"DYNAMIC PROPERTIES OF CONTOLLED LOW STRENGTH MATERIALS WITH TREATED OIL SAND WASTE AS AN ADMIXTURE- A REVIEW"

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Abstract - *Controlled Low-Strength Materials (CLSM) is a self-compacted self-levelling cementitious material with compressive strength of 8.3 MPa or less. CLSM is widely used as a replacement for soil-cement material in many geotechnical applications such as structural backfill, pipeline beddings, void fill, pavement bases and bridge approaches. Treated Oil Sand Waste (TOSW) is a waste obtained from oil sand industries is used as a partial replacement of sand and flyash in CLSM to improve the fresh and hardened properties of CLSM. Studies on incorporation of TOSW with CLSM showed that it has increased the flowability of the mixture thus reducing the water demand and increasing the compressive strength of the mixture. This will provide a safe recycling method for oil sand wastes while reducing the environmental footprints of both construction and oil sand industry.*

Key Words: Controlled Low Strength Materials, Oil sand waste, Drill cutting waste, Shrinkage, Leaching

1. INTRODUCTION

In many developed countries, concern on waste production, resource preservation, and reduced material cost have focused attention on reusing solid waste. Waste materials when processed can meet certain design specifications of some construction. Oil sand industries produce millions of tons of oil containing tailings and drill cutting every year and are pumped to tailing ponds and landfills. 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. Also, the water in tailings ponds is toxic to aquatic life and will affect the migratory birds that might land in these huge parts. (M. Aboutabikh, A. Soliman, M.H. El Naggar, 2015).

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 technology is Thermo-mechanical Cutting Cleaner (TCC) which separates water and oil from the oil sand solid waste. The remaining part of the tailing is fine particles, mainly quartz crystals, which is referred herein as Treated Oil Sand Waste (TOSW). (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

Controlled low strength material (CLSM) is self-compacted self-levelled mixture usually composed of cement, water, and aggregate and is used as a replacement of compacted soil backfill. This material is also referred as flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, soil-cement slurry, K-Krete and other various names. In 1964, the U.S. Bureau of Reclamation documented the first use of CLSM as the bedding material for 515 km long pipe line in the Canadian River Aqueduct project done by the US Bureau of Reclamation. CLSM is widely used for different construction applications such as pipeline beddings, void filling, structural backfill, bridge reclamation and pavement bases. CLSM serves as an excellent host for the fine TOSW without affecting its properties due to its low strength requirements. (Maithili K.L, 2018).

Studies on incorporation of TOSW with CLSM were done to investigate the potential of TOSW as a fine filler material in order to produce green CLSM. This will be an important contribution to the efforts of reducing the footprint of oil sands industry by recycling TOSW and reducing the amount of natural sand used in CLSM.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The CLSM mixture contained Type 10 Ordinary Portland Cement (OPC) with Blaine fineness of 360 m^2/kg and specific gravity of 3.15 and Class F fly ash as binding material according to ASTM C618. It contained 61% Tricalcium Silicate (C3S), 11% Dicalcium Silicate (C2S), 9% Tricalcium Aluminate (C3A), 7% Tetracalcium Aluminoferrite (C4AF), 0.82% equivalent alkalis and 5% limestone. Treated Oil Sand Waste (TOSW) is used as a silicate base fine filler material with a Blaine fineness of 1440 m^2/kg and specific gravity of 2.23. The physical properties and the chemical composition of the cement, fly ash and TOSW are shown in table 1 and table 2. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

Prepare and test three groups of mixtures based on proportion guidelines reported by ACI committee 229. Group 1 includes control mixtures mixed with natural river bed sand with a specific gravity of 2.65. Group 2 includes six mixtures containing TOSW as a partial replacement of sand by volume at rates of 5%, 10% and 15%. Group 3 includes nine mixtures prepared with TOSW as a replacement of 100% of the fly ash along with partial replacement of sand by volume at rates 5%, 10% and 15%. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018)

