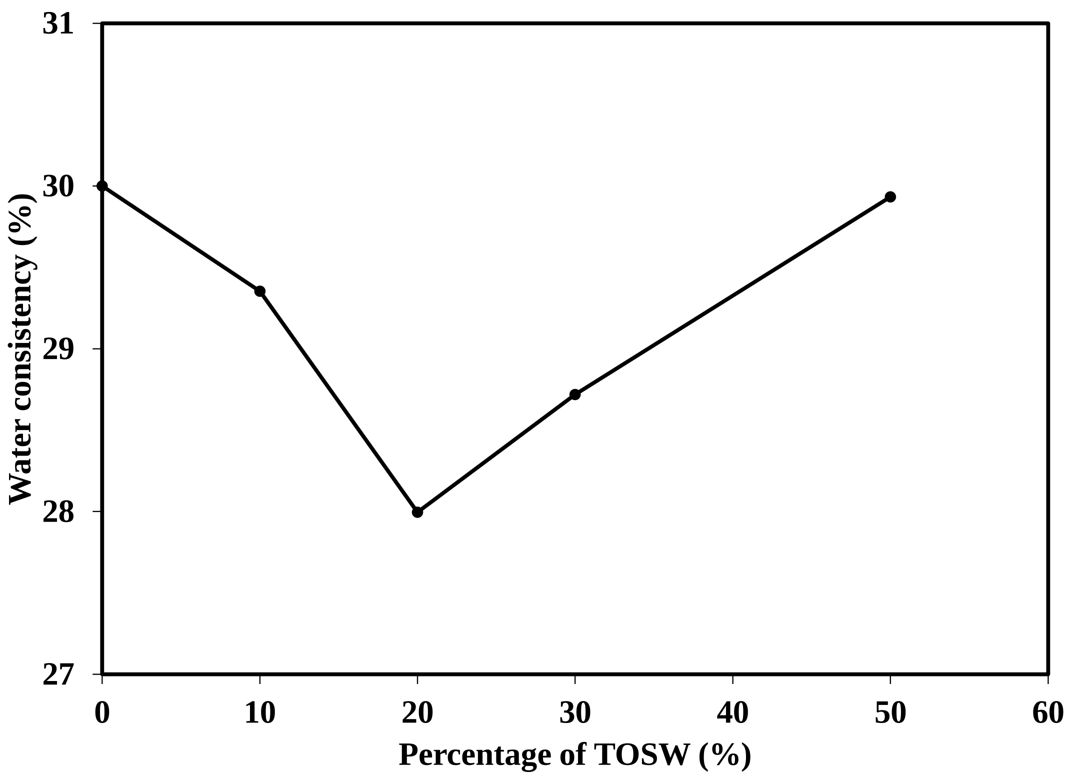


Figure 3.3: Effect of TOSW replacement rate on cement paste water of consistency

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 (Yahia *et al.*, 2005). Therefore, the main controller 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 20% addition of TOSW can be considered as the threshold value and is highly depended 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 percentage go above 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 (El-Alfi *et al.*, 2004).

3.3.2. Heat of Hydration

Figure 3.4 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.

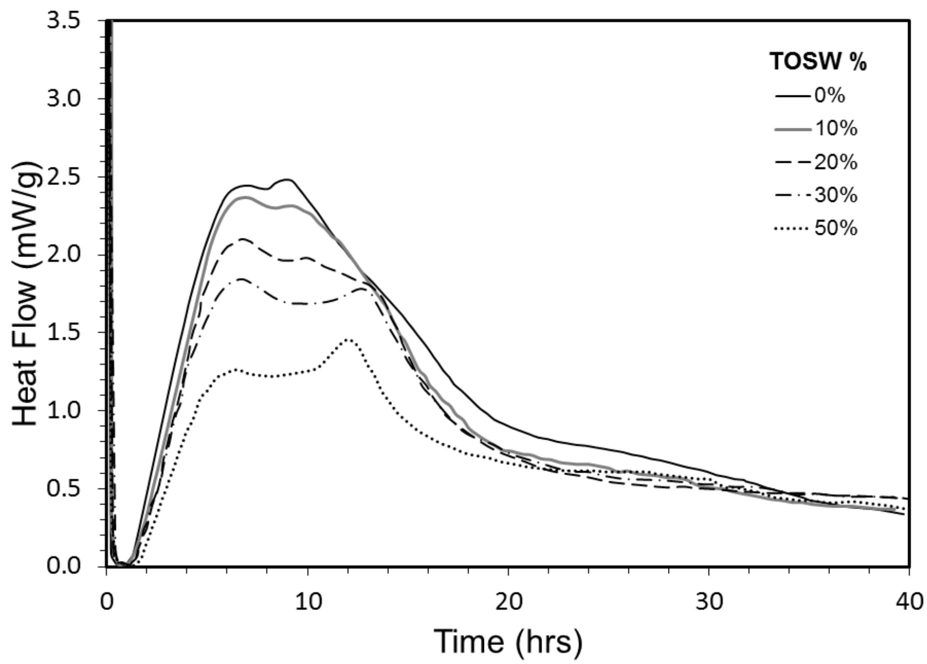


Figure 3.4: Effect of TOSW replacement rate on cement paste Heat flow

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 (Rahhal and Talero, 2005). 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). 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 (Hewlett, 2003; Taylor, 1997).

In order to characterise 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 respect to the mass of binder. This actually results in a lower heat flow per gram of binder. **Figure 3.5** represents the adapted reference curves and the curves with actual substitutions of mineral additions.

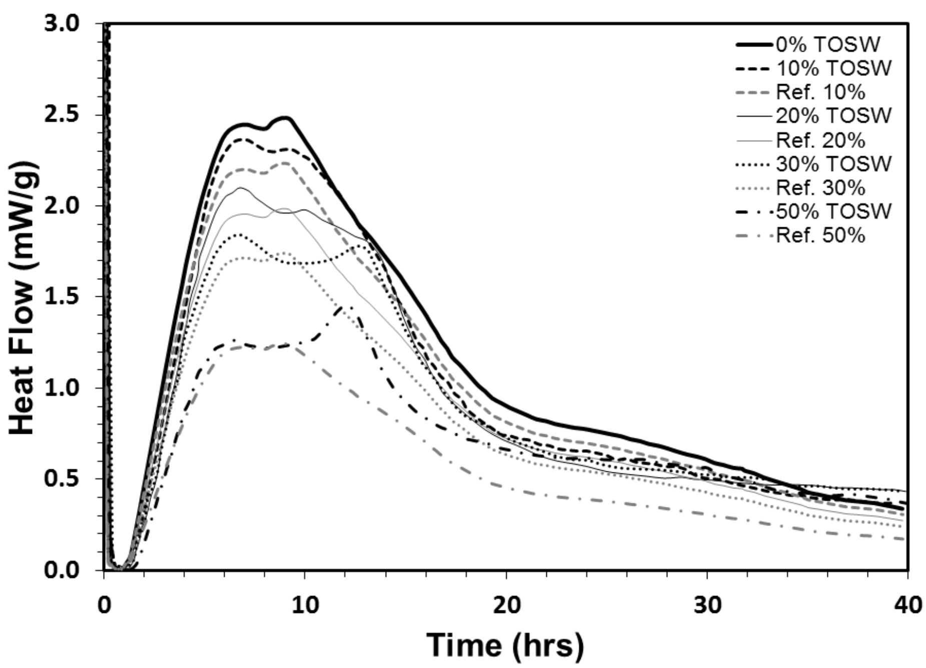


Figure 3.5: Heat of hydration with adapted reference curves for cement pastes incorporating different percentage of TOSW

The magnitude of the main peak of the cement pastes with TOSW is slightly greater than the peaks of the adapted reference curves. For instance, cement paste mixture incorporating 20% TOSW exhibited a 7.60% higher heat flow peak than that of the adapted curve based on 20% substitution percentage (i.e. Ref. 20%). However, a chemically inert behaviour does not mean that the hydration kinetics cannot be influenced and only retarded due to the dilution effect. Previous study conducted by Lawrence *et al.* (2005) on the influence of chemically inert mineral additions in mortars showed that the degree of hydration can be altered. This can explain the increase in the slopes of hydration curve during the acceleration periods (i.e. slopes of heat flow curves up to the second peak), which can be regarded as indicators of nucleation effect (**Table 3.3**).

Table 3.3: Slopes of heat flow curves during the acceleration periods for tested mixtures

Curves	**10% TOSW**	**Ref-10%**	**20% TOSW**	**Ref-20%**	**30% TOSW**	**Ref - 30%**	**50% TOSW**	**Ref - 50%**
Slope	0.51	0.48	0.49	0.43	0.42	0.37	0.30	0.27
Increase (%)	6%		14%		14%		11%	

These results were confirmed by setting time results which showed a slight variation in the measured setting time. For instance, the initial setting time setting time for all tested cement paste mixtures ranged between 2.68 hrs and 2.93 hrs. Moreover, changes in the value and location of the third peak are more pronounced as TOSW addition rate increases.

Figure 3.4 shows that as the percentage of TOSW increases the third peak starts to decrease at its original location along with the occurrence of a shoulder after the third heat peak. Moreover, at high percentage of TOSW, the third peak is noticeable at around 18 hrs which is correlated with the hydration of C_3A (Schutter, 1999). This can be explained as follows: TOSW addition enhances and accelerates the ettringite formation by offering nucleation sites (Nocuń-Wczelik, 2000). Hence, higher amount of C_3A is consumed leading to depletes of aluminates. Simultaneously, TOSW represents another source for aluminates, which will react with limestone to form calcium carboaluminates. This was confirmed by thermogravimetric analyze for selected cement paste samples.

In thermogravimetric analyzer, the change in mass of a sample placed in a controlled atmosphere is continuously recorded. Thus, decomposition and water loss from hydration products are observed and quantified (Ramachandran, 1969). The derivative thermogravimetric curves (DTG) allow identifying different decomposition processes as shown in **Fig. 3.6**.

Four peaks can be distinguished on DTG curves. Weight loss associated to the loss of combined water of calcium silicates hydrates (CSH) (peak 1), ettringite (AF_t) (calcium aluminate hydrates) (peak 2), decomposition of mono- (M_c) and hemicarbonate calcium aluminate (H_c) (peak 3). Weight loss peak that occurs at temperature range 450–500 °C is related to the dehydroxilation of portlandite (CH) (peak 4) (Ramachandran, 1988). It is clear that the intensity of the endothermic peak for M_c/H_c increases as the amount of TOSW increases which implies the increase in M_c/H_c formation.

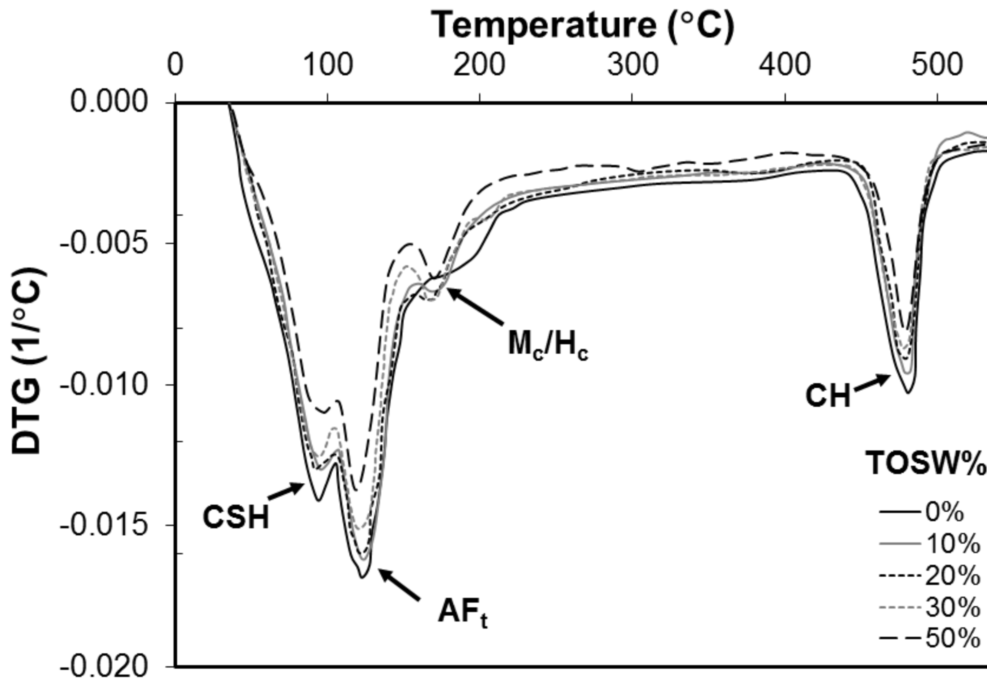


Figure 3.6: DTG curves for cement pastes incorporating different percentages of TOSW

3.3.3. Compressive Strength

Figure 3.7 shows the compressive strength results for mixtures incorporating different percentages of TOSW. Generally, the compressive strength had increased for all paste mixtures with time. However, addition of TOSW resulted in some reduction in the achieved compressive strength; the higher the TOSW, the greater the reduction in the compressive strength. For instance, mixtures incorporating 10% and 30% of TOSW as a partial replacement of cement exhibited 12% and 34% reduction in the 7 days compressive strength with respect to that of the control mixture. This can be explained based on both dilution and filler phenomena.

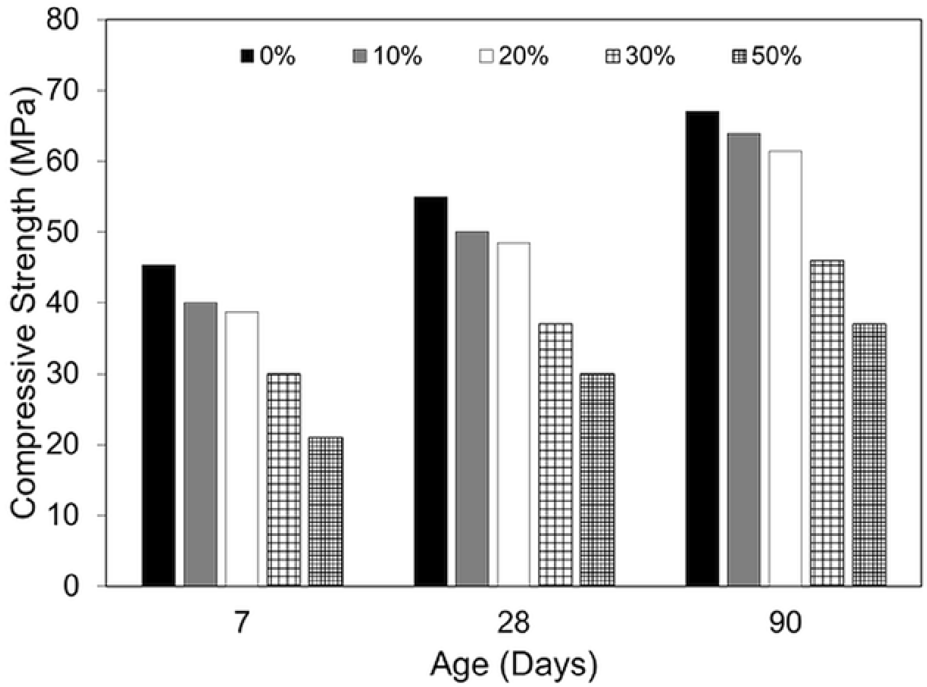


Figure 3.7: Compressive strength results for mixtures incorporating different percentages of TOSW

At early ages, the strength development rate depends mainly on the rate of hydration and formation of hydration products. Addition of a fine filler to cement modifies the early hydration rate primarily due to dilution effect. Replacing cement by TOSW decreases the total cement content leading to a lower formation for hydration products. However, the large specific surface of the TOSW small particles increases its potential as nucleation sites that promotes the precipitation of hydration products. Although nucleation is a physical process, it accelerates the hydration process of cement. This can partially compensate for the reduction in the hydration rate due to the dilution effect (Cyr *et al.*, 2006). Consequently, at low replacement rates (i.e. 10%), the dilution effect will have lower influence on strength development than at high replacement rates (i.e. 30%). This is in agreement with previous heat of hydration (**Fig. 3.4**) and DTG results (**Fig. 3.5**). At later ages, the rate of hydration is very slow and consequently the strength gain rate is low. On the other hand, at this later age, filler materials are able to reduce gaps and spaces needed to be filled by hydration products, which can compensate for the dilution effect leading to a recovery in the strength. **Figure 3.8** shows the reduction in the compressive strength with respect to control mixtures at different ages.

