Maximum and minimum void ratio characteristics of MBT waste

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Abstract

Mechanical-biological treatment (MBT) of municipal solid waste (MSW) includes mechanical processing of MSW with subsequent biological treatment of its biodegradable components. One of the many possible outputs of the MBT plant is the so called "fine fraction" of MBT waste which is characterised by particle sizes smaller than 25 mm. This mechanically refined granular material is only partially stabilised during the aerobic degradation process which takes place under controlled conditions in the MBT plant (bio-drying). Rich in organic components, the "fine fraction" of MBT waste is suitable for landfilling into a bioreactor landfill with the aim of biogas production. Mechanical behaviour of the bioreactor landfill, during construction and use, is significantly influenced by the physical characteristics of the MBT waste material that is being installed. In this study, the physical and geotechnical properties of the MBT waste material were determined, with emphasis on the determination of maximum and minimum void ratios. Correlations relating maximum to minimum void ratios are also presented. Test results are compared to the results obtained for soils and some other granular materials, found in the available publications.

Keywords

MBT waste, geotechnical properties, landfill, void ratio

1 Introduction

Basic waste management principles for the EU member states are laid down by the Directive 2008/98/EC on waste (Waste Framework Directive). One of the major requirements of the abovementioned Directive is the reduction of the biodegradable component of waste before the waste is ultimately deposited to a landfill. Landfilling biodegradable waste is the least preferred option in managing such waste as it poses a significant environmental threat. When decomposing in landfills, biodegradable waste produces methane, one of the gases that contributes to the greenhouse effect. Landfilling of biodegradable waste is addressed in the Landfill Directive (EU Landfill Directive 1999/31/EC of April 1999) which requires the diversion of biodegradable municipal waste from landfills. According to the Directive, member states are required to only landfill wastes that have been subjected to treatment, leading to a reduction in their quantity or hazard to human health and the environment (DI LONARDO ET.AL., 2012., ROBINSON ET AL., 2005).

Regarding the production of material suitable for landfilling, the waste pre-treatment objectives should relate to minimising the adverse consequences of disposal (HEERENKLAGE AND STEGMANN, 1995; LEIKAM AND STEGMANN, 1995; RIEGER AND BIDLINGMAIER, 1995;

SCHEELHAASE AND BIDLINGMAIER, 1997; KOMILIS, 1999; SOYEZ AND PLICKERT, 2002; FRICKE ET AL., 2005; MUNICH ET AL., 2006; MONTEJO ET AL., 2010; VELIS ET AL., 2010), including:

- minimisation of volume and mass of waste to be disposed in landfill;
- inactivation of biological and biochemical processes in order to reduce leachate and methane production and odour emissions;
- immobilisation of pollutants of the waste to be disposed of in order to reduce leachate contamination;
- reduction of landfill settlement;
- reduction of the duration of the landfill site aftercare. (DI LONARDO ET.AL., 2012)

Mechanical-biological treatment of MSW in the MBT plant consists of mechanical processing of waste, which generally includes shredding (i.e., size reduction and densification, separation of waste by particle sizes, density or magnetic properties), and biological treatment of MSW by means of aerobic or anaerobic degradation.

2 Material and methods

Sampling of the MBT waste specimens used for the purpose of this study took place at the Regional Centre for Waste Management, Mariscina. The centre is located in the Istria region in the south-west of Croatia. It is functioning as an MBT plant with the main focus on processing MSW which is collected in the local municipalities. Since the composition of input MSW varies seasonally, as a consequence of the tourist season during the summer, it is also worth mentioning that the MBT waste samples were collected in the winter season.

For a short period of time, the collected MSW is stored in the receiving pit of the MBT plant. Shredding of MSW to a fraction with particle sizes smaller than 200 mm is the first step in its mechanical processing. After the initial shredding, MSW is transported to the bio-drying bioreactor where biological treatment takes place. In the bioreactor, MSW is dried by a combination of heat that is produced during aerobic decomposition of the organic fraction of waste and excess aeration. Waste is subjected to bio-drying for a period of 7 to 10 days.

