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Influence of Chemical Stabilization on Geotechnical Properties of Municipal Solid Waste

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Abstract. Challenges while redeveloping closed landfill sites include gas emissions and improving engineering properties. Many studies on the chemical stabilization of soils have been reported. However, stabilization for improving the properties of degraded Municipal Solid Waste (MSW) has not been explored. This study reports the findings of experimental investigation to determine the geotechnical properties of treated and untreated MSW with Fly Ash (FA) and Calcium Carbide Residue (CCR). The samples for testing were prepared by mixing degraded MSW with a mixture of FA-CCR with a ratio of 3:1. The study shows an improvement in the geotechnical properties of MSW treated with an FA-CCR. Maximum dry density was increased by 33%, and optimum moisture content was reduced by 38% at a 20% FA–CCR mixture. The permeability of an untreated specimen was 1.10 E-02 cm/s and reduced to 8.32E -05 cm/s. In samples mixed with 20 % FA –CCR. It was also observed that by increasing FA- CCR mixture from 0 to 20%, the angle of shearing resistance increased from 16^0 to 27^{0,} and cohesion increased from 21 kPa to 30 kPa.

Keywords: Municipal Solid Waste, Chemical Stabilization, Fly ash, Calcium Carbide Residue

1 Introduction

Due to an ever-expanding population in the world and industrial growth, municipal solid waste disposal in landfills is increasing daily. As per the annual implementation report of Solid Waste Management Rules, around nine landfills from different states were in the capping stage in India [1]. India's planning commission report states that around 77 % of the increase in MSW by 2050 is expected, resulting in a scarcity of land in urban areas. The shortage of land in and around urban areas and uncontrolled waste dumping has created many problems, including groundwater contamination and air pollution. To overcome such situations, the redevelopment of closed landfill sites is an alarming solution in front of professionals. However, challenges can be faced during the redevelopment of closed landfill sites, including gas emissions, improving engineering properties such as shear strength, compaction, hydraulic Conductivity, and health and environmental issues. Developers are not interested in municipal solid wastes due to their low shear strength, high moisture content, and compressibility. Nevertheless, despite the potential risk to human health and the environment, there is a high perspective on reusing these sites for redevelopment [2].

1.1 Landfill stabilization techniques

Practitioners prefer soil stabilization techniques to improve MSW's physical, mechanical and biochemical properties. Literature shows an implementation of Preloading, Jet Grouting, and Deep Dynamic Compaction (DDC) techniques as practical techniques in the stabilization of MSW. Kinman et al. (1989) studied pressure injection grouting using lime/fly ash slurries to stabilize sanitary landfills and prevent methane gas formation [3]. The effectiveness of DDC for the stabilization of MSW has been reported by Zekkos et al. (2012) [4]. Their findings showed the dependency of the settlement of MSW on applied energy; furthermore, the depth compaction achieved in MSW is less compared to cohesionless soil. Fatahi and Khabbaz (2013) used fly ash (FA) and quicklime with a ratio of 3:1 to improve the geotechnical properties of municipal solid wastes. Significant increases in shear strength parameters, compaction characteristics, and a decrease in compression ratios were observed as the percentage of FA: quicklime increased. In the extension of their study, the authors studied the effect on hydraulic conductivity [5]. The coefficient of permeability of the untreated specimen was 6.2x 10^{-8} m/s, and it was reduced to 3.2 x10^{-8} m/s for an increased mixture of FA and quicklime. It was due to a reduction in void spaces and the conversion of soluble calcium hydroxide to cementitious compounds during the increased chemical stabilization of MSW.

Very few studies are available on chemical stabilization to improve the geotechnical properties of degraded MSW. However, literature shows that fly ash and quicklime can be stabilizing materials for MSW.

Calcium carbide residue (CCR), an industrial by-product of acetylene gas manufacturing industries, is an excellent binding agent containing 76% lime. CCR is now widely studied in stabilizing weak and problematic soils [6]. In this study, an attempt has been made to use the FA: CCR mixture as a stabilizing agent to enhance the geotechnical properties of degraded MSW. Compaction characteristics, shear strength parameters, and hydraulic Conductivity of MSW were evaluated.

