Experimental Investigation of the Influence of Cement on Soil-Municipal Solid Incineration Fly Ash Mix Properties

G. Aouf, D. Tabbal, A. Sabsabi, R. Aouf

Abstract**—**The aim of this study is to assess the viability of utilizing Municipal Solid Waste Incineration Fly Ash (MSWIFA) with Ordinary Portland cement as soil reinforcement materials for geotechnical engineering applications. A detailed experimental program is carried out followed by analysis of results. Soil samples were prepared by adding cement to MSWIFA-soil mix at different percentages. Then, a series of laboratory tests were performed namely: Sieve analysis, Atterberg limits tests, Unconfined compression test, and Proctor tests. A parametric study is conducted to investigate the effect of adding the cement at different percentages on the unconfined compression strength, maximum dry density (MDD), and optimum moisture content (OMC) of clayey soil-MSWIFA. The variations of admixtures' contents were 10%, 20%, and 30% for MSWIFA by dry total weight of soil and 10%, 15%, and 20% for Portland cement by dry total weight of the mix. The test results reveal that adding MSWIFA to the soil up to 20% increased the MDD of the mixture and decreased the OMC, then an opposite trend for results were found when the percentage of MSWIFA exceeds 20%. This is due to the low specific gravity of MSWIFA and to the greater water absorption of MSWIFA. The laboratory tests also indicate that the Unconfined Compression Test values were found to be increased for all the mixtures with curing periods of 7, 14, and 28 days. It is also observed that the cement increased the strength of the finished product of the mix of soil and MSWIFA.

Keywords**—**Clayey soil, cement, Municipal Solid Waste Incineration Fly Ash, MSWIFA, unconfined compression strength.

I. Introduction

STABILIZATION, in a wider sense, is to apply methods to modify the properties of soil to enhance its engineering performances. Engineering works involve using stabilization in many projects, the most common use is for the construction of roads and airfield pavements, as well as constructions related to buildings and maintenance of infrastructures. Stabilization projects require different tests, basic analysis, and calculation procedures for advancing solutions. Stabilization is classified into four groups: Mechanical Methods, Hydraulic Methods, Inclusion and Confinement Methods, and Chemical Methods. For chemical method, Soil is to stabilize by mixing additives with top layers at a depth. Additives can be industrial byproducts, natural soils, waste materials, or other chemical materials that may react with the ground. Cement, fly ash, and lime are examples of conventional admixture and they are typically calcium-based.

One of the oldest techniques used for soil stabilization is cement since 1960s [1]. Soft soil such as tropical peat soil was stabilized by the combination of cement and bentonite in several proportions. This technique led to enhanced soil strength [2].

Using MSWIFA as embankment, aggregates in road and landfill have been demonstrated by many research papers [3]. MSWI ash can help with ecological problems or even related issues [4]. Geotechnical engineers sometimes encounter soils such as clayey soil that are marginal for construction. the soil decreased its MDD when the MSWIA content increased up to 25% and increasing MSWIA up to 25%, the UCS of the mixture increased; afterward, the UCS decreased when the MSWIA content increased [6]. Using fly ash as an admixture to stabilize weak soil improved the strength of stabilized samples by 75 times more than that of the untreated clay [7].

Physical properties of finished products are improved by mixing MSWIFA with soils such as concrete, lime, or cement [5]. Adding cement to soil-fly ash mixture increases the UCS value [8]. Researchers have shown that the strength of soil gain due to stabilization depends mainly upon three factors; ash content, molding water content and compaction delay soil [9].

The broad objective of this research is to assess the engineering performance of stabilized weak soil. Thus, this paper shows that the addition of MSWI Fly ash with Portland cement within clay can enhance the soil properties.

II. Materials and Methods

The locally available soil sample obtained from Abi Samra, Tripoli, Lebanon was used. The physical and mechanical attributes, such as Atterberg's limit, specific gravity, optimum moisture content, maximum dry density, and unconfined compression test values of the soil, were in accordance with various ASTM standards.

The soil that is used has a liquid limit of 46, a specific gravity of 2.65, a plastic limit of 12, and a plasticity index of 34 as shown basing on ASTM D4318. The Classification of the soil was determined to be *Lean clay with sand* as USCS (Unified Soil Classification System).

