Implementation of Treated Oil Sands Waste in Continuous Flight Auger Piles Concrete Mixtures

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ABSTRACT
Concrete is the major constituent of continuous flight auger (CFA) piles, hence, understanding the concrete mixture behaviour and optimizing its design are essential. A laboratory study was undertaken to evaluate the fresh and hardened properties of CFA concrete mixtures incorporating treated oil sands waste (TCCW). Variation of hardened properties with curing time has been quantified. Results show that TCCW addition had an insignificant effect on the concrete flowability. Strength gaining rates for concrete mixtures incorporating TCCW were near that of the control mixture. Results suggest that TCCW can be used in CFA piles which will lead to both economic and environmental benefits.

RÉSUMÉ
Le béton est le constituant majeur des pieux à tarière continue (CFA), par conséquent, la compréhension du comportement du mélange de béton et l'optimisation de sa conception sont essentielles. Une étude en laboratoire a été réalisée afin d'évaluer les propriétés fraîches et hydratées du mélange de béton CFA en incorporant des déchets de sables bitumineux traités (TCCW). La variation des propriétés du béton hydraté en fonction du temps de cure a été quantifiée. Les résultats montrent que le TCCW avait un effet négligeable sur la fluidité du béton. Le taux de résistance gagné dans les mélanges de béton incorporant le TCCW était près de celui du mélange de contrôle. Les résultats suggèrent que le TCCW peut être utilisé dans les pieux CFA, conduisant à des avantages économiques et environnementaux.

1 INTRODUCTION

Continuous flight auger (CFA) piles are used widely in North America. Concrete have been used in the construction of CFA piles. Generally, CFA concrete mixtures usually contain cement, coarse and fine aggregates, and water. Consumption of these natural materials represents wasting to the natural resources. Hence, utilization of industrial by-products or solid wastes in producing concrete is an optimum solution. Different industrial wastes had been used in concrete such as fly ash (FA), bottom ash, waste foundry sand and waste glass. However, for an example, current and future Environmental Protection Agency (EPA) restrictions on coal burning power plants have and will continue to impact the availability and usability of FA. Therefore, it is imperative that suitable alternatives be found.

On the other hand, oil sands discovered in northern Alberta is now the focus of intense development due to the high demand on hydrocarbon products. Alberta's crude oil reserve is considered the second largest in the world after Saudi Arabia (ERCB, 2010). Oil sands are extracted and then passes by different processes resulting in bitumen and tailings (i.e. oil sands waste) as final products. These tailings represent one of the most difficult challenges for the oil sands mining sector (Fine Tailings Fundamentals Consortium, 1995). Different technologies had been applied as a pre-treatment process to convert these tailings to a reusable product.

Generally, oil sands deposits exist below the ground surface by 30 to 90 meters. Oil sands typically contain 8 to 14 % (by weight) bitumen and 3 to 5 % (by weight) water, and the rest are mineral solids (i.e. sand, silt, and clay) (Gosselin, et al., 2010). Two methods typically used to extract bitumen from oil sands, in-situ mining and open pit mining.

In-situ mining is suitable for bitumen deposits deeper than 70 m. Bitumen has a very high viscosity which decreases at high temperatures. Therefore, bitumen is thermally treated to reduce its viscosity to a value similar to water using steam with temperature above 250 °C pumped to the ground. This makes pumping bitumen from the ground easier. Open pit mining is applicable for formations with depth up to 70 m. Oil sands are excavated and then the bitumen rich sands transported to crushers where oil sands ore is broken to similar lumps. After crushing, the ore is transported through conveyor into hot water to make slurry with temperature between 45 °C to 60 °C. By pumping air pebbles into the slurry, the bitumen droplets attaches to the air bubbles and float on the surface, while the solids settle to the bottom and then separated and discharged into large ponds (Gosselin, et al., 2010). This process is called hot water process. The resulting products from this process are bitumen and tailings (i.e. warm aqueous suspension of sand, silt, clay and residual bitumen) (Fine Tailings Fundamentals Consortium, 1995). Tailings are pumped into large tailing ponds. Once the tailings pumped, the coarse sand settles to form the dykes of the ponds while the fines and the residual bitumen are carried as slurry. The fines in the slurry then begin to settle with time. The water containing bitumen remaining at the surface is recycled and the bitumen existing in it is recovered (Fine Tailings Fundamentals Consortium, 1995).