2 Experimental Investigation

2.1 Sample collection and characterization

A fresh MSW sample was collected from the dumping site of Sangmaner, Ahmednagar (Maharashtra, India). Approximately 200 kg of MSW sample was collected and placed in plastic bags. The collected fresh MSW samples were mixed thoroughly, air-dried, and the representative sample was taken for characterization [7]. Table 1 shows the composition of the fresh MSW sample. Nearly 80% of waste was biodegradable to hardly biodegradable, 16% inert, and 4% soil-like particles.

2.2 Degraded MSW sample preparation

A small-scale bioreactor simulator of 150 mm in diameter and 500 mm high was used to degrade MSW in an anaerobic condition. MSW sample passing through a 20 mm sieve was used to prepare the sample to avoid boundary effect. The resultant moisture content in the sample was 60% on a wet-weight basis. The sample was placed in a simulator using a standard proctor hammer in three layers with minimal compaction at 6.65 kN/m^3. In addition, a 20 mm layer of gravel (25 mm size) overlaying with filter paper was used to avoid clogging the bottom drainage port.

Table 1. Composition of Fresh MSW sample

Sr.No	Category	Component	Percentage by weight mass (%)	
1	Easily Biodegradable	Food	41.2	56.8
		Garden	15.6	
2	Medium Biodegradable	Paper	3.6	7.6
		Cardboard	4	
3	Hardly Biodegradable	Textile	7	15
		Wood	8	
4	Inert Waste	Ferrous metal	2.8	16.8
		Non-Ferrous metal	2	
		Glass	2.6	
		Plastic	6	
		Stones	3.4	
5	Residual Fines	Soil (Fine <20 mm)	3.8	3.8

The degree of decomposition was measured on the targeted days. The degree of decomposition and organic content achieved 81.7% & 32%, respectively, at 101 days and were measured [8]. A degraded sample was taken for further chemical stabilization laboratory investigation. Table 2 shows the organic content and degree of decomposition. The grain size distribution of the degraded MSW sample was done as per IS 2720-4 [9]. Figure 1 shows that 50% of particles are finer than 4μm.

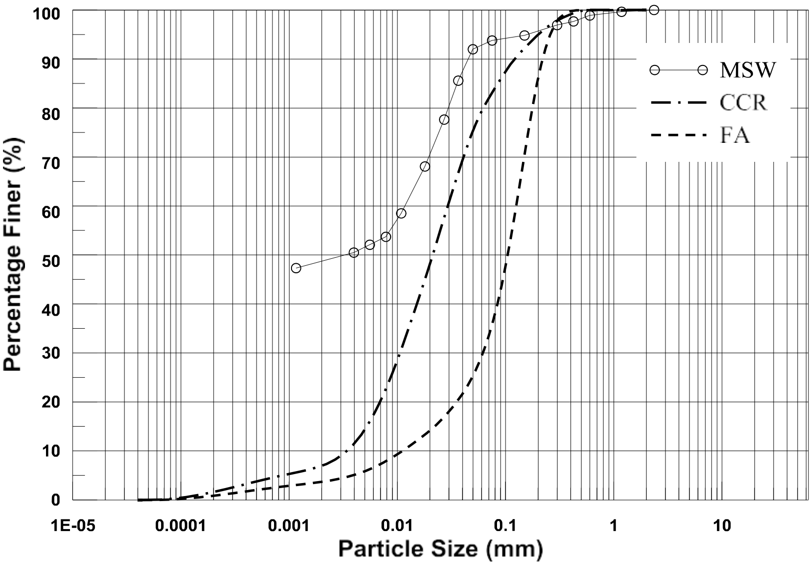

Fig. 1. Grain size distribution of MSW, CCR, and FA

Table 2. Organic content and degree of decomposition.