The ordinary Portland cement used is fabricated by Holcim (Lebanon) S.A.L, according to the Lebanese specifications

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LIBNOR (NL 53:1999) for the cement PA-L, 42.5. The specific gravity and the density were found to be 3.15 and 1551 kg/m^3. The sample of MSWIFA must be dried at 105 °C until a constant mass is reached to prepare for X-Ray analysis.

Table I shows that the percentage of the chemical composition of MSWIFA is in a normal range according to ASTM C618 and the amount of CaO presented in the ash is significant which has some cementitious properties and practical to use for stabilization of a weak soil. The density of the MSWIFA is 2.6 g/cm^3. The MSWIFA is considered a natural pozzolan due to its fineness because the percentage retained on sieve No. 325 (13%) after achieving a wet sieving analysis test is less than the maximum limit (34%) specified by ASTM C618. Different percentages of MSWIFA and cement were considered when preparing stabilized soil samples.

TABLE I
CHEMICAL COMPOSITION OF FLY ASH [10]

SIO_2	14.68	Na_2O	5.94
AL_2O_3	12.74	TiO_2	1.91
Fe_2O_3	4.35	MnO	0.05
CaO	26.32	P_2O_5	0.57
MgO	2.25	Cr_2O_3	0.026
SO_3	3.05	Cl	11.77
K_2O	4.30	LOI	12.01

The testing program can be grouped into different categories based on the percentage of the studied parameter(s) added to the soil sample: MSWIFA was added to the soil at 10%, 20% and 30% (by total weight of the soil) and Portland cement used as the cementing material was added to the MSWIFA-soil mix at 10%, 15%, and 20% (by dry weight of the mix). 50 tests are used in the present study to evaluate the potential benefits of using MSWIFA, and cement namely: Proctor Test and Unconfined Compression Test.

Soil and MSWIFA are oven-dried at 105 °C before mixing and sieved through a 0.425 mm sieve for the uniformity of the samples. The clayey soil and mixtures were mixed homogenously with different percentages of water. The specimens were conducted by proctor tests according to ASTM D (1557-78) to determine their MDD and OMC. Then unconfined compression test was conducted for the mix; the dry soil and admixtures were mixed homogenously with a percentage of water obtained by a Proctor Test for a particular mix. Then the soil specimens obtained were conducted inside a PVC mold with dimensions of 38 mm diameter and 76 mm long. the PVC molds of the mix were stored in 100% humidity at room temperature, and cured for 7, 14, and 28 days.

III. RESULTS AND DISCUSSION

A. Proctor Compaction Test

The Proctor Compaction Curves for reinforced/unreinforced soil samples are presented in Fig. 1 as a plot of moisture content versus dry density for some of Soil-MSWIFA mixes where the MSWIFA is represented by FA.

Results in Fig. 1 indicate that the MDD of original soil is 17.8 kN/m^3. It can be observed that the MDD of soil decreases from 17.8 kN/m^3 to 16.6 kN/m^3 when the % added of MSWIFA increases from 0% to 30%. This reduction in MDD is due to the low density of MSWIFA when compared to the initial soil.

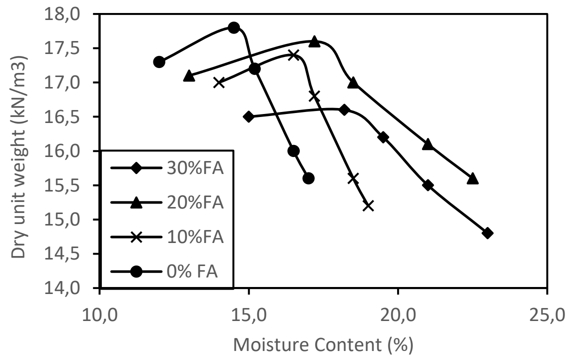

Fig. 1 MDD and OMC variation in mix specimens of varying degree of MSWIFA content

Since the MSWIFA has a high capacity of absorbing water, thus Fig. 1 shows that the OMC is high in all cases; for 10% of cement, an increase of MSWIFA from 0 to 20% increased the OMC by 20% (from 15.7% to 18.9%).

