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Paper Components Effect on Hydraulic Characteristics of Biodegradable Municipal Solid Waste

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ABSTRACT

Indonesian municipal solid waste (MSW) is dominated by biodegradable MSW (organic and paper). Due to the degradation process, the physical and hydraulic characteristics of these components can change. It is important to study the physical and hydraulic characteristics of MSW, because landslides occurred in several landfills in Indonesia after heavy rains. Field observations showed that landslides occur due to reduced paper components in the landfill (due to high recycling activities), and cause high percolation of water into the landfill. In the research, 38 samples consisting of two variants of MSW samples (organic and 80% organic + 20% paper), were prepared under the conditions of optimum moisture content. The organic sample of MSW is leaf, while the paper sample of MSW is newspaper, which were shredded to a diameter of about 1 cm. The tests of moisture content, bulk density (in the mould of permeameter), particle size distribution, and permeability were carried out on both sample variants for 90 days, with a test frequency of once in 5 days. The results showed that there was an increase in the moisture content and density, and a decrease in particle size and permeability in both variants of MSW sample. Organic MSW + paper has lower permeability and higher density than organic MSW. This requires further study, because a high paper recycling ratio can lead to a change in the landfill characteristics.

Keywords: biodegradable, density, MSW, paper, permeability

INTRODUCTION

The hydraulic conductivity of fresh MSW uses the constant head test method, ranging from $0.28 \cdot 10^{-2}$ to $1.18 \cdot 10^{-2}$ cm/s (Reddy et al., 2009). The high conductivity of fresh MSW allows rainwater to infiltrate into the landfill and cause an increase in the moisture content and pore water pressure. However, the hydraulic conductivity of organic MSW can decrease with the density, pressure, and degradation age (Hadinata et al. 2017; Hadinata et al., 2019; Wang et al., 2018). Yang et al. (2018) recapitulated the impact of the increasing moisture content (after heavy rain) and/or the increasing of pore water pressure in landfills, which caused landslides in several countries, namely: Leuwigajah Landfill (2005), Chongqing Shapingba Landfill (2002),

Payatas Landfill (2000), Dona Juana Landfill (1997). Several landslides also occurred after the heavy rains in Indonesian landfills, including: Cilowong Landfill (January, 2019), Pasir Sembung Landfill (2019), Sumur Batu Landfill (April, 2019), Cipeucang Landfill (June, 2019), Bakung Landfill (July, 2019), Sarimukti Landfill (December, 2019). These events, some of which have resulted in casualties and ecological pollution, make the knowledge of MSW characteristics necessary (Hadinata, 2019). On the basis of observations and field investigations, Koda et al. (2020) found that the groundwater contamination is generally due to the failure of the leachate collecting system. This knowledge is needed to compile the design standard and the boundaries in landfill operations, so the probability of structural failure in a landfill can be minimized.

Indonesian MSW is dominated by three components, namely organic, plastic and paper (Damanhuri and Tri Padmi, 2016). In Palembang City, the composition of MSW, in% wet weight, consists of 61% organic MSW, 16% paper MSW, 17% plastic MSW, and 6% others (SIPSN, accessed September 02, 2019). Organic MSW and biodegradable MSW (organic + paper) dominate the composition of MSW, and are the objects of this research. MSW characteristics change along with the degradation process (Thakur et al., 2019; Yang et al., 2018). Increasing in the moisture content can reduce the friction angle for the organic waste that has been degraded (Hadinata et al., 2015). The precipitation effect depends on the MSW hydraulic conductivity, where the smaller the hydraulic conductivity of MSW, the greater the precipitation effect on the safety factor (Albert and Faur, 2014). Reddy et al. (2009) showed that void ratio affects the MSW hydraulic conductivity. The MSW hydraulic conductivity in landfill also determines the amount of leachate, closely related to the height and the unit weight of the MSW (Yang et al., 2016).

According to Zeng, et al. (2017), the decrease of hydraulic conductivity significantly affects the pressure and degradation, due to the increasing density and the finer fraction of MSW particles, resulting in lower porosity of MSW. Conversely, the larger of the grain size, the higher the permeability (Gavelyte et al., 2016). The reliability index in the safety factors estimation decreases with the increasing of unit weight variation related to MSW height (Datta and Babu, 2016). The value of MSW unit weight depends on the composition and landfilling operations, such as: compaction, soil placement and leachate management (Zekkos, 2006). The particle size is one of the parameters that affect the MSW unit weight. Albert and Faur (2014) suggests studying the hydraulic and geotechnical parameters of MSW for more reliable stability calculations. This underlines the importance of the research related to the physical and hydraulic characteristics of MSW,

and the changes that occur due to the organic MSW degradation process. This research examines the changes in the physical characteristics (unit weight and grain size distribution) and hydraulics (permeability) of artificial organic MSW, which is made from leaf MSW, as an initial study. Degradable MSW (organic and organic + paper) was chosen as variance of sample because the the degradable MSW dominate the Indonesian MSW (Damanhuri and Tri Padmi, 2016).

