



*Original Article*

## Soil mechanical properties of MBT waste from Luxembourg, Germany and Thailand

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### Abstract

Mechanical and biological treatments (MBT) of waste have become well known in Europe and Asia. The maximum particle size of waste is reduced by the removal of larger plastic materials from municipal solid waste during mechanical processing. The mechanical properties of the MBT waste are significantly changed by this process. An effective treatment system can lead to a better quality of output materials which do not cause environmental problems. This paper shows the comparative mechanical properties of MBT wastes from Luxembourg, Germany and Thailand.

This research focused on the smaller 10 mm-fraction of MBT samples, in order to describe and evaluate the potential application of the small size material as a cover liner in landfill sites. Therefore the smaller 10 mm-fraction of MBT samples were tested for geotechnical properties. The small size waste particles were analysed in laboratory tests in order to determine their particle size, particle shape, compaction, permeability, shear strength, porosity and water absorption capacity, including comparison with the properties of soil material. The results showed that reduced particles were likely to act as a compact, low permeable material with a high potential for water absorption. The amount of remaining fibre and foil components in the materials cause different mechanical and hydraulic behaviours in the samples. The leachate of MBT samples showed very low concentrations of chemical oxygen demand, ammonium, and heavy metals, compared to the landfill leachate of untreated waste.

**Keywords:** MBT waste, soil mechanical properties, municipal solid waste treatment, MBT technology, landfill

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### 1. Introduction

In Europe, mechanical and biological treatment (MBT) is used in order to comply with the EU landfill Directive (99/31/EC). MBT normally involves a mechanical stage – removal of recyclable and bulky materials, particle size reduction - shredding and screening; and a biological stage - an aerobic or anaerobic processes for the reduction of biodegradability (Velkushanova *et al.*, 2011). The changed structure of the material has consequences on its physical properties e.g. particle size distribution, compaction, permeability, shear strength parameters and landfill stability (Bauer *et al.*, 2006).

In many cases, the quality of the outputs is too low for any use or disposal route other than landfill (Archer *et al.*, 2005). The removal of large reinforcing elements from the waste during mechanical processing will change its geotechnical properties, perhaps reducing landfill stability (Bauer *et al.*, 2006; Fernando *et al.*, 2009) but the aftercare phase of the landfill is distinctly reduced because of the lower emissions compared to untreated wastes (Ziehmann *et al.*, 2003; Xie *et al.*, 2006; Wagner *et al.*, 2007). This study tried to evaluate and compare the potential application of different types of MBT waste through testing soil mechanical properties. Xie *et al.* (2006) reported that the low permeability of MBT waste is related to the particle size, content of organic materials, plastic fragments embedded in the samples and the degree of compaction. Bauer *et al.* (2006) reported that the higher density and the smaller pore volume of the MBT waste lead

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to a lower hydraulic conductivity. A higher homogeneity of waste in landfill, compared to the past will have positive effects on long-term landfill behaviour.

## 2. Materials and Methods

### 2.1 Materials

Three countries were chosen for this comparative study due to their unique performance in the MBT implementation. Germany was the first country which introduced MBT technology in Europe. This technology is approved under the strict German landfill site regulations as an environmentally safe technology. The MBT samples from Germany were taken at Singhofen MBT plant located in the Rheinland-Pfalz region, western Germany. The process used in Germany is well-regulated MBT technology. Luxembourg has only one MBT plant, which is located in Fridhaff. The MBT technology used in Luxembourg is a process which was transferred from Germany. Thailand was the first country in South-East Asia to successfully test MBT technology, and it has done so since 2005 in Phitsanulok. The technology from Germany used in Phitsanulok was properly transferred from Faber Ambra Company. Table 1 shows the details of MBT processes in the study areas.

The samples were taken from the composting heaps of the final treatment process prior to sending them to landfills. The sample was reduced to a manageable size of 300-500 kg by the quartering<sup>1</sup> method before characterization at each study site.