Subsequent mechanical processing of the bio-dried MSW includes further shredding/refinement and extraction of recyclables (e.g., ferrous and non-ferrous materials, plastics etc.). The final results of MBT processing are various material outputs with different characteristics. For the purpose of this study, the so-called "fine fraction" of bio-dried MBT waste was used (Figure 1). This output fraction of MBT waste is characterised by nominal particle sizes smaller than 25 mm and is appropriate for landfilling in the bioreactor landfill.

Figure 1 “Fine fraction” of MBT waste material

Physical and geotechnical properties of the MBT waste material were determined according to the internationally accepted ASTM standards for laboratory testing of soils.

2.1 Moisture content

Water content was determined according to the ASTM D 2216 Standard for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. In order to preserve the original in-situ moisture of the waste specimens, immediately after sampling and prior to transport, waste specimens were placed in plastic vacuum bags and airtight sealed. The test was performed shortly after the arrival of the waste specimens to the laboratory. Since the MBT waste material is rich in organic components, the standard drying temperature was reduced and set to 60°C, as is proposed in the standard. Samples were oven-dried for a period of 24 h. Mass of moist and dried samples was determined using a balance, and the average value of in-situ moisture content was calculated as 9.60 %.

2.2 Physical composition

The physical composition of MBT waste samples was determined by means of manual separation. Different material components contained in the waste sample were identified visually. Due to the intensive mechanical and biological treatment that the waste material has been subjected to in the MBT plant, for almost 70 % of mass of the waste sample it was not possible to determine with certainty its physical composition. Waste material with undetermined physical composition was sieved through a 2.00 mm sieve. Portions of material retained and passing the 2.00 mm sieve were weighed and marked as “Unidentified > 2 mm” and “Unidentified < 2 mm”.

Mass of each individual material component was determined on a balance and mass percentages were calculated, as shown in Table 1.

Table 1 Mass percentages of different material components of MBT waste

Material Component	Mass percentage [%]
Plastics	6.43
Textile	0.22
Glass	10.62
Metal	0.94
Paper/Cardboard	4.71
Wood	1.18
Bones/Skin	0.20
Stones	2.76
Ceramics	0.46
Rubber	0.13
Kitchen waste	2.15
Unidentified > 2 mm	42.48
Unidentified < 2 mm	27.71
Total	100

2.3 Particle size distribution

Quantitative determination of the particle sizes in the MBT waste samples was conducted according to the ASTM D 422 standard commonly used for particle-size analysis of soils. A mass of roughly 10 kg of the MBT waste material was oven-dried during a period of 24 hours at constant temperature of 60°C. Prior to sieve analysis, dry material was divided into 25 smaller samples (231-600 g of mass per sample). Samples were mechanically sieved through a set of sieves with various sizes of screen openings (from top to bottom sieve: 31.5 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm and 0.5 mm).

Based on the results of the sieving analysis of all 25 samples, an average value particle size distribution curve of the MBT waste material was constructed and is shown in Figure

2 below. For comparison, four additional particle size distribution curves for bio-stabilised (composted) waste are also shown, of which the top two are for Austrian bio-stabilised waste (PETROVIC, 2016), and the bottom two for bio-stabilised waste from the UK and Germany (VELKUSHANOVA, 2011).

