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Geotechnical Properties of Fresh and Degraded MSW In the Foothill of Shivalik Range Una, Himachal Pradesh

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***Abstract**: The aim of the present study is to determine the physical and geotechnical characteristics of municipal solid waste (MSW) from an open dump site located in Una town, Himachal Pradesh (India) for the analysis of settlement and structural stability of landfill. Degraded waste was tested for different time intervals ranging from 6 months to 6 years. The physical characterization and the geotechnical tests were performed to determine the composition and the engineering properties of MSW respectively. The presence of moisture content in the fresh waste was 49.5±1.05% but for the degraded (or old) waste it varied between 39.8 to 51.6%. The specific gravity of fresh and old waste varied between 1.83±0.05 and 1.85 for 6 months old waste and 2.28 for 5-6 years old degraded waste respectively. The maximum dry density (MDD) was observed to be 4.28 kN/m^2 for fresh waste at the optimum moisture content (OMC) of 78.1% and 4.47 kN/m^3 for 6 months old waste and 6.25 kN/m^3 for the degraded waste of 5-6 years at 80.2, 85.4% of OMC respectively. The hydraulic conductivity (k) of MSW was found to be decreasing with the degradation of MSW and the overburden pressure whereas the shear strength increased along with the degradation of the waste. The cohesion (c) and angle of internal friction (φ) increased respectively from 31.2 kPa(fresh) to 38 kPa(degraded) and 14° to 22° with the increase in waste degradation. The compression ratio of fresh waste was within the ranges of 0.19-0.29 and for degraded MSW it varied between 0.12 for 6 months old waste and 0.17 for 5-6 years old degraded waste respectively.*

Keyword: Municipal Solid Waste, Degradation, Fresh Waste, Geotechnical Properties, Compaction, Shear Strength.

I. INTRODUCTION

With rapid growth in industrialization, urbanization and economic growth in India the generation of municipal solid waste in India has increased to a great extent which causes problems to habitats and urban local bodies [1,2]. The increase in the waste generation in the country as a result of the population growth which is expected to increase up to 1.7 billion by 2050 with an annual growth rate of 1.2% [3,4].The total waste generated in the country is 1,33,760 T/day, of which about 91152 (68%) tons are collected and approximately 25,884 (19%) tons are treated [5]. The engineered landfill is considered as an effective, affordable and environmentally acceptable method for waste disposal. In India, about 10-20% of the total waste generated is disposed of in an engineered landfilled site with the remaining fraction being disposed of in an unsatisfactory manner [1,4,6]. Hence for disposing the municipal solid waste it requires the construction of an engineered landfill system. The waste disposal creates challenges in designing and operation of landfills, particularly in the hilly terrains. The MSW disposed of in landfill have complex properties arising due to the interaction between the waste and require the analysis of settlement, seepage, slope stability and cracking which leads to difficulties in engineering design of landfills [7,8,9,10]. The geotechnical characteristics of MSW are important parameters for designing of landfill which considers engineering aspects like stability under seismic and static conditions, settlement (compression) behavior and during earthquakes, dynamic response of waste material as given in Table I [11,12,13]. The geotechnical aspects for designing of landfill include determination of unit weight, hydraulic conductivity, compressibility, shear strength characteristics of the municipal solid waste [7,9,11-23]. The degradation of waste changes engineering properties of MSW which are useful for designing the various components of the landfill and also for assessing the geotechnical stability. The MSW is heterogeneous in nature and large in size than organic soil or clay, sand. Therefore, shredding of waste samples is required to utilize conventional equipment and to simulate the laboratory conditions. In the literature the effect of shredding and size of apparatus has not found any rational basis but has a significant effect on compression, shear strength properties which are having a dependency on degradation level [24].

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Table I: Important geotechnical parameters for landfill designing, stability analyses [8,46].

Parameters	Unit Weight	Hydraulic Conductivity	Shear Strength	Lateral Stiffness	Compressibility
Leachate collection and removal system	✓	✓	✓	✓	✓
Drainage System integrity	✓				
Waste slope stability	✓	✓	✓		✓
Cover System Integrity	✓		✓		✓
Subgrade stability	✓		✓		
Subgrade integrity	✓		✓	✓	
Steep slope liner stability	✓	✓	✓		
Steep slope liner integrity	✓		✓	✓	✓
Shallow slope liner stability	✓	✓	✓		
Shallow slope liner integrity	✓		✓	✓	✓

The presence of moisture content increases the rate of degradation due to the presence of micro-organism in waste [25] thereby affecting the unit weight, stability, and settlement of MSW. The biodegradation of organic content results in the settlement of MSW up to 25-50 % of the initial height of landfill [25,26]. The composition of the waste varies for developing countries where moisture content is more because of higher organic content and less for developed countries where organic content is less [27,28].