Table -1: Physical Properties of Cementitious Materials

Physical Properties	OPC	TOSW	Fly Ash
Surface area (m^2/kg)	360	1440	280
Specific gravity	3.15	2.23	2.5

Table-2 : Chemical composition of Cementitious Materials

Chemical Composition	OPC	TOSW	Fly Ash
SiO_2	21.60	61.24	43.39
Al_2O_3	6.00	8.73	22.08
Fe_2O_3	3.10	3.00	7.74
CaO	61.41	5.55	15.63
MgO	3.40	0.92	-
K_2O	0.83	1.60	-
Na_2O	0.20	0.85	1.01
P_20_5	0.11	0.15	-
SO_3	1.76	3.00	1.72
TiO_2	-	0.46	-

2.2 Mixing Procedure

Mix Cement, fly ash and TOSW for 1min without adding water to form a homogeneous distribution. Gradually add about half of the water to the mixture and mix for another one minute. Add the rest of the water and mix it for another minute. After adding water, allow the mixture to rest for one minute and before sampling mix the mixture for another two minutes. Addition of no special admixtures is required to adjust the properties of the mixture. During the addition of water, measure the flowability of the mixture continuously to get the desired normal flowabiliy range of 150mm-200mm. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2016)

2.3 Testing

Evaluate the fresh properties, including flowability, unit weight and bleeding for fresh mixtures according to ASTM standards D6103-04 (Flow Consistency of Controlled Low Strength Material), ASTM D6023-07 (Density, Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low-Strength Material) and ASTM test method C232 (Standard Test Method for Bleeding of Concrete), respectively. Evaluate the effect of mixing materials on drying shrinkage using the drying shrinkage test following the ASTM test method C490-11. Determine the compressive strength as per ASTM test method D4832-10 (Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders. Conduct the CLSM specimens for splitting tensile strength at age of 28 days following ASTM standards C496/C496M (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). Investigate the leaching of heavy metals from hardened CLSM to assess the environmental impacts of incorporating TOSW in CLSM mixtures. The test is done while the samples are immersed in distilled water. Environmental assessment is conducted only on samples having the highest content of TOSW, to represent the most critical impact of using TOSW as a fine material in CLSM mixtures. After immersing the sample for 2, 7 and 28 days in distilled water the leachate is collected and analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The results are compared with the groundwater standards of the Canadian Council of Ministers of Environment (CCME, 2004). In addition, TOSW is tested separately in order to evaluate its leaching properties. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

3. RESULTS AND DISCUSSIONS

3.1 Flowability

The normal range of flowability ranges from 150 to 200mm. Chart 1 depicts the flowability of CLSM ranged from 185 to 250mm, which fall within the range according to ACI committee 229R. Using TOSW reduced the amount of water required to achieve the flowability range. In case of TOSW, the fine particle size helps to enhance the powder packing and release the water entrapped between cement particles making it available for lubrication and increases the flowability of the mix. Addition of TOSW helped in filling voids between coarse particles and the fine texture of TOSW made it act as a lubricant between them. TOSW addition is more efficient in increasing flowability than fly ash. Also results showed that changing cement content while maintaining the same flyash has no significant effect on CLSM. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

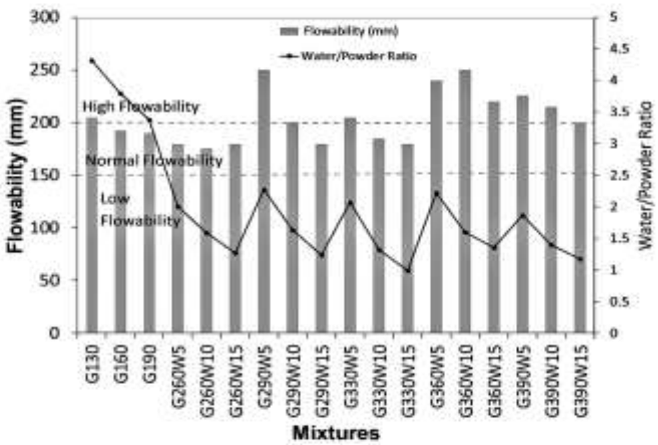

Chart -1: Flowability and Water/Powder ratio chart.