Typical variation of MDD was observed for soil-MSWIFA-cement mixtures in Fig. 2. It reveals the same trend of results when MSWIFA is added to the cement-soil mix. For soil with 10% of cement, adding of 20% MSWIFA to the soil cement mix increases the MDD from 1.81 g/cm^3 to 1.91 g/cm^3. A further increase in the % of MSWIFA to the soil-cement mix decreases the MDD. Similarly, same trend of results is obtained for 20% cement. In other words, Fig. 2 shows that the addition of cement content by more than 10% to the mix decreases the MDD of the mix as well the addition of fly ash content more than 20% becomes uneconomical. This behavior is due to the formation of a cluster-like coarse aggregate when the cement (pozzolanic material), MSWIFA, and soil particles were reacted quickly together [11]. These clusters cause a decrease in the MDD value due to the large space occupied by the cluster which increased their volume.

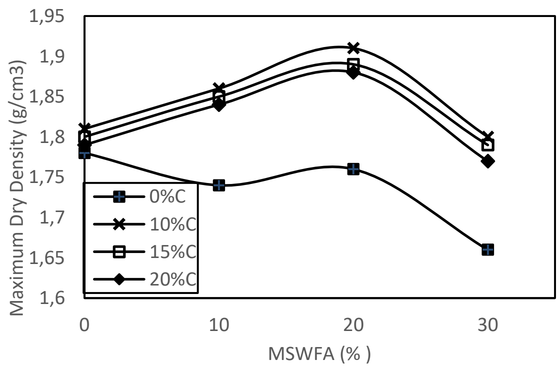

Fig. 2 Influence of Cement on the MDD for Clayey Silty Soil-MSWIFA Mix

Fig. 1 also showed an increase in OMC for all cases. The increase in OMC may be related to the heat of hydration when the admixtures interact with cement. Since cement is a very fine material, thus the demand for moisture content increases.

B. Unconfined Compression Test

Fig. 3 gives the variation of the bearing capacity of soil-MSWIFA-cement mixtures with 7, 14 and 28 days. It can be noted from Fig. 3 that the UCS increased with the curing period. The strength gain is found to be great in the first 14 days.

Variation of unconfined compression test for Soil-MSWIFA with different percentage of cement is shown in Fig. 4. By analyzing the test results obtained, it can be found that for 10% added cement at 28 days, the UCS values of the soil +10%MSWIFA, soil+20%MSWIFA, and soil+30%MSWIFA mixes are 633.6 kPa, 779.3 kPa, and 1175.2 kPa, respectively. A comparison with the UCS values of reference mixes (where only MSWIFA was used) S1 (10%MWSIFA), S2 (20%MSWIFA), and S3 (30%MSWIFA), which were found 620 kPa, 750 kPa, 800 kPa respectively, gives that the addition of 10% of cement increases the UCS value by 2%, 4 % and 47% for 10%, 20% and 30 % of MSWIFA respectively. Same trend of result was found for 15% cement added to the reference mixes. The addition of 15% cement increases the UCS value by 95%, 89 % and 113% for 10%, 20% and 30% of MSWIFA respectively. Same trend of result was found for 20% cement added to the reference mixes. The addition of 20% cement increases the UCS value by 196%, 149% and 179% for 10%, 20% and 30 % of MSWIFA respectively.

Fig. 5 presents a comparative analysis for the compressive strength as a function of % MSWIFA for the different amounts of cement added in the mixture at 28 days. From Fig. 5, we can realize that when the cement content is added to the soil-MSWIFA mixture, a significant improvement in compressive strength will occur. The compressive strength of the stabilized soil sample increases with the increase in the percentage of added cement and that for the different % MSWIFA. We conclude that the optimum strength was obtained for the stabilized mix having soil with 30% MSWIFA, 20% cement. This behavior of soil can be explained by the fact that the hydration of cement produces CSH which reacts as cementing materials causing bonding with soil particles and release free cement which reacts with the active silica of MSWIFA and makes more cementitious composites.