In this context, the variations in properties of waste were observed from fresh state to decomposed state. The moisture content for fresh waste and MSW at the different phase of degradation was reported to be varied from 37 to 100% and 28 to 75% respectively [12,16,19,29]. The variation in unit weight is due to a moisture content that is high in summer and lower in winter and increases from 7 kN/m^3 to 20 kN/m^3 with depth and rate of degradation [30,31]. The degradation of waste led to the decomposition of waste mass into finer components. The degradation of MSW increases bulk unit weight, compaction characteristics resulting in decreased saturated hydraulic conductivity of sample [20]. The dry densities of waste exhibit variation in permeability of waste which decreases with a higher degree of compaction [7,32]. The permeability of fresh waste ranges from 10^{-8}m/s to 10^{-4} m/s and for landfilled sample (degraded sample) it ranges from10^{-6} m/s to 10^{-14} m/s [33-35]. There are few studies existing on analyzing the properties of degradation of waste for landfill stability [20,36]. The strength characteristics of waste have an important role in designing of a landfill, which is a function of the waste composition, unit weight, degradation rate, moisture content [11,22]. The compressibility of waste decreased for degraded waste than fresh waste. The change in the compressibility of waste changes the volume of MSW and affects the differential settlement in the landfill. The shear strength parameters get affected due to varied composition and degradation level of MSW which were considered to be most critical for the analysis of slope stability of landfill [16,18,22,37-39]. The degradation of waste varies shear strength parameters as increases cohesion from 12 to 67 kPa and decreases the angle of internal friction from 38° to 24° [19,22,36,38,40]. However, the studies of various researchers [22,23,41] showed that the variation in c and φ values of samples did not follow any trend with the rate of degradation and similarly the effect of degradation on shear strength parameters was not following any pattern [23]. Some studies [18,23,41] showed that decreases in c and increase in φ values were observed with decomposition. The study conducted by the researcher [16], reported that with an increase in degradation of waste φ increases but any correlation of decomposition with c was not found. Alternatively, decrease in angle (φ) and an increase in cohesion (c) value was reported with age and decomposition of waste [20,42]. The shear strength of municipal solid waste is dependent upon shear displacement, and is observed to be increased with an increase in deformation [14]. The strain in MSW was observed to be increased in reported studies [9-11,38] leading to high strength of MSW. During the initial stage, the stability of landfills may be influenced by an increase in unit weight and pore water pressure developed within landfill which decreased the shear strength of waste [22,31,40]. The mechanical behavior of MSW helps in determining the stability during the degradation phase of MSW and also, the strength characteristics for the stability of landfills.This paper describes a laboratory study conducted for determination of geotechnical characteristics of fresh and landfilled waste at an open dump site. The laboratory experiments for compaction, permeability, shear strength, compressibility characteristics were conducted under increased moisture content and density. The requirement of testing the MSW from the geotechnical perspective is at the time of closing landfills and its usefulness for land development practices. Also, these properties were evaluated to determine the behavior of MSW under different conditions of loading in order to analyse the landfill stability and settlement characteristics.

II. MATERIAL AND METHODS

A. *Site location*

The dump site is located in Una district of Himachal Pradesh, approximately 5 km from the town at coordinates 31.47°N, 76.28°E in the foothill of Shivalik range (Figure 1a). The site receives 5.5 tons of municipal solid waste on a daily basis and is discarded in an unsatisfactory manner.

B. *Sample Collection and Initial Characterisation*

The sampling of waste was done as per [43] ASTM D 5231 [2,21]. The fresh samples of MSW were collected for a week, to observe the composition of waste. Average 100 kg of waste is segregated on plastic sheet with the help of rag pickers from the waste collected during a week. The physical component of MSW like biodegradable, paper, plastic, wood, metals and inert were analysed using segregation of waste. The segregated components were weighed to determine the physical characterization of waste. In this context, the gradation of the fresh sample was determined after shredding sample and moisture content was determined using a dry gravimetric method [26].

The samples of degraded waste were collected from several points at varying depths from 0.5m to 6m with corresponding age between 0.5 years to 6 years. The identification of sampling points for degraded samples was done with the help of personnel from MC Una and workers at the dump site. In Figure 1(b), the location of the sampling points is shown. The sampling points 1,2,3,4 and 5 showed the location of collected samples depending upon the period of dumping. The sampling point 1,2,3,4 and 5 showed the waste collection point with age not more than 6 to 7 months, 1 to 1.5 years, 2 to 3 years, 3 to 4.5 years and 5 to 6 years respectively. Based upon the disposal of waste the location of samples was identified. The degraded waste samples were collected from different depths with the help of auger. The MSW collected in auger was weighed and the volume of waste was determined by borehole diameter and depth, to evaluate in-situ unit weight. Samples collected were (fresh and landfilled) packed in polythene bags and were brought to laboratory for testing.

The moisture content of waste samples was determined in accordance with ASTM D 2216 after drying samples at 60^o C. The wet gravimetric moisture content method is used for determining the moisture content for landfill practices [20]. The rate of degradation of MSW was determined based upon the organic present in the fresh and degraded waste. Thus, the degree of degradation is evaluated using the following equation [20]:

$$DOD = \left(1 - \frac{X_{fi}}{X_{fo}}\right)\frac{1}{(1 - X_{fi})} \times 100 \quad \text{.....(i)}$$

where X_{fo} is the initial organic content and X_{fi} - organic fraction at any stage of degradation.

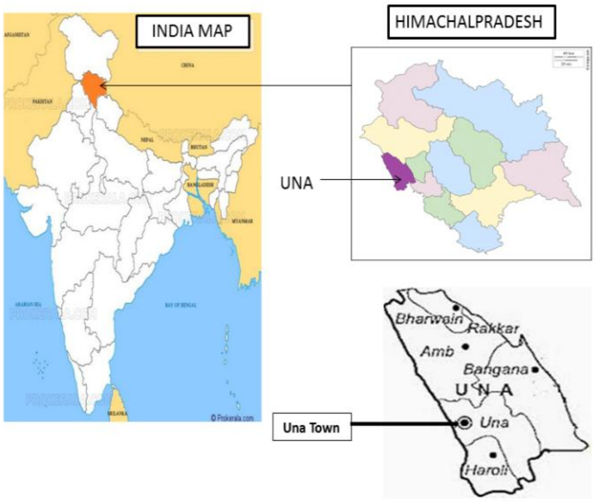


Figure 1(a). Location of dump site.