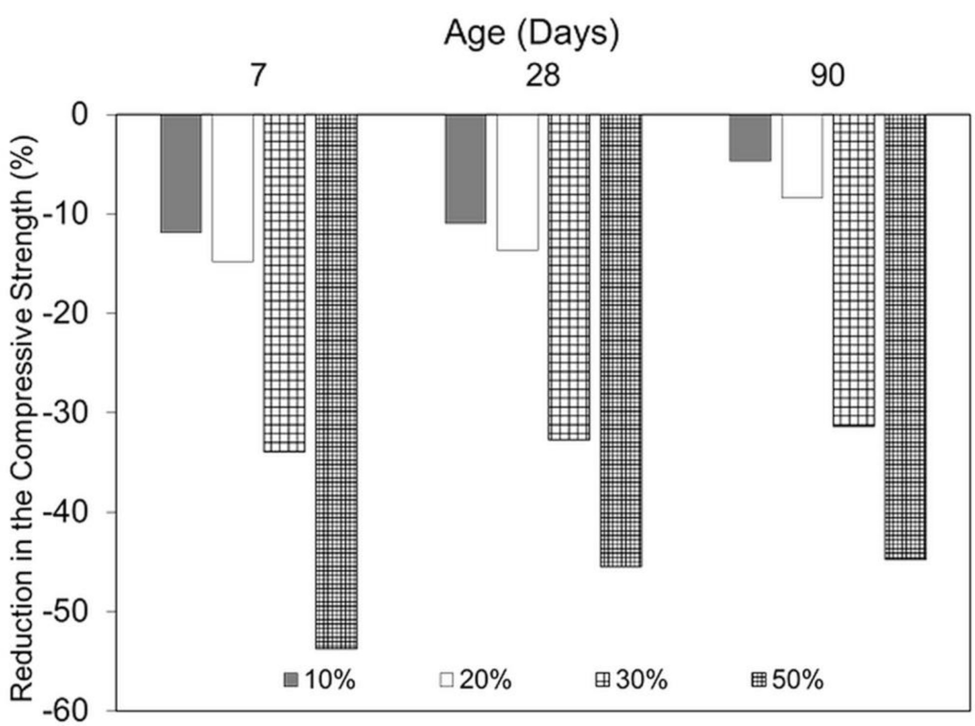


Figure 3.8: Reduction in compressive strength due to TOSW incorporation at different ages

Figure 3.8 indicates that the percentage reduction in compressive strength of the paste mixtures decreased as sample age increased. Moreover, it seems that partially replacing cement by TOSW with a rate higher than 20% causes significant reduction in the compressive strength. For instance, reductions in the compressive strength for mixtures incorporating up to 20% and more than 20% TOSW as partial replacement of cement were <15% and >30% regardless of the sample age, respectively. This indicates that the dilution effect in pastes with TOSW > 20% will dominate, leading to a reduction in strength. It should be mentioned that even though the compressive strength decreased due to the addition of TOSW, it is still within the range for several construction applications. For example, in micropile applications, the Federal Highway Administration (FHWA) specified the minimum design compressive strength as 28 MPa for the grout used.

3.3.4. Drying Shrinkage

Figures 3.9 and **3.10** illustrate the drying shrinkage and mass loss results for mixtures incorporating different percentage of TOSW. Regardless of the percentage of TOSW, shrinkages and mass losses for tested cement paste mixtures incorporating TOSW are practically higher than that of the control mixture without TOSW, and the measured shrinkage was greater for mixtures with higher percentage of TOSW. For instant, mixtures incorporating 10% and 20% of TOSW as partial replacement of cement exhibited 11% and 19% higher shrinkage than that of the control at age 28 days, respectively. Thermal shrinkage of the cement paste mixture may be ignored due to the small size of the tested specimens which assure quick dissipation of the hydration heat (Remond *et al.*, 2002, Baroghel-Bouny *et al.*, 2006, Soliman and Nehdi, 2011). Therefore, shrinkage was mainly due to the evacuation of water from the test specimens.

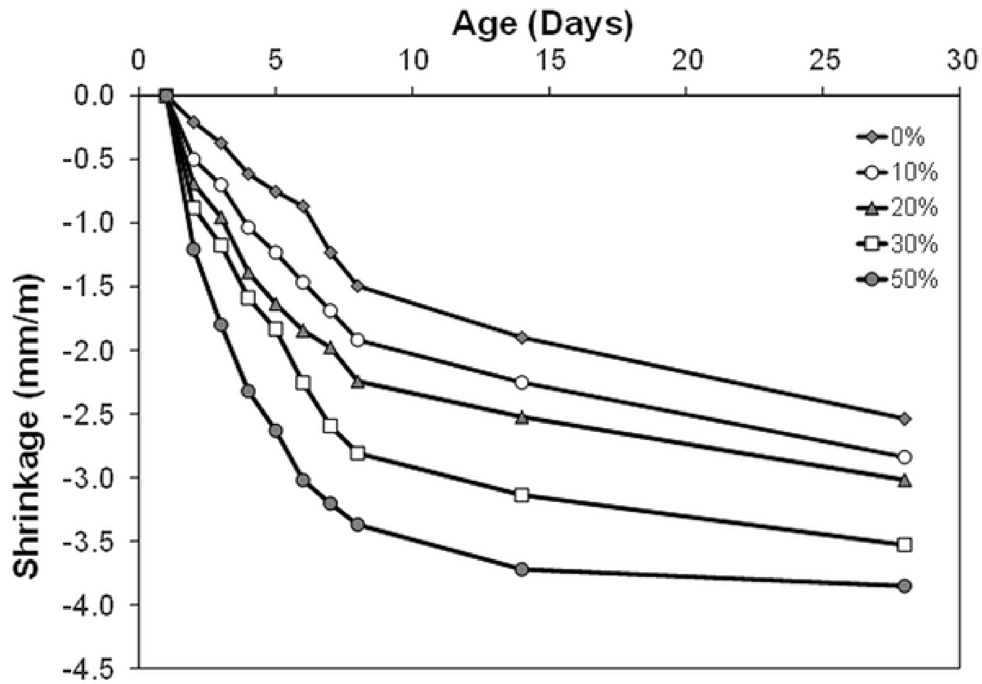


Figure 3.9: Measured shrinkage for mixtures incorporating different percentages of TOSW

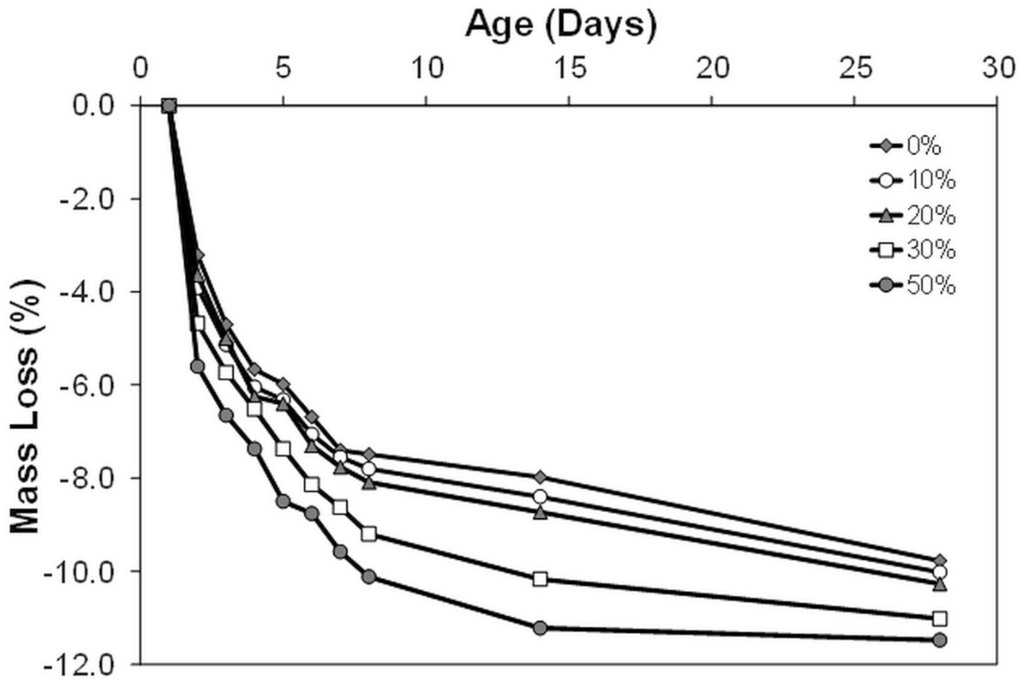


Figure 3.10: Measured mass loss for mixtures incorporating different percentages of TOSW

Hardened cement paste is a porous medium. The formation of the pore structure largely depends on the degree of hydration and water content. Pore structure gives an idea about the degree of interconnection between the pores and the pore size distribution in the hardened cement (Richardson, 2002). From shrinkage point of view, capillary pores are the most important type of pores as their sizes will control the amount of internal tensile stresses and consequently shrinkage. The finer the capillary pores, the higher the shrinkage (Meddah and Tagnit-Hamou, 2009). Capillary pores are formed because the hydration products do not fill all the space between hydrated cement particles. Hence, the presence of TOSW will influence the microstructure of the cement paste including the total porosity and the critical pore diameter along with the connectivity of capillary pores and thus water exchange. Therefore, shrinkage and mass loss results can be explained based on the two concurrent effects induced by TOSW addition: Filling and diluting. Adding the TOSW, which is a very fine material, act as a filler leading to finer pores, which in turn leads to higher shrinkage. **Figure 3.11** shows the porosity measured for the tested mixtures.

It is clear from **Fig. 3.11** that the addition of TOSW had refined the pore sizes. Meanwhile, replacing cement with TOSW reduces the cement content leading to formation of lower amounts of hydration products. Consequently, lower amount of water is consumed in the hydration reactions, besides the depercolation/disconnection of capillary pores is delayed (Bentz, 2006). Hence, more free water became available for evaporation and can easily find its path to the surrounding environment, leading to a higher mass loss, i.e. higher mass loss occurs as the TOSW percentage increases. For instant, mixtures incorporating 20% and 50% TOSW as a replacement of cement exhibited 5% and 29% higher mass loss than that of the control specimens at age 7 days, respectively. Thus, the measured shrinkage for the tested mixtures is attributed to the combined effects of: refined pores leading to higher capillary stresses and lower hydration product formation leading to greater availability of free water.

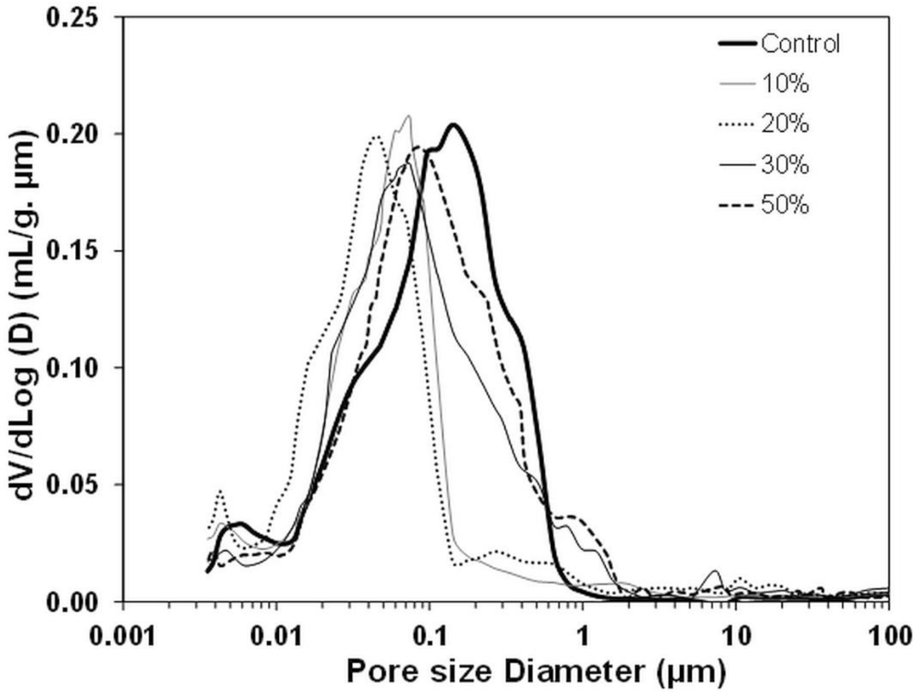


Figure 3.11: Pore size distribution for mixtures incorporating different percentages of TOSW

3.3.5. Leaching

Based on the previous results, it seems that adding TOSW more than 20% as a partial replacement of cement will adversely affect the cementitious material performance. Therefore, the leaching test was conducted only on specimens incorporating 10% and 20% of TOSW as a partial replacement of cement. In order to identify the leaching properties of heavy metals that existed in the TOSW, leaching test was conducted on TOSW before being incorporated into the cementitious material. **Table 3.4** shows the results of heavy metal leaching test for TOSW sample and cement paste samples incorporating 10% and 20% TOSW.

Table 3.4: Leaching test results of TOSW

Element	Symbol	Raw TOSW leaching (mg/l)	Cementitious material leaching (mg/l)	
			10% TOSW	20% TOSW
Silver	Ag	0.005	0.002	0.001
Aluminum	Al	1.656	0.349	0.815
Arsenic	As	0.012	0.003	0.006
Barium	Ba	1.100	0.066	0.101
Cadmium	Cd	0.066	0.001	0.004
Chromium	Cr	0.006	0.003	0.004
Copper	Cu	0.012	0.007	BDL*
Potassium	K	80.580	3.586	24.84
Lithium	Li	0.013	BDL*	BDL*
Magnesium	Mg	4.852	0.571	0.39
Manganese	Mn	0.011	BDL*	BDL*
Molybdenum	Mo	0.056	0.005	0.005
Sodium	Na	116.358	1.746	6.438
Nickel	Ni	0.017	0.009	0.006
Strontium	Sr	3.604	0.059	0.123
Vanadium	V	0.038	0.018	0.026

*BDL: Below Detecting Limits

It is clear that both tested cementitious samples with 10% and 20% TOSW showed a reduction in metal leaching compared to that of the raw TOSW sample. Moreover, metal leaching results was below groundwater standard of the Canadian Council of Ministers of Environment (CCME). For instance, leaching of Aluminum, Arsenic, Cadmium, Copper, Nickel, and Vanadium from cement mixtures incorporating TOSW was below CCME standards within the range of 22% to 96%. This can be attributed to the solidifying of the TOSW in the microstructure of the cementitious mixtures.