MATERIALS AND METHODS

This research is a laboratory scale test conducted at the Laboratory of Soil Mechanics, Sriwijaya University, with the following test steps.

Sample preparation

The selected organic waste samples were dry leaves (which had fallen) from rubber trees in the Pangkalan Balai area, South Sumatra. After the organic MSW samples (dry leaves) have been collected, it was chopped at Kalidoni's Material Recycling Facilities, so that the MSW sample size was less than 1 cm. The paper MSW samples were used newspapers which were also shredded so that the maximum size was 1 cm. Then, the organic samples (chopped leaf) and shredded paper samples were dried in open air (Figure 1). After the organic sample and dry paper, two sample variants were prepared, namely (a) organic waste sample consisting of 100% organic (organic), and (b) a mixture of organic waste and paper consisting of 80% organic and 20% paper (in % by weight). The ratio between the organic weight and paper weight refers to the ratio of organic and paper composition of domestic MSW in Palembang City, which is 63%: 15%, or close to 80%: 20%. Furthermore, the Proctor standard test (ASTM D-698) was performed to determine the optimum moisture content of the two sample variants. From the results



Figure 1. Sample preparation: (a) chopping, (b) drying, (c) Proctor Standard test, (d) sample's reactor

of the Proctor standard test, it was known that the organic samples had an optimum moisture content of 160% and 80% organic samples + 20% paper had an optimum moisture content of 180%. Henceforth, the sample prepared under the initial condition with the optimum moisture content.

For both sample variants (organic and organic + paper), nineteen samples were prepared under the conditions of optimum moisture content, namely by adding a certain amount of water to the air dry sample. Thus, a total of 38 samples were stored in 38 chambers, to be tested at pre-determined times. The test was carried out every 5 days (Gabr, et al., 2002) for 90 days (Thakur, et al., 2019). At each test day interval, moisture content measurement, size distribution analysis, and permeability coefficient were performed. The sample density inside the mold was also calculated, by dividing the weight of the sample that entered the mold and the volume of the mold filled with the MSW samples.

Physical characteristic and hydraulic test

Nineteen specimens for organic MSW sample variants and nineteen others for organic waste + paper samples were measured for their hydraulic conductivity using the Constant Head Permeameter method (ASTM D2434-19), referring to the test conducted by Reddy et al. (2009). The sample was inserted (and compacted) gradually into the permeameter mold with a diameter of 6.4 cm, so that the height of the sample in the mold reached 16 cm. In each permeability test, the sample weight that entered the mold was recorded. Thus, by dividing the weight to the volume of the mold filled with waste samples, the density of the samples that enter the mold permeameter could be measured. Before the permeability test, the moisture content test – which was presented in % dry weight (ASTM D2216-19) – as well as filter analysis (ASTM D6913) were carried out, especially for the organic MSW. The measurement of grain size distribution was carried out using a sieve, because no MSW sample passed the No. 200. Since the sample had a grain size like coarse-grained soil, the permeability test was carried out using the constant head method. The paper waste could not be filter tested because of its large size. Dry density of the waste samples in the mold can be calculated by dividing the bulk density by the measured moisture content. The values of bulk density and moisture content could be different at each test time.

RESULTS AND DISCUSSION

Change in grain size distribution of MSW samples

The paper MSW in the sample was relatively unchanged, but a change/degradation occurred in the organic sample (leaf). Figure 2 showed the comparison of the grain size of organic MSW from the two sample variants (organic and 80% organic + paper). At the same particle size (organic waste), the sample at the beginning of the test had a smoother mass percent smaller than the sample at the middle and end of the test. There was no difference in phenomena between the MSW samples with and without paper.

Effect of paper on density of MSW samples in mold permeameter

With a uniform method of inserting the MSW samples into the permeameter on each test day, various MSW densities were obtained. The MSW sample at the beginning of the test had a lower density than the sample at the end of the test, linear with the size of the MSW that was smaller by the time. For organic MSW, bulk density increased from 0.19 tonnes/m³ at the start of the test, to 0.55 tonnes/m³. Meanwhile, for organic waste + paper, the bulk density increased from 0.40 tonnes/m³ to 0.84 tonnes/m³. The test results showed that the sample with paper components was denser than the sample without paper (Figure 3), where the dry density of the organic MSW + paper sample was higher than the organic MSW. Dry density of organic MSW was measured at 0.07–0.17 tonnes/m³, while for samples of organic MSW + paper, the measurement was 0.14–0.23 tonnes/m³. Hadinata (2017) also obtained dry density values from degraded organic MSW samples and shredded paper of 0.20–0.30 tonnes/m³. Figure 3 shows the increase in density between solid MSW components, which is represented by the increase in dry density. If we look at the increase in dry density which is not as large as the increase in bulk density (Figure 3), and see that the moisture content of the sample is relatively constant, then the increase in bulk density is linear with the increase in the amount of water in MSW sample, and is not only caused by the increase in dry density of solid components from MSW.