Figure 1(b). Location of sampling points on dump site.

C. *Geotechnical Testing of MSW*

The samples collected from the site were shredded without pre-sorting and were characterized for determination of moisture content, particle size distribution (PSD), organic content. Geotechnical testing was conducted for determination of unit weight, compaction, hydraulic conductivity, shear strength and compressibility. The samples were tested as per guidelines in American Standards (ASTM) [43].

D. *Physical Properties*

The physical properties of MSW from a geotechnical perspective include determination of organic content, specific gravity, particle size distribution. The determination of specific gravity of samples was done using a 1000 ml capacity pycnometer as per ASTM as used by many researchers [19,36,44].

The samples were analysed for particle size distribution (PSD) having sieve size openings from 0.075 mm to 100 mm after drying at a temperature of 60°C. The moist waste samples were sieved using a set of three sieves 100mm, 50mm, 20mm [46]. The larger particles of MSW were measured manually. The MSW was shredded using low-speed torque shredder to obtain the representative sample because of difficulty to use larger sized particle for laboratory testing [19,23,46]. The shredded samples varied in size between 0.75mm to 40 mm. The wet sieve analysis of waste was done on a weight basis as per ASTM D 422 [46].

The gradation, unit weight, water content, depends upon the composition of MSW collected from the site and were determined based upon volume and weight of the material. The unit weight of waste is used for analysis of the stability of slopes, leachate collection and removal system designing, settlement prediction and structural integrity of pipe systems [10,30,47]. The unit weight of MSW samples depends upon the composition of waste, placement conditions, environmental conditions and stress conditions (overloading condition) [48].

E. *Compaction Test*

The samples of MSW were shredded and oven dried (100-105ºC), [12] to evaluate the dry density as per ASTM D 698 [48]. The mould of a diameter of 100 mm was used for the compaction test. The samples were compacted using 25 blows for three layers using rammer. The dry densities of waste samples for both fresh and aged waste were evaluated for different moisture contents during testing. Leachate was used instead of water to simulate the field conditions. At different moisture contents of 44%, 60%, 80%, and 100%, the testing of MSW sample was done. The dry density of waste is plotted against moisture content.

F. *Hydraulic Conductivity*

The constant head permeability tests as per ASTM Standard [43,49] was performed for determining hydraulic conductivity of MSW. The hydraulic conductivity of waste varies significantly with the composition of waste, degree of compaction; overburden stress applied but also depends upon the degradation process which changes the composition, size distribution of waste [7,8,33]. The permeability of the MSW sample varies with the amount of plastic fraction present, which obstructs the flow of liquid through the sample [50]. The fresh and landfilled samples were compacted at dry density in small scale rigid wall permeameter of diameter 6.3 cm and height of 10 cm. The shredded fresh MSW samples (8-10 kg) were compacted in layers of 6-8 cm thickness using 15 blows per layer by a hammer. The samples were then tested under zero confinement and gradually increased normal stresses (0, 50, 100, 150, 200, 276 kPa). After saturation of the sample, the flow rate through the sample was determined using Darcy's law under constant hydraulic gradient [7,19,33].

G. *Direct Shear Strength*

The determination of shear strength of waste was done in the laboratory using a direct shear test as per ASTM D 3080. Laboratory testing for shear strength evaluation is the most appropriate method used by many researchers [14,18,19,22,23,38,47], so a direct shear test was conducted on MSW samples. The samples were placed in the shear box of size ($60\times 60 \times 50\ mm$), subjected to the vertical stress (σ) of 50-300 kPa and sheared at a horizontal displacement rate of 1 mm/min at OMC of waste [7,39,51]. The fresh samples were collected during 5 days sampling period and degraded samples were collected within the dump site from a varying depth of 0.5 to 6 m having age between 0.6 to 6 years. The large metal, glass particles were removed from waste and shredding of the sample was done before placing in the shear box. Each layer of the sample was compacted by a hammer to the pre-determined unit weight. The friction between the two surfaces in the shear box is reduced by polishing and below the lower box, steel balls were provided to reduce the friction. The samples were tested under different normal stress levels and the effect of MSW particles on strength was accounted. Initially, the loads were applied (50 kPa, 100 kPa, 150 kPa, 200 kPa, and 300 kPa) and each vertical load on the sample was sustained for at least 2 hrs for ensuring that no further settlement occurs before shearing [7,51].

H. *Compressibility*

Compressibility testing of MSW samples was determined using oedometer test for evaluating compressibility of fresh and degraded waste samples under different moisture content as per ASTM D 2435 [43]. The samples were placed between porous stones in an oedometer with dimensions 63mm diameter and 25 mm thick circular ring. The waste samples were prepared at OMC and compacted with the tamping device. Initially, 48 kPa load was applied on the sample and for about 24 hrs, the compression was measured at different time intervals. The load was increased to 96 kPa after 24 hrs or when compression ceases and again compression at different time intervals for the next 24 hrs was measured. The compression of samples was measured for normal stresses (σ) of 150, 250, 300 and 400 kPa. Thus, strain variation with normal pressure was plotted and the compression ratio was evaluated.

III. RESULTS AND DISCUSSION

Physical characterization of MSW

Initially, physical characterization of MSW samples was done according to US EPA (2010) [52], during the sample collection. Table II represents the physical characterization of fresh and old MSW in the site. It was observed that the biodegradable fraction comprised of 68.3% and the non-biodegradable fraction was observed to be 31.7% of total waste [53]. As the age of waste increases, the biodegradable matters present in waste tends to degrade. The fraction of organic matter in waste decreases to about 12.2 % to 3.3 % for waste age from 6 months to 6 years. Thus, inert fraction in waste increases to 70.3 % to 80.53 % for old waste which is much less for fresh waste.