In addition, the fine particles of TOSW act as a filler decreasing the void spaces and blocking the pores and thus higher amount of metal is entrapped (Sabatini and Knox, 1992).

3.4. CONCLUSIONS

The experimental results show that employing TOSW as construction material can represent an interesting and viable alternative to final landfill disposal. Based on the results of this study, the following conclusions can be drawn:

- Water of consistency of cement paste mixtures slightly decreases as the percentage of TOSW increases.
- As the proportion of TOSW in the mixture was increased, the compressive strength decreased; above 20% TOSW, the strength reduction was more than 30%. Therefore, it would be appropriate to use TOSW within 10% to 20% content by weight.
- Addition of TOSW was found to induce higher shrinkage, hence, when using TOSW in cementitious materials, it would be appropriate to apply a shrinkage mitigation method (i.e. the use of shrinkage reducing admixture). This point needs further investigation.
- Lastly, the leaching tests carried out on cementitious mixtures incorporating TOSW confirmed that the process makes it possible to obtain materials with a pollutant potential lower than that characterizing the TOSW.

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CHAPTER FOUR

PERFORMANCE OF HOLLOW BAR MICROPILES USING SUSTAINABLE GROUT*

4.1. INTRODUCTION

Micropiles are small diameter (typically less than 300 mm), drilled and grouted non-displacement reinforced pile (Cadden *et al.*, 2004). The micropiles construction in North America is growing fast since it was first introduced in the United States in the 1970s (Bruce, 1988). Nowadays, micropiles are widely used in various applications such as underpinning for existing foundations, in-situ reinforcement, seismic retrofitting and as foundations for new construction. The main advantages of micropiles are: high grout to ground bond strength, fast and limited space installation causing minimal disturbance to adjacent structures (Abd Elaziz and El Naggar, 2012 and 2014).

Micropiles are classified as installation-dependent piles. According to the Federal Highway Administration-National Highway Institution (FHWA-NHI, 2005), micropiles can be categorised into different types based on the applied grouting method during installation (Abd Elaziz and El Naggar, 2014). Drilling, placing reinforcement and grouting

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are the main three steps during micropiles installation. However, grouting is considered as the most contributing factor to the micropile capacity (Timothy *et al.*, 2012).

Generally, grout mixtures consist of cement, water and, in certain cases, additives such as superplasticizers to enhance the grout properties (FHWA-NHI, 2005). Grout has several purposes in a micropile system including: i) transfers loads between the reinforcement and the surrounding ground, ii) forms a part of the load-bearing cross section of the micropile, and iii) acts as a protective layer for the steel reinforcement from corrosion. Hence, applied grout should meet certain requirements of flowability, strength and stability (Shong *et al.*, 2003). The Federal Highway Administration Guidelines for Micropiles Design and Construction require a minimum 28 days design compressive strength of 28 MPa for grout used in micropile application (FHWA-NHI, 2005).

On the other hand, cement production is still one of the major contributors to CO_2 emission worldwide. Every year more than 1 m^3 cementitious materials is produced per person worldwide. This huge amount of cement production contributes from 5% to 8% to the CO_2 emissions around the world (Garcia *et al.*, 2010). However, in many grouting applications, excessive amount of cement is wasted in filling voids and soil gaps. Therefore, the addition of filler materials as a replacement of cement, while maintaining the same performance, is an optimum solution that provides both economic and environmental benefits. Implementing industrial wastes as the filler materials will significantly contribute to worldwide efforts targeting sustainable construction

Oil sands drill cuttings waste represents one of the most difficult challenges for the oil sands mining sector (Söderbergh *et al.*, 2007). Several technologies were applied as a pre-treatment process to extract more hydrocarbons from oil sands drill cuttings waste. One of the recent treatment technologies for the oil sands waste is Theremo-mechanical Cuttings Cleaner (TCC) (Ormeloh, 2014). The by-product of TTC is a very fine quartz powder which has the potential to be used as a filler material in many constructional applications. Utilizing this TOSW in micropiles grouting could offer an innovative solution for waste management problems associated with oil sands industry.

Therefore, this study investigates the effect of incorporating TOSW on the behaviour of hollow bar micropiles. This would pave the way for a wider implementation of TOSW in several construction applications, transforming oil sands drill cuttings waste into a high-value product.

4.2. EXPERIMENTAL PROGRAM

4.2.1. Materials and Mixture Proportions

Ordinary Portland cement (OPC) Type 10 containing 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 was used as a binder material. The TOSW material used is a silicate-based material. Chemical compositions and physical properties for OPC and TOSW are provided in **Table 4.1**.

Four grout mixtures were selected to assess the effect of TOSW addition on the behaviour of hollow bar micropiles. TOSW were added to grout mixtures as a partial replacement of cement at percentages of 0%, 10%, 20% and 30% and will be denoted as

C100, C90, C80, and C70, respectively. A constant water-to-powder ratio of 0.42 was used in all grout mixtures.

Table 4.1: Chemical composition and physical properties of cementitious materials

Chemical Analysis	Material	
	OPC	TOSW
SiO_2	21.60	61.24
Al_2O_3	6.00	8.73
Fe_2O_3	3.10	3.00
CaO	61.41	5.55
MgO	3.40	0.92
Physical properties		
Density (g/cm^3)	3.15	2.23
Surface area (m^2/g)	1.07	4.85

4.2.2. Testing Procedure and Methodology

This section provides an overview for micropile system, including the used grout and threaded hollow bar, installation process and conducted tests to characterise the performance of micropiles incorporating TOSW.

4.2.2.1. Grout testing and evaluation

During hollow bar micropiles installation, flowable grout is injected through the hollow core under high pressure. In practice, flowable grout is characterized by flow time in the range of 14 to 22 seconds based on the ASTM C939-flow cone test (Turner, 1997). Injecting such flowable grout under high pressure enhances the grout/ground skin friction, permeates grout in soil replacing loosened soils, densifies grout through forcing excess water out (i.e. pressure filtration behaviour (Kazemain and Barghchi, 2012), compacts surrounding soil and increases the diameter of the pile in the bond zone (Shong *et al.*, 2003). All these benefits would probably improve micropiles performance.

Therefore, effects of TOSW addition on flowability, compressive strength and modulus of elasticity of grout mixtures used for micropile were investigated following ASTM C939, ASTM C109 and ASTM C496, respectively. All grout mixtures were prepared according to ASTM C305. Specimens for each test were cast from each tested grout mixture and cured inside a moist curing room at ambient temperature = 23± 2°C and relative humidity = 98% until testing age. In addition, the effect of the injection process under high pressure on grout mechanical properties was evaluated on cubic samples (50 mm) cut from the grout body of the tested micropile.

4.2.2.2. Hollow bar micropile installation

Threaded hollow bar micropiles with 1.3m length were tested with different grout mixtures. The hollow bar system comprised of a fully threaded hollow steel bar with 21 mm inner diameter and 36.4 mm outer diameter (**Fig. 4.1a**). In addition, a carbide chisel cross cut bit (90 mm diameter) is threaded to the end of each hollow bar (**Fig. 4.1b**). This drill bit has three nozzles to facilitate grout injection through the hollow core of the threaded bar during micropiles installation. Hence, drilling and grouting are conducted in a single installation step (Abd Elaziz and El Naggar, 2012).

(a)

(b)

Figure 4.1: Micropile a) R38-420 DYWI Hollow Bars and b) Carbide button cross cut drill bit (d = 90mm)

All micropiles were installed in a 1.35 m diameter and 1.95 m depth steel tank filled with concrete sand (**Fig. 4.2**). To insure the verticality of hollow bars, a guiding system was constructed over the steel tank as shown in **Fig. 4.3**. In addition, during hollow bars installation, torpedo level was used frequently to assure the verticality of the installed micropiles.

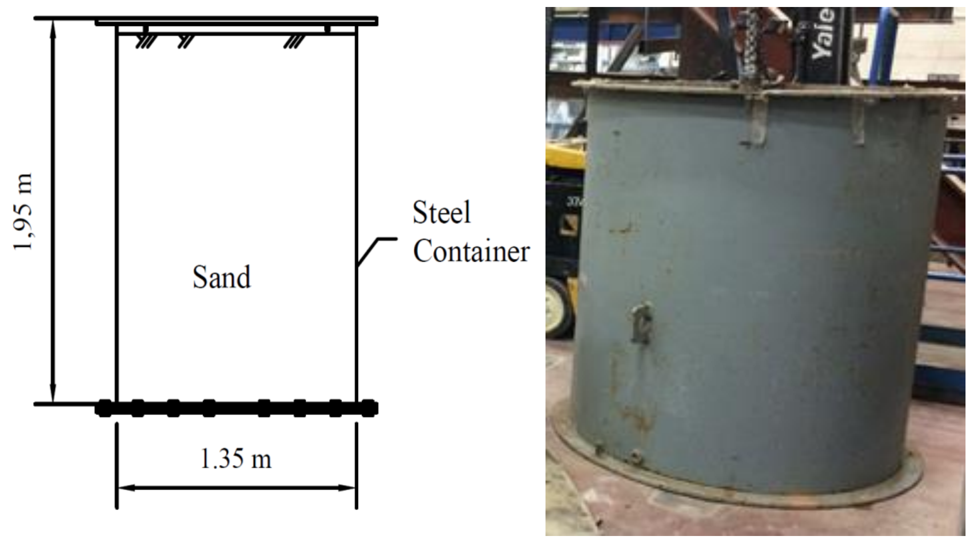


Figure 4.2: Steel tank used in the installation of micropiles

Figure 4.3: Guiding system to insure verticality of hollow bar micropiles

The steel tank was filled and compacted in layers 25 cm thick each. Each layer was manually compacted using a 10 kg tamping rod with a 20 cm by 20 cm bearing plate and using a constant number of blows per lift. A consistent relative density (i.e. D_r = 35%) was maintained in all tests. Geotechnical properties for the used concrete sand were evaluated, including: natural water content (ASTM D2216), dry unit weight (ASTM D7263), direct shear tests (ASTM D3080), specific gravity of soil solids (ASTM D854), and standard proctor tests (ASTM D1557). These properties are listed in **Table 4.2**.

Table 4.2: Concrete sand soil properties

wc %	γ_{max} (g/cm^3)	G_s	e_{max}	e_{min}	ϕ_p°
3	1.98	2.69	0.78	0.35	41

Initially, TOSW was mixed with water for 30 seconds, then cement was added and mixed for additional 5 minutes to insure adequate blending of TOSW. After mixing, grout was placed and injected under pressure with the aid of a special fabricated steel cone (**Fig. 4.4**). Injecting pressure was monitored and measured through a pressure gauge and valve fixed on the steel cone.

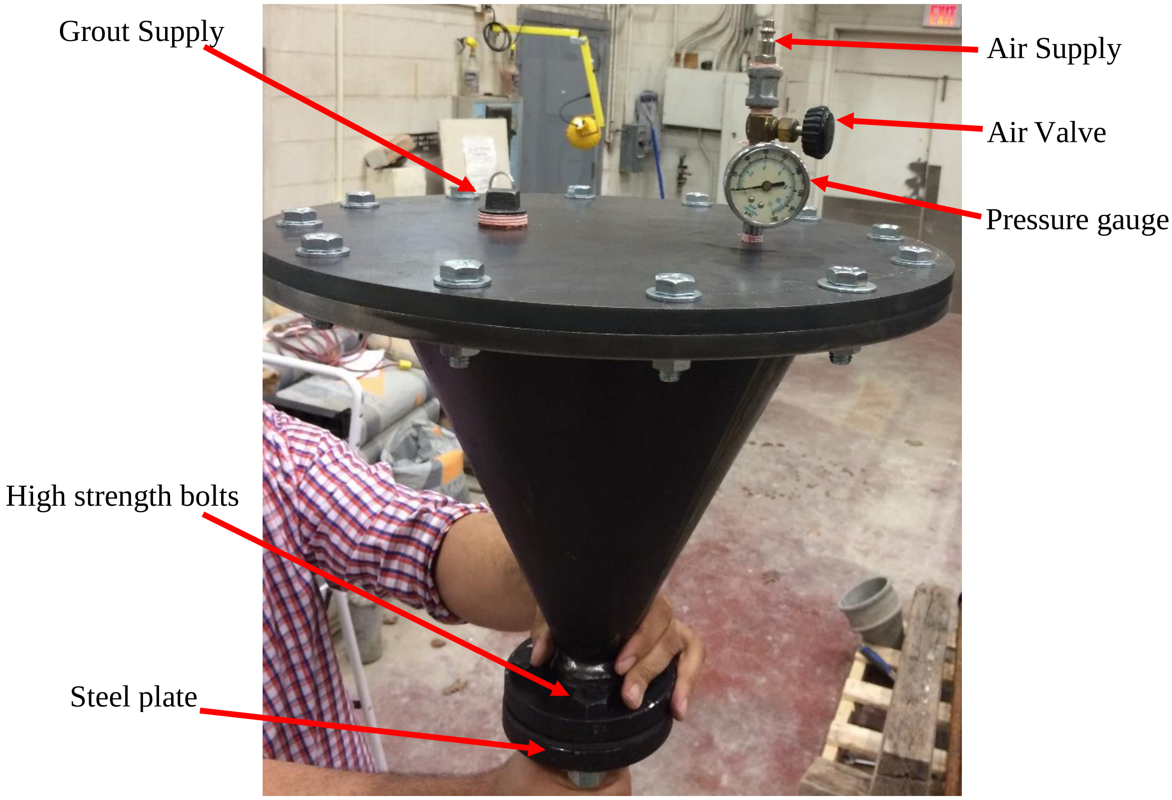


Figure 4.4: Pressure cone used for injecting grout under pressure

4.2.2.3. Hollow bar micropile axial compression loading test

Figure 4.5a shows the setup for the axial compression loading test. Four linear variable displacement transducers (LVDTs) were placed over the pile head to monitor the pile displacement. A load cell at the micropile head was used to measure the applied load. In addition, each pile was instrumented with six strain gauges in order to evaluate the load transfer mechanism (**Fig. 4.5b**).

All data from the LVDTs, strain gauges and the load cell were collected using a data acquisition system during test. A quick maintained static load test procedure according to ASTM D1143 was adopted. Micropiles were loaded in increments of 5% of their expected failure load. Each load increment was maintained for 5 minutes. All the installed micropiles were loaded to the point of failure, where rapid movement occurred under slightly increased load.