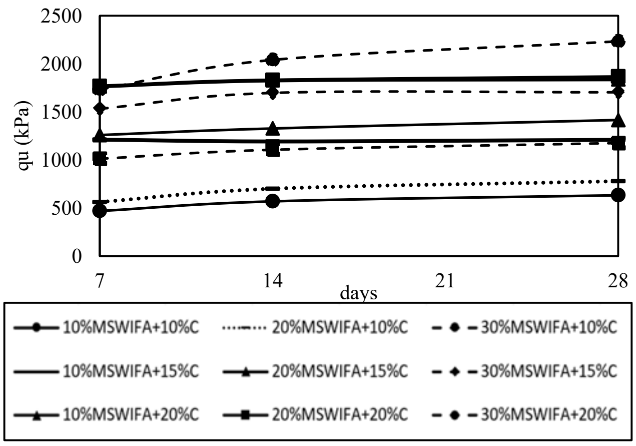

Fig. 3 Bearing capacity variation of soil-MSWIFA-cement mixtures with days

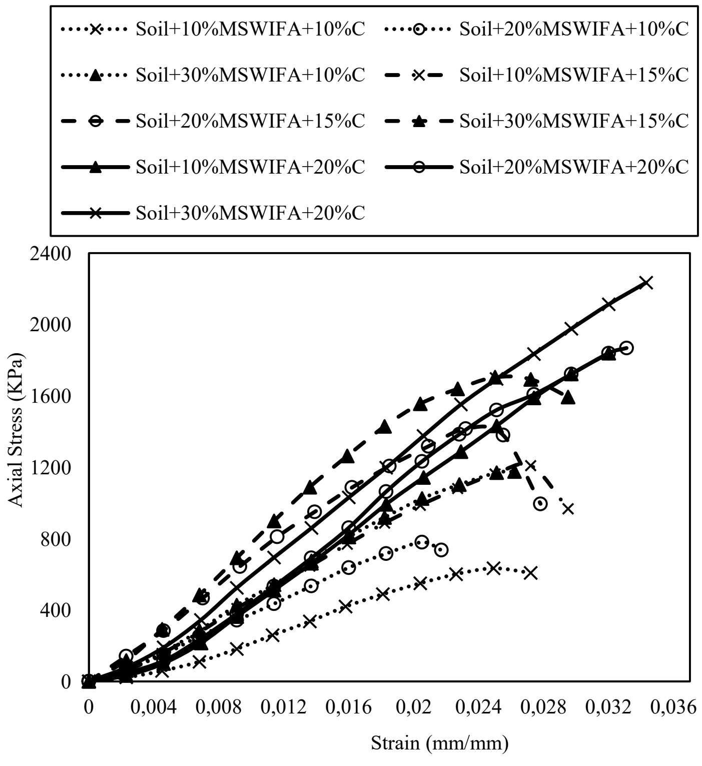

Fig. 4 Stress-Strain behavior for silty-clay soil mixed with different percentage of MSWIFA for 10, 15 & 20% cement content

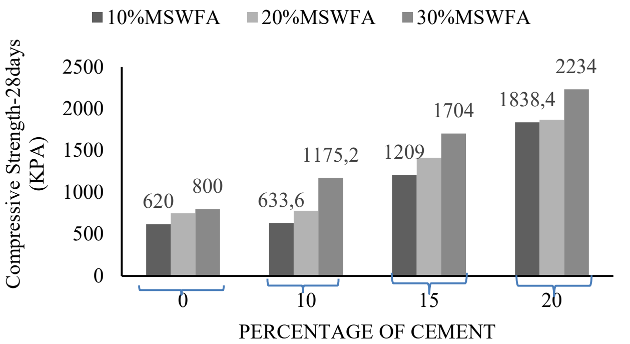

Fig. 5 Compressive strength (28 days) of the mixture versus MSWIFA content for different % of cement

IV. Conclusion

In this paper, the effect of adding cement with MSWIFA as stabilizer materials on weak soil is studied. Based on the obtained results from the parametric study, we conclude that an increase in the MDD was found with the increase in MSWIFA content up to 20% to the soil-cement mix, then an opposite trend for results was found. The OMC value is increased due to the higher water absorption of MSWIFA. The combination of MSWIFA and cement increased the unconfined compressive strength of the composite soil. This is due to the pozzolanic reactions produced by the chemical reaction between cement and MSWIFA together. Finally, we conclude that the MSWIFA can be utilized for treatment of weak soils and consequently improve the mechanical and physical properties of the soil. Therefore, the issue of the accumulated wastes creating an area for disease-carrying insects and consuming spaces in waste disposal sites can be treated by utilizing them in soft soil stabilization.

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