The moisture content of three representative samples for each fresh and old waste was determined without pre-sorting, immediately after collection of waste from the site at 60°C as per ASTM D 2216 [54].

The dry gravimetric moisture content of waste is used and is defined as a ratio of the mass of water to mass of dry MSW. The temperature 60°C was maintained to avoid the combustion of organic content in MSW. The moisture content (Table II) was found to be 49.5±1.05 % for fresh and 39.8 to 51.6% for old waste respectively. The loss on ignition method (LOI) was used as per ASTM D2974 [55] for determining the organic content of MSW. The dry samples both fresh and landfilled MSW were heated at a temperature of 440°C in a muffle furnace for 72 hours. The organic content of waste was found to be 74.1% for fresh and 20.75 % to 38.1 % old waste (Table III).

Geotechnical Characteristics

The specific gravity of fresh waste was 1.83-1.92 and old waste was found to be in the range of 1.85-2.28 as given in Table III. For the present study, the specific gravity of waste was observed to be within the range reported in the literature. However, little variation in results is due to composition and fibrous content in waste.

It was observed from Table III that with a decrease in particle size, compaction, degradation of waste, specific gravity of sample increases. Thus, due to decomposition of organic matter, decrease in organic content of waste samples occurs. As the age of waste sample increases, it causes an increase in the degree of decomposition [47,56].The moisture content of waste was found but did not follow any trend with depth. Initially moisture content increased from 0.5m to 2m and then decreased from 2.5m to 6m. Figure 2 shows the variation in moisture content values with depth. The moisture content variation was found to be less than reported literature. It was found that with the increase in depth the unit weight of MSW increases from 6.97kN/m^3 to 10.4 kN/m^3 (Figure 3). However, the unit weight of MSW varies with degradation due to an increase in fines present in MSW. The denser packing of particles results in the increased unit weight of MSW.

Table II: Characterization of fresh and degraded MSW in Una, Himachal Pradesh.

Sr. No.	Components	Composition (%)					
		Fresh Waste	Degraded Waste				
			3-6 month	1-1.5 year	2-3 year	3.5-4.5 year	5-6 year
1	Organic matter	56.1	12.2	5.53	6.58	4.3	3.3
2	Paper	12.2	2.53	1.35	1.89	1.03	0.76
3	Polythene/Plastic	10.3	4.34	2.48	2.27	2.31	1.12
4	Glass	1.0	0.6	1.2	1.5	0.6	0.2
5	Metal	1.2	0.93	1.04	1.86	0.51	0.16
6	Inert	10.5	70.3	75.1	74.3	78.46	80.53
7	Others	8.7	9.1	13.3	11.6	12.79	13.93
	Total	**100**	**100**	**100**	**100**	**100**	**100**

Note: All component values are in percentage (%).
Other includes leaves, wooden matter, thermo-cole, coconut etc.
Inert includes soil particles from street sweeping, after degradation of waste.

Table III: Properties of waste samples (Fresh and Degraded)

Sample	Age (years)	Moisture Content (%)	Specific Gravity (G_s)	Organic Content (%)	Comparison with literature	
Fresh	0	49.5	1.83±0.05	74.1	G_s= 0.85 Moisture content = 44% O.C = 76-84% G_s= 1.89-1.95 Moisture content = 35% G_s= 1.34 Moisture content = 46%	Reddy et al., 2009c Feng et al., 2016 Breitmeyer 2011

Landfilled (old) Sample	3-6 months	44.3	1.85±1.97	38.1	**0.3 year**, G_s-1.83-2.27, m/c- 42.5-47.9 **2 years**, G_s – 1.88-1.93, m/c- 58.5-68.9% **2-2.5 year**, G_s -1.95, m/c-43.9, O.C- 33.1% **3-4 year**, G_s -2.00, m/c-35.8, O.C.- 21.1% **4.5-6 year**, G_s -2.40, m/c-20.1, O.C.- 15.9% G_s - 1.51(S), 1.88(M), 2.14 (D)	Feng et al., 2016 Ramaiah et al. 2017 Wu et al., 2012
	1-1.5 year	51.6	1.93±2.04	26.1		
	2-3 years	48.9	1.91±2.24	29.8		
	3.5-4.5 years	46.4	2.15±2.28	33.2		
	5-6 years	39.8	2.14±2.23	20.75		

S= Small depth, M= Medium Depths, D= Large depths

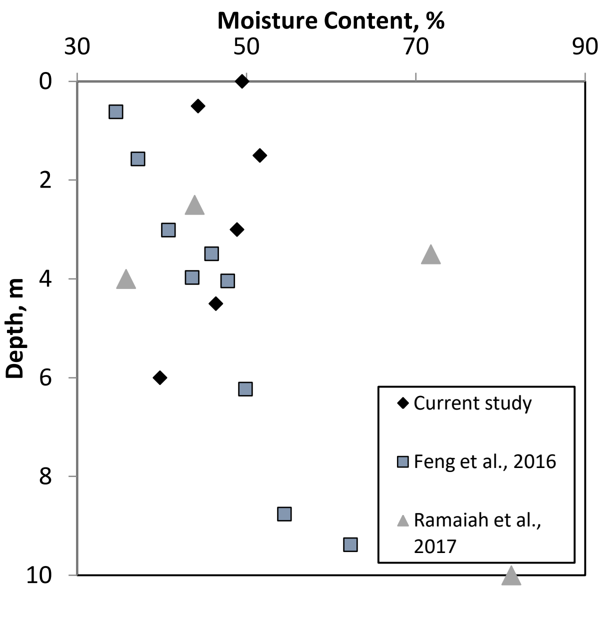


Figure 2. Water content variation with depth.