Degradation level in days	Organic content (%)	Degree of Decomposition (%)
0	72	0
27	67	20.90
41	61	39.23
55	64	54.34
69	40	74.07
101	32	81.7

2.3 Stabilizing Materials- Calcium Carbide Residue and Fly Ash

Calcium Carbide Residue (CCR) was obtained from Swastika Industrial Gas Manufacturing Pvt. Ltd. Nasik, India. It was oven-dried at 105º C for 24 hrs and ground in a Los Angeles abrasion machine. Both CCR and FA passed through.425 µm sieve and used for further experimentation. Class "F" fly ash was collected from Dirk India Private Limited, Eklehere Nasik. Table 3 shows the chemical composition of CCR and FA. Figure 2 shows the SEM images of CCR and FA. The spherical shape of FA particles can be seen from the SEM image, while CCR particles are irregular.

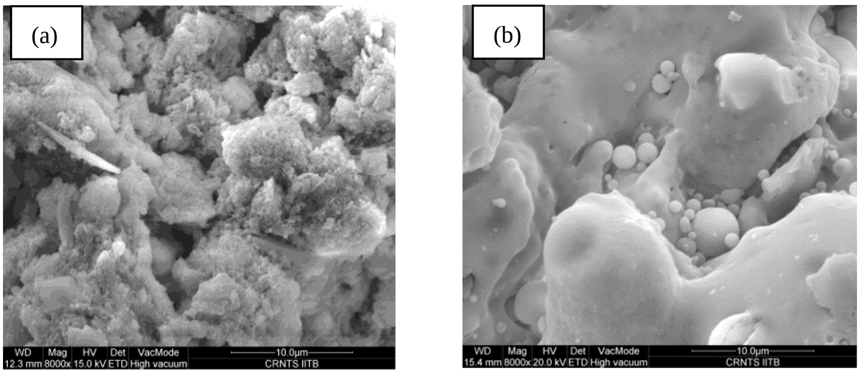

Fig. 2. SEM images of (a) CCR (b) FA

Table 3. Chemical composition of CCR and FA

Chemical Composition (%)	CCR	FA
Cao	55.73	0.76
SiO_2	2.81	60.23
Al_2O_3	0.50	26.51
Fe_2O_3	0.10	7.00
MgO	0.21	0.50
SO_3	0.38	ND
Na_2O	0.057	0.07
K_2O	0.002	1.26

The total amount of the major components responsible for a chemical reaction (SiO_2, Al_2O_3, and Fe_2O_3) in FA was 93.74%. Chemical composition shows a CaO content of 55.73% in CCR, indicating a possible reaction with pozzolanic material and the production of cementitious material. The grain size distribution of FA and CCR compared with that of MSW is shown in Figure 1. The D_{50} of CCR and FA were 0.02 and 0.1 mm, respectively.

2.4 Preparation of CCR: FA stabilized specimens

As explained in section 2.1, decomposed waste material was used for experimentation. Samples were prepared by mixing CCR and FA at a ratio of 1:3. The composition of stabilizing mix is shown in table 4. A dry mix of stabilizers and MSW was preferred concerning the high moisture content of degraded MSW. After mixing, the specimens were prepared for the compaction, hydraulic conductivity, and direct shear test.

Table 4. Composition of stabilizing mix

Material	Composition				
	Untreated	5%	10%	15%	20%
CCR	0	3.75	7.5	11.25	15
FA	0	1.25	2.5	3.75	5
MSW	100	95	90	85	80

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2.5 Compaction Characteristics

Compaction characteristics of MSW were assessed using a light compaction test [10]. Because MSW gets less compacted in landfills than in soil, compaction tests were carried out at different energy levels: 331.08 kJ/m^3(E$_1$), .551.8 kJ/m^3 (E$_2$) by adjusting the number of proctor hammer blows on each layer. As a result, samples were prepared at different compositions, as mentioned in section 2.1. In addition, the initial water content was adjusted considering moisture in degraded MSW samples. During each compaction test, ten compaction test results were generated to determine the relationship between maximum dry unit weight (γ_{dmax}) and optimum moisture content (w_{opt}).