Disposal of oil sands tailings is a critical part of the HWP. Current inventories of the volume of tailings indicate much more than 720 million-m^3 covering a total area of 130 km^2 (ERCB, 2011). This volume continues to increase with the expansion of oil sands extraction process. However, site investigations conducted by Mackinnon *et al*. (2005) demonstrated that the contaminated tailing water reached the ground water at a point a few kilometers away from the pond. Moreover, Environmental Defence (2009) claimed that all the current tailing ponds are leaching together a volume of 11 million L/day. This requests an urgent need to find alternative ways for disposing or reusing the oil sands tailings.

Recently, an innovative technology (so called Thermo-mechanical Cuttings Cleaner (TCC)) for treating tailings while recovering hydrocarbons was proposed. In the TCC, the tailings are heated to a temperature just high enough to evaporate oil and water. The oil and water will be brought back to a liquid phase in separate condensers. The remaining solids (i.e. by-product) of TCC is a very fine quartzes powder with a high surface enrichment of Aluminum/Silica which increases its potential to be reused and recycled in constructional applications.

Therefore, this study investigate the potential of implementing high percentage of TCC by-product (TCCW) in the CFA pile concrete mixtures. Results of this study will pave the way for the use of TCCW in concrete, saving natural resources and the environment from pollution, and reducing the cost of oil sands waste management. In addition, it will provide practical information to designers in order to achieve sustainable CFA pile.

2 EXPERIMENTAL PROGRAM

The effect of adding different percentage of TCCW on hardened properties of CFA concrete mixtures was evaluated. Hardened properties included compressive, tensile, and modulus of elasticity. In addition, leaching test was conducted on selected concrete samples to evaluate any environmental risk.

2.1 Materials

An ordinary Portland cement containing 61% tricalcium silicate (C_3S), 11% dicalcium silicate (C_2S), 9% tricalcium aluminate (C_3A) , 7% tetracalcium aluminoferrite (C_4FA) , 3% sulfur trioxide (SO_3) and 0.82% equivalent alkalis was used as the binder material. TCCW, which is a silicate based-material with an average particle size of 2.7 µm, was added as a partially replacement of sand. Major oxides in TCCW and cement were determined by Fusion x-ray florescence technique as shown in Table 1. Trace elements in TCCW were analyzed by pressed pellet x-ray fluorescence technique, and aqua-regia digestion and inductive coupled plasma atomic emission spectrometry technique as shown in Table 2.

Table 1. Chemical properties of Thermo-mechanical cuttings cleaner waste

Constituent	TCCW (wt%)	Cement (wt%)
Silicon dioxide (SiO_2)	61.00	21.45
Titanium dioxide (TiO_2)	0.46	0.22
Aluminium oxide (Al_2O_3)	8.78	4.45
Iron(III) oxide (Fe_2O_3)	3.03	3.07
Magnesium oxide (MgO)	0.92	2.42
Calcium oxide (CaO)	5.48	63.81
Potassium oxide (K_2O)	1.61	0.83
Sodium oxide (Na_2O)	0.85	0.20
Phosphorus pentoxide (P_2O_5)	0.15	0.11

Table 2. Analysis of the Thermo-mechanical cuttings cleaner waste

Element	Symbol	XRF analysis (µg/g)	ICP-AES Analysis (µg/g)
Aluminum	Al		7399
Antimony	Sb		< 0.05
Arsenic	As	6	20
Barium	Ba	7318	4795
Beryllium	Be		< 0.05
Cadmium	Cd		< 0.05
Chromium	Cr	76	19
Cobalt	Co	8	5
Copper	Cu	68	13
Iron	Fe		14024
Magnesium	Mg		2649
Manganese	Mn	251	201
Mercury	Hg		< 0.05
Molybdenum	Mo	5	< 0.05
Nickel	Ni	34	25
Selenium	Se		< 0.05
Silver	Ag		< 0.05
Vanadium	V	152	30
Zinc	Zn	130	101

Gravel with size 5 to 10 mm was used as coarse aggregate with an absorption of 0.8% and fines content lower than 1%. The fine aggregates consists of natural siliceous, washed, concrete sand with an absorption of 1.5 %. Coarse and fine aggregates were dried in environmental chamber for 24 hours. Table 3 presents a summary of the aggregate properties. Figure 1 presents gradation curve of the coarse and fine aggregates. Tap water was used in all the series. A polycarboxylic ether based superplasticizer complying with ASTM C-494 type F was used. Air entraining admixture by BASF complying with ASTM C 260, AASTO M 154, was used. Table 4 shows a summary for tested mixtures compositions. The concrete mixture was designed to obtain a minimum 28-day compressive strength of 35 MPa (Brown, 2007).