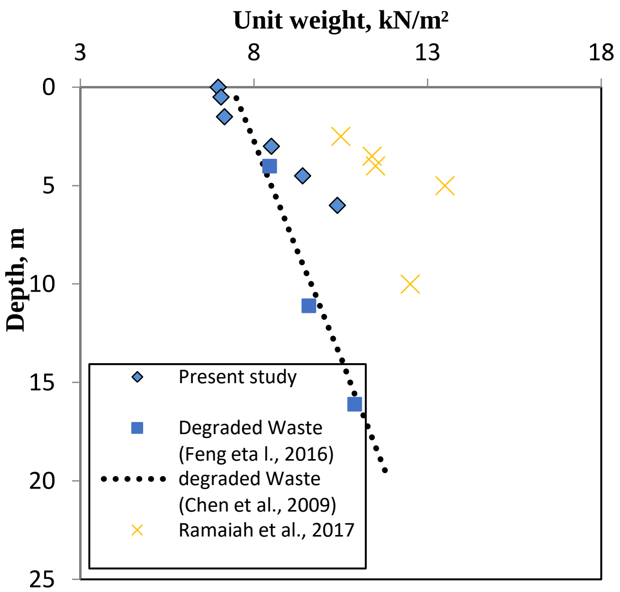


Figure 3. Unit weight variation with depth.

The particle size of samples was determined as per ASTM D 422. Initially, MSW samples were sieved (on wet basis) through 100mm, 50mm, and 20mm sieves and 57%, 14.5%, 10% of fresh MSW, 51%, 17%, 14% of landfilled MSW was found to be retained on respective sieves. But for analysis of MSW, large particles were found unsuitable, so the representative samples should be obtained by shredding samples. The samples collected from the site were shredded using high torque shredder to obtain a representative sample for geotechnical testing. After oven drying, samples were sieved through the sieve of opening from 0.075mm to 40mm. The average size of the particle after shredding ranges from 0.75mm to 40mm.

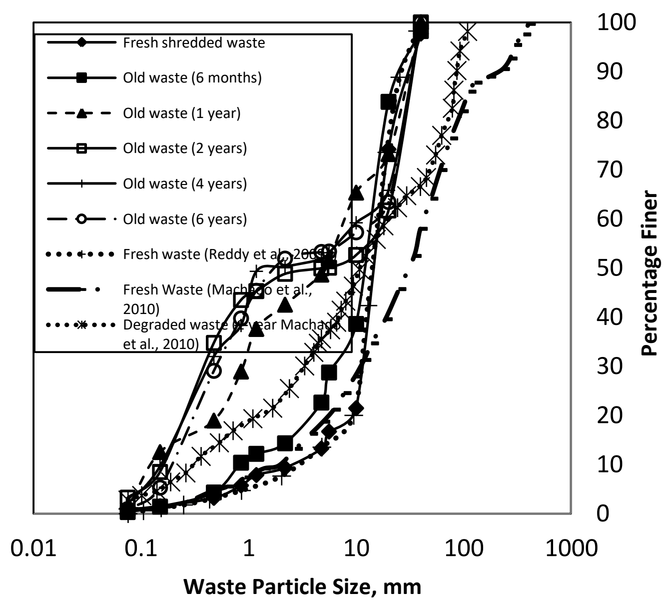


Figure 4. Comparison of particle size distribution of fresh and degraded waste samples of present study with literature.

Figure 4 shows the grain size distribution curves for fresh and old waste samples. It was observed that the with degradation of waste presence of finer particles increases [8].

This is because of the biodegradation of waste which disintegrates the MSW particles.

Compaction Characteristics

Compaction test performed on MSW samples (fresh and degraded) using Standard Proctor test showed that the fresh shredded sample having MDD of 4.28 kN/m^3 at optimum moisture content of 78.1% and old samples (degraded samples) of MSW having MDD of 4.47 kN/m^3–6.25 kN/m^3 at optimum moisture content between 80.2% - 85.4%.

Figure 5 showed that the dry density of waste increases with the degradation of MSW. The increase in dry density of MSW with depth and age of waste is due to the presence of fines, degraded particles in waste. The fines present in degraded MSW causes an increase in densities with the increase in moisture content [39]. The observed results were found to be within the range reported in the literature. The proctor test for fresh waste gives the MDD of 4.2 kN/m^3 at 70% moisture content 5.25 kN/m^3 at 62% OMC for laboratory prepared MSW [19]. For landfilled waste, the MDD increased up to 6 kN/m^3 at an OMC of 77% [39].

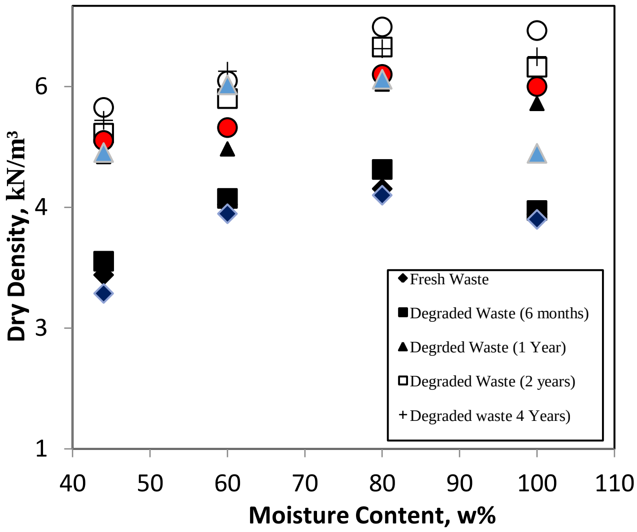


Figure 5. Comparison of compaction characteristics of MSW (fresh and landfilled waste) from current study with literature.