2.6 Hydraulic conductivity (k)

A schematic of a rigid wall permeameter to determine the k of treated and untreated MSW is shown in figure 3. The permeate consisted of a mild steel mold with an inner diameter of 200 mm and a height of 400 mm. Mold was encased in between two end plates using O rings. The water inlet, gas collection, and pressure meter were provided on the top cap, while the drainage valve was installed on the bottom plate. Samples were prepared as discussed in section 2.3. Each sample was compacted to its maximum density obtained from compaction curves. Saturation was done by allowing water to percolate in an upward direction. The generated gas was removed from the simulator before the discharge measurement. The constant head method was then performed by collecting discharge up to 60 sec. [11] Equation 1 was used to determine the k.

$$k = \frac{Q*L}{A*h*t} \qquad (1)$$

Where Q = quantity of flow, t=time interval, length of the sample, A=Cross sectional area of a sample, and h=constant head. Each specimen was tested for determination of k after 28 days of curing.

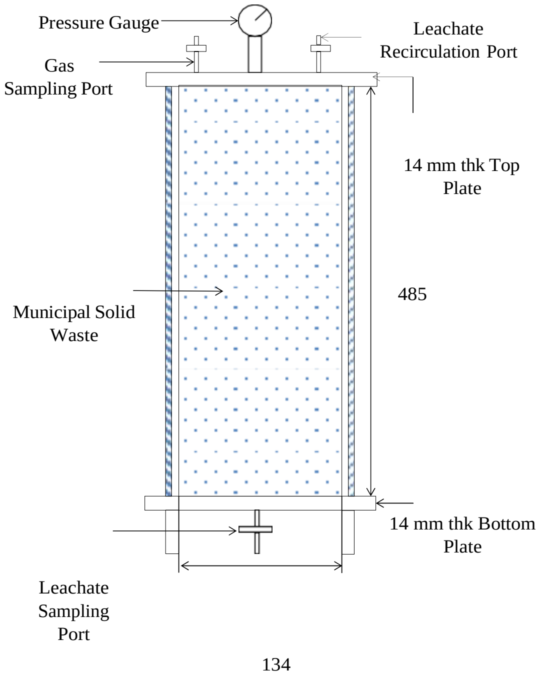

Fig. 3. Schematic diagram of the simulator and its components

2.7 Shear Strength

The shear strength of treated and untreated MSW samples was determined using a direct shear test [12]. Each specimen of the desired composition was tested after 28 days of curing. The 60 mm x 60 mm in the plan and 50 mm high shear box was separated horizontally by a groove used for laboratory testing. The strain-controlled instrument can apply a shear rate of 1.25 mm/min. Each sample was compacted in the shear box to its maximum density obtained from compaction characteristics. Samples were sheared under normal stresses of 0.5 kg/cm^2, 1 kg/cm^2, and 1.5 kg/cm^2. maximum shear stress recorded, and its corresponding strain was used to plot the Mohr Coulomb failure envelope.

3 Results and Discussion

3.1 Compaction characteristics

The compaction characteristics of treated and untreated samples were investigated at two energy levels, E_1 and E_2. Figure 4 (a): (b) shows the compaction curves of E_1 and E_2 for untreated and treated samples at 5%, 10%, 15%, and 20% compositions of FA: CCR. The results show an increased γ_{dmax} and a decreased w_{opt} as the percent composition of the binder increases from 5% to 20%, and the energy level increases from E_1 to $E_{2.}$ (Table 5). Almost a 33% increase in γ_{dmax} and a 38% decrease in w_{opt} is evidence of the effectiveness of binders used in this study.