They were divided into three fractions by the dry sieving method, a small size fraction with a diameter of <10

mm, a medium size fraction with a diameter of 10-40 mm, and a large size fraction of >40 mm. At present, the larger 10 mm-part of MBT waste is used as a refuse - derived fuel (RDF) in energy production for the industrial sector. The use of smaller 10 mm-parts as a cover liner for landfill development is becoming popular. The smaller 10 mm-fraction of MBT samples were tested in the laboratory with the conventional soil mechanical devices. Samples were analysed for physical and chemical characterization in the laboratory. The composition of MBT samples was determined by visual identification (human eyes). The research methodology flow is shown in Figure 1. A microbial analysis was not performed in this study.

#### 2.1.1 MBT-waste from Fridhaff, Luxembourg (LU)

The small size sample (<10 mm) contained 72% by weight of organic material, 3% by weight of plastics, 17% by weight of glass and ceramics, and 8% by weight of other materials. The sample showed an average pH of 8.3, water (44% by weight), TOC (12.5 % by weight), COD (3,631 mg/L) and ammonium (19 mg/L). *Pb*, *Cd* and *As* were 0.25 mg/L, 0.003 mg/L and 0 mg/L, respectively.

#### 2.1.2 MBT-waste from Singhofen, Germany (DE)

The small size sample (<10 mm) contained 98% by weight of organic material and 2% by weight of plastics. The sample presented an average pH of 8.2, water (31% by weight), TOC (11.3% by weight), COD (2,185 mg/L) and ammonium (21 mg/L). The values of *Pb*, *Cd*, and *As* were 0.29 mg/L, 0.004 mg/L, and 0 mg/L, respectively.

Table 1. Mechanical-biological treatment (MBT) of waste.

MBT processes	Luxembourg	Germany	Thailand
Mechanical process	Shredding, magnetic separator, screening machine (size of sieve ca. 150 mm), homogenization with leachate	Shredding, magnetic separator, screening machine (size of sieve ca. 80 mm), homogenization with leachate	Shredding, no screening machine
Biological process	Single stage: aeration 18 - rotting tunnels with leachate recirculation duration (6 weeks)	Two stages:- indoor aeration composting heaps or aeration rotting tunnels with leachate recirculation duration (3-5 weeks)- outdoor aeration composting heaps with or without turning machine, duration (9-12 weeks)	Single stage: passive aeration chimney system, trapezoidal composting windrow, covered with coconut husks, duration (48 weeks)

<sup>1</sup>Quartering is a method to reduce the amount of sample; the gross sample is mixed and piled in a conical heap. The cone is flattened to approximately one quarter of its original height. The flattened heap is divided into four equal portions. Two opposite quarters are rejected and the remaining pair is mixed together. The above procedure is then repeated until the required sample quantity is obtained.

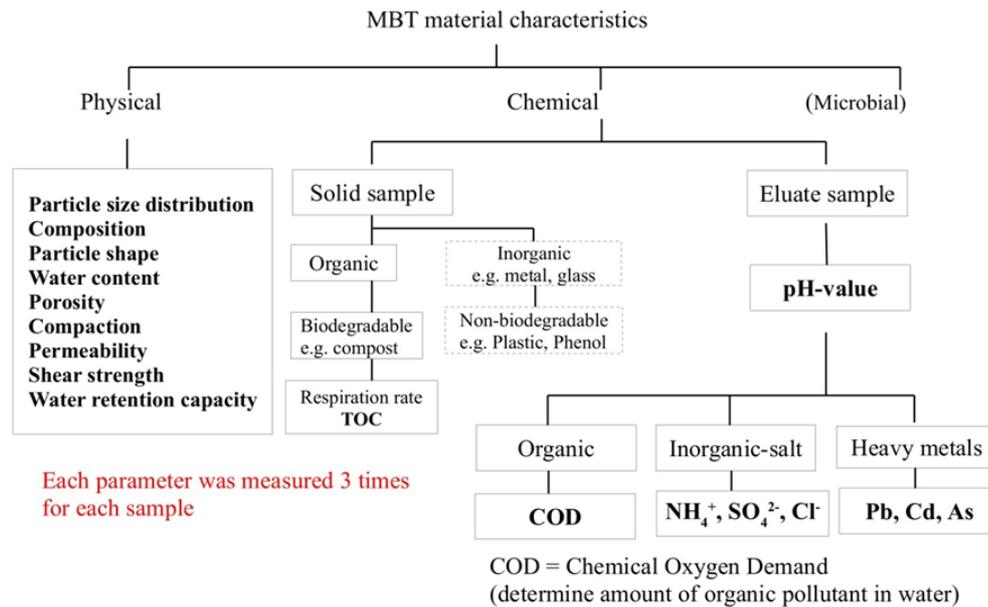


Figure 1. Flowchart of the research methodology to determine the characteristics of MBT waste (<10 mm).