(a)

(b)

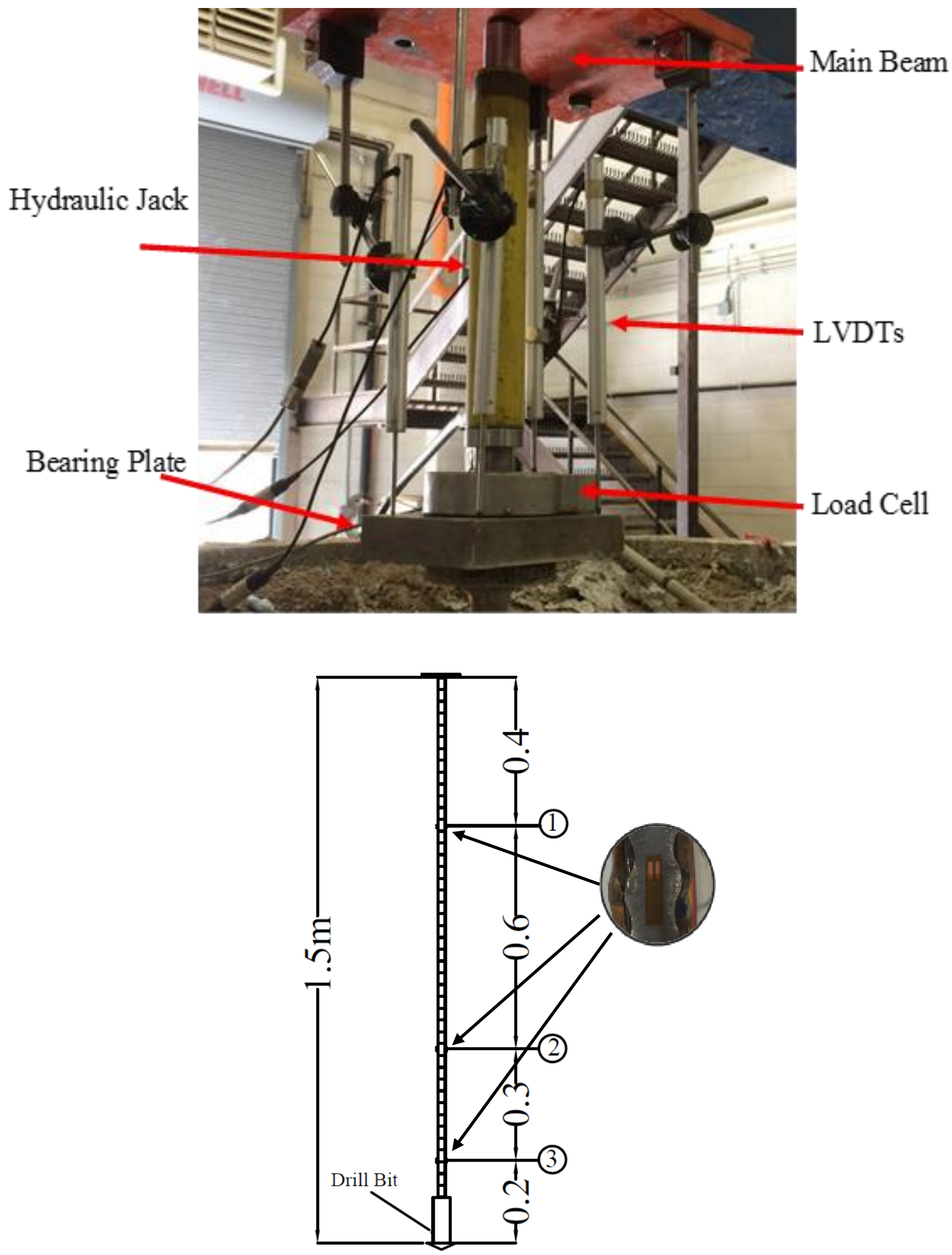


Figure 4.5: Illustration for a) axial Compressive testing setup and b) locations of strain gauges on the micropile

4.2.2.4. Surface profile evaluation of hollow bar micropiles

The interface behaviour is an important factor for the design and performance of many geotechnical applications such as friction piles, soil nails, anchors, and micropiles. It depends on soil type, grain size distribution, surface roughness and normal stresses at the surface of interface (Giraldo *et al.*, 2013). Therefore, determining soil-foundation interface properties is essential for geotechnical applications that depend on the frictional resistance between the construction material and surrounding soil material (Bhengu *et al.*, 2013).

In micropiles design, the maximum applied compression and tension loads must be resisted through grout to ground bond over the contact area between the grout and soil along the bond length of the micropile. Therefore, in most cases, micropiles attain load carrying capacity mainly through skin friction rather than end bearing (FHWA-NHI, 2005).

Therefore, installed hollow bar micropiles with different percentages of TOSW were extracted from the soil after testing in order to investigate their actual profiles through measuring the effective diameters, cross section details and interface properties (i.e. roughness and grout to soil interface friction angle).

4.2.2.4.1. Roughness evaluation

The pile surface roughness has a major impact on its interface behaviour with surrounding soil. According to the literature, surface roughness can be classified into micro and macro-roughness. Micro-roughness is relevant at the scale of soil particle size being sheared against the surface. Macro-roughness describes the undulations along the surface of the tested specimens, which can result in more internal work when the shearing follows this path (Giraldo *et al.*, 2013). Surface roughness can be calculated using different methods. The simplified approach presented by (Giraldo *et al.*, 2013) was adopted in this study to evaluate the surface roughness. In this method, surface roughness is calculated by measuring the average displacements measured at each data point, known as the total roughness (R_t), and the root mean square of the same points gives the average roughness (R_a) as shown in **(Eq. 4.1)**.

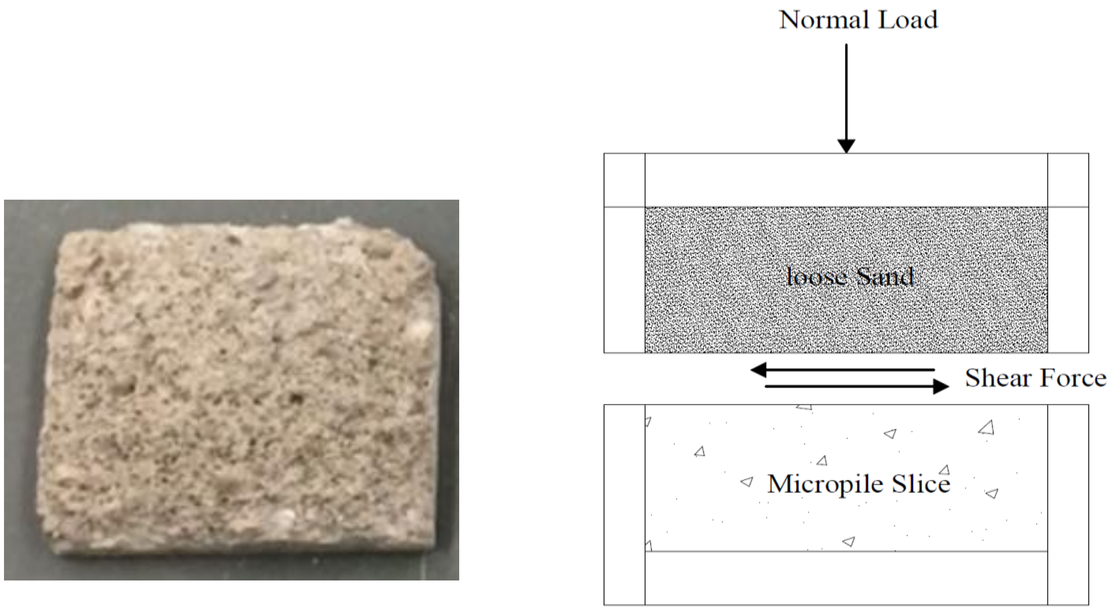
$$R_t = \frac{h_1 + h_2 + \cdots + H_n}{n}, R_a = \frac{\sqrt{h1^2 + h1^2 + \cdots + Hn^2}}{n} \quad (4.1)$$

The roughness profiles were determined using Barton Comb profiling tool (Barton and Choubey, 1976; Urian, 2013). Barton Comb consists of linear arranged wires that can take the shape of irregularities when pressed against the surface of specimens. Different sections along the grout body of micropiles were studied. The average roughness height and the total roughness height of each section were calculated.

4.2.2.4.2. Interface friction angle

Previous shear strength studies have shown that the interface friction angle increases as the relative surface roughness increases (Pando *et al.*, 2002). The interface shear strength was evaluated using a direct shear test apparatus which consisted of a shear box with inside dimension 60 mm × 60 mm and a 25.5 mm height. The confining pressure (i.e. vertical stresses) was applied to the specimen by a steel bearing arm using weights. Slice specimens with dimension of 60 mm × 60 mm were cut from the grout body of micropiles (**Fig. 4.6a)** and placed in the lower portion of the box. The box was carefully reassembled and sand was fitted to ensure complete interface contact between sand and the tested sample (**Fig.**

4.6b). The direct shear tests were conducted under three different confining pressure of 25, 50 and 100 kPa. A constant strain rate was used during the tests.



(a) **(b)**

Figure 4.6: Direct shear test a) slice sample and b) test configuration

4.3. RESULTS AND DISCUSSIONS

4.3.1. Grout Properties

As previously mentioned, micropile capacity will be mainly governed by its skin friction and consequently the load transfer behaviour, which in turn relies on the used grout properties (Juran *et al.,* 1999, Shong *et al.,* 2003). **Table 4.3** summaries fresh and hardened properties for the tested grout mixtures. The results show that the addition of TOSW had shortened the flow time producing a higher flowable grout.

Table 4.3: Grout mixtures fresh and hardened properties

Mixture	Flow Cone (sec)	Compressive strength (MPa)		Modulus of Elasticity (GPa)
		7 D	28 D	
MP0	15.2	44.5	52.0	15.1
MP10	14.7	36.5	48.5	15.0
MP20	14.5	33.0	46.0	14.8
MP30	14.0	28.0	39.0	14.6

The effect of TOSW addition can be considered as a resultant of two compensating effects: TOSW is a very fine material; hence, it increases the surface area in the mixture leading to a higher water demand. Simultaneously, small particles size of TOSW allows it to penetrate between cement particles filling the inter-particle spaces and freeing entrapped water. Consequently, the increase in the free water content reduces the flow resistance of grout making it more flowable (Khaleel and Razak, 2012).

As shown in **Table 4.3**, the higher the replacement rate of cement by TOSW, the lower the achieved hardened properties. For instance, at age 28 days, grout mixtures incorporating 10%, 20% and 30% exhibited 5.3%, 11.1% and 27.0% lower compressive strength than that of the control grout mixture, respectively. This can be explained as follows: development of hardened properties of grout is mainly related to the progress in the hydration reactions between cement and water. Hence, replacing cement by TOSW, which is an inert filler material, will lead to a dilution effect resulting in a slow hydration progress and consequently lower hardened properties (Amen, 2011). At later ages, filler addition improves compressive strength of grout as it fills voids and reducing the volume needed to be filled by hydration products leading to more homogenous and denser grout (Jaturapitakkul *et al.*, 2011). It should be mentioned that, even though the achieved strengths by TOSW grout mixtures were lower than that of the control mixture, it still meet the target strength (i.e. 28 MPa at 28 days (FHWA-NHI, 2005)).

4.3.2. Micropiles Profile

This section investigates the profile of hollow bar micropiles installed using grout with and without TOSW. **Figure 4.7** shows the diameter change over the length for each micropile installed using different percentages of TOSW. It seems that the addition of TOSW slightly improved the penetrability of grout to the surrounding soil. Micropiles installed using 0% and 10% TOSW grout mixtures exhibited the same average diameter (i.e. about 15.0 cm = 1.65 drill bit), while micropiles installed using 20% and 30% TOSW grout mixtures showed a slight increase in the achieved average diameter (i.e. 15.3 =1.7 drill bit and 15.8 cm =1.75 drill bit, respectively). Hence, it could be concluded that the addition of TOSW will not adversely affect the size of the grout body formed around the steel hollow bar.

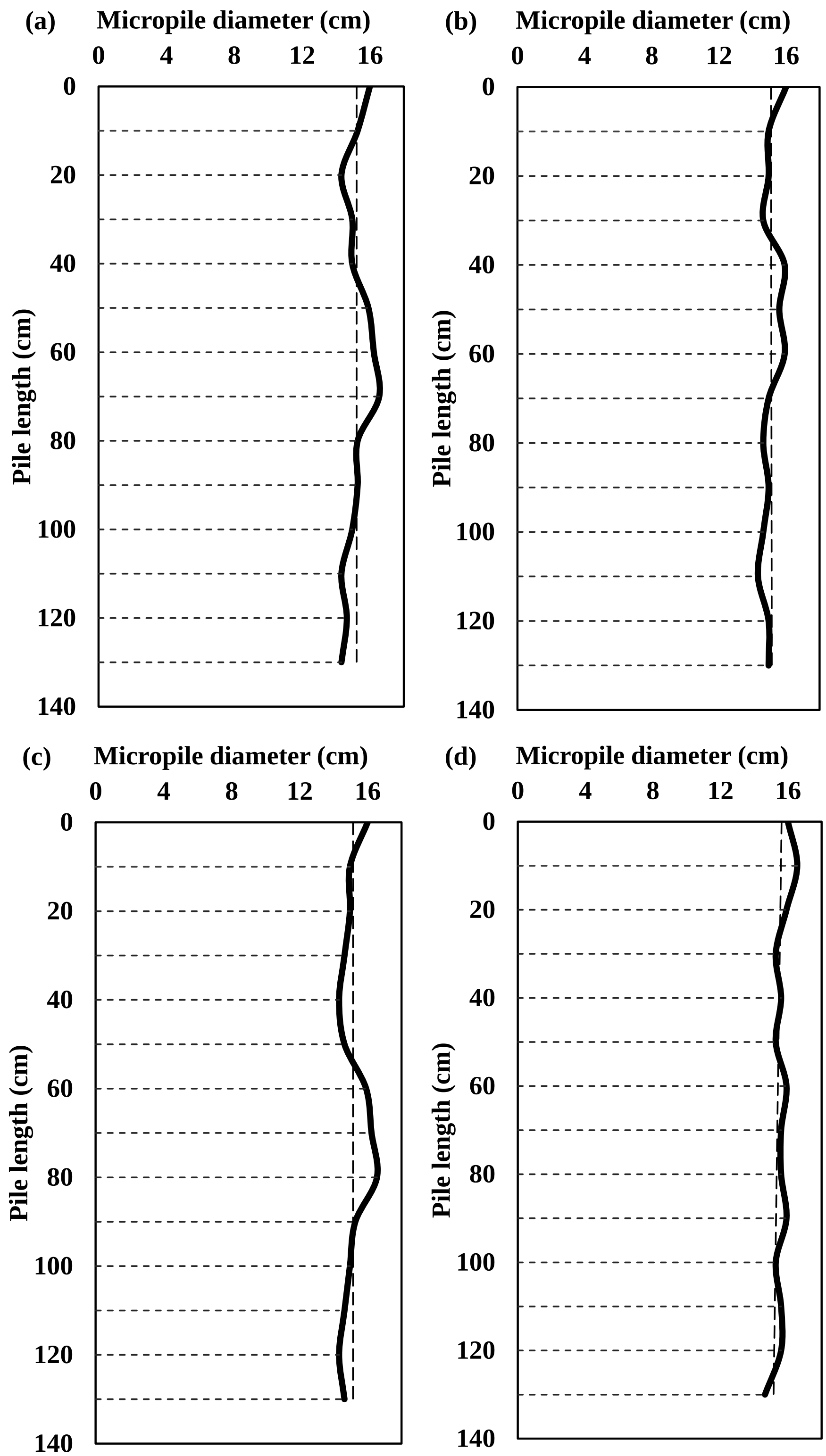
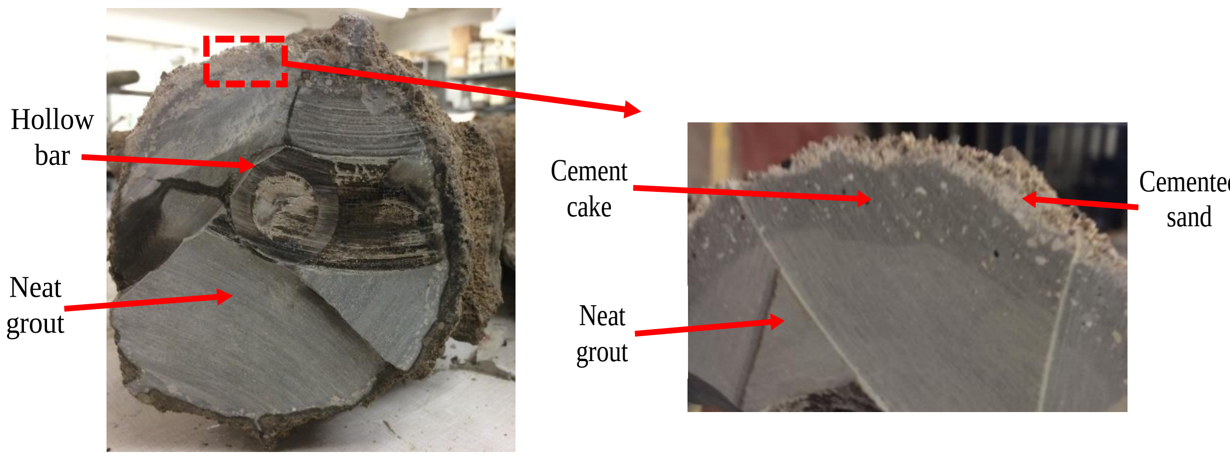