Hydraulic Conductivity

The obtained results from the tests were plotted in Figure 6. The results depict that the hydraulic conductivity of fresh samples is greater than that of degraded samples. Hydraulic conductivity of MSW in rigid wall permeameter is considered under zero confinement and then under increased pressure. The zero pressure is simulated with MSW placed near the top surface of the landfill so for explaining practically zero confinement, the pressure was converted to equivalent heights of MSW under average dry gravimetric moisture content (78.1% for fresh waste and 80.2% - 85.4% for degraded waste) [7,19]. The hydraulic conductivity of fresh sample was 1.30×10^{-4} m/sec to1.4×10^{-7} m/sec and for old samples, it varies from 1.34×10^{-5} m/sec to 8.90×10^{-8} m/sec with an increase in vertical pressure.

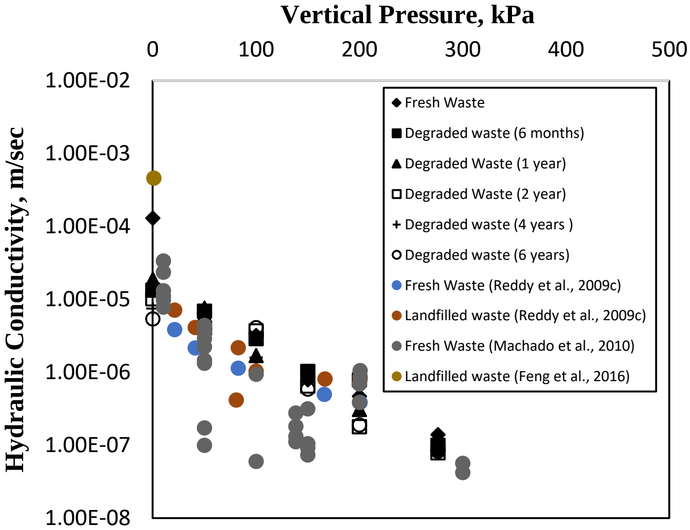


Figure 6. Variation in hydraulic conductivity of MSW (fresh and old) and comparison with reported literature.

It was observed that with the increase in vertical pressure from 0 to 276 kN/m^2,hydraulic conductivity of MSW decreased. The obtained results were compared and were found to be in compliance with reported literature. The hydraulic conductivity of MSW depends upon the waste composition, overburden pressure [36,57]. The decrease in hydraulic conductivity of samples is due to the disintegration of particles resulting in denser packing of particles. The presence of plastics fraction in the MSW samples also affects the hydraulic conductivity. The influence is higher as the amount, size of particles increased in waste samples [50]. The hydraulic conductivity of MSW is considered as an important property for designing a leachate collection system [32]. It was clear from Figure 7, that as the depth increased from 0.5m to 6m, the hydraulic conductivity of waste decreases with increasing fines due to degradation. The hydraulic conductivity of waste samples decreases due to the effect of composition of waste, compaction, overburden pressure and decomposition rate [32].

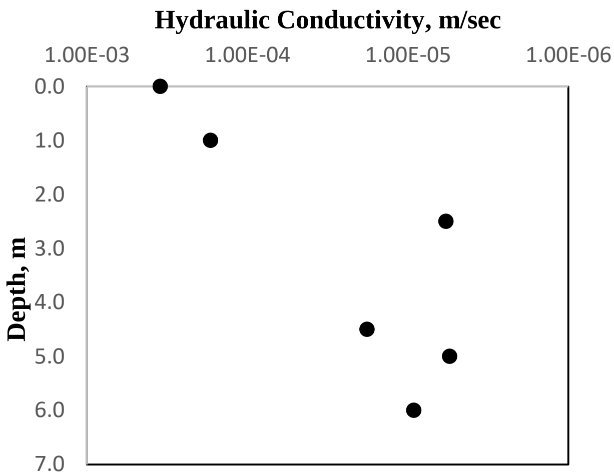


Figure 7. Hydraulic conductivity variations with depth.

Direct Shear Test

The testing of samples (fresh, old) was done as per ASTM D 3080. The results obtained from the testing depict that with increasing normal stress, the shear strength increases. The strength of the fresh sample was less than degraded samples taken from different depths. Figure 8 showed the shear strength envelope for fresh and degraded samples. But it was clear from the results that difference in the strength of samples at 4m and 6m is very less. The friction angle and cohesion (φ,c) for fresh sample was 31.2 kPa, 14° and for old samples with the degradation of waste, cohesion and friction angle varies from 30.9 kPato 38 kPaand 13° to 22°. The cohesion of waste did not show any trend but φ increased with depth and degradation of waste which agrees with the studies of [22,23,41]. The response of shear stress-horizontal displacement for fresh and highly degraded waste was shown in Figure 9(a), (b). The samples exhibit gain in strength with increase in horizontal displacement. With the increasing degradation rate of MSW, cohesion decreases and the angle of internal angle increases. Also, the variation in results may be due to different MSW composition and less paper, wood and fiber in MSW may results in lower shear strength [23,38].