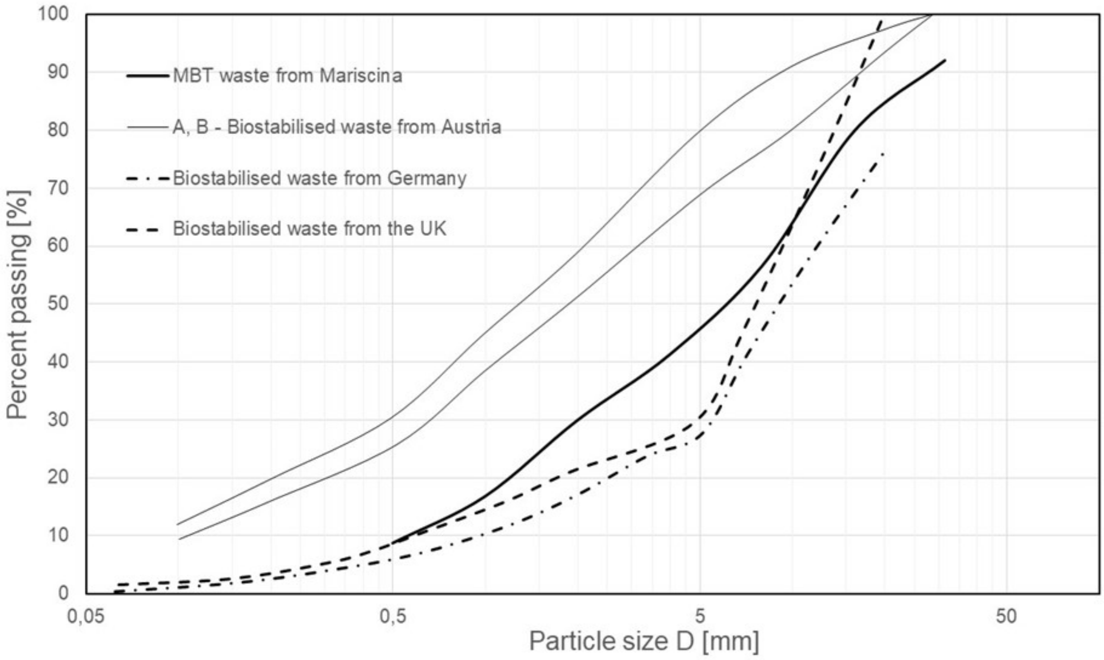

Figure 2 Particle size distribution curves of MBT and bio-stabilised waste

According to the particle size distribution curve values for MBT waste, the coefficient of uniformity (Cu) and the coefficient of curvature (Cc) were calculated as: Cu = 14.23 and Cc = 1.07, while the median grain size D_{50} was 6.27 mm, and the effective grain size D_{10} was 0.58 mm. In comparison with soil, MBT waste can be defined as a coarse-grained and well graded material with Cc and Cu values such as in the case of well graded gravel (GW).

2.4 Organic matter content

The organic matter content of MBT waste was determined on a representative sample, assembled according to the material component mass percentage results shown in Table 1. The procedure was carried out in accordance with the ASTM D 2974 standard, Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils. The sample was heated in a furnace at 440°C until no further change of mass occurred after a period of heating. The organic matter content value of the representative MBT waste sample was calculated as 51.60 %.

2.5 Particle density

For the purpose of particle density determination, a modified constant-volume gas pycnometer was used, in accordance with the ASTM D 5550 standard. The obtained values fall within the range between 1.69 g/cm^3 and 2.19 g/cm^3. Average value, in the case of in-situ conditions of MBT waste material, was calculated as 1.87 g/cm^3.

2.6 Maximum and minimum index densities

Maximum and minimum index densities of MBT waste samples were determined through laboratory tests conducted according to ASTM D-4253 and ASTM D-4254 standards, respectively.

Considering the results of the particle size distribution, minimum index density tests were conducted in accordance with the test method "A" of the ASTM D-4254 standard. As it is defined in the standard, minimum index density represents the loosest condition of a cohesionless material that can be attained by a standard laboratory procedure. A total of 14 oven-dried MBT waste samples were prepared by the quartering method. The first seven samples were subjected to minimum index density tests and the second seven to maximum index density tests.

According to ASTM D-4254 standard, samples were poured into a standard mould with a hand scoop. Prior to testing, the volume of the mould was calibrated according to both direct measurement and water-filling methods.