Figure 4.7: Changes in hollow bar micropile diameter over the length for a) 0%, b) 10%, c) 20%, and d) 30% TOSW

Furthermore, **Figure 4.8a** shows a cross section for a hollow bar micropile installed using grout incorporating TOSW. The hollow bar micropile grout body consists of the hollow steel bar, neat cement, a cake like cement paste and a thin layer of cemented sand that covers the grout body. The same cross section profile was found for micropile installed using conventional grout. This confirms that grout with and without TOSW had similar performance.



(a)

(b)

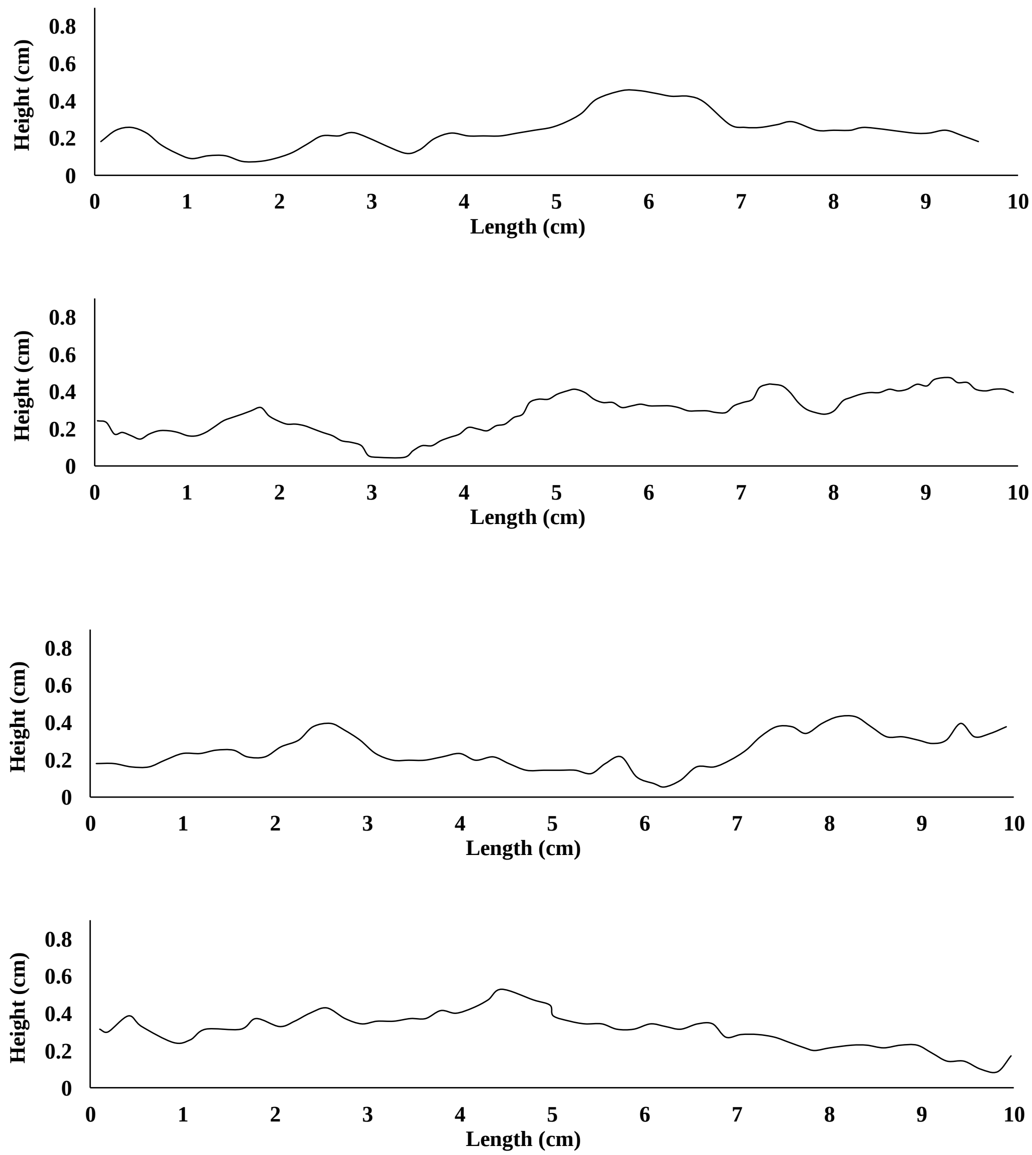
Figure 4.8: Illustration for a) Cross-section for a tested micropile and b) Threaded bar - grout bond surface profile

4.3.2.1. Micropiles interface Roughness

Based on the simplified approach described previously, the average roughness height (R_a) and the total roughness height (R_t) for each section were calculated using **Eq. 4.1**. **Figure 4.9 (a,b, c, and d)** shows different roughness profiles for the installed hollow bar micropiles incorporating different percentages of TOSW. It is clear that the addition of TOSW had a minor effect on the roughness of hollow bar micropiles. The maxmium varaitions in R_h and R_a were only around 5% and 2%, respectively. **Table 4.4** summarizes the roughness measurments for the tested micropiles.

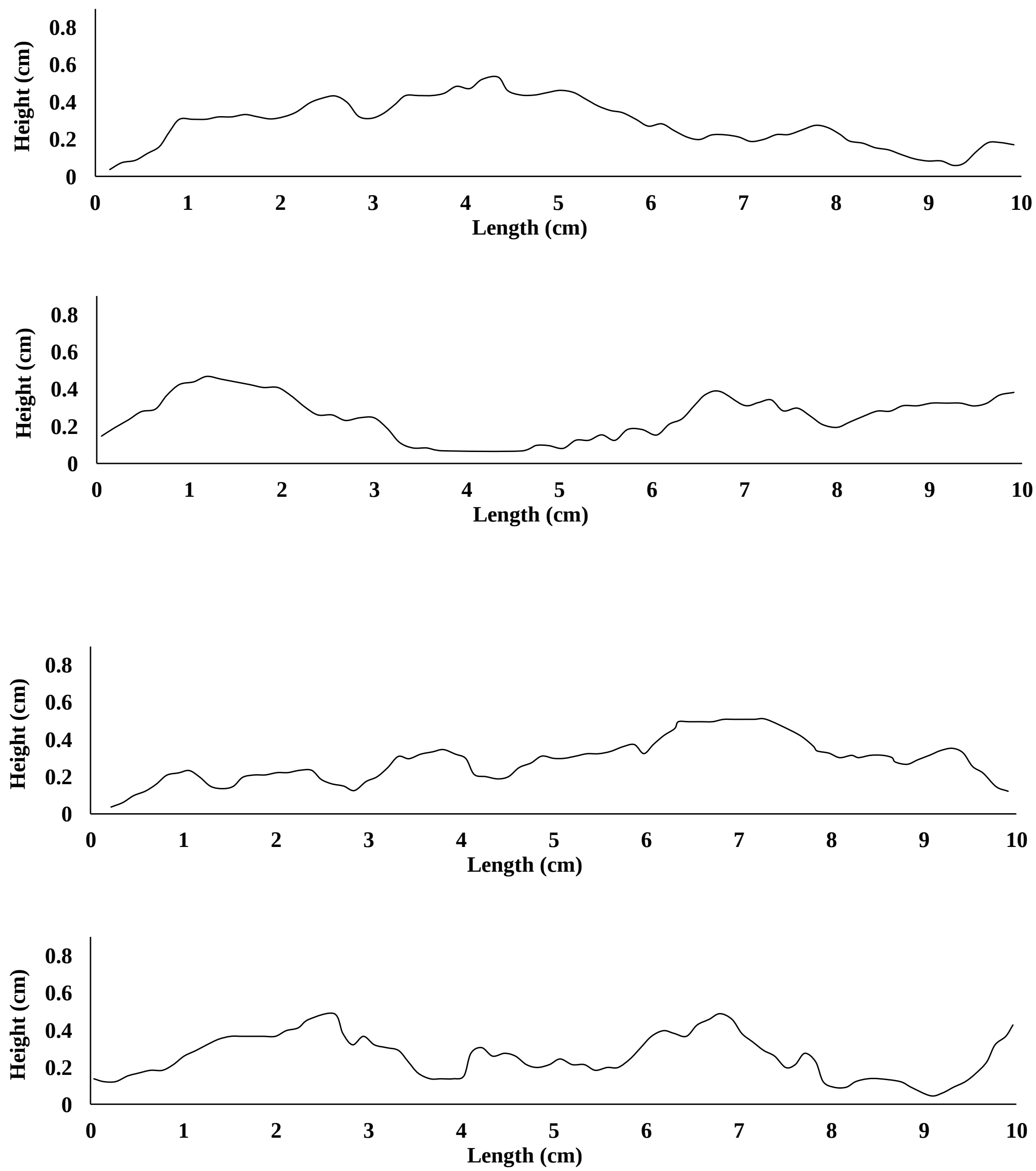
Table 4.4: Pile interface roughness and shear strength properties

Interface	R_h (mm)	R_a (mm)	φ°	δ°	δ/φ	tanδ/tanφ
Micropile 0%	2.61	1.63	41	48.4	1.185	1.295
Micropile 10%	2.70	1.65	41	48.15	1.175	1.285
Micropile 20%	2.65	1.62	41	49.275	1.2	1.335
Micropile 30%	2.74	1.66	41	48.56	1.185	1.305



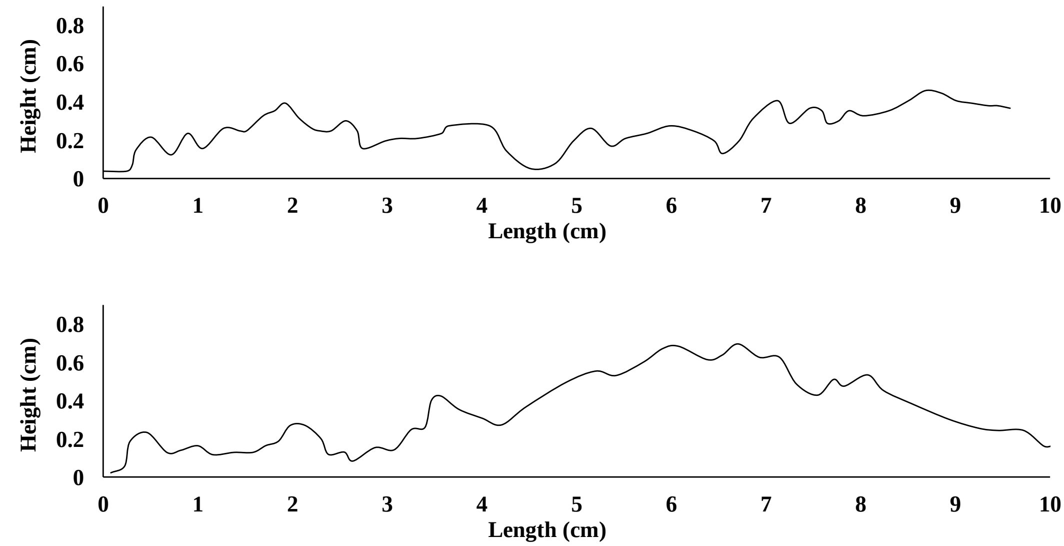
(a)

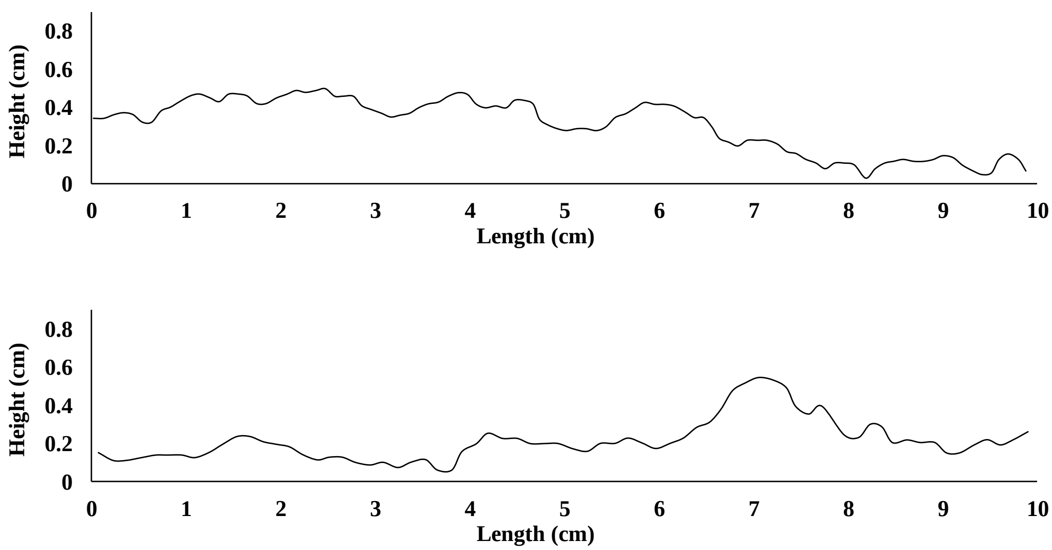
Figure 4.9: Roughness profile of different hollow bar micropile sections, a)control micropile, b) 10% TOSW, c) 20% TOSW and d) 30% TOSW



(b)