Figure 4 shows a simulation of solid materials weight and the water weight in 1 m³ of MSW pile

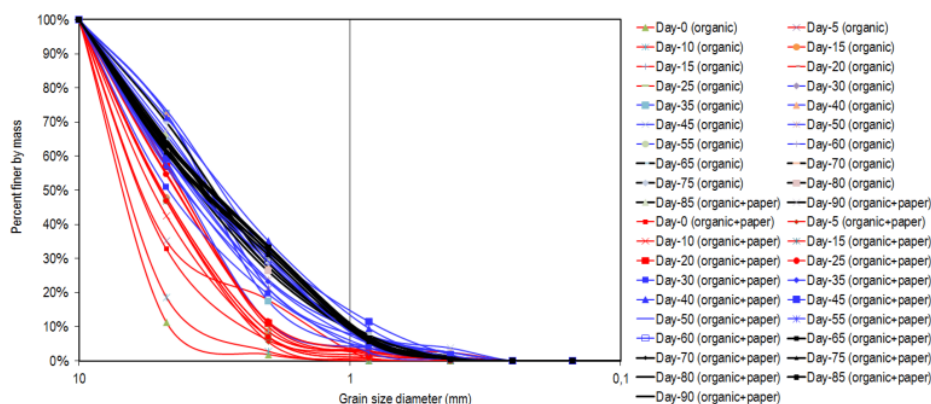


Figure 2. MSW sample grain size distribution (organic and organic + paper)

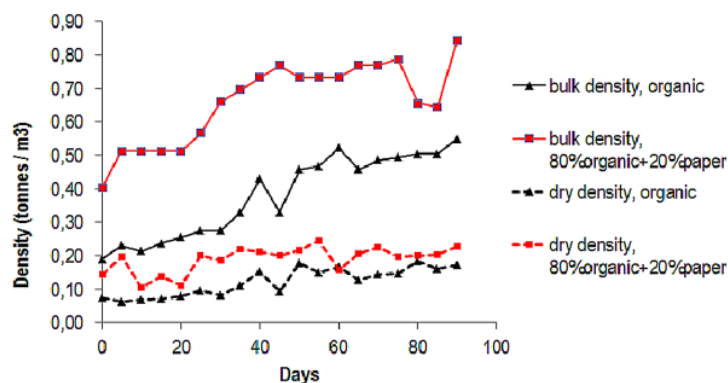


Figure 3. Bulk and dry density of the MSW sample

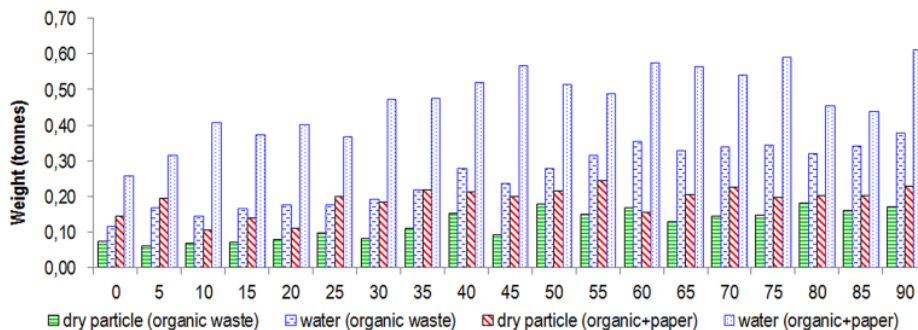


Figure 4. Simulation of solid weight and water weight in 1 m³ of MSW pile, according to the density data and moisture content of the MSW from the test results

(in undrained conditions), for 90 days, according to the density data and MSW moisture content in both variants of MSW samples. In the simulation, in the same volume (1 m³), there is an increase in the weight (and density) of MSW, which was

contributed by the increase in dry matter weight and the increase in water volume. This requires further study, because there is a possibility of an increase in the pore water pressure in the MSW pile, if the leachate drainage does not go well. Under

this condition, the effective shear strength of MSW may decrease as the pore water pressure increases in MSW, and increases the risk of collapse in the landfill. Further research is needed to clarify this hypothesis. Hadinata et al. (2019), Yang et al. (2018), and Kölsch et al. (2005) indicated that the magnitude of the water content and the increase in pore pressure should be noticed, and may be responsible for landslides in the landfill.