Minimum (dry) index density was calculated as follows:

$$\rho_{dmin} = \frac{M_s}{V} \quad (1)$$

where:

ρ_{dmin} – minimum index density [g/cm^3 or kg/m^3]

M_s – mass of the tested dry sample [g or kg]

V – volume of the tested dry sample or calibrated volume of mould [cm^3 or m^3]

Calculated minimum index density values varied in the range of 145.47 kg/m^3 to 213.97 kg/m^3, with an average value being 176.39 kg/m^3.

Maximum index density tests were conducted in accordance with the test method "1A" of the ASTM D-4253 standard. The vertically vibrating table and the mounted mould assembly with the installed MBT waste specimen are shown in Figure 3 below.

Figure 3 Maximum index density test setup

Analogously to the equation (1) the following expressions can be written:

$$\rho_{dmax} = \frac{M_s}{V} \quad (2)$$

where:

ρ_{dmax} – maximum index density [g/cm^3 or kg/m^3]

M_s – mass of the tested dry sample [g or kg]

V – volume of the tested dry sample [cm^3 or m^3]

Values of maximum index density varied in the range of 340.20 kg/m^3 to 424.04 kg/m^3 , with an average value of 383.34 kg/m^3.

2.7 Maximum and minimum void ratios and their correlation

Combining the calculated minimum and maximum index densities and previously obtained average value for particle density, the corresponding maximum-index and minimum-index void ratios were calculated by equations:

$$e_{max} = \frac{\rho_s}{\rho_{dmin}} - 1 \quad (3)$$

where:

e_{max} – maximum index void ratio [1]

ρ_s – particle density [g/cm^3 or kg/m^3]

ρ_{dmin} – minimum index density [g/cm^3 or kg/m^3]

and

$$e_{min} = \frac{\rho_s}{\rho_{dmax}} - 1 \quad (4)$$

where:

e_{min} – minimum index void ratio [1]

ρ_s – particle density [g/cm^3 or kg/m^3]

ρ_{dmax} – maximum index density [g/cm^3 or kg/m^3]

The experimental results are presented in Table 2. As can be seen, the results vary from 3.41 to 4.50 for e_{min}, and from 7.75 to 11.87 for e_{max}, with the average values being 3.91 for e_{min} and 9.77 for e_{max}. Standard deviation is calculated as 0.37 and 1.30 for e_{min} and e_{max}, respectively.

According to the calculated average values, the simple relationship based on the ratio between e_{max} and e_{min} can be written as:

$$e_{max} \approx 2.50 \cdot e_{min} \quad (5)$$

and

$$e_{min} \approx 0.40 \cdot e_{max} \quad (6)$$

The maximum to minimum void ratio relation of granular materials has been investigated by several researchers. MIURA ET AL, 1997, conducted a study on around 200 samples of different granular materials, including mostly clean sands but also glass beads and light-weight aggregates. Based on their results, the following equation was derived:

$$e_{max} = 1.62 \cdot e_{min} \quad (7)$$

CUBRINOVSKI AND ISHIHARA, 2002, carried out a study on the data for over 300 soils from Japan, which included clean sands, sands with various fines content (F_c) and clay content (P_c), and silty soils. The following relations were calculated:

For clean sand ($0 < F_c < 5$ %)

$$e_{max} = 0.072 + 1.53 \cdot e_{min} \quad (8)$$

For sand with fines ($5 < F_c < 15$ %)

$$e_{max} = 0.25 + 1.37 \cdot e_{min} \quad (9)$$

For sand with fines and clay ($15 < F_c < 30$ %, $5 < P_c < 20$ %)

$$e_{max} = 0.44 + 1.21 \cdot e_{min} \quad (10)$$

For silty soils ($30 < F_c < 70$ %, $5 < P_c < 20$ %)

$$e_{max} = 0.44 + 1.32 \cdot e_{min} \quad (11)$$

Equations (7 to (11) have been developed based on the data obtained from tests conducted according to the methods stipulated in the Japanese Geotechnical Society standards (JGS).