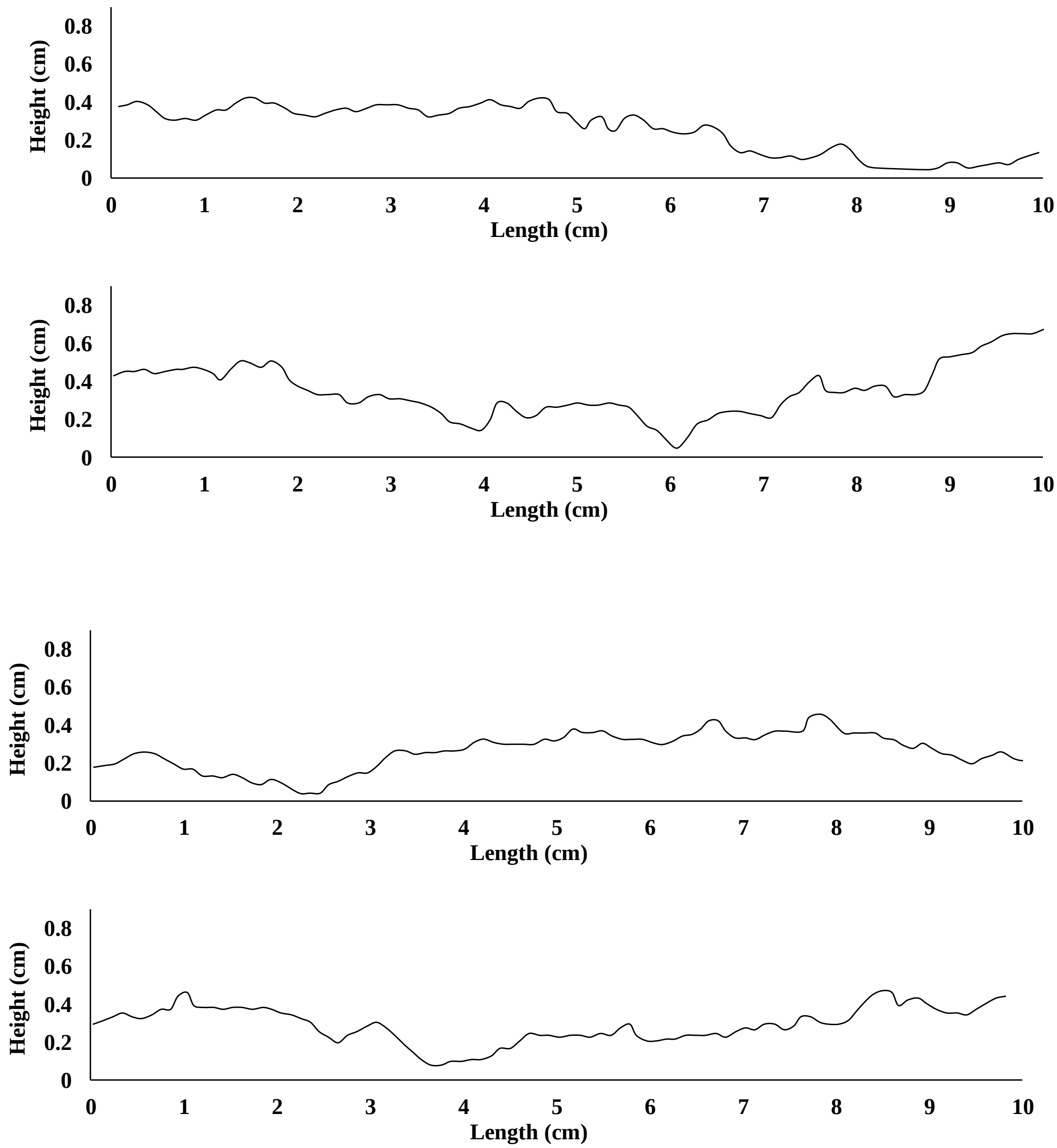
Figure 4.9 Contd': Roughness profile of different hollow bar micropile sections, a)control micropile, b) 10% TOSW, c) 20% TOSW and d) 30% TOSW





(c)

Figure 4.9 Contd': Roughness profile of different hollow bar micropile sections, a)control micropile, b) 10% TOSW, c) 20% TOSW and d) 30% TOSW



(d)

Figure 4.9 Contd': Roughness profile of different hollow bar micropile sections, a)control micropile, b) 10% TOSW, c) 20% TOSW and d) 30% TOSW

4.3.2.2. Micropiles interface shear strength

Figure 4.10 illustrates results of direct shear tests between sand and slice samples from the micropile grout body. The shear failure envelopes showed a similar trend for all the tested samples. **Table 4.4** summarizes the results in terms of the ratio between the interface frictional angle and the sand internal friction angle (δ/ϕ).

It seems that the addition of TOSW in the grout mixtures did not affect the interface properties of hollow bar micropiles. This is in agreement with surface roughness results as interface behaviour of any material is directly linked to its surface roughness (Lehane *et al.*, 1993). Generally, a high surface roughness leads to a high interface friction and vice versa (Frost *et al.*, 1999). One interesting finding is, the interface friction angle between the sand and micropile slice samples was higher than that of the used sand. The average calculated interface friction angle for micropiles slices was 48°.

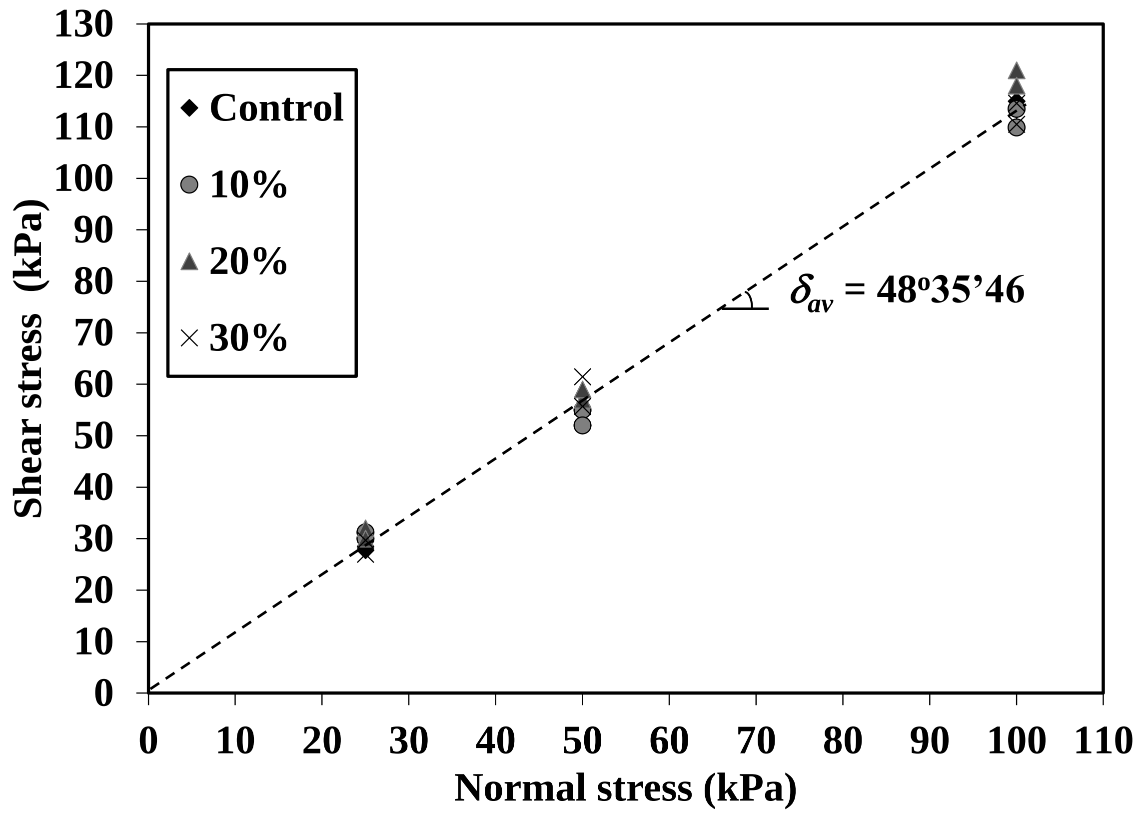


Figure 4.10: Calculated interface angle using direct shear test results

Usually, the upper bound for the interface angle (δ) is assumed to be equal to the angle of internal friction ϕ° of the soil in contact (Vaid and Rinne, 1994). However, in the literature, it was reported that the calculated interface angle for rough materials can have values higher than the angle of internal friction of the contact soil. For instance, previous study conducted by (Giraldo *et al.*, 2013) to investigate the interface properties of clay with different construction materials, showed that the ratio between the interface frictional angle of grout and clay internal friction angle (δ/ϕ) was about 1.64. Similar behaviour was also reported by (Chu *et al.*, 2006) who investigated the shear strength interface between granite and a cement grout material using direct shear apparatus. This higher interface angle can be ascribed to the high surface roughness of the tested sample leading to a large waviness angle at the contact between the grout and surrounding sand along with inducing a turbulent shear failure (i.e. round particles tend to rotate neglecting the orientation of the platy particles) (Giraldo *et al.*, 2013, Chu *et al.*, 2006).

4.3.3. Axial Behaviour of Hollow Bar Micropiles

Micropiles transfer axial loads by two mechanisms: skin friction and end bearing. The skin resistance is the result of relative movement and displacement along the grout body of the micropiles, and is commonly referred to as the adhesion between the soil and the micropile. The end bearing resistance results from the bearing load between the bottom of the micropile and the soil (Urian, 2009). However, the capacity of micropiles is limited by its small cross-section area. Therefore, the skin friction of micropiles is usually reported as the primary contributor to the load transfer. Moreover, the Federal Highway Administration for Micropile Design and Construction (FHWA-NHI, 2005) recommend considering the skin friction only in the geotechnical design of micropiles. Recently, this was confirmed by (Drbe and El Naggar, 2014) as results showed that the end bearing resistance can be neglected in the design of micropiles.

Therefore, in this study, skin friction was considered as the dominant factor controlling the design of micropiles installed using grout with 0%, 10%, 20% and 30% TOSW denoted as MP0, MP10, MP20 and MP30, respectively.

4.3.3.1. Load-displacement curves

Micropiles MP0, MP10, MP20, and MP30 were loaded to failure in order to evaluate their ultimate capacities. The measured load-displacement curves for different tested micropiles are shown in **Fig. 4.11**.

As shown in **Fig. 4.11**, all loading tests indicate the occurrence of plunging failures, which confirms that most of the applied load was transferred through the micropile shaft. The load-displacement curves for MP0 and MP10 show a plunging failure occurred at approximately 53 kN. Plunging failures for MP20 and MP30 occurred at slightly higher loads compared to that of the control (i.e. 56 kN and 59 kN, respectively). These loads causing plunging can be considered as the micropile ultimate capacity.

To confirm these results, another method for estimating the failure load of piles presented by (Fuller and Hoy, 1970) was applied. In this method, a failure load is defined using a tangent to the load-settlement curve sloping at 0.15 mm/kN. This method is recommended by (FHWA-NHI, 2005) for micropiles and it is suitable for short piles tested under quick maintained tests (Drbe and El Naggar, 2014). The pile ultimate capacity values for the tested piles are presented in **Table 4.5**.

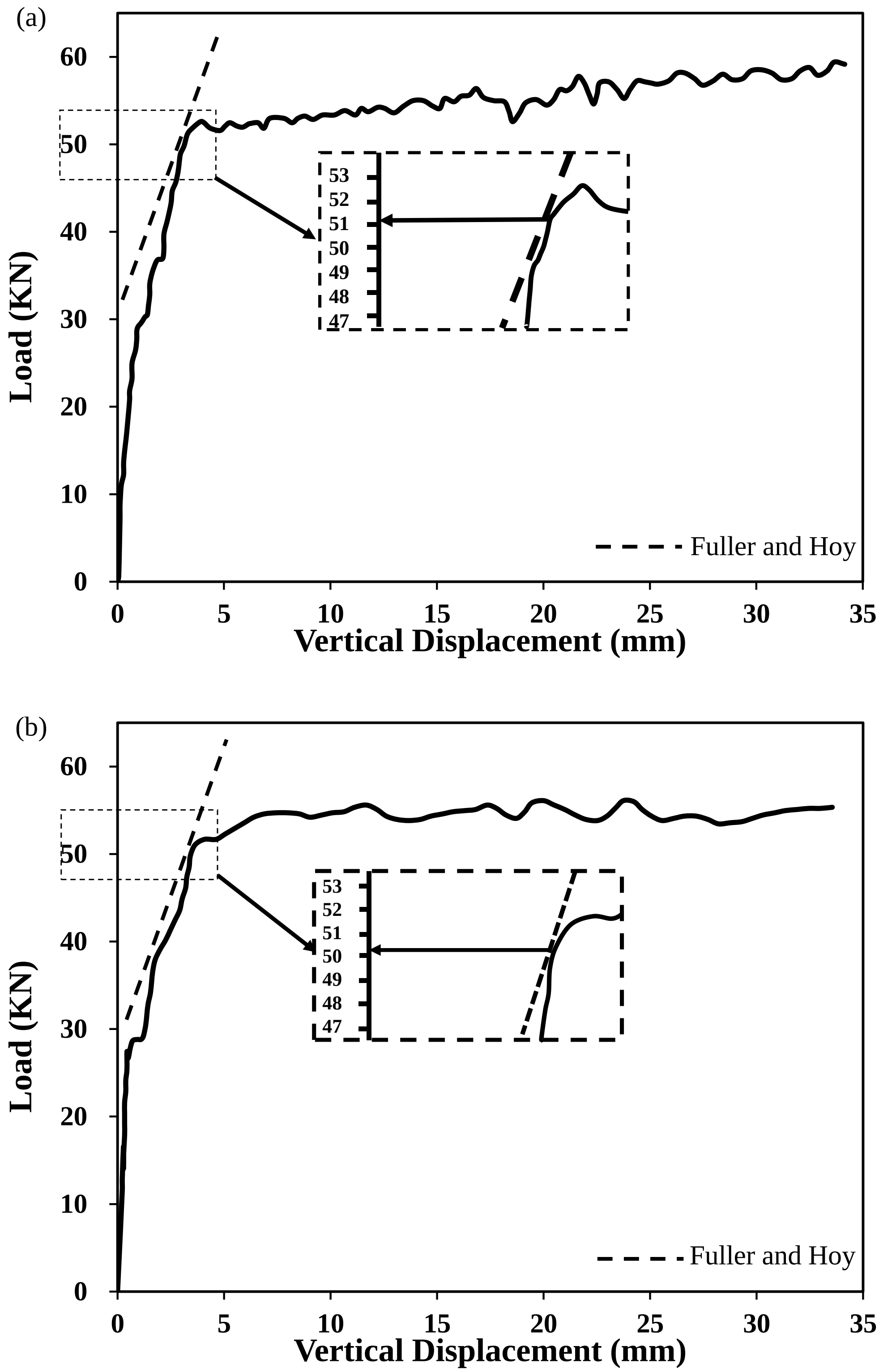
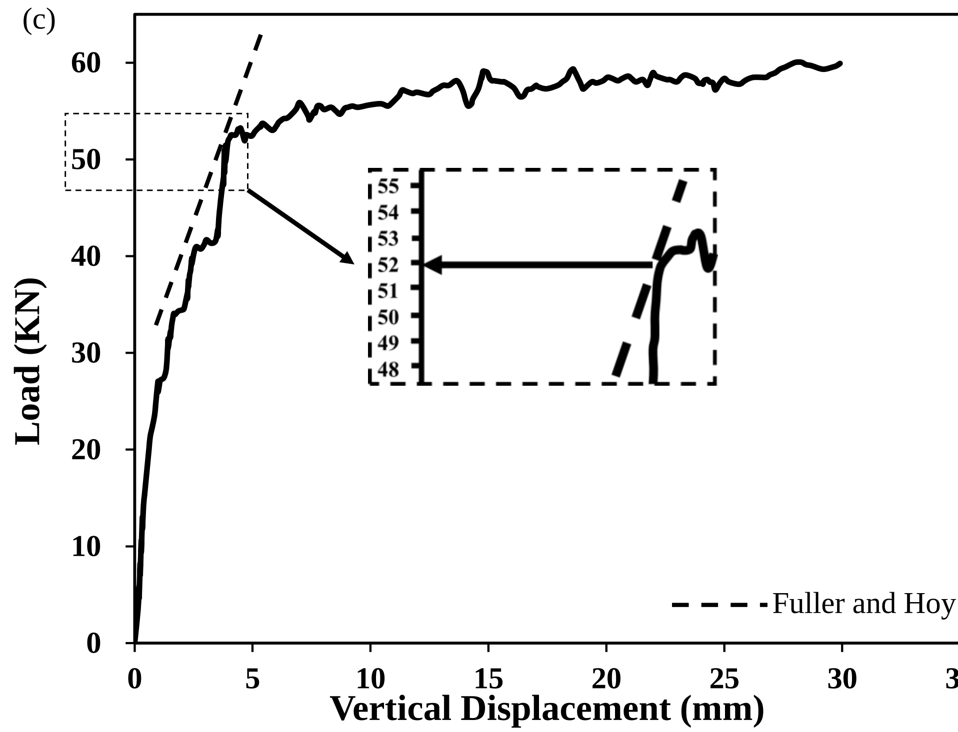