### 2.1.3 MBT-waste from Phitsanulok, Thailand (TH)

The small size sample (<10 mm) contained 100% by weight of organic material. The sample presented an average pH of 8.0, water (31% by weight), TOC (8.5% by weight), COD (2,783 mg/L) and ammonium (29 mg/L). *Pb*, *Cd* and *As* were 0.22 mg/L, 0.004 mg/L and 0 mg/L, respectively.

Leachate of young untreated waste showed an average COD concentration of about 50,000 mg/L. The average ammonia concentration of the untreated waste was about 2,200 mg/L (Fellner, 2008). In comparison to the leachate of MBT samples from the study areas, the COD concentration (2,158-3,631 mg/L) in the MBT wastes is reduced by about 20 times. The ammonium concentrations of the MBT samples ranged from 20-29 mg/L. MBT waste produced less landfill leachate. It also has a much lower specific pollutants load compared to the untreated waste.

## 2.2 Methods

The research methodology used to determine the MBT samples is shown in Figure 1. Each parameter was measured three times for each sample. Methods of the analysis for the MBT samples are explained as follows.

### 2.2.1 Particle size distribution

Each type of MBT waste was sieved by the dry sieving method into seven size fractions, 8-10 mm, 6.3-8 mm, 4-6.3 mm, 2-4 mm, 1-2 mm, 0.5-1 mm, and <0.5 mm. The particle size of samples was screened by mechanical shaking through a stack of aggregate sieves according to DIN 18123.

### 2.2.2 Particle shape

The particle shape test of samples was performed by the scanning electron microscope (SEM). This is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern.

### 2.2.3 Porosity

The porosity test was carried out according to DIN EN 12901. The samples were screened into three fractions, <10 mm, <4 mm, and <1 mm. A dry and loose sample of each fraction without any compaction was placed into a measuring beaker (250 mL). Each beaker was gently filled with water. The amount of water in each beaker was measured and recorded; then this amount was subtracted from the starting amount to determine the total amount of water held for each size of sample.

### 2.2.4 Compaction

Standard Proctor compaction tests were carried out according to DIN 18127. A minimum of five samples with different water content were compacted. Once the optimum water content for each sample was identified, the new compacted samples were prepared for their permeability tests.

### 2.2.5 Permeability

Permeability tests were performed by the falling head method with a PVC cylinder having a height of 30 cm and a

diameter of 10 cm. Because of the heterogeneity of MBT wastes, the particle size of samples was too large to be tested with a triaxial cell of soil mechanical device. The sample in the PVC cylinder was fully saturated into the water. The permeability values were calculated only when the inflow and outflow rates were equal.

**2.2.6 Shear strength**

The direct shear strength test was carried out in the shear box apparatus under undrained conditions according to DIN 18137. The samples were barely compacted. They were placed in a cylindrical ring with a volume of 140 cm<sup>3</sup>. Then they were placed into a circular direct shear apparatus. The initial height of the specimen was 2 cm. The rate of shear was 0.1 mm/min. Shear load is applied to the lower half of the box, the upper half being restrained by a proving ring or load cell which is used to record the shear load. Four samples were tested with increasing normal forces (20, 40, 80, and 100 kN/m<sup>2</sup>) in order to make a graph of the shear strength value.

**2.2.7 Water absorption capacity**

The samples were screened into three fractions, <0.25 mm, 0.25-0.315 mm, and 0.315-0.4 mm. They were dried in an oven for a specified time and temperature according to German standard DIN 18132. Water absorption was measured using the Enslin-Neff device. The apparatus was filled with water up to the filter platen and a small amount of the oven-dried sample (1 g) was placed on the platen. Water absorption was determined when the sample was completely soaked, and calculated in percent by weight of the mass of absorbed water compared to the dry mass of the specimen (1 g/cm<sup>3</sup> = density of water at 20°C).

**3. Results**

The tests were particle size distribution, particle shape, porosity, compaction, permeability, shear strength, and water absorption capacity. Their results are as follows.

