COMPRESSIBILITY OF JAPANESE LANDFILLED/BURIED WASTE SAMPLES: MEASUREMENT OF COMPACTION CURVES AND CONSOLIDATION TEST FOR COMPACTED WASTE SAMPLES AT DIFFERENT COMPACTION LEVELS

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Abstract

Compressibility characteristics of landfilling and buried waste samples are highly heterogeneous, depending on various waste compositions, degree of organic matters, decomposition, and so on. Measured data presented in this paper are the results from laboratory tests for different types of landfilling and buried waste such as incineration ash, industrial waste (plastics, rubbers, etc.) and un-burnable domestic waste (glasses, ceramics, etc.) and buried industrial solid waste fully mixed with soil from an industrial waste landfill at Saitama Prefecture in Japan, respectively. Prior to the compaction and consolidation tests, each sample was dried and the waste composition and particle size distribution were determined. Standard proctor compaction tests were carried out to discuss the compaction properties. For the buried industrial solid waste fully mixed with soil (two sample fractions: < 2 mm and < 9.5 mm) and incineration ash samples, optimized water contents (w_{opt}) which gave the maximum dry bulk densities can be measured similar to typical soil samples. On the other hand, for the industrial and domestic waste samples mainly composed of plastics and glasses, the values of w_{opt} could not be clearly observed and measured dry bulk densities were not controlled by the initial water content of samples. Consolidation tests for compacted samples at different compaction levels were carried out by using a specially designed oedometer in the laboratory. Based on the results from consolidation tests, the compressibility characteristics will be discussed based on the consolidation indices such as compression and consolidation coefficient, and their dependency of waste composition and fraction and surrounding environment (e.g., temperature).

KEYWORDS: Compressibility, Landfilling waste, buried waste, Compaction curve, Consolidation test.

1. Introduction

Compaction of wastes at a landfill is the main factor that controls short-term density and resulting placement efficiency of wastes in the landfills. Maximizing waste density allows to reduce landfill space requirements or to prolong the life of a facility (Hanson et al, 2010). Moreover, the compaction of landfill waste enhances the engineering properties of waste material and then influences the stability of landfills. Moisture-density characteristics influence hydraulic response and compressibility of wastes. Overall, the as-placed moisture-density characteristics of solid waste are critical for both operation of landfills and engineering response of wastes (Hanson et al, 2010). However, the types of solid waste in a landfill are in a wide range such as domestic waste, Industrial waste, etc. The inconsistence and heterogeneous composition of landfill material make determination of its engineering properties difficult. Then, it is important to have a wide knowledge about the engineering properties of different landfill waste to make good engineering judgements about the stability and settlement of landfills.

The landfill settlement is an important concern when designing and in the long term waste management planning of an engineering landfill. However, the landfill settlement is characteristically irregular. Basically, there is a large settlement at the early stage and, the magnitude, then, decreases with time due to decomposition of organic matter. The mechanics of compression of refuse are many and complex; even more so than for a soil due to the extreme heterogeneity of, large voids present in the refuse fill. The main mechanisms involved in refuse settlement are the following (Sowers, 1973; Edil et al., 1990),

1. Mechanical (distortion, bending, crushing and reorientation; similar to consolidation of organic soils)
2. Ravelling (movement of fines in to large voids)
3. Physical-chemical change (corrosion, oxidation and combustion)
4. Bio-chemical decomposition (fermentation and decay, both aerobic and anaerobic processes)

The settlement of landfill affects the design of protection system such as covers, barriers and drains. Besides, an excessive large post-closure settlement is undesirable from maintenance point of view, since it may lead to surface pond, fracture of covers, and then increase the amount of moisture entering the landfill, which, in turn, will produce more leachate (Dixon et al. 2005). The compaction of wastes reduces its compressibility characteristics significantly, but still considerable compared to soil.

In this study, a comprehensive laboratory study on compaction and compressibility was conducted on different landfill wastes in Japan. The considered waste samples are incineration ash, industrial waste, and un-burnable domestic waste. Additionally, a buried industrial landfill waste fully mixed with soil collected from a post-closure landfill was considered. This paper describes the compaction characteristics and the Compressibility characteristics of these different wastes samples and comprehensive study with previous literatures.