3.2 Density

Specific gravity of filler material mainly controls the density of CLSM. Density of fresh and hardened CLSM samples are measured at different stages up to 28 days of curing. The fresh density of control mixtures ranged from

2190 to 2195 kg/m3. There is a decrease in density up to 17% in Group 2 compared to control mixtures and the density ranged from 1816 to 1901 kg/m3, which lies within the range of normal CLSM reported by ACI Committee 229. The reduction of density is due to the low specific gravity of TOSW. The fresh density of Group 3 mixtures ranged from 2067 to 2325 kg/m3, which is also within the range of normal CLSM. In Group 3, fly ash is replaced by TOSW. This resulted in an increase in fresh density up to 6% followed by a decrease in fresh density with age at a rate slower than Group 2 mixtures. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

3.3 Bleeding

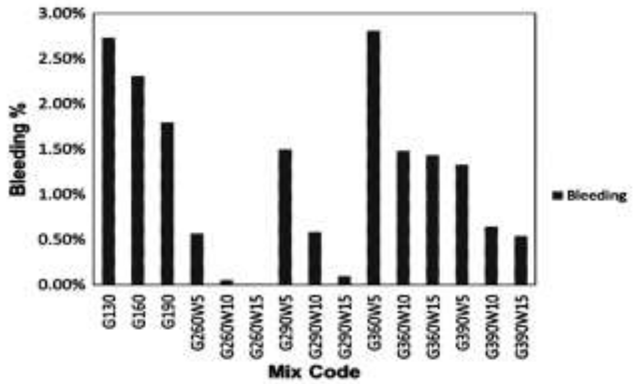

Chart-2 Bleeding results as percentage of volume

Bleeding is reduced by about 34% in control mixtures due to the increase in cement content from 30 to 90 kg/m3. There is a significant reduction in bleeding for mixtures containing TOSW. It is about 76% to 100% for G260 mixtures and from 17% to 95% for G290 mixtures and up to 17% and 70% for G360 and G390 mixtures compared with bleeding control mixtures as depicted in Chart 2. The increase in fine materials content in the mixture caused the reduction in bleeding which is directly related to the water/powder ratio. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

3.4 Drying Shrinkage

The measurements of drying shrinkage for G260 and G290 mixtures are shown in Chart 3. Measurements for control mixtures G160 and G190 showed that with the increase in cement content, the hydration products are increased and it leads to less free water for evaporation and caused reduction in shrinkage.

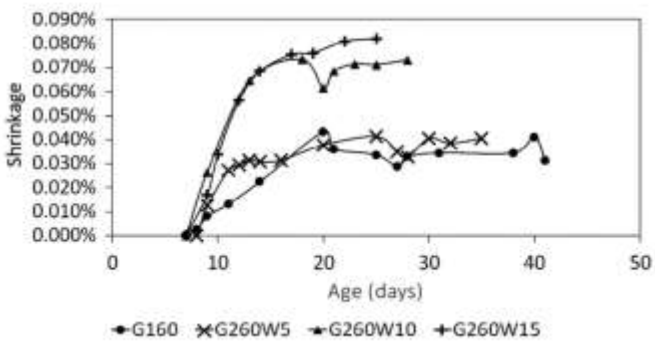

Chart-3 Measurement of drying shrinkage for G160 and G260 mixtures

Chart 4 shows that mixtures containing TOSW experiences increase in shrinkage. Shrinkage of G260 and G290 mixtures increased from 0.031% to 0.082% and from 0.038% to 0.072% compared to that of the control mixtures. This increase in shrinkage is related to the water/powder ratio and amount of bleeding observed. Mixtures with high bleeding values showed lower shrinkage as the water dried from the surface is more than from the bulk of the material. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

