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PRELIMINARY STUDY OF THE COMPRESSIBILITY OF MUNICIPAL SOLID WASTE IN INDONESIAN LANDFILL

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ABSTRACT: The lack of studies on the compressibility of Municipal Solid Waste (MSW) increase the uncertainty in the design and monitoring of the landfill settlement in Indonesia. This study aims to assess the compressibility of MSW in Indonesian landfill. Compression cell was made with a diameter and height of the mold at 350- and 500 mm. Compression test performed with the initial pressure of 2.04 kPa, and was increased every 24 hours, with the constant addition of 2.04 kPa, until reached a pressure of 10.20 kPa. Test performed on; paper waste with medium density ($Paper_{MD}$), paper waste with high density ($Paper_{HD}$) and compost with medium density ($Compost_{MD}$). For $Paper_{MD}$ and $Paper_{HD}$, moisture content of the sample was reduced by 4.45% and 1.39% (% of wet weight), whereas in $Compost_{MD}$, the moisture content of the samples did not change. End of immediate compression (ε_{EOI}) detected after 6 hours for $Paper_{MD}$, and 4 hours for $Paper_{HD}$ and $Compost_{MD}$. Immediate compression ratio (C_c') obtained at 0.2949, 0.0696 and 0.0932, each for $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$. While, secondary compression ratio (C_α) for $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$, respectively - each 0.0211, 0.0056 and 0.0060. The bulk density of the sample at the end of the test for $Paper_{MD}$ and $Compost_{MD}$, respectively increased by 20.12% and 6.70%, while the bulk density at $Paper_{HD}$ was not increased. From this study, it was shown that the compressibility of the waste sample is inversely proportional to the initial density, and directly proportional to the ability to drain the leachate.

Keywords: Compressibility, Compression ratio, Density, Moisture content, Waste

1. INTRODUCTION

Settlement is one of the parameters to be monitored from a landfill, and as a measure of the stability of the landfill, in addition to leachate and biogas [1]. Settlement occurs due to the characteristics of MSW that is compressible, and related to the capacity, age, and the stability of the landfill. MSW will continue to settlement along the increasing load on it, increasing time as a mechanical creep and biodegradation process of waste materials. The amount of settlement depends on the compressibility of MSW. Understanding the compression behavior of waste materials is important to the operation and rehabilitation of landfill sites [2]. Compressibility of MSW correlates with moisture content, self weight and percentage of biodegradable components [3].

In the process of settlement in landfills, there are three common mechanisms, include immediate compression, mechanical creep and biocompression [4]. Initial settlement mechanism is immediate compression due to the increasing in stresses. Mechanical creep is a physical compression process in which the cavity volume decreased over time, while biocompression involving biochemical processes associated with the anaerobic decomposition of the organic fraction of MSW [3]. Settlement can be reduced by the addition of chemicals [5].

Immediate compression ratio (Cc'), is a parameter that is used to predict the strain in immediate compression (εi) of MSW [6]. According to [4], the methodology that is used in soil mechanics to identify the transition between the primary and secondary consolidation could not be applied because the MSW was not saturated and the excess pore pressure did not disappear, and assessing immediate compression required the definition of a strain in which immediate compression ends and time-dependent compression begins, which is called end-of-immediate-compression-strain (ε_{EOI}). [7] presented an alternative method, based on the procedure of first order rate equation (FORE) to determine ε_{EOI} of MSW. FORE simulate physical processes at the beginning of the process, while the semilog equation simulate physical processes continuously to the logarithm of time. After determining ε_{EOI} for any additional stress on the tests performed, C_c' is determined by the least squares linear regression of $\Delta\varepsilon_{EOI}$ versus $\Delta\log \sigma_v$ relationship [4]. [8] got C_c' between 0.19 to 0.24 for landfilled MSW, and between 0.24 to 0.33 for fresh MSW, and also found that the C_c' on landfilled MSW positively correlated with the moisture content, while fresh MSW had no correlation with the moisture content. Compressibility of MSW material is high, hence the expected settlement would be high [9].

MSW has a high heterogenity, which Indonesia has characteristics of that MSW, i.e: high biodegradable component and initial compaction under moderate conditions [1]. Unfortunately at this time, there are no studies related to settlement of landfill in Indonesia. The lack of studies on the compressibility of MSW increase the uncertainty in the design and monitoring of the landfill settlement in Indonesia. As a result, settlement in landfills often ignored in the calculation of the capacity and lifespan of landfills. The purpose of this study is as an early review of the behavior of the compressibility of the MSW and settlement in landfills in Indonesia.