Figure 4.11: Load-displacement curves for micropiles a)MP0, b)MP10, c) MP20 and d)MP30



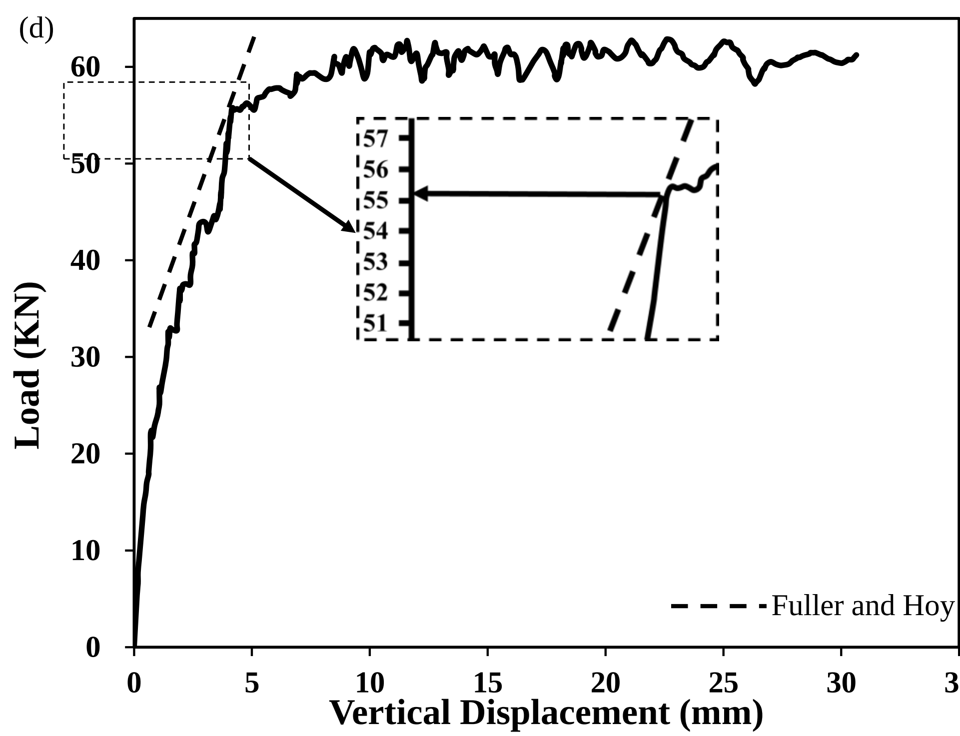


Figure 4.11 Contd': Load-displacement curves for micropiles a)MP0, b)MP10, c) MP20 and d)MP30

It is noted that failure loads derived from Fuller and Hoy's method were close to those defined by the plunging failure. Moreover, there is a minor difference between the capacity of the control micropile and micropiles incorporating different percentages of TOSW. The variation in the achieved micropile capacity was in the range of -1.9% and +7.2%. The slight increase in MP30 can be attributed to the enlargement in its average diameter enhancing the soil/ground interface properties.

Table 4.5: Pile ultimate compressive capacity

Pile	Ultimate capacity Fuller and Hoy (kN)
MP0	51
MP10	50
MP20	52
MP30	55

On the other hand, according to the federal highway administration for micropile design and construction (FHWA-NHI, 2005), hollow bar micropiles are classified as Type B micropiles. For Type B micropiles installed in loose to medium dense sand, a grout-to-ground nominal strength ranges between 70 kPa and 170 kPa. In this study, considering the relative density of the soil used in the installation of micropiles, the grout-to-ground bond ultimate strength used in the calculated design capacity was 85 kPa. Therefore, the ultimate capacity for micropiles with 90 mm drill bits, having an average diameter of 15.2 cm, should have an average ultimate capacity of 55 kN. Following the load displacement curves presented in **Fig. 4.11,** there is an agreement between the measured ultimate capacity for the installed micropiles and the calculated ultimate capacity based on (FHWA-NHI, 2005) design equations. It should be mentioned that the difference between the back calculated grout-to-ground bond values from the observed results and those presented in (FHWA-NHI, 2005) was only in the range of 1% to 6%.

4.3.3.2. Load transfer mechanism:

Strain gauges reading were used to evaluate the load transfer mechanism. The axial forces at different depths (P_z) were calculated based on the measured strains **(Eq. 4.2):**

$$P_z = \varepsilon A_p E_p \tag{4.2}$$

Where ε is the measured strain, A_p is the cross-sectional area of the micropile, and E_p is the elastic modulus of the micropile material. In hollow bar micropiles, the grout is fully bonded with the hollow bar, hence, strains in the grout and the hollow bar can be assumed to be equal (Drbe and El Naggar, 2014). This was confirmed with the threaded bars grout bond surface profile captured in **Fig. 4.8b**. It is anticipated that this non-uniform surface will probably enhance the bond capacity between the grout and the hollow bar. The elastic modulus of micropiles under compression loads can be calculated using the following **(Eq. 4.3)**:

$$A_p E_p = A_s E_s + A_g E_g \tag{4.3}$$

Where E_s is the elastic modulus of steel, A_s is the steel cross-sectional area, E_g is the elastic modulus of grout, and A_g is the grout cross-sectional area. Compressive strength for cubic specimens cut from the grout body was almost the same as that for specimen cast during installation indicating the minimal effect of injecting process (**Fig. 4.12**).

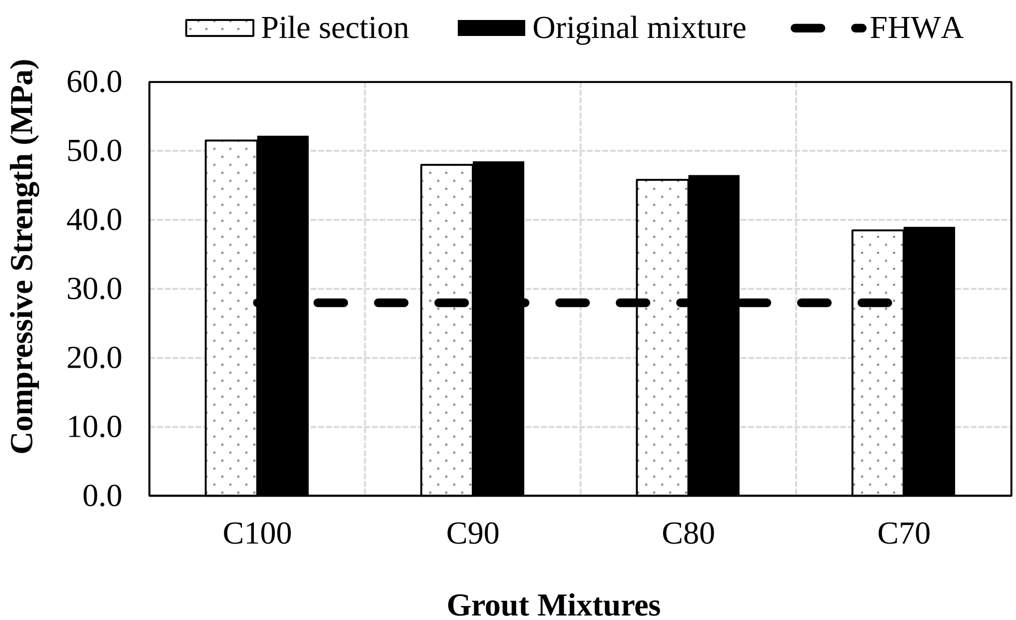
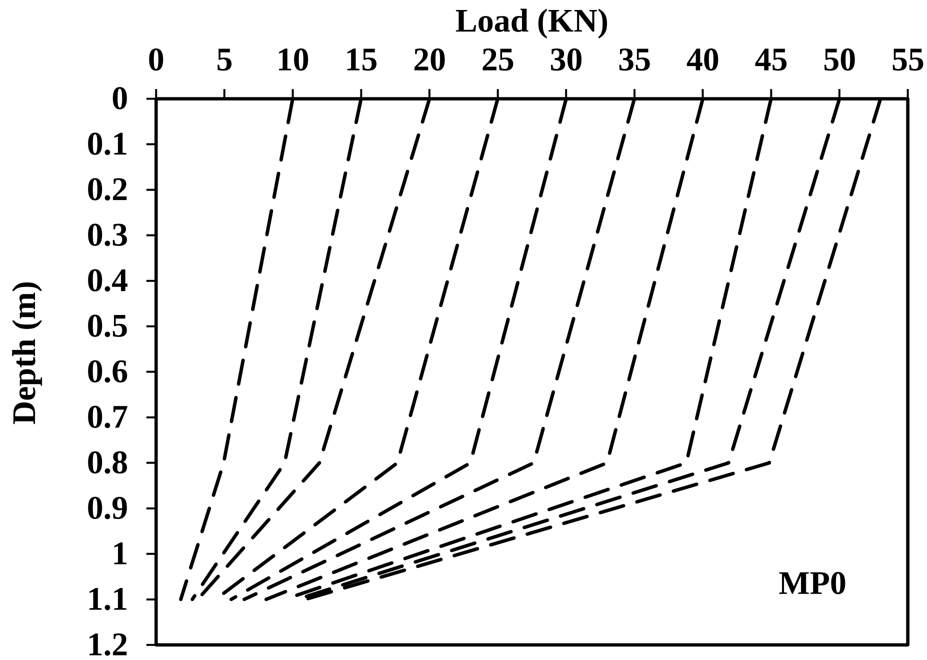


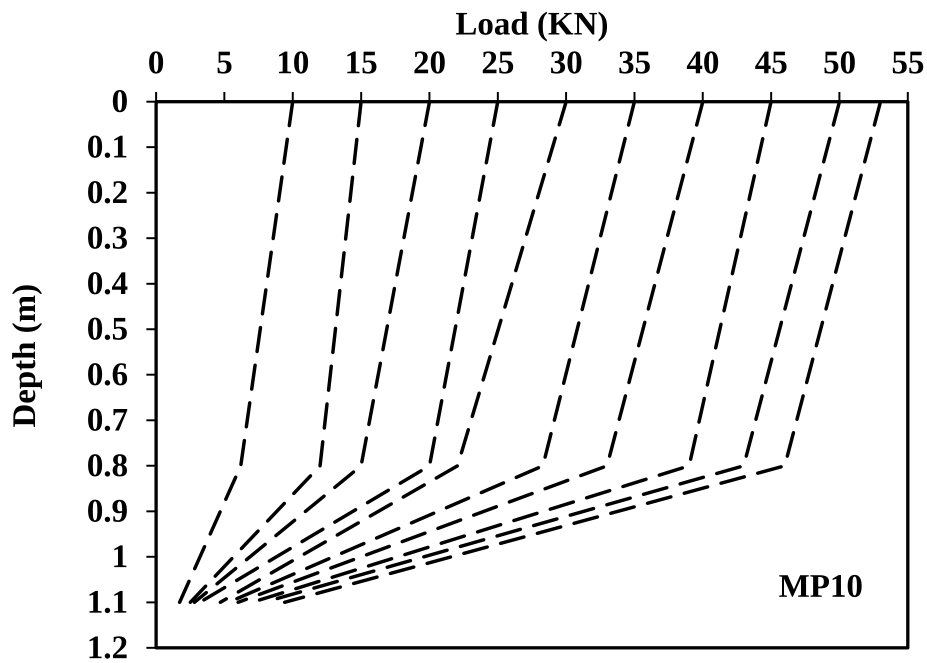
Figure 4.12: Compressive strength results for original grout and injected grout

According to Sideris (2003), there is a linear relationship between grout compressive strength and its modulus of elasticity. Therefore, modulus of elasticity for grout will not be affected by the injecting process and Eg will be taken equal to values shown in **Table 4.3**.

The load distributions over the length of installed micropiles are illustrated in **Fig. 4.13**. It should be mentioned that, due to challenges during the installation process, some mounted strain gauges were damaged and did not function properly (i.e. for MP20 at location 3 shown in **Fig. 4.5b**.