**3.1 Particle size distribution**

The particle size distributions of the samples are shown in Figure 2. The results showed that the coarse particle size for particles <10 mm increases more in Thailand than in Germany and Luxembourg. The calculation of the gradation of these materials classifies these MBT wastes as poorly sorted (wide ranges of different sizes). These small particles are visibly similar to soil material. The highest number of coarse particles was found in the sample from Luxembourg. Particle size distribution between the samples from Germany and the samples from Thailand were similar. An effective mechanical system, organic composition and an extended period of composting will generally increase uniformly and cause a smaller particle size distribution of

waste materials.

**3.2 Particle shape**

Figure 3 shows the microstructure of MBT sample <10 mm from Thailand by SEM. It is at a scale of 100 micrometres. The image shows a mixture of round, cube and needle grains. Aggregate and smooth surface areas were often found on the MBT materials.

**3.3 Porosity**

Figure 4 shows the comparative value of average porosity for different size fractions of MBT material. The porosity percentage increased with decreasing size fractions. The porosity in the small size fraction increased in Thailand greater than in Germany and Luxembourg for all size fractions. The maximum porosity is highest in the sample from Thailand (average 44%), the sample from Germany came second (average 38%) and the lowest porosity was found in the sample from Luxembourg (36%).

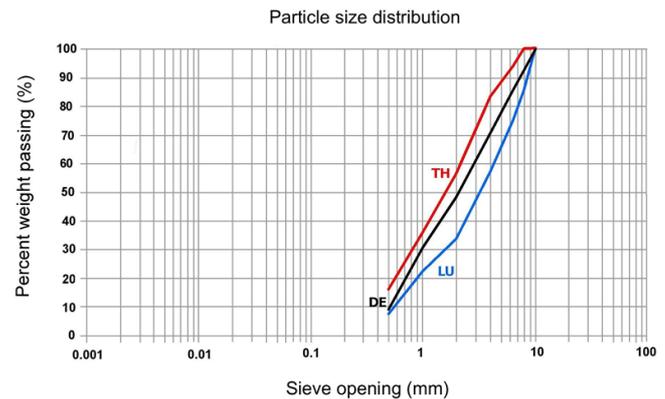


Figure 2. Particle size distribution curves of MBT wastes (<10 mm), LU = Luxembourg, DE = Germany, TH = Thailand.

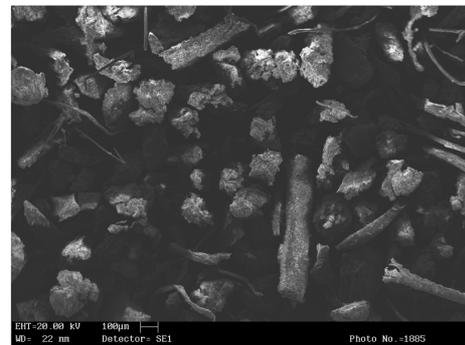


Figure 3. Particle shape of MBT material <10 mm at a scale of 100 micrometres of sample from Phitsanulok (SEM photo by Oscar Baeza-Urrea).

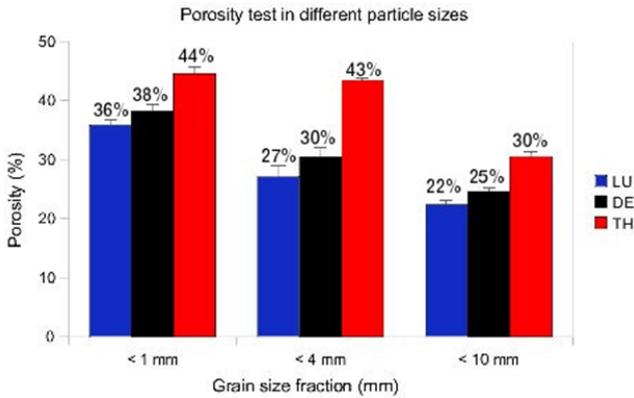


Figure 4. Porosity of MBT wastes (<10 mm).