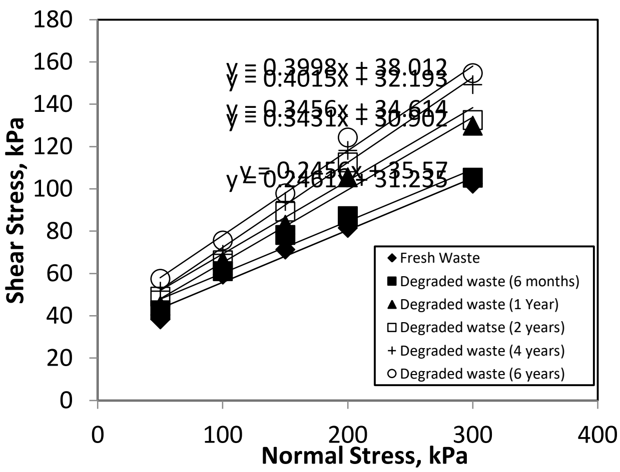
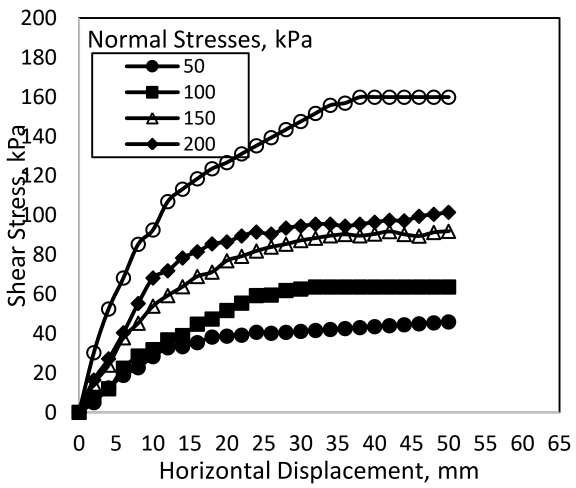
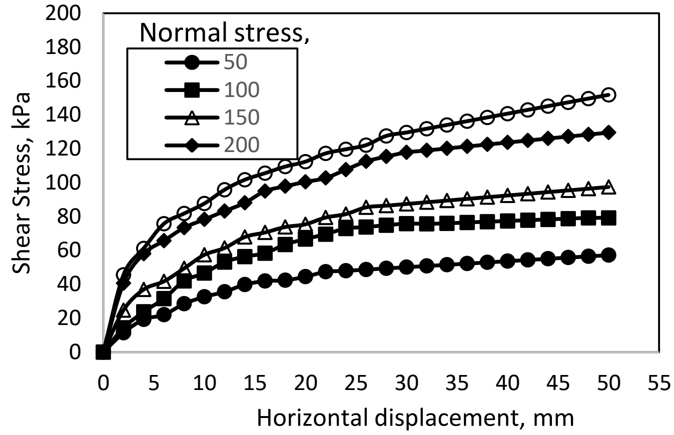


Figure 8. Shear test results for MSW samples (fresh and degraded).



(a)



(b)

Figure 9. Shear stress-horizontal displacement response of
(a) fresh and (b)degraded waste.

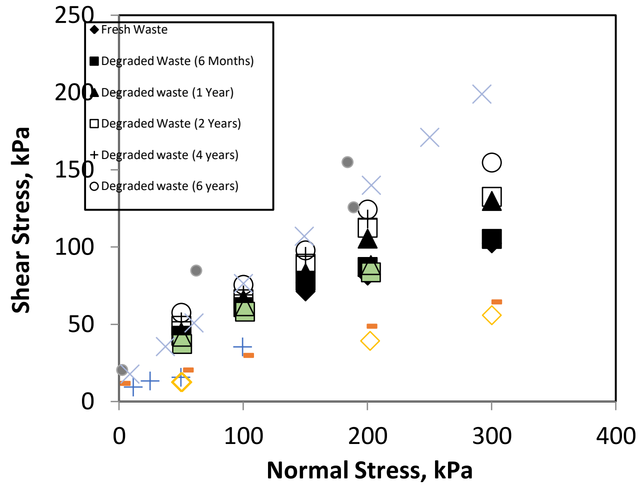


Figure 10. Comparison of DST results of present study with reported literature.

Compressibility

The MSW specimens were subjected to compression under vertical load increment for evaluating immediate compression. Figure11 showed the variations in the compression ratio with each stress increment with changing moisture content. The compression ratio of fresh waste was in the range of 0.19-0.29 and for degraded MSW it ranges from 0.12-0.17. The obtained results showed lower values of compression index than literature [19,20,40,58]. It was observed that the compression index of the old was lesser as compared to fresh waste. This may be due to the effect of degradation, results in finer inert and soil-like material.However, the difference is observed in old wastes samples because of the level of degradation increased with depth [15,37,56].

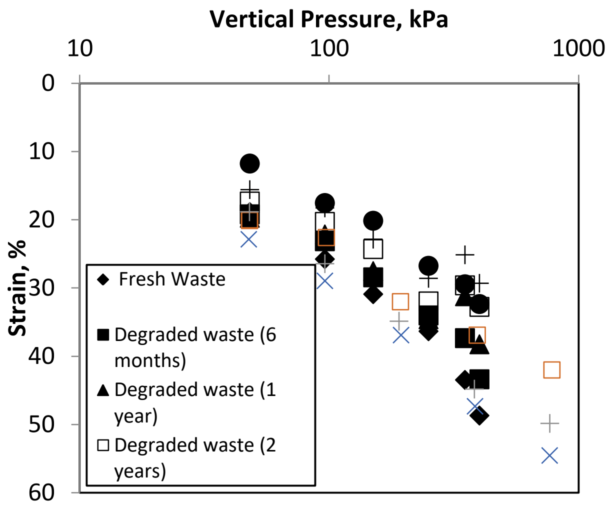


Figure 11. Compressibility of fresh and degraded MSW from current study and comparison with literature.