2. Sample collection and characterization

In this study, different types of landfill (fresh) and buried waste were collected from two landfill sites in Saitama Prefecture, Japan. The collected landfill waste samples (fresh waste) were incineration ash

(Waste-A), industrial waste mainly consist of plastic and rubber (Waste-B), and un-burnable domestic waste mainly consist of glasses, ceramics, etc (Waste-C). These samples were collected prior to mixing in the landfill. Additionally, disturbed buried industrial solid waste fully mixed with soil (Waste-D) was collected from a post-closure landfill. This recovered waste was presumed to be about 20 yrs old based on landfill records. Although this landfill is considered as an industrial solid waste landfill, thin compost layers could be seen in between industrial waste layers, consequently, in sampling that compost material and cover soil were mixed with industrial buried waste sample. The waste samples were wet, and their colour was black to very dark brown.

The collected samples were then sieved and the particle size distribution curves for all waste samples are shown in Fig. 1. The particle distribution of four samples are significantly different and the mean diameters are 0.95 mm, 16.0 mm, 5.4 mm, and 1.6 mm for Waste-A, Waste-B, Waste-C and Waste - D, respectively. Information on the waste composition is of assistance in evaluating engineering properties of the waste. However, only the sample fraction greater than 5 mm was analyzed since it was not possible to visually determine the composition of finer fractions. Table 1 represents average results of eleven composition of each waste samples by weight.

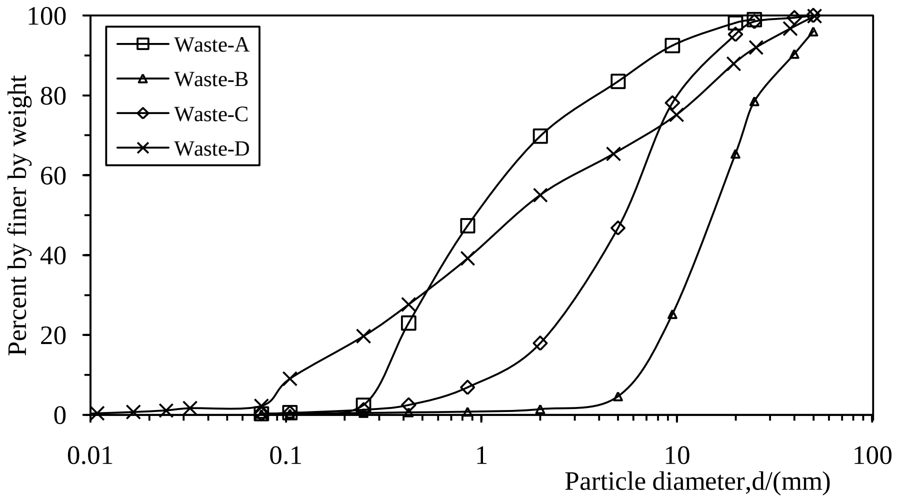

Fig. 1: Particle size distribution of different waste samples.

Table 1: The composition of waste samples.

Waste Category	*% of Total Weight*			
	Waste -A	***Waste-B***	***Waste -C***	***Waste-D***
Plastic	*n.a.*	*68.13*	*0.11*	*2.31*
Ceramic	*2.21*	*0.61*	*12.00*	*1.19*
Rock	*4.49*	*1.67*	*n.a.*	*8.42*
Metal	*1.84*	*3.52*	*0.09*	*0.74*
Wood	*n.a.*	*2.22*	*n.a.*	*0.71*
Glass	*1.89*	*2.48*	*38.21*	*0.95*
Vinyl	*n.a.*	*0.12*	*0.01*	*0.08*
Paper	*n.a.*	*0.16*	*0.18*	*n.a.*
Rubber	*n.a.*	*13.56*	*n.a.*	*0.13*
Textiles	*n.a.*	*0.31*	*n.a.*	*n.a.*
Residue (< 5mm)	*89.57*	*7.21*	*49.40*	*85.48*