Table 3. Properties of the aggregates

Aggregate type	Fineness modulus	Absorption %	Specific gravity
Gravel	1.0	0.8	2.60
Sand	0.9	1.5	2.66

2.2 Testing Procedures

Fresh concrete properties including slump flow and bleeding were determined according to ASTM specifications C143/C143M-12 (Standard Test Method for Slump of Hydraulic-Cement Concrete) and C232/C232M-14 (Standard Test Method for Bleeding of Concrete), respectively. Cylinders size 100 mm × 200 mm (4 in × 8 in) were casted for compressive strength, tensile strength, and modulus of elasticity. At ages 7 and 28 days, specimens were removed from the curing chamber and tested. Compressive strength, splitting tensile strength, and modulus of elasticity tests were conducted according to ASTM specifications C39/C39M-14a (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens), C496/C496M-11 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens), and ASTM C469 (Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression), respectively.

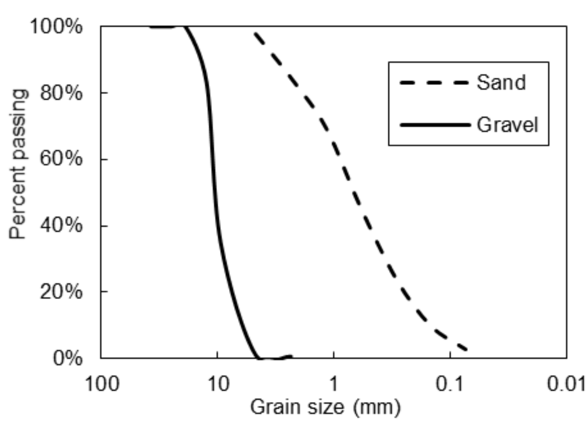

Figure 1. Size gradation of coarse and fine aggregates

Moreover, leaching test was conducted on four types of specimens. The first specimen type was unsolidified TCCW soaked as a raw material in the test water. The second type was control concrete specimen without involving TCCW. The third and fourth types were concrete specimens containing 10 % and 20 % of TCCW respectively.

Table 4. Mixtures composition

Properties	Control	10% TCCW	20% TCCW
Cement (kg/m^3)	425	425	425
Sand (kg/m^3)	760	680	605
Gravel (kg/m^3)	1040	1040	1040
TCCW (%)	0	10	20
TCCW (kg/m^3)	0	65	120
W/C	0.42	0.42	0.42
Superplasticizer (kg/m^3)	4.3	5.1	6.8
Superplasticizer (%)	1.0%	1.2%	1.6%
Air entrainment (kg/m^3)	0.2	0.2	0.2
Air entrainment (%)	0.05	0.05	0.05
Slump (mm)	200	200	210
Concrete temperature (C°)	17	18	18
Air temperature (C°)	22	24	24
Bleeding (mm^3)	0	0	0

Specimens of size 150 × 150 × 150 mm were prepared for all mixtures. The specimens were removed from the molds after 24 hours. They were then placed in curing chamber for 28 days at 20 C° and >90% RH. Cubes were rinsed, initially with tap water then deionized water. They were then sprayed with 100 mg/litre of an aqueous solution of free chlorine and allowed to stand for 30 minutes. Finally samples were again rinsed with tape water and deionised water. Test water used consisted of deionised water with 5 mg/liter sodium hypochlorite. The concrete surface area to test water volume ratio (s/v) was 1.2 dm^2/liter (Dransfield, 2004). Test water was changed and analyzed every 3 days for 18 days. For every concrete mixture, two specimens were tested and for every specimen, three leachate samples were analyzed every 3 days. Inductively coupled plasma mass spectrometry (ICP-MS) were used for metals analysis.

3 ANALYSIS AND DISCUSSION

3.1 Particle size Distribution

Table 5 summarizes the particle size distribution results for TCCW and cement Type 10 as a reference material. The surface area moment mean of TCCW is around one-third of that of the cement. This indicates that TOSW has a greater percentage of fine particulates in the size distribution. As shown in Figure 2, the volume moment mean, which reflects the size of those particles which constitute the bulk of the sample volume, for the TCCW is about 77% lower than that of the cement. Figure 3 shows the particle size distribution. By monitoring these three parameters, it is clear that the variation in the mean particle size for TCCW is lower than that of the cement. For instance, the variation in size for about 80% of the particles was around 9.055 µm and 35.252 µm for TCCW and cement, respectively. This indicate the high uniformity of TCCW with respect to that of the cement.