The observed values for the geotechnical characteristics of MSW were given in Table IV.The results obtained from the current study were observed to follow the pattern given in the literature. Table V, showed the comparison of percentage variations in parameters with literature to find out the variations in parameters with respect to varying characteristics of waste, environmental conditions.

Table IV: The test results for fresh and degraded MSW

Sr. No.	Parameters	Fresh	Degraded
1	Specific Gravity (G_s)	1.83±0.05	1.85-2.28
2	Moisture Content (%)	49.5±1.05	39.8-51.6
3	Organic Content (%)	74.1±2.17	20.75-38.1
4	Unit Weight (kN/m^3)	6.97±0.85	7.05-10.4
5	Dry Density (kN/m^2)	4.28	4.47-6.25
6	OMC (%)	78.1	80.2-85.4
7	Hydraulic conductivity (m/sec)	1.3×10^{-4}	1.34×10^{-5}
8	Cohesion, c (kPa)	36.3	39.2- 45.02
9	Angle of internal friction, φ	14°	13°- 22°
10	Compression index	0.19-0.29	0.12-0.17

Table V: Percentage variation in results of current study with reported literature.

Sr. No.	**Parameters**	**Average percentage variation of results of current study with literature**			
		Ramaiah et al. 2017	Feng et al. 2016		Reddy et al. 2009a
Type of waste		**Degraded (%)**	**Fresh (%)**	**Degraded (%)**	**Fresh (%)**
1	Specific Gravity	5.4-8.6	1.6-3.2	0.44-1.1	1.2
2	Moisture Content	10-28	37-65	6.7-33.5	12.5
3	Organic Content	13-28	-	-	2.5
4	Unit weight, (kN/m^3)	1-9.6	3.2-7.6	4-16.8	-
5	Dry Density (kN/m^3)	9.5-27	-	-	1.9

6	Hydraulic conductivity, (m/sec)	-	9.3	13.2	9.09
7	Cohesion, c (kPa)	29.4	24.3	35.4	5.2-29.6
8	Angle of internal friction, φ	37	12	17.8	15-60
9	Compression index, C_c	3.5	-	-	9.25

The results showed that the waste from the study area having variation in specific gravity for a fresh and degraded waste of about ≈1.2-3.2% [7,20] and ≈0.44-1.1%, 5-8% respectively with the literature [7,23]. For moisture content, variation results from ≈12.5-60% for fresh and 6-33% for degraded waste. The unit weight of MSW varies from 3-8% for fresh and 1-17% for degraded waste.The results showed that variation in waste characteristics was due to a change in the composition of MSW for different cities and countries [4,27]. Hydraulic conductivity of MSW depends upon degradation, varies 9% for fresh and 13% for degraded MSW. The variation in φ, c of the waste was approximate 15-20%, 5-25% for fresh waste and 17-37%, 29-35% for degraded waste respectively. The variation in shear strength parameters (c,φ) is more due to reason that the fresh waste of the current study area has fewer fibers content which causes the lesser c, φ and the degradation of MSW is lower than compared literature thus having a large variation in properties.

IV. CONCLUSION

The physical and geotechnical characterization of fresh and degraded MSW collected from the dump site were performed. The organic content in the fresh MSW was 74.1% which decreased with the rate of degradation. The characteristics like dry density, shear strength, hydraulic conductivity depends upon the composition, moisture content and overburden pressure on MSW. These above-mentioned parameters were considered for stability and designing process of the landfill. The small change in the properties is owed to the variation in MSW composition, standard of living and habitual behavior of the people residing near the study area.

The geotechnical properties of MSW were determined and the following conclusions were drawn:

- The composition of MSW was found to be rich in organic content but as the waste degraded there were changes in the composition of waste which resulted in decrease in the amount of organic content, paper as well as wood. The degree of decomposition of fresh waste was absent and for an old waste degree of decomposition was 78.1%-90% with increasing age of waste.
- The unit weight of waste is a significant characteristic for analysing landfill designing. It was observed from the results that the unit weight of waste increased with depth and degradation of MSW. An increase in unit weight is due to denser packing of particles which results from the degradation of waste. The permeability of waste reduced with depth with an increase in overburden pressure.
- The degraded waste was found to possess lesser hydraulic conductivity than fresh waste. The decrease in hydraulic conductivity for degraded MSW is the result of increase finer particle due to degradation. The vertical pressure applied on waste decreased the hydraulic conductivity from 10^{-4} m/sec to 10^{-7} m/sec for fresh waste and from 10^{-5} m/sec to 10^{-8} m/sec for degraded waste respectively.
- The shear test results showed lower strength parameters for fresh waste than the old waste. The change in strength with shallow depth is significant but with further increase in depth, strength changes slowly. The angle of internal friction and cohesion showed increasing trend with degradation of waste.
- The compressibility of MSW shows a decreasing trend with degradation. The compression ratio for fresh waste and degraded waste was observed to be in the range of 0.19-0.29 and 0.12-0.17. The change in the compressibility of fresh waste was not much significant and showed a slight increase with pressure applied.

The correlation between the degree of degradation and geotechnical properties of waste is lacking because of heterogeneous nature of MSW. Additionally, large scale testing of waste should be done for incorporating the scale effect. However, the characteristics of MSW observed in this study can be utilized for analyzing landfill stability and analysis of settlement. Based upon the geotechnical analysis, determination of the effect of MSW on soil and its remedial measures for minimizing the harmful effect along with the recreation of soil needs to be done. The present study showed that open dumping has affected the properties of soil to a certain extent but with time and increased generation of waste, the soil gets deteriorated and settles due to degradation. So, analysis needs to be done to determine if any recreational work or construction work might be done in the future.

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