The organic + paper MSW sample has a higher dry density than the paperless organic MSW sample. With a smaller pore, there is a possibility that the stability of a landfill with a paper component will be better than a landfill without a paper component. This requires further study related to the shear strength of the MSW from the two sample variants.

The effect of paper components on the permeability coefficient of MSW samples

The hydraulic conductivity of organic waste decreased, ranging from $15,17 \cdot 10^{-2}$ cm/s at the beginning of the test to $0,76 \cdot 10^{-2}$ cm/s at the end of the test (day 90th). The same thing happened to the MSW sample of 80% organic and 20% paper, where the graph also shows a decrease in hydraulic conductivity from $9,12 \cdot 10^{-2}$ cm/s at the beginning of the test, to $0,07 \cdot 10^{-2}$ cm/s at the end of the test (day 90th), see Figure 5. Organic + paper samples have a smaller permeability coefficient, and reach constant values faster. This phenomenon may be due to the higher density of the organic MSW + paper sample (Figure 3). Density increases by the

bio-settlement along with the degradation process. Along with the degradation process, the particle size of the MSW sample decreases, and affects the permeability of the MSW sample (Gavelyte et al., 2017; Naveen, 2018).

The high density and the low permeability of organic MSW + paper (compared to organic MSW) is quite surprising, because with a paper component that has a larger size, organic waste + paper should have a smaller density and greater permeability. This may be related to the stickiness and ability of the paper to absorb water. Al-Zubaidi et al (2019) found the high water absorption capacity of paper which is used as an additive to concrete.

The high compressibility of Indonesian MSW, describe the low density of MSW layer in Indonesian landfill, related to high moisture and high organic matter contents (Hadinata et al., 2018), so the effect of paper components in increasing the dry density of MSW and slows down the entry of water into landfills (due to smaller permeability) becomes important and needs to be studied further. If there is a possibility of loss of paper components in landfill, for example by recycling activities, reduced density (and stability) is probable, especially for fresh waste on the top layer of the landfill. This phenomenon was noted by Albert and Faur (2014), related to the case of landslides in several landfills where the paper component in the landfill was reduced due to the high recycling ratios, and caused very high water percolation, where percolation is generally related to paper components.

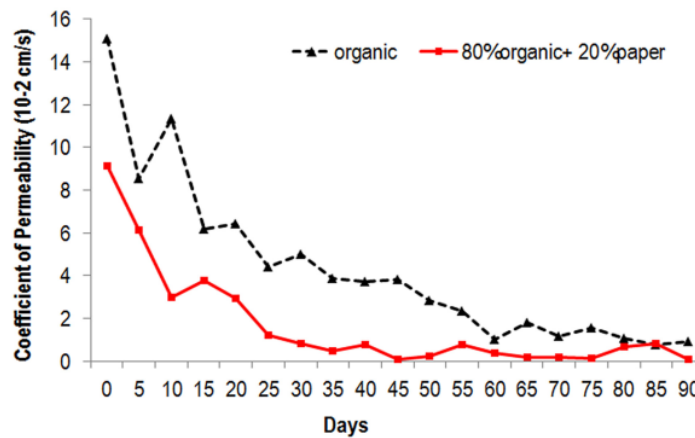


Figure 5. Permeability coefficient of MSW sample

CONCLUSIONS

From the result of the research, it was found that the MSW characteristics change, those are: moisture content increase, the smaller particle size, bulk and dry density increase, and permeability decrease. In the same sample volume, there is an increase in the weight (and density) of the MSW, which is contributed by the increase in dry matter weight and the increase in water volume. This requires further study, because there is a possibility of an increase in pore water pressure, if the leachate flow in the landfill is hampered, can reduce the stability of the landfill. The permeability coefficient of the MSW samples decreased exponentially, from $15 \cdot 10^{-2}$ cm/s at the start of the test, to $0.1 \cdot 10^{-2}$ cm/s at the end of the test (90th day). The permeability coefficient starts to be constant on day 25 and day 60, where the variant of the MSW with paper components reaches a constant permeability (day 25) faster than the variant of organic MSW without paper (day 60). This phenomenon may be related to the characteristics of the organic MSW + paper variant which has a higher moisture content and density (wet) than the organic MSW variant. The ability of paper to absorb water seems to make the MSW sample denser and increase the constant permeability coefficient value. The existence of a paper component might improve the landfill stability, which is important for further study and is closely related to the landfilling applications, especially in Indonesia that is dominated by biodegradable MSW (organic and paper).

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