Table 5. Particle size distribution for Cement type 10 and TCCW

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

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

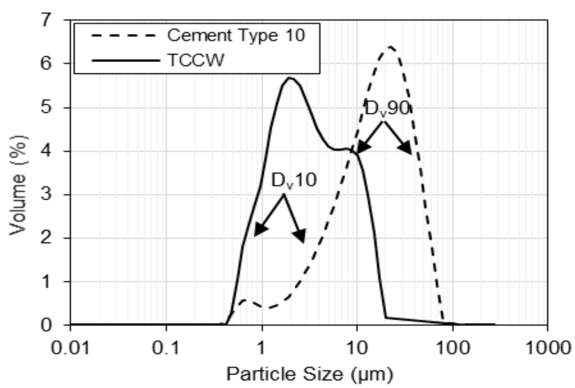

Figure 2. Particle size distribution based on volume percentage

3.2 Compressive Strength

Compressive strength results of TCCW mixtures are given in Table 6. All mixtures had meet the target compressive strength at age 28 days (i.e. 35 MPa). For example, the compressive strength of the 10% and 20% TCCW mixtures after 28 days were 48.74 MPa and 47.55 MPa, respectively. However, there was a decrease in the compressive strength of concrete mixtures incorporating TCCW as a replacement of regular sand.

The percentage decrease in compressive strength with respect to reference mixture at various ages is within 10%. For examples, mixture incorporating 10% TCCW exhibited strength lower than that of the control mixture with about 4% at both ages 7 and 28 days. As TCCW replacement rate increased to 20%, achieved strength was lower than that of the control mixture with 10% and 6% at ages 7 and 28, respectively. This reduction in compressive strength resulted from using TCCW is less than that resulted from using Waste foundry and bottom ash as a replacement of regular sand(Aggarwal and Siddique, 2014).

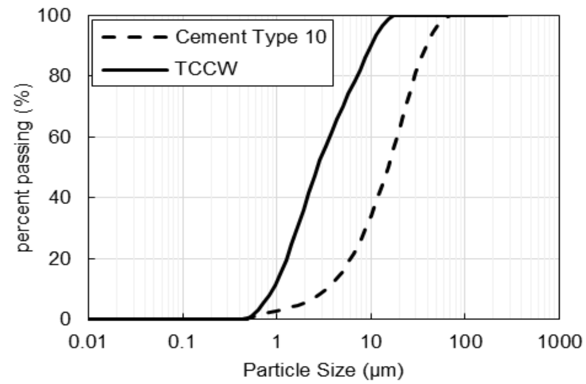

Figure 3. Particle size distribution of Thermo-mechanical cuttings cleaner waste and cement type 10

Table 6. Various strengths for control and Thermo-mechanical cuttings cleaner waste mixes

Properties	Mixture	Age (Days)	
		7	28
Compressive Strength (MPa)	Control	46.27	50.59
	10% TCCW	44.31	48.74
	20% TCCW	41.70	47.55
Splitting tensile strength (MPa)	Control	4.33	5.08
	10% TCCW	4.25	4.80
	20% TCCW	4.25	4.76

3.3 Splitting Tensile Strength

The splitting tensile strength showed consistent result with the compressive strength result. Table 6 shows the splitting tensile strength results. At age 7 days, tensile strengths for mixtures incorporating 10% and 20% TCCW were 2% lower than that of the control mixture without TCCW. Moreover, tensile strength decreases with about 5% and 6% at age 28 days for the 10% and 20% TCCW replacement rate, respectively.

Table 7 shows the ratio between the splitting tensile strength and the compressive strength. At age 7 days, the ratio was increasing by increasing the TCCW content. The ratio at 7-days was 0.094, 0.096, and 0.102 for control, 10% TCCW, and 20% TCCW, respectively. At 28, days the ratio for all mixtures was consistent at about 0.1. The resulted ratio calculated at different concrete ages (≈ 0.1) is consistent with that calculated in the literature (Nihal et al., 2006).

Table 7. Ratio of splitting tensile strength to compressive strength

Mixture	7 Days	28 Days
Control	0.094	0.100
10 % TCCW	0.096	0.098
20 % TCCW	0.102	0.100

3.4 Modulus of Elasticity

The modulus of elasticity results are shown in Table 8. It was measured at 7 and 28 days. The modulus of elasticity of the 10% TCCW mixture, decreased by 3% at both ages 7 and 28 days with respect to the control mixture. Similarly, by increasing the TCCW content to 20%, the modulus of elasticity decreased by 11% at both ages 7, and 28. The range of reduction in the modulus of elasticity is nearly equal that of the other hardened properties mentioned before.