### 3.4 Compaction

Figure 5 presents the comparison of compaction curves for MBT samples. The maximum dry density of MBT samples varied with contents of the organic matter. The compaction curve of the sample from Luxembourg shows a

slow increase on the dry side of optimum water content. The sample had a greater proportion of inorganic material. Plastic and inert components in the sample were light, thin and elastic, not easily compacted and they became dense material. This small fraction had quite a large surface area. The optimum water content was relatively high. The material took up more water than other samples. The water can be stored above the thin plastic sheets, in particular horizontally oriented sheets. The compaction curve for the sample from Germany shows a quick increase of dry density on the dry side of the optimum water content. The sample material from Germany had about 2% by weight of inorganic matter. In this case, the sample showed a higher maximum dry density and higher optimum water content than the sample from Thailand.

### 3.5 Permeability

The permeability values increased with a higher percentage of plastics and fibrous materials which were embedded in the fine fraction. The comparison of permeability of each sample is shown in Figure 6. The lowest permeability was found in the sample from Thailand (average  $8.04 \times 10^{-9}$  m/s, no plastics). The sample from Germany came

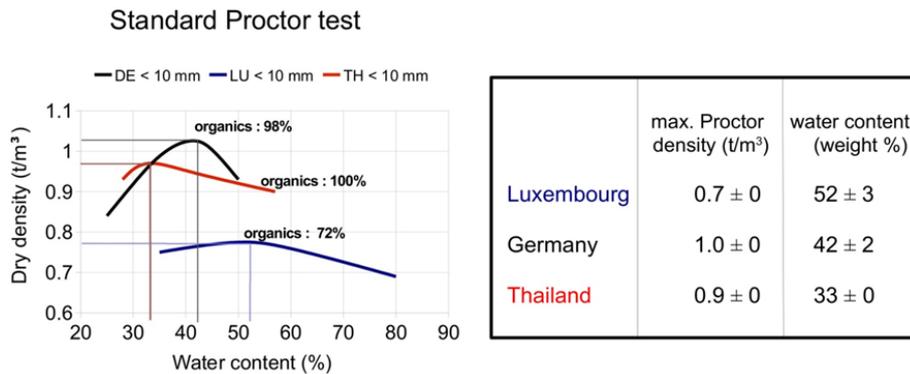


Figure 5. Proctor density of MBT wastes (<10 mm), LU = Luxembourg, DE = Germany, TH = Thailand.

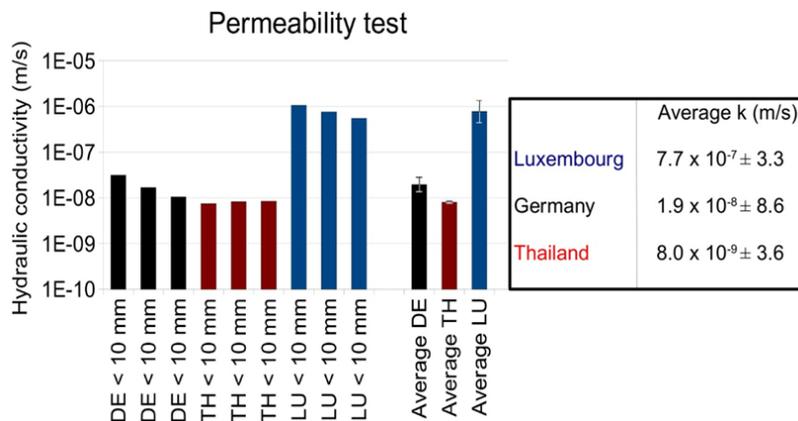


Figure 6. Permeability of MBT wastes (<10 mm), LU = Luxembourg, DE = Germany, TH = Thailand.

second (average  $1.95 \times 10^{-8}$  m/s, 2% plastics) and the highest value was found in the sample from Luxembourg (average  $7.71 \times 10^{-7}$  m/s, 3% plastics).

### 3.6 Shear strength

The effect of increasing normal forces on MBT samples was tested by the direct shear strength method. Figure 7 shows the shear strength curves of MBT material from each country. The shear strength of three different samples varied with the organic content in each sample. As

the normal force increases, the shear strength of MBT material also increased. The shear strength seems to increase with a higher amount of light-weight plastics (Thailand no plastics, Germany 2%, Luxembourg 3%).