n.a.- not available

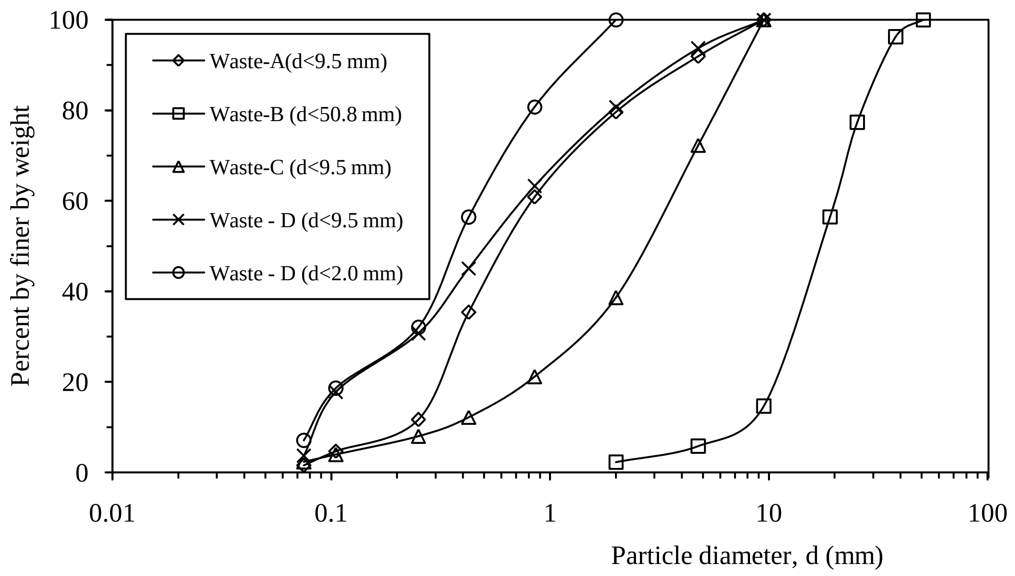

Fig. 2: Particle size distribution of test samples.

As the wide variety of particle sizes presents in waste, it is difficult to conduct experiments in the laboratory. Hence, for Waste-A, Waste-C, and Waste-D, maximum grain size was limited to 9.5 mm. For Waste-B, maximum grain size was limited to 50.8 mm for compaction test. Additionally, for Waste-D, the tests were conducted for particle size lesser than 2 mm also. The particle size distributions of test samples are shown in Fig. 2. The mean diameters of test samples are 0.63 mm, 19.0 mm, 2.8 mm, 0.5 mm and 0.38 mm for Waste-A, Waste-B, Waste-C, Waste-D coarser, and Waste-D finer, respectively.

The physical and chemical properties of the waste materials were evaluated using laboratory tests including Particle density, Atterberg limits, ignition loss, pH, EC and C/N ratio according to the current procedure established by ASTM for soils. The basic waste physical and chemical properties of each fraction of different waste samples are given in Table 2. Additionally, Particle density test for finer fraction (d < 2 mm) of Waste-A and Waste-D were conducted and the values were 2.68 and 2.72, respectively. Hence, finer fraction shows higher specific gravity than that of coarser fraction.

Table 2: Basic physical and chemical properties.

Waste type	*Maximum particle size, <d, mm*	*particle density, ρ_s (g/cm^3)*	*Liquid Limit*	*Plastic limit*	*Ignition loss (%)*	*pH*	*EC mS/cm*	*C/N*
Waste-A	*9.5*	*2.63*	*n.a*	*n.a*	*1.65*	*11.2*	*1.99*	*86*
Waste-B	*25.0*	*1.37*	*n.a.*	*n.a.*	*81.2*	*7.9*	*0.32*	-
Waste-C	*9.5*	*2.45*	*n.a.*	*n.a.*	*1.15*	*7.2*	*0.24*	*17*
Waste-D	*9.5*	*2.62*	*65*	*42*	*17.2*	*8.8*	*2.8*	*33*

n.a., not available

3. Testing Program

3.1 Compaction characteristics

The waste's moisture-density relationship was determined using the standard proctor test prescribed in ASTM D 698-7 for soil with incidental modification. The tests were conducted by means of 102 mm diameter mould (944 cm^3) for the test samples of Waste-A, Waste-C, and Waste-D. Additionally, the test was conducted for the finer fraction (d < 2mm) of Waste D. however, for Waste B, as the particle size is large, and contains higher amount of inorganic materials such as plastics and rubbers, it was not possible to find out compaction characteristics. However, as a reference, the possible average dry density at in-situ moisture content for standard compaction energy was determined.