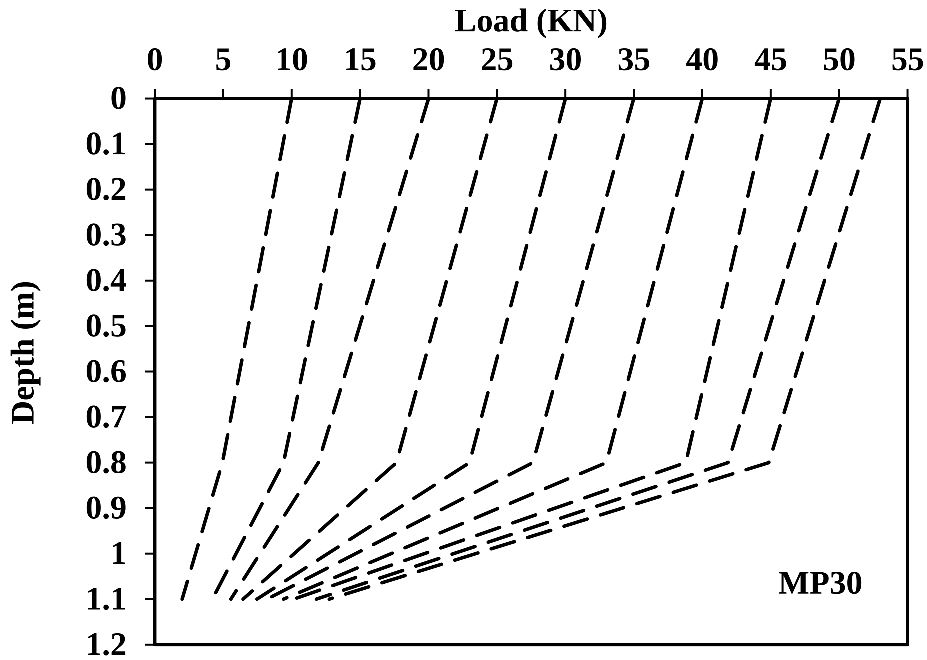


(a)



(b)

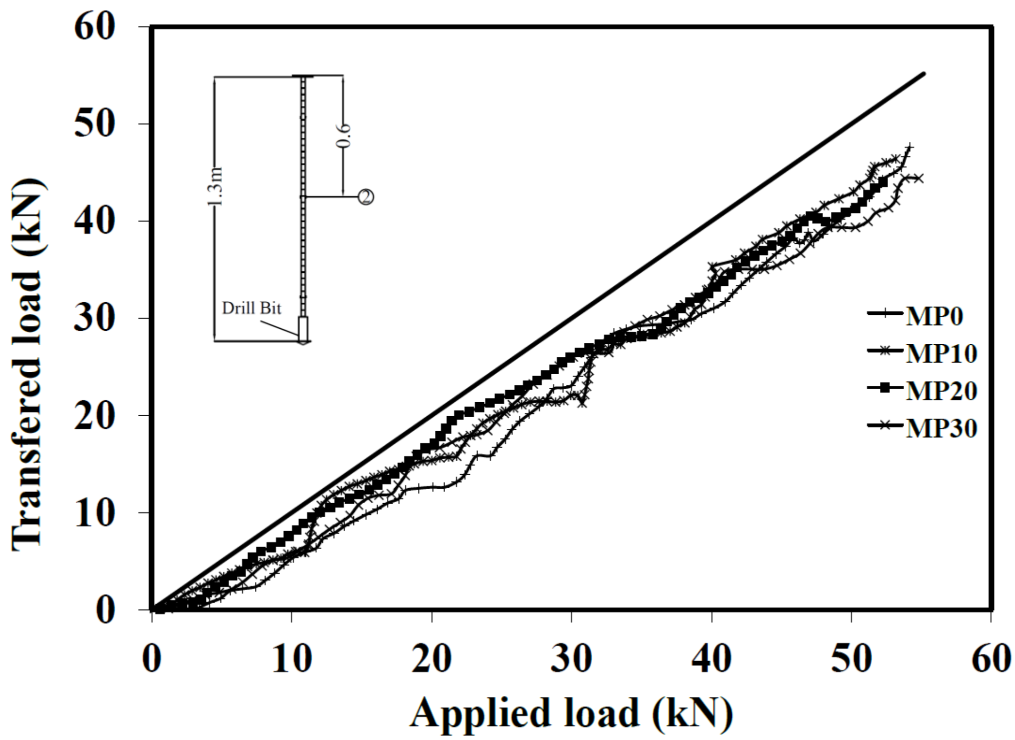
Figure 4.13: Load distribution for the applied load for a) MP0, b) MP10 and c) MP30 micorpile



(c)

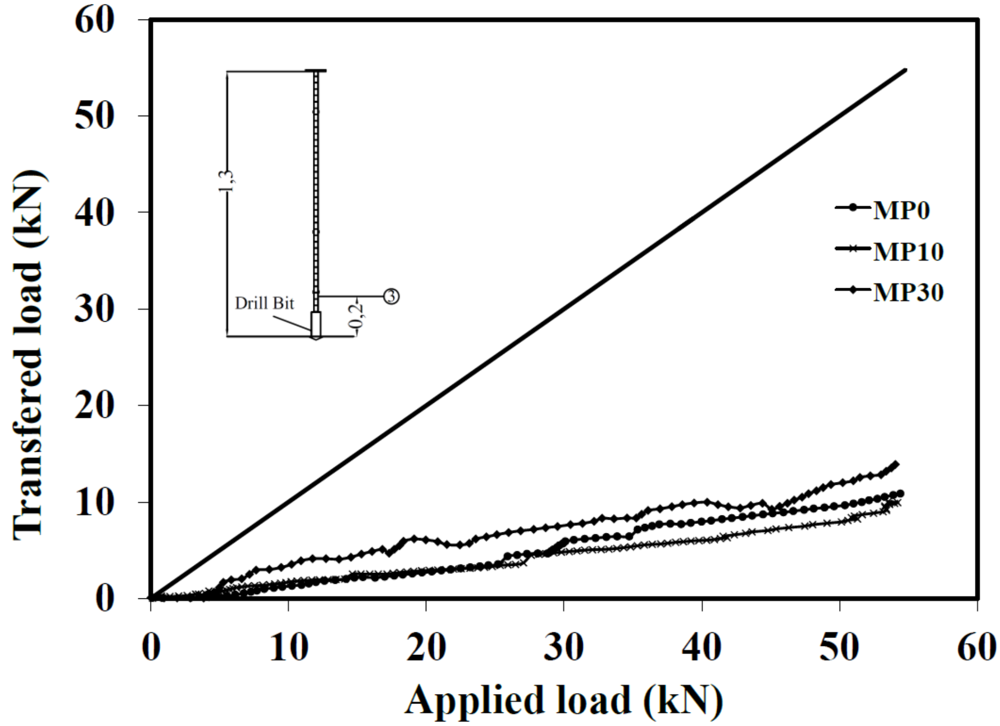
Figure 4.13 Contd': Load distribution for the applied load for a) MP0, b) MP10 and c) MP30 micorpile

Moreover, the drill bit, attached to the micropile end, hindered the mount of strain gauges. Hence, the nearest strain gauge to end of the micropile (20 cm from the end) was used for the evaluating the end bearing behaviour. Based on strain gauge readings at location 3, about 82% of the applied loads for MP0 and MP10 were transferred to the soil through the shaft resistance. This implies the high shaft resistance of the tested micropiles which can be considered as the governing mechanism for the load transfer mechanism. One interesting point is that, at the same strain gauge location, for MP30 only 76% of the applied load was noticed to be transferred through the shaft resistance. This result can be explained by the fact that MP30 had a larger diameter relevant to other tested micropiles (i.e. MP0, MP10, and MP20) leading to a higher toe resistance. This was confirmed by load transfer curves at strain gauge at locations 2 and 3 for different tested micropiles as illustrated in **Fig. 4.14**.



a) Load transfer at location (2)

Figure 4.14: Variations in the load transferred at different micropile sections



b) Load transfer at location (3)

Figure 4.14 Contd': Variations in the load transferred at different micropile sections

It is noted that the load transferred through the shaft continued to increase at almost the same rate as micropiles settlement increased (**Fig. 4.14a**). Moreover, a similar load transfer trend for MP0 and MP10 is noticed (**Fig. 4.14b**). On the other hand, a lower shaft resistance was noticed at MP30 at same strain gauge location which confirms the effect of enlargement of toe diameter and associated increase in the end bearing capacity of micropiles.

4.4. CONCLUSIONS

Incorporation of TOSW in grout mixtures used for hollow bar micropile applications was experimentally evaluated. The following conclusions can be drawn:

- Addition of TOSW reduces the compressive strength of grout; however, it still meets the requirements suggested for micropiles applications.
- The injection process under high pressure has a minimal effect on grout mechanical properties.
- Addition of TOSW did not adversely affect the roughness and profile of micropile grout body.
- Micropiles installed using conventional and sustainable grout show similar axial compression performance.
- TOSW has a high potential to be used as a filler material in geotechnical applications.

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CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. SUMMARY

The main objective of the research presented in this thesis was to investigate the effects of incorporating treated oil sands waste (TOSW) in hollow bar micropiles grout on the grout fresh and hardened properties as well as the micropile capacity characteristics. Different grout mixtures were used and evaluated in this study with different TOSW percentage of 0%, 10%, 20%, 30%, and 50% replacement of cement by weight. In addition, four hollow bar micropiles installed using grout incorporating TOSW with percentages up to 30% were load tested. Axial compression tests were performed on all the installed micropiles to evaluate the effect of TOSW addition on hollow bar micropiles performance.

To investigate the effect of treated waste addition on hollow bar micropiles performance, the research was conducted in two stages. In stage 1, a total of five grout mixtures were tested to study the behaviour of cementitious materials incorporating different percentages of TOSW. All mixtures were achieved by adding the treated waste as a partial replacement of cement at a constant water to powder ratio of 0.42. Fresh grout tests were performed to assess the effect of TOSW addition on grout water consistency and flowability. In addition, grout reactivity was monitored through measuring the heat of hydration of the tested mixtures. Also, the effect of TOSW addition on the hardened properties of grout was examined. Finally, heavy metals leached from different mixtures were assessed using coupled plasma mass spectrometry (ICP-MS).

The second stage involved testing four hollow bar micropiles installed with grout mixtures implementing treated oil sands waste at percentages of 0%, 10%, 20% and 30%. In this stage, the axial compression capacity and load transfer mechanisms of all the installed micropiles were studied. In addition, the effect of the treated waste on micropiles diameter change and cross section were investigated. Finally, the effect of TOSW addition on the interface properties of micropiles grout body was evaluated.

This innovative use of TOSW in micropiles construction can be an efficient solution to oil sands waste management. In addition, it present a new alternative that can be utilized to reduce the amount of cement consumed in micropiles construction leading to a more sustainable foundation construction practices.

5.2. CONCLUSIONS

5.2.1. Properties of Cementitious Material Incorporating Treated Oil Sands Drill Cuttings Waste

The experimental results on the effect of treated oil sands waste on addition on the properties of cementitious materials revealed the following:

- The addition of treated oil sands waste slightly decreases the water consistency of grout used in the construction of micropiles.
- As the percentage of TOSW increases, the compressive strength and heat of hydration decrease. On the other hand, above 20% TOSW addition, the strength reduction was noticed to be at higher levels. Therefore, it is suggested to use TOSW within 10% to 20% content by weight.
- It was noticed a higher shrinkage induced in the grout mixtures mixed with higher percentages of TOSW. Hence, it would be appropriate to apply shrinkage mitigation methods.
- The leaching tests carried out on different grout mixtures showed that it is possible to implement TOSW in grout mixtures to obtain materials with a pollutant potential lower than that characterizing the treated oil sands waste.

5.2.2. Performance of Hollow Bar Micropiles Using Sustainable Grout

The experimental results on the axial compression performance and its interpretation revealed the followings:

- The addition of TOSW in micropiles grout reduces the compressive strength; however, it still fulfills the requirements recommended for micropiles applications.
- The high injection pressure of grout during the installation of micropiles has a minimal effect on the grout mechanical properties.
- The roughness and profile of micropiles grout body is not affected by the addition of the treated oil sands waste in grout mixtures.

- Similar axial compression behaviour is noticed for micropiles installed using conventional and grout incorporating TOSW.
- Treated oil sands waste has a high potential to be used as a filler material in geotechnical applications.

5.3. RECOMMENDATIONS FOR FUTURE RESEARCH

The current research revealed that some further studies on the effect of treated oil sands waste on grout used for micropiles constructions may be needed. The following are recommendations for future research:

- Investigate the effect of treated oil sands waste on the durability of grout used for micropiles constructions.
- Investigate the effect of TOSW implementation in micropiles installed in cohesive soil.
- Study the behaviour of larger hollow bar micropiles installed incorporating TOSW
- Investigate the lateral behaviour of hollow bar micropiles installed using grout incorporating the treated waste.
- Investigate the effect of pressure variation on hollow bar micropiles installed using grout incorporating TOSW.

VITA

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Post-Secondary Education and Degree:	Alexandria University Alexandria, Egypt 2007-2012 B.Sc. (Civil Engineering) The University of Western Ontario London, Ontario, Canada 2013-2015 M.Sc (Civil Engineering/Geotechnical)
Related Work Experience:	Research and Teaching Assistant The University of Western Ontario 2014-2015

PUBLICATIONS

1. **Moustafa Aboutabikh**, Ahmed M. Soliman and M. Hesham El Naggar (2015) "Effect of Treated Oil Sands Drill Cuttings Waste on Micropiles Grout Properties," In Proceeding of the 68th Canadian Geotechnical Conference, Quebec City, Quebec, Canada. **Published**
2. **Moustafa Aboutabikh**, Ahmed M. Soliman and M. Hesham El Naggar (2015) "Properties of Cementitious Materials Incorporating Treated Oil Sands Drill Cuttings Waste," Construction and Building Materials. **Accepted**
3. **Moustafa Aboutabikh**, Ahmed M. Soliman and M. Hesham El Naggar (2015) "Performance of Hollow Bar Micropiles Using Sustainable Grout," The ASCE Journal and Geoenvironmental Engineering. **Submitted**
4. **Moustafa Aboutabikh**, Ahmed M. Soliman and M. Hesham El Naggar (2015) "Application of Different Industrial Waste Materials in Geotechnical Applications," Proceedings of the Annual Conference of the Canadian Society for Civil Engineering, London, Ontario, Canada. **Submitted.**
5. **Moustafa Aboutabikh**, Ahmed M. Soliman and M. Hesham El Naggar (2015) "Sustainable Micropiles Grout: Properties and Performance," Proceedings of the Annual Conference of the Canadian Society for Civil Engineering, London, Ontario, Canada. **Submitted.**

HONOURS AND AWARDS

- 2014-2015: Western University WGRS
- 2015: L.G. Soderman award "Geotechnical Research Center Annual Award"
- 2015: 1st place of the "Big Beam Contest" and best video award, international zone, sponsored by PCI institute"
- 2014: 1st place of the "Big Beam Contest", international zone, sponsored by PCI institute"

OTHER RELATED EXPERIENCE

- 2012-2013 Structural Engineer, (Full Time)
  Alshams for Contracting, Cairo, Egypt
  - Supervised average of 30-40 workers (including junior engineers) while overseeing two buildings
  - Allocated construction resources and estimated costs of different work activities
  - Monitored the progress of projects and prepared feedback
  - Directed construction, operations and maintenance activities and project site
  - Maintained a safe and clean work place resulting an accident free work environment
- 2012 Designer, (Full Time)
  Center of Design and Engineering Consultations, Alexandria, Egypt
  - Worked as a design engineer at the construction of SUMED (Arab Petroleum Pipelines Company) residential compound. Gained experience in producing structural drawings and design of RC buildings.

VOLUNTEER WORK

2007-2012 President G.E.L.F.I. (NGO), College Saint Marc, Alexandria, Egypt.

- Arranged camps for up to 40 children (from 8-13 years old) to help them develop social skills.
- Design a variety of interesting activities for young children while collaborating with 10-15 team members.
- Organized camps and activities for orphaned children to introduce them to new experiences.
- Planned and managed field trips ensuring safety and wellbeing of up to 50 children.
- Managed a team of 70-80 volunteers providing training and guidance in working effectively with special needs children
- Arranged 5 days camps for up to 20 children with special needs to help the kids gaining useful skills and to spend enjoyable time.

2015 Engineering Preview Day, University of Western Ontario

- Provided tours at the structural laboratory of civil and environmental engineering department during winter and fall term. Hosts 1200 visitors average size of my tour was 15 visitor per tour