### 3.7 Water absorption capacity

The water absorption capacity curves of 3 fractions of MBT samples were very slow and increased gradually (Figure 8). There is a quicker increasing trend in water absorption in the fraction of <0.25 mm of the sample from

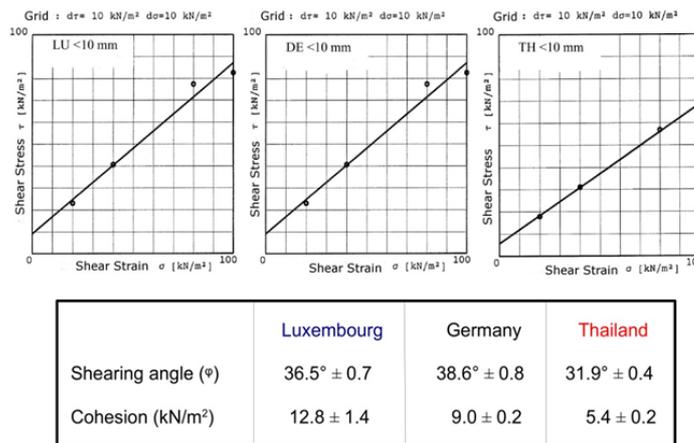


Figure 7. Shear strength of MBT wastes (<10 mm), LU = Luxembourg, DE = Germany, TH = Thailand.

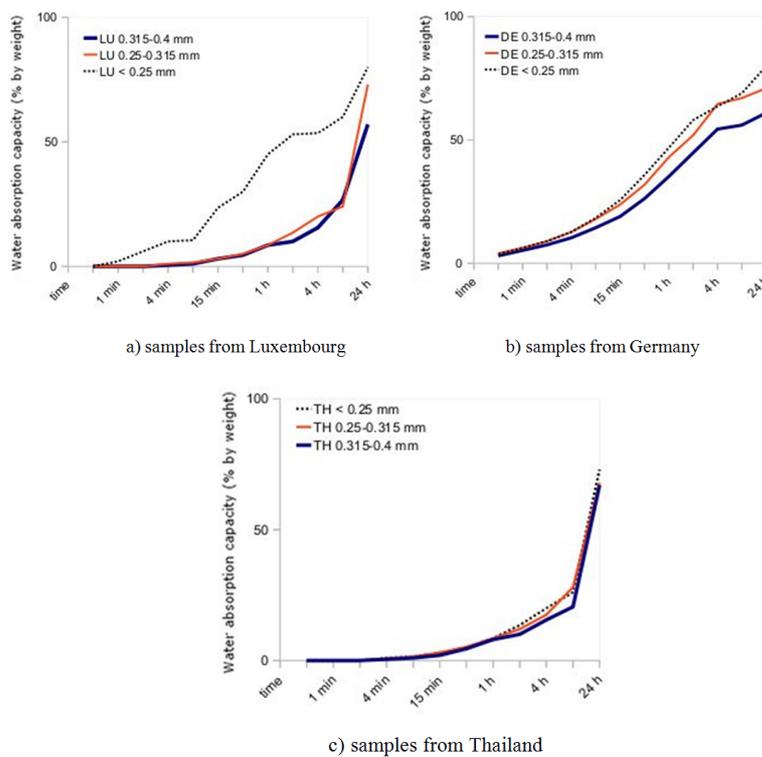


Figure 8. Water absorption capacity curves of MBT wastes, a) samples from Luxembourg, b) samples from Germany, and c) samples from Thailand.

Luxembourg. This sample contained a higher amount of plastic than other sample fractions of more organic materials (which have tendencies to creep). Plastics in form of powders when immersed in water show unconstant water absorption. Various shaped plastics in nonhomogenous material effect the rate of water absorption. The absorption might be greater through cut edges than through rounded surfaces (Klein, 2011). The maximum percentage was found in the <0.25 mm grain size fraction (80% average) in the samples from Luxembourg and Germany. An average of 73% was found in the sample from Thailand.