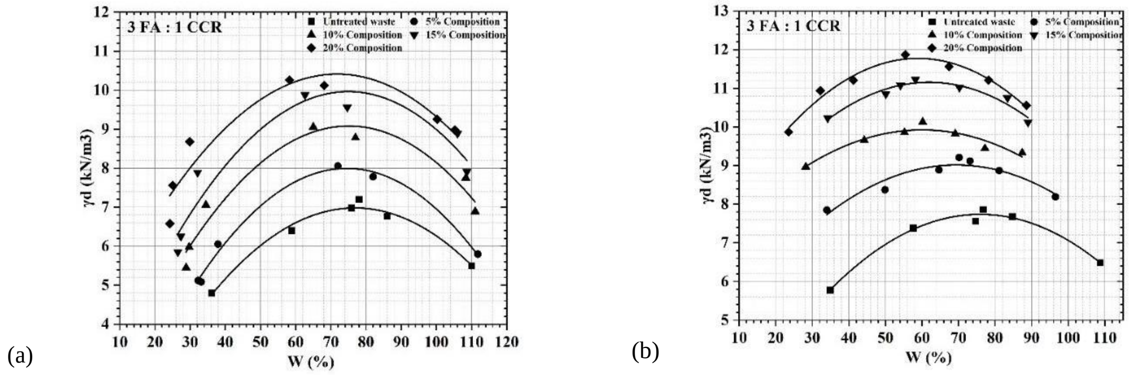

Fig. 4. Compaction curves for untreated and treated MSW samples at energy level: (a) E_1 (b) E_2

Table 5. γ_{dmax} and w_{opt} for different compositions at E_1 & E_2

Composition type	E_1		E_2	
	γ_{dmax} (kN/M^3)	w_{opt} (%)	γ_{dmax} (kN/M^3)	w_{opt} (%)
Untreated	7.20	78.00	7.86	76.77
5%	8.06	71.98	9.20	70.20
10%	9.06	65.00	10.13	60.21
15%	9.88	62.0	11.2	58.2
20%	10.26	58.23	11.87	55.45

3.2 Hydraulic Conductivity

It was observed that the coefficient of permeability (k) was reduced as the composition of FA: CCR increased from 5% to 20%. The value of k for untreated MSW specimens was 1.10 E-02 cm/s and reduced to 8.32E -05 cm/s in treated samples at 20 % FA – CCR. The formation of cementitious compounds leads to a decrease in void spaces, contributing to the permeability reduction. Table 6 gives the summary of hydraulic conductivity measurements.

Table 6. Summary of hydraulic conductivity measurement at 28 days of curing period

Composition	Untreated	5%	10%	15%	20%
k (cm/s)	1.10E-02	1.08E-02	6.34E-03	5.58E-04	8.32E-05

3.3 Shear Strength of Treated & Untreated MSW

Figure 5 (a) to (e) shows the stress-strain response of treated and untreated MSW samples. Figures show there is a steady gain in strength for horizontal deformation. Therefore, shear strength parameters were determined for the maximum horizontal load-carrying capacity of the sample. Figure 6 compares the Mohr-Coulomb strength envelopes obtained from the test for all FA - CCR stabilized MSW compositions. By increasing FA- CCR content from 0 to 20%, the angle of shearing resistance increased from 16^0 to 27^0, and cohesion increased from 21 kPa to 30 kPa.