3.2 Compressibility test

The primary compression index is commonly used in engineering practice to characterize the compressibility of a porous medium (Chen et al, 2009). Several researches have reported various methods that may be used in settlement predictions of waste fills. However, the state of practice is based mainly on the use of the method first proposed by Sowers (1973). This involves traditional settlement theory with the addition of a term to account secondary consolidation (Gabr et al., 1995). Consolidation tests were conducted on all the waste material except Waste-B and the tests were conducted according to the ASTM D2435 with some incidental modification. In this study, consolidation tests were carried out by means of especially designed oedometer with 10-cm diameter and 10-cm height and the load increment was done by 9 loading stages from 3.53 kPa to 904.32 kPa. However, in the loading, the load was doubled in the next stage at all loading cases similar to standard test and compression was observed for 24 hrs. Additionally, in each loading, 100% primary consolidation was checked by $\sqrt{t}$ method. In this study, compacted samples were tested. The samples were prepared by means of the standard proctor test procedure and the each sample was cut in to the required height to accommodate the compression cell. The different degree of compaction was achieved by changing initial moisture content of the compacted sample. The initial moisture content was taken from the compaction curve of each waste sample and four different initial moisture contents were selected to get a reasonable range of degree of compaction for study. The selected moisture contents are air-dry, 0.6 w_{opt}, w_{opt}, and 1.5 w_{opt} of each waste. The compression index was calculated from the graph of void ratio (e) versus log consolidation pressure (log σ).

4. Results and Discussion

4.1 Compaction characteristics

The results of the moisture-density relationships are shown in Figs. a, b and c for Waste-A, Waste-C, and Waste-D, respectively. For Waste-A and Waste-C, the dry density was not characterized by the initial moisture content and high dry density was exhibited at air dry condition. Both Waste-A and Waste-C are characterized as cohesionless and this type of irregular variation is typical for cohesionless materials (Wei-Hsing et al., 1994, Lee et al., 1972). For Waste-A, the dry density was in the range between 1.53-1.74 g cm^{-3} and for waste-C, it was in the range of 1.78-1.83 g cm^{-3}. For Waste-D, the highest densities and optimum moisture content were obtained as 1.39 g cm^{-3} and 1.34 g cm$^{-3,}$ and 31% and 34% for coarser (d<9.5 mm) and finer fractions (d<2.0 mm), respectively. For Waste-B, the average dry density at in-situ moisture level for standard compaction energy was 0.62 g cm^{-3}.