#### 4. Discussion

According to the grain size classification after Gladstone (Gladstone, 1992), the smaller 10 mm-fraction of MBT waste can be classified as gravel material but its mechanical properties are different. Proctor curves of MBT waste often show a pre-dominantly flat gradient, therefore the range of optimum water content is relatively high (Bauer *et al.*, 2006). It is interesting that the small size of sample from Germany which consisted of mainly organic matter (98%) seemed to behave like a soil material, in particular as clay. This was in contrast to the sample from Thailand which had no plastic and the sample from Luxembourg which had a much lower amount of organic matter (72%). This behaviour of the sample from Germany can be explained by the fact that the small particle size of the organic waste easily fills the small spaces between small amounts of plastic fragments during compaction. It increases the cohesive forces between particles. It can lead to a higher density for this sample.

In theory, the higher density leads to a lower hydraulic conductivity and a high percentage of plastic sheets in the sample should lead to lower permeability (Xie *et al.*, 2006).

However, laboratory tests showed that the amount of plastic in the small size particle sample from Germany was too small to have an effect on permeability. The main reason for a decrease in permeability is the grain size of the sample, as shown in Figure 6 (Thailand < Germany < Luxembourg). However, the smaller 10 mm fraction from Germany and Thailand had a similar high amount of organic matter. In comparison to soil materials, both samples can have low permeability as in silt material, despite the fact that MBT waste has a coarser granular composition.

Permeability and porosity are generally linked. It is known that soil with a well sorted soil grain size has plenty of connectedness of pore space, high porosity and high permeability. Consequently, the extended period of composting makes the MBT materials finer. The porosity increases in the finer particles. Water molecules hold more tightly to the finer particles than to coarser particles. The sample retained more water. The porosity of the MBT materials increases but the permeability decrease, like clay soil not like sand.

The tested MBT wastes had the shear strength in the range of 31°- 38° which can be considered as properties of sand (Table 2). The shear strength of the MBT waste is higher after compaction (Leikam *et al.*, 1998). The shearing angle of materials decreases when finer particles are increased. A good compaction will increase the density of waste and stability in landfill will be improved.

In conclusion, the geotechnical properties of the smaller 10 mm-fraction of MBT waste was found to be as good as natural soil materials. In comparison to untreated waste, MBT waste is more homogenous, denser, more compact, has lower permeability and lot of water absorbing materials. The MBT sample from Germany was found to be the most suitable material among the MBT samples from the three countries, due to a high proctor density value, a high

Table 2. Comparison of compaction, permeability, shear strength and porosity tests for MBT wastes and soils. Soils grain size classification (Gladstone, 1992), Proctor density (Das, 1998), permeability (FAO, 2011), direct shear strength (Das, 1998) and porosity (Fetter, 1994).

Materials	Max. grain size (mm)	Proctordensity ( $\rho$ ) Dry density ( $t/m^3$ )	Optimum water content (OWC) (%)	Coefficient of permeability (k) (m/s)	Direct shear strength ( $\phi$ ) (°)	Porosity ( $\Phi$ ) (%)
MBT-LU (72% organics)	<10	0.7	52	$7.7 \times 10^{-7}$	36	22-36
MBT-DE (98% organics)	<10	1	42	$1.9 \times 10^{-8}$	38	25-38
MBT-TH (100% organics)	<10	0.9	33	$8.0 \times 10^{-9}$	31	30-44
Gravel	2 to 60	1.8-2.0	14-11	$10^{-10}$ - $10^{-2}$	34-48	25-25
Sand	0.06 to 2	1.6-1.9	21-12	$10^{-2}$ - $10^{-5}$	27-38	20-35
Silts	0.002 to 0.06	1.5-1.9	24-12	$10^{-5}$ - $10^{-9}$	26-35	35-50
Clay	<0.002	1.0-1.6	45-21	$10^{-9}$ - $10^{-11}$	14-20	33-60

shear strength value and a low hydraulic conductivity value. Their outstanding geotechnical results support the use of the smaller 10 mm-fraction of MBT waste as a suitable cover liner in landfill development. However, the most important standard criteria of an alternative barrier for landfill in Germany is given to a hydraulic conductivity value of  $<5.0 \times 10^{-9}$  m/s (TASi, 1993). Therefore, in order to ensure the use of this material as a final landfill cover in Germany, the hydraulic conductivity value should be improved to meet the standard criteria.

Additionally, the results of leachate qualities from the MBT samples showed a strong reduction of common leachate pollutants, as mentioned above. Effective MBT operation and treatment in Germany provides predominantly to completely stabilized final MBT material. There are different aspects explain here.