ILGAC ET AL., 2019, compiled a large database which, amongst others, contains maximum and minimum void ratio values for natural soils (from silts to gravels) and reconstituted granular material (rice, glass beads, mica) mixtures. For the majority of values, tests were performed according to ASTM and JGS standards. A summary of database statistics reveals that the mean values of e_{max} and e_{min} are 0.92 and 0.55, respectively.

By rearranging equations (3) and (4) the following terms can be written:

$$\rho_s = \rho_{dmin} \cdot (e_{max} + 1) \quad (12)$$

$$\rho_s = \rho_{dmax} \cdot (e_{min} + 1) \quad (13)$$

and further, combining the above equations:

$$\frac{\rho_{dmin}}{\rho_{dmax}} = \frac{e_{min}+1}{e_{max}+1} \quad (14)$$

$$\frac{\rho_{dmax}}{\rho_{dmin}} = \frac{e_{max}+1}{e_{min}+1} \quad (15)$$

Finally, by taking into account the average values obtained for minimum and maximum index densities, 176.39 kg/m^3 and 383.34 kg/m^3 respectively, the following equations are derived:

$$e_{min} \approx 0.46 \cdot e_{max} - 0.54 \quad (16)$$

$$e_{max} \approx 2.17 \cdot e_{min} + 1.17 \quad (17)$$

The derived expressions present a relation between the two extreme void ratio values and therefore can be used for e_{min} and e_{max} values calculation if one of the extreme values is known. For instance, if e_{max} value of the MBT waste material is familiar, then the approximate e_{min} value can be calculated by equation (16), or in case the e_{min} value is known, then the approximate e_{max} value can be obtained by equation (17).

A comparison of e_{min} and e_{max} values obtained empirically, and calculated by equations (5), (6), (16) and (17), is presented in Table 2. The linear relation between e_{min} and e_{max} values calculated with equations (5), (6), (16) and (17) is shown in Figure 4.

Table 2 Comparison of minimum and maximum void ratio values (experimental vs. calculated values)

Specimen #	**e_{min} [1] - experimental**	**e_{min} [1] - calculated by equation (6)**	**e_{min} [1] - calculated by equation (16)**
1	4.50	4.75	4.92
2	3.86	4.13	4.21
3	4.29	3.61	3.61
4	4.03	4.33	4.44
5	3.85	3.10	3.03
6	3.41	3.99	4.05
7	3.44	3.45	3.43

Specimen #	**e_{max} [1] - experimental**	**e_{max} [1] - calculated by equation (5)**	**e_{max} [1] - calculated by equation (17)**
8	11.87	11.25	10.94
9	10.33	9.65	9.55
10	9.02	10.73	10.48
11	10.83	10.08	9.92
12	7.75	9.63	9.52
13	9.98	8.53	8.57
14	8.62	8.60	8.63