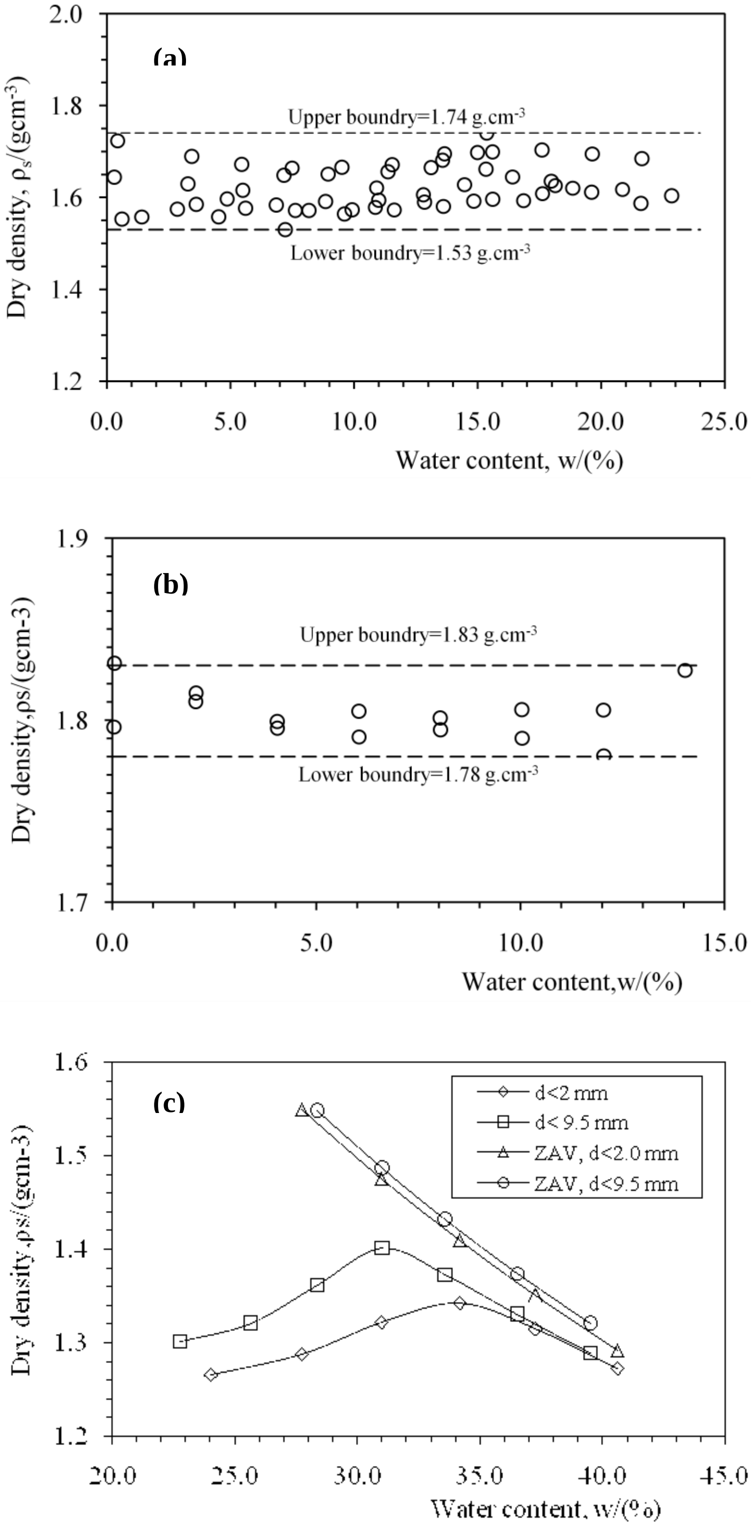

Fig. 3: Moisture-dry density relationships: (a) Waste-A, (b) Waste-C, and (c) Waste-D. Zero air void lines are also shown

Table 3: List of research literature reporting compaction characteristics.

Landfill Component	Source	Material	$\rho_{s \cdot max}$ /g.cm^{-3}	w_{opt}, (%)
Cover soil	*Wickramarachchi et al.(2011): d < 35mm and 2mm respectively, Landfill in Saitama, Japan*	*Cover soil*	*1.90* *1.85*	*10* *12*
	Wickramarachchi et al. (2011): d< 2mm, Landfill in Maharagama, Sri Lanka	*Cover soil*	*1.93*	*13.8*
Solid waste	*Acar et al. (1994): d<19 mm, by product of coal power plant, Lousiana, USA*	*Boiler slag*	*1.78*	*18.5*
	Wei-Hsing et al. (1994): by-product from coal power plant, Indiana, USA	*Bottom ash*	*1.48-1.82*	*n.a.*
	Gabr et al. (1995): d<9.5mm, pioneer crossing landfill, Pennsylvania, USA	*Landfilled MSW (aged)*	*0.95*	*31*
	Reddy et al.(2009): d<40mm, Orchards hill landfill, Illinois, USA	*Fresh MSW*	*0.42*	*70*

Table 3 shows the summary of compaction characteristic of different waste material from previous studies. As moisture-density relationship is important for other landfill infrastructure such as cover soil, the compaction data are presented for final cover soil for comprehensive study. It can be seen that the range in maximum dry density for Waste-A and Waste-C are comparable to the bottom ash. And also, for Waste-D, it can be comparable with aged municipal solid waste (MSW). However, aged MSW exhibit lesser maximum dry density, it can be due to presence of high organic content in MSW. Moreover, from the result, it can be noted that the maximum dry density of solid waste increases with the age but optimum moisture content decreases. This can be due to decomposition of organic matter.

4.2. Compressibility characteristics

The tests were conducted on the samples of Waste-A, Waste-C, and Waste-D, and Waste-D; the tests were carried out for both finer and coarser fractions. The tests were repeated for the samples at different initial degree of compaction. However, for Waste-A and Waste –C, the tests were done only for the samples compacted at air dry condition as there was not significant change of dry density with initial moisture level in compaction test. The test results and some previous studies from literatures are presented in Table 4.

Table 4: Compression index of different types of waste.