The first and most important aspect is associated with the quality of the source separation system and the mechanical process. The source separation in European countries is well regulated as it is set out in the solid waste management policy of all the EU countries. In Germany, plastics and recyclable materials are completely separated from organic waste in households. This reduces the contamination of organic waste with plastics and other chemical components. Plastics and other chemical components have a negative influence negatively on the biological degradation of bacteria and other living micro-organisms.

The size of sieve screening machine in Germany is small enough to separate a large amount of recyclable materials from organic waste. In contrast, organic household waste in Thailand is not collected separately. There is a high amount of organic materials in waste at the landfill site with a high moisture content of about 60% of dry substance (Schoell, 2006). Plastic bags are the second most important component. One single bag contains a series of other smaller bags inside, partially full of organic matter from food remains, which makes access of fresh air for an aerobic decomposition of the organic content barely possible.

The second aspect is related to the proper biological treatment system. MBT technology focuses on the principal of decomposing the organic waste components under aerobic conditions before the waste is finally dumped in landfill sites. On this second aspect the biological treatment system in Germany has been developed with extensive experience in MBT technology for the local context. One focus of the two stages of biological treatment is the factor of efficient degradation for MBT waste.

The use of MBT waste as a cover liner can result in one or more of the following environmental problems, if the environmental management of MBT processing facility is poor,

1. Air quality impacts such as odours, wind-blown litter and particulate matter,
2. Water and soil pollution, and
3. The presence of vermin in excessive numbers.

## 5. Conclusion

This paper shows the results of various soil mechanical properties tests for the three different MBT wastes. Based on the testing of the mechanical properties of the smaller 10 mm-fraction of MBT samples, it can be stated that this part of MBT material is suitable for use as an alternative material cover liner. However, decision-makers might not easily accept it, as it was tested only on a laboratory scale. In the long-term, a large-scale test in the field of the geotechnical properties of MBT wastes remains a subject of continuing investigation.

The reason for differences among MBT wastes is related to the method of MBT treatment and implementation. They differ due to local policy application, funding, experience and cultural reasons. Of the tested MBT wastes, the sample from Germany showed outstanding mechanical properties for use as a bio-filter layer in the final cover of the landfill. It is a highly compressible material and with a dry density value similar to soil material like clay, it has a low permeability, high porosity, high water retention capacity and high shear strength.

Additionally, landfilling MBT waste is cheaper than landfilling untreated waste. MBT technology involves the reduction of a high volume of waste and environmental impacts. The first reason is that MBT waste has a highly stable waste body and no settling effects. MBT waste build-up can easily reach double the height of conventional landfill. MBT waste extends the life time of the landfill site due to its high compaction ratio. After compaction in landfill, MBT material can reach a density of 1.2 to 1.6 t/m<sup>3</sup>, compared with a density of 0.4 t/m<sup>3</sup> for untreated waste (Fellner, 2008).

The second reason is that MBT waste leads to a very high reduction in the specific pollutants load present in leachate compared to untreated waste. This leads to a strong reduction of all common environmental impacts found in conventional sanitary landfill sites: smell, leachate, methane and unstable waste bodies. The results of chemical properties tests showed a very high reduction of the specific pollutants load present in landfill leachate. The cost of leachate treatment, the monitoring cost and the aftercare cost of the landfills are distinctly reduced because of the lower emissions. (Ziehmann *et al.*, 2003; Xie *et al.*, 2006; Wagner *et al.*, 2007). These are the reasons, why landfilling MBT waste was approved as cheaper than landfilling untreated waste.

An additional reason is that the smaller 10 mm-fraction of MBT waste should be used as a cover liner instead of soil. Use in a daily cover with soil for active landfill is unsuitable for landfilling untreated waste. On one hand, the soil cover prevents the access of air to the waste body at a very early stage, immediately bringing about anaerobic conditions. This causes a formation of methane and a development of a strong smell. On the other hand, the waste itself produces such a high amount of leachate that it is

imperative to drain it fast into the leachate collection system, as the soil layer impedes this circulation. Soil cover is typically employed where the waste is much dryer and contains more material, to ease circulation. At this point, availability is not limited and the costs for the use of MBT waste as a cover liner in landfill development for sustainable waste management are not high.

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