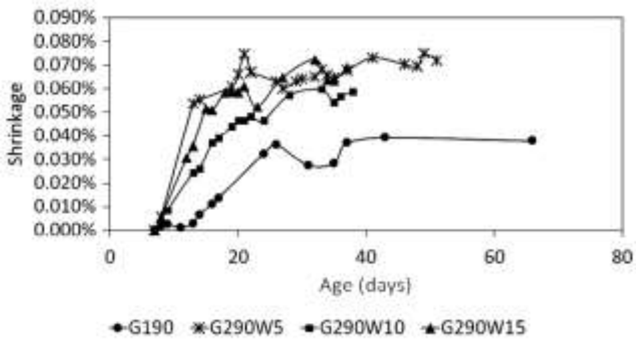

Chart 4 Measurement of drying shrinkage for G190 and G290 mixtures

3.5 Leaching Of Heavy Metals

Chart 5 and chart 6 shows the results of the conducted (ICP MS) analysis on the leachates. The TOSW has little to no contribution to the concentration of Lithium and Chromium of the leached material. In mixtures containing cementitious materials (fly ash and cement), the concentration of these metals increased with age, while in TOSW samples the concentration of these metals are within detectable levels. On the other hand, for raw TOSW sample the leaching of arsenic, strontium, cadmium, and barium are prominent and for samples containing cementitious materials with fly ash, the concentration of these metals is greatly reduced.

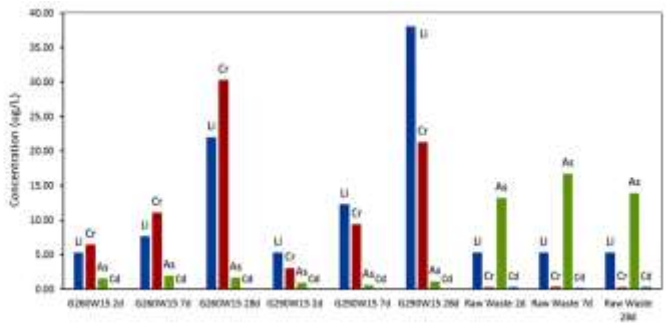

Chart- 5 Results of ICP-MS analysis showing effect of curing days on Group 2 leachates samples.

The concentration of Strontium and Barium are higher in Group 3 mixtures as the replacement of fly ash by TOSW reduced the amount of cementitious materials. Chart 6 shows a clear reduction in the concentrations of Lithium and Chromium for samples with TOSW replacing flyash (Group 3) compared with mixtures containing flyash (Group 2) after 28 days of leaching. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

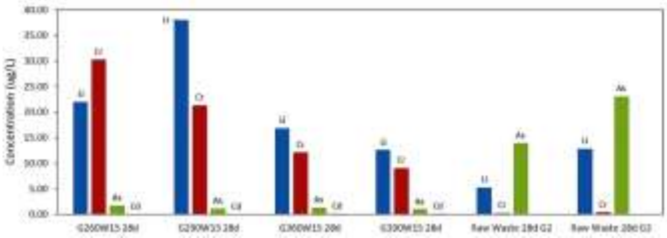

Chart-6 ICP-MS analysis showing results of 28 days of curing on Group 2 and Group 3 mixtures.

3.6 Compressive Strength

The compressive strength is calculated for the 3 control mixtures of CLSM and 15 mixtures with different cement, TOSW and fly ash contents, CLSM samples are tested after 7, 14 and 28 days of curing. When compared with G190 mixture (cement content of 90 kg/m3), G130 and G160 mixtures (cement content of 30 kg/m3 and 60 kg/m3) exhibited slow rate of strength gain.