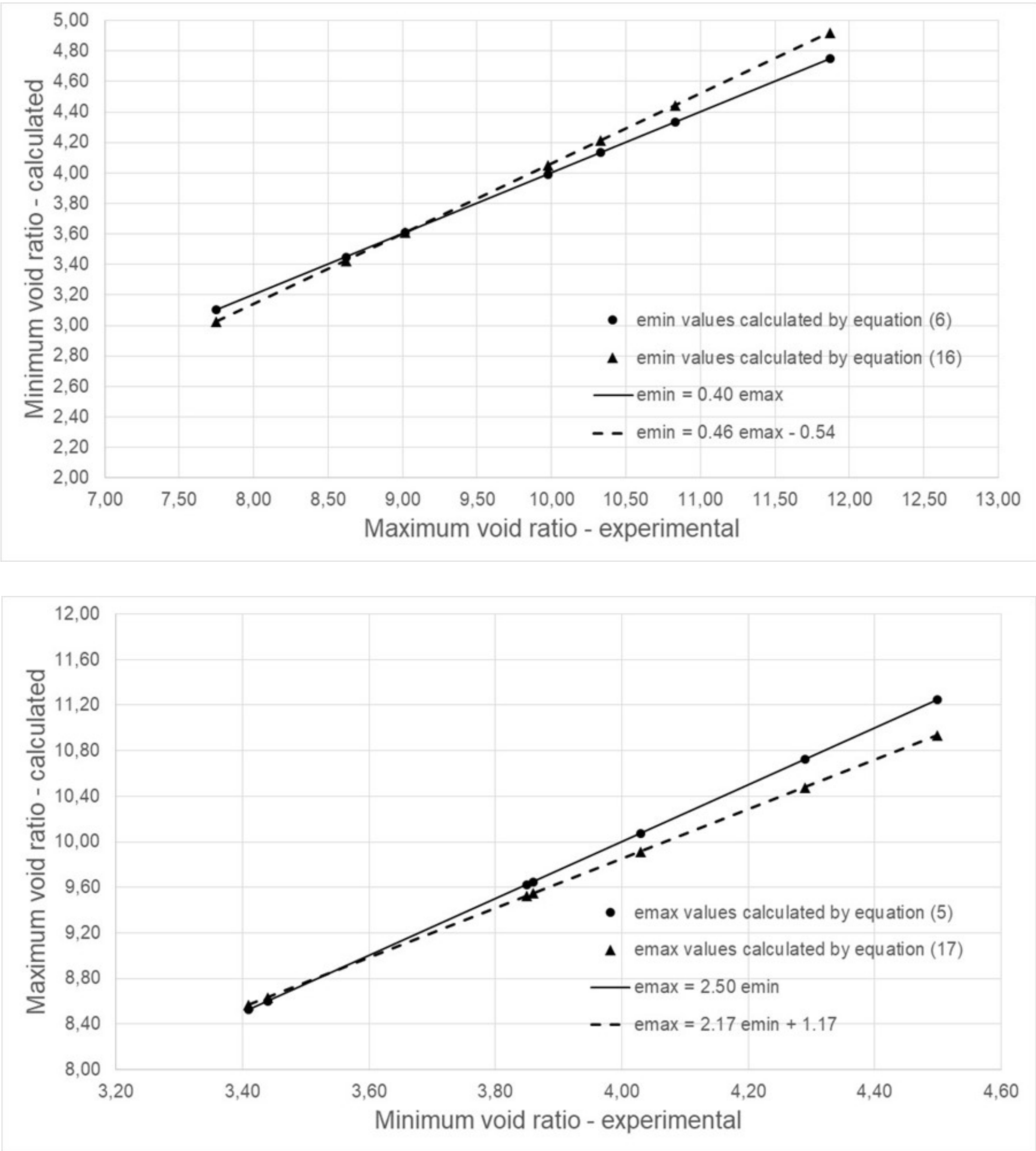

Figure 4 Minimum and maximum void ratio correlation calculated using equations (5), (6), (16) and (17)

3 Conclusion

As a part of this research, mechanically-biologically treated MSW, the so called “fine fraction”, was analysed. MBT waste is a granular material whose structure is comparable to that of a cohesionless soil. Physical and geotechnical properties of the MBT waste samples were determined according to the applicable ASTM standards for testing of soil.

Minimum and maximum void ratios of granular material depend on its physical properties such as particle size distribution, particle shape, coefficient of uniformity, angularity, and its fines content. MBT waste is a very heterogeneous material and presents a mixture of different material components. Physical and mechanical properties and the mechanical behaviour of these individual components also vary significantly. Due to its complex physical composition, with prevailing light-weight components (plastics, paper, wood, kitchen waste), the obtained minimum and maximum index density values for MBT waste are significantly lower when compared to the typical values obtained for soil. Consequently, the calculated values of void ratios for MBT waste material are several times higher in comparison to those of soil.

Based on the experimental results, simple correlations between e_{max} and e_{min} were derived. To confirm the validity of the relations, as presented in equations (5), (6), (16) and (17), further research is necessary.

Acknowledgements

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4 Literature

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