Table 8. Modulus of elasticity (MPa)

Concrete mix	Age (Days)	
	7	28
Control	34821	36125
10% TCCW	33917	34767
20% TCCW	31117	32063

3.5 Leaching

Leachate was collected then analyzed by ICP-MS for trace of elements (Table 9). Analysis was carried out to determine the effect of involving TCCW on the concrete leaching. ICP-MS analysis of the control, 10 % TCCW, and 20 % TCCW concrete specimens showed that leaching of some elements was reduced after involving TCCW. By increasing TCCW content in the concrete, leaching decreased with respect to the control mixture. As a result leaching of silver, cobalt, chromium, iron, lead, and zinc decreased from 2% to below detection limit (<0.003 mg/l). However, Leaching of aluminum, calcium, potassium, nickel, and strontium increased within the range from 9 % to 216 %.

Solidifying the TCCW in the concrete mixes decreased the metals leaching. Although some metals leaching increased by increasing TCCW content in concrete, it decreased if it is compared to raw TCCW leaching. For examples leaching of aluminum decreased by 51% with respect to raw TCCW leaching.

Treated oil sand waste particle size is smaller than that of the cement. It is working in the concrete as a filler material decreasing the void spaces and permeability. As a result the leachate from most elements decreased by increasing TCCW percentage.

Table 9. Measured metals in TCCW mixtures

Element	Symbol	Leachate variation as a percentage of Control (%)	
		10% TCCW	20% TCCW
Silver	Ag	77%	61%
Aluminum	Al	109%	120%
Calcium	Ca	104%	114%
Cobalt	Co	97%	29%
Chromium	Cr	42%	23%
Iron	Fe	49%	22%
Potassium	K	95%	137%
Nickel	Ni	139%	127%
Lead	Pb	15%	---
Strontium	Sr	131%	165%

4 CONCLUSION

All mixtures had meet the target compressive strength at age 28 days (i.e. 35 MPa). The splitting tensile strength showed consistent result with the compressive strength result. The hardened properties in general insignificantly affected by TCCW incorporation. All the concrete mixtures tested in this study satisfy the minimum requirements for the CFA piles concrete mixtures

TCCW can be used in CFA piles concrete mixture without compromising the required properties. It decreased the compressive strength by about 11% for both mixtures. Generally it has insignificant effect on the concrete properties. The leaching was minimal. The solidification process contained the leaching of the harmful metals.

REFERENCES

AASHTO 2006. Standard Specification for Air-Entraining Admixtures for Concrete. American Association of State Highway and Transportation Officials.

Aggarwal, Y., and Siddique, R. 2014. Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates. Construction and Building Materials, 54: 210-223.

ASTM-C260/C260M-10a 2010. Standard Specification for Air-Entraining Admixtures for Concrete. ASTM International.

ASTM-C494/C494M-13 2013. Standard Specification for Chemical Admixtures for Concrete, ASTM International.

Brown, D.A., Dapp, S.D., Thompson, W.R., and Lazarte, C.A. 2007. Design and Construction of Continuous Flight Auger (CFA) Piles. Technical Report, Federal Highway Administration.

Dransfield, J. 2004. Leaching of organic admixtures from concrete. Concrete (London), 38(5): 52-54.

ERCB 2010. Alberta's Energy Reserves 2009 and Supply/Demand Outlook 2010-2019. Energy Resources Conservation Board.

ERCB 2011. Oil Sands. EnerFAQs 12. Frequently Asked Questions on the Development of Alberta's Energy Resources. Alberta: Energy Resources Conservation Board, Calgary.

FTFC (Fine Tailings Fundamentals Consortium). 1995. Advances in Oil Sands Tailings Research. Alberta Department of Energy, Oil Sands and Research Division, Edmonton.

Gosselin, P., Canadian Electronic, L., and Royal Society of, C. 2010. The Royal Society of Canada Expert Panel: environmental and health impacts of Canada's oil sands industry : report. Royal Society of Canada, Ottawa, - Book.

Mackinnon, M., Kampala, G., Marsh, B., Fedorak, P., and Guigard, S. Indicators for assessing transport of oil sands process-affected waters2005. IAHS Press, pp. 71-80.

Nihal, A., Girgin, Z.C., and Ergin, A. 2006. Evaluation of Ratio between Splitting Tensile Strength and Compressive Strength for Concretes up to 120 MPa and its Application in Strength Criterion. ACI Materials Journal, 103(1): 18-24.