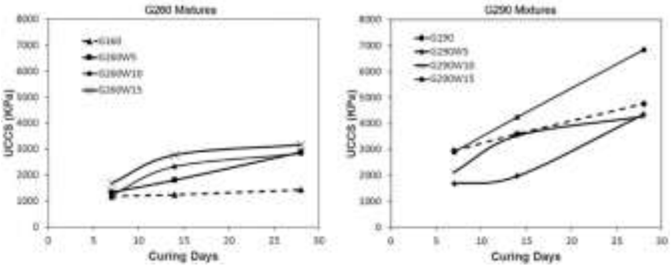

Chart-7 Development of compressive strength with age of Group 2 selected mixtures.

For mixtures containing TOSW, the compressive strength mainly depends on the water/powder ratio. As shown in Chart 7 and Chart 8, in G290 mixture, regardless of the waste content the strength increased with the decrease in water/ powder ratio. However, in Group 2 mixtures, the ability of the TOSW to enhance flowability reduced the amount of water needed for the mixture, which led to an increase in strength when the same flowability is maintained as noticed for G260 mixtures. On the other hand, in Group 3 mixtures, fly ash is replaced by TOSW. Due to the lack of pozzolonic activity of fly ash in Group 3 mixtures, the bonding between particles are reduced. This resulted in a significant reduction in strength of Group 3 mixtures. By increasing cement content this reduction in strength can be compensated. For some CLSM applications, it is important to maintain a low strength to facilitate future excavation. The ACI Committee 229 recommends a compressive strength lower than 2.1 MPa if future excavation is anticipated. (A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

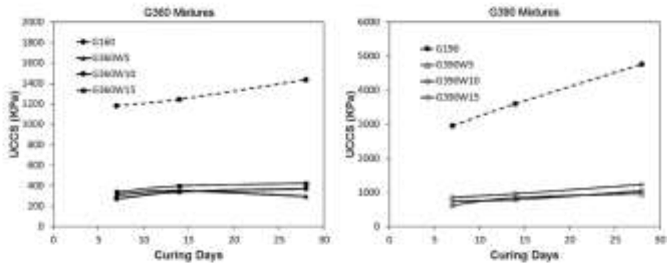

Chart- 8 Development of compressive strength with age of Group 3 selected mixtures.

3.7 Tensile Strength

Tensile strength of CLSM cylinders is calculated according to ASTM test method C496/C496M (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). Chart 9 shows a good linear relationship between the tensile strength and the compressive strength of the tested CLSM samples. The tensile strength ranged from 7% to 17% of the compressive strength and this range is very close to the normal range of Portland cement concrete, which is 8% to 14%.(A. Mneina, A.M. Soliman, A. Ahmed, M.H. El Naggar, 2018).

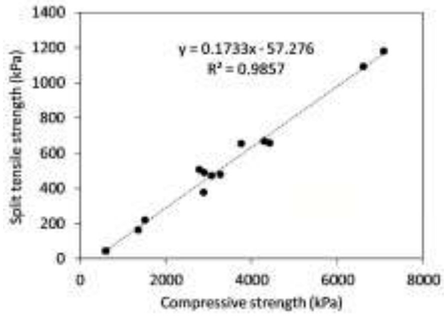

Chart-9 Relationship between split tensile strength and compressive strength.

4. CONCLUSIONS

The use of CLSM as a backfill and void filling material is widespread throughout the world. The engineering properties and economical attributes of CLSM are making it the most preferred alternative for many applications. The results of this study concludes the advantages of substituting fly ash with TOSW in CLSM, when used in geotechnical application. Inclusion of TOSW in CLSM would

- Increases flowablity of the mixture, thereby reducing the water demand for achieving the desired flowability value. Which in turn increases the compressive strength in Group 2 mixtures.
- Lowers the dry density making it suitable for field application with weak soils.
- Significantly reduces the bleed water.
- Lowers pollutant potential of TOSW.
- Increases the unconfined compressive strength at 28 days with proportional increase in TOSW content.
- Lowers strength and elastic modulus and useful in application where such characteristics are desired.
- Maintains the properties as is the case with fly ash.

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