Source	*Waste type*	*Max. Particle size/mm*	*Compression index, Cc*	*Initial void ratio, e_0*
Current study	*Waste-A*	*9.5*	*0.042*	*0.559*
	Waste-B	*9.5*	*0.013*	*0.296*
	Waste-C	*9.5*	*0.071– 0.136*	*0.849 -1.264*
	Waste-D	*2.0*	*0.083 -0.166*	*1.027-1.336*
Acar et al.(1994)	*Boiler slag*	*19.0*	*0.107*	*0.710*
Chen et al. (2009)	*MSW (age<1.0 yrs)*	*n.a.*	*0.806-1.421*	*3.40-3.81*
	MSW (1<age<5yrs)	*n.a*	*0.362-1.122*	*1.15- 4.20*
	MSW (Age>5 yrs)	*n.a.*	*0.229-0.738*	*1.10-2.80*
Villar et al. (2005)	*MSW (age ≈ 15 yrs)*	*50.0*	*0.52 – 0.92*	*2.4 – 2.7*
Gabr et al. (1995)	*MSW(15<age<30yrs)*	*9.5*	*0.40–0.80*	*1.0 –3. 0*

n.a., not available

Both Waste-A and Waste-C exhibit smaller compression index and can be comparable with similar material of boiler slag from literatures. These types of waste material have very less organic material and exhibit cohesionless properties and usually use as alternative construction materials for sand. MSW exhibit a wide range of compression indexes and initial void ratios. Usually, high initial void ratio displays high compression index. From the literature, it is observed higher compression index as well as higher initial void ratio at the early stage of the solid waste but with the time both compression index and void ratio decreases (Gabar et al., 1995: Sowers., 1968). This can be due to degradation of large organic matters in to smaller particles by microbial activity and hence reducing the pore volume. However, for Waste-D, the compression values are significantly smaller than the literature recorded. This can be due to presence of less organic matter. For a landfill, the compression index is highly controlled not only by the waste composition but also the compaction level. A landfill with highly compacted waste exhibit lesser compression index. Figure 4 shows the change of compression index with different degree of initial compaction for Waste-D. Degree of compaction is the percentage ratio between the dry density of test sample and the maximum dry density of the waste.

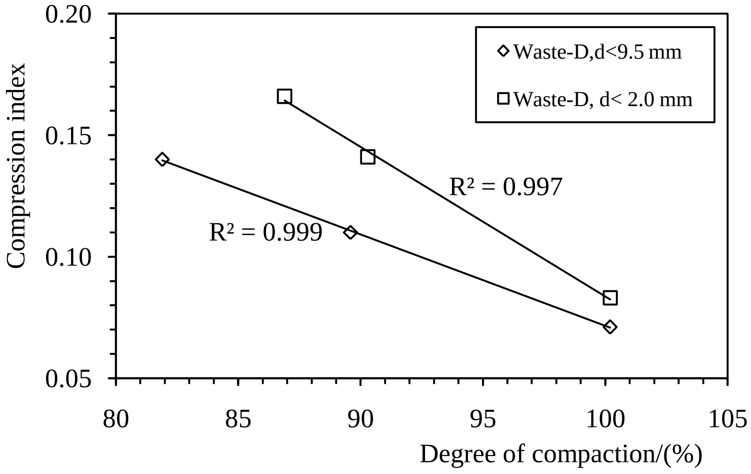

Fig. 4: Change of compression index with the degree of compaction for Waste-D.

5. Conclusion

The study has presented the laboratory studies on the compaction and compressibility characteristics of different landfill waste material in Japan. Based on the laboratory studies, it can be concluded that compaction characteristics of incineration ash, fresh industrial waste and un-burnable domestic waste do not exhibit an apparent variation with increasing moisture level during compaction. Therefore, it may be beneficial to compact these type of waste at in-situ moisture level. Thus much effort and cost in the control of moisture content during compaction can be saved. However, the compaction characteristics of aged industrial solid waste mixed with cover soil reveals an apparent relationship with the increasing moisture content and can be comparable with previous literature studies. Moreover, it may be beneficial to study the change of compaction characteristics with age of waste as well as by mixing with other wastes and cover soil. Compressibility properties for highly compacted waste samples of buried industrial waste in this study show relatively small compressibility characteristics as compared to the previous studies. This can be due to the decrease of initial void ratio during compaction and also presence of very less organic content. Furthermore, this study reveals that compressibility of waste material significantly vary with the grain size distribution and hence, the maximum particle size. The incineration ash an un-burnable domestic waste give very less compressibility characteristics and their property may be comparable with cohesive material of sand and gravel.

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