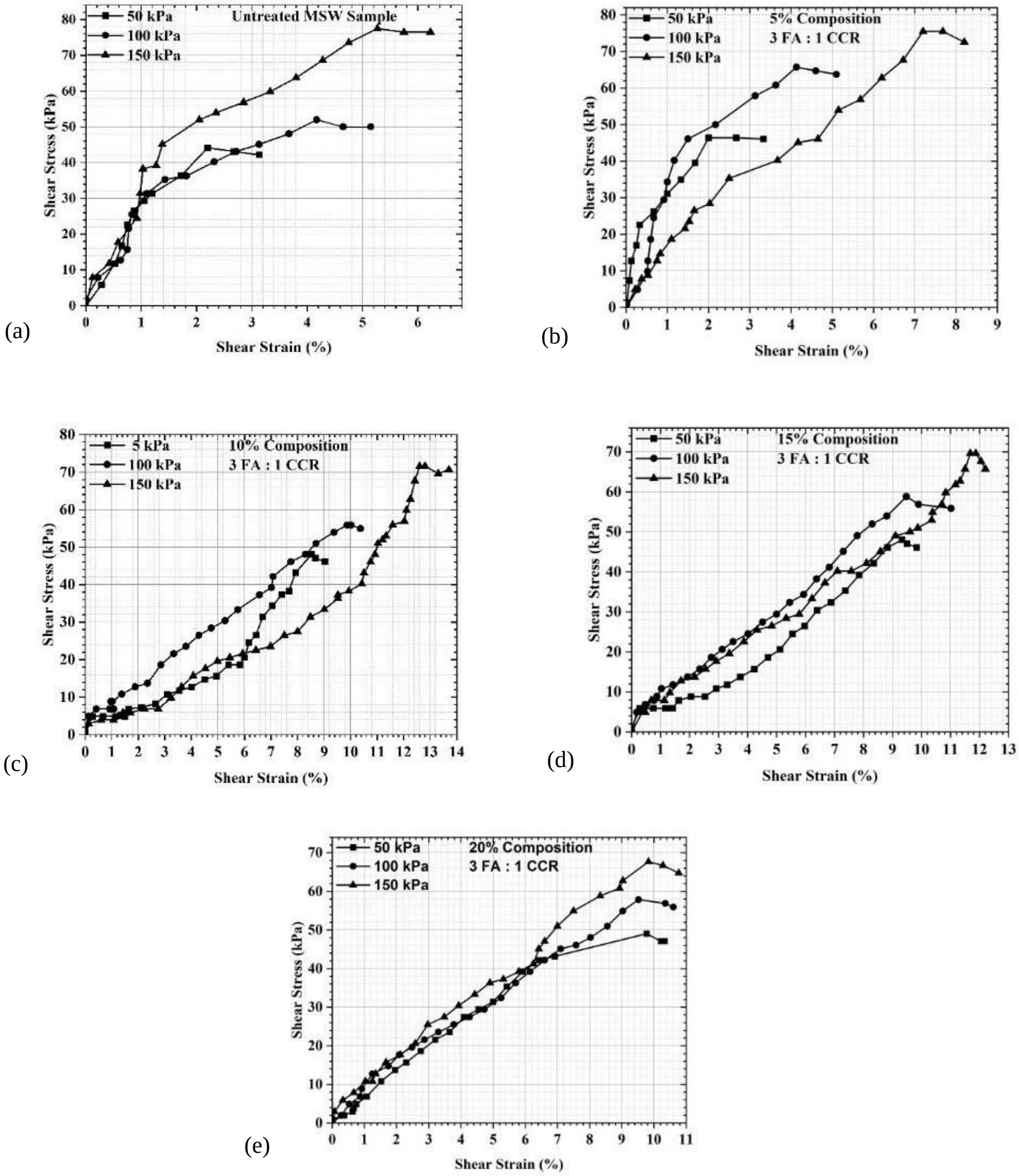

Fig. 5. Stress-strain response under direct shear test sample (a) Untreated MSW, (b) 5% Composition, (c) 10% Composition, (d) 15% Composition, (e) 20% Composition.

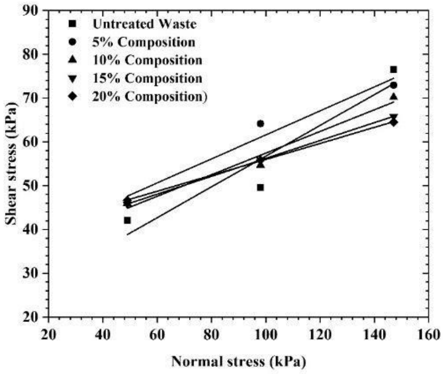

Fig.6. Strength envelopes of untreated and tread MSW specimens.

4 Conclusions

The geotechnical properties of treated and untreated MSW with Fly Ash (FA) and Cal- cium Carbide Residue (CCR) were investigated. Compaction characteristics, permea- bility, and shear strength tests were conducted using fly ash (class F) mixed with CCR (3:1) to stabilize decomposed municipal solid waste at 5%,10%, 15%, and 20% resp. The findings of this experimental program can be summarized as follows:

1. The fly ash–CCR in the specimen reduced the permeability coefficient by increasing the composition from 5% to 20% resp. The permeability coefficient for an untreated specimen was 1.10 E-02 cm/s and reduced to 8.32E -05 cm/s on stabilization.
2. The compaction characteristics of treated MSW at various energy levels proved the effectivity of FA: CCR composition as a binder, wherein density could be increased by 33%.
3. It was also observed that by increasing FA- CCR mixture from 0 to 20%, the angle of shearing resistance increased from 16^0 to 27^{0,} and cohesion increased from 21 kPa to 30 kPa.
4. The results of this experimental research will be beneficial and effective in redeveloping closed landfill sites incorporating chemical treatments.

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