2. METHODOLOGY

2.1 Assembly of Compression Cell

Compression cell is a device used to study the compressibility of synthetic MSW samples. The parameters to be measured are the immediate compression ratio (C_c') and the secondary compression ratio (C_α). Compression cell was created in which stress could be controlled and there was a leachate collection system. A schematic of the compression cell shown in Figure 1. Mould in the form of a cylinder with a diameter of 350 mm of PVC material, was placed between the upper plate of 50 mm thick nylon material and the base plate of 60 mm thick nylon material, which was tied with tie rod. A hole in the top plate was made to take gas samples. Leachate was collected through an outlet in the base plate. Sieve was placed between the base plate and the specimen to prevent clogging of the leachate collection system.

Leachate was collected in the base plate after passing through the drainage plate from perforated PVC. Loading plates were used to incriminate the compression cell, which was then distributed to the sample. Time and displacement recorded during the test using a timer and vernier calliper. Table 1 presents the material and the working principle of the compression cell.

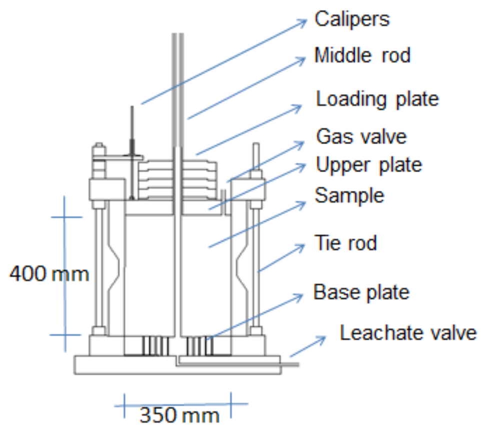

Fig. 1 Scheme of the compression cell.

Table 1 Materials and working principle of compression cell.

	Description
Materials	Mould : Silinder PVC. Tie rod : Sild Bolt Base plate : Nylon Upper plate : Nylon. Middle rod : Aluminum pipe. Loading plate : Cast iron. Strain gauge : Vernier Caliper.
Working Principle	• Controlling displacement due to vertical pressure. • There was a leachate collection system at the base plate. • The load was distributed to a sample of synthetic MSW through the upper plate. • Time and displacement was measured with a timer and caliper. • Initial stress was 2.05 kPa, the addition of the stress is done every 24 hours at 2.05 kPa. • This stress represents a daily layer of MSW in Indonesian landfills, with a height of 0.5 m per layer and density of 0.4 tonnes/m^3.

2.2. Compression Test on Paper Waste and Compost

Shredded paper (newspaper) and compost were used as a sample of synthetic MSW. Paper was chosen to represent the component of fresh MSW that having a large pores, while the compost samples represented MSW which have been degraded and more compact. The paper was shredded up to a maximum size of 3.5 cm (10% of the diameter of the cell compression mold). Table 2 shows the conditions of the test on paper and compost. Measurements of moisture content was done at the beginning and the end of the test.

Table 2 The conditions of the test

Component	Description
Sample	Paper waste at medium density ($Paper_{MD}$), paper waste at high density ($Paper_{HD}$), and compost at medium density ($Compost_{MD}$), chopped with a maximum size of 35 mm.
Treatment	• The moisture content of the sample was measured, add water until the moisture content 60-75% (% wet weight). • The moisture content of the sample was increased by soaking in water for 24 hours, then measured the moisture content. • Once the moisture content was fulfilled, the sample was introduced into the mold, then testing begins.
Input samples and loading	• $Paper_{HD}$ compacted every 10 cm. • $Paper_{MD}$ and $Compost_{MD}$ leveled every 10 cm (not compacted). • Initial stress = 2.05 kPa, settlement/strain was recorded for 24 hours. • Additional stress = 2.05 kPa. Settlement was recorded for every additional stress. Final stress = 10.20 kPa.
Drainage of leachate	Drained valve to drain the leachate opened.
Standard reference test	ASTM D2435 - Standard Test Method for One - Dimensional Consolidation Properties of Soils.

3. RESULTS AND DISCUSSION

3.1 The Test Results on the Paper and Compost Waste

3.1.1 Tests on paper waste with a high density

Weight of the sample was put into the mold of the compression cell was 42.10 kg, which filled the space in the mold of 38,465 cm^3. This indicated a density of 1.0936 ton/m^3 (in conditions of high density, according to [10]. The initial moisture content of the sample was 72.04% (% of wet weight). The temperature when the test around 26ºC – 27ºC. The relationship between time and sample deformation of $Paper_{HD}$ is shown in Figure 2. The moisture content of the sample after the test completed becomes 70.65% (% of wet weight), along with the discharge of leachate from the compression cell for 1,990 ml. Meanwhile, the density of the sample at the end of the test same as before the test.

3.1.2 Tests on paper waste with a medium density ($Paper_{MD}$)

Air temperature when the test was done at 24 - 26°C with samples inserted into the mold of the compression cell was 28.8 kg. The samples filled the space in the mold of 38,465 cm^3, which indicated the initial density of 0.7487 tonnes/m^3 (in the medium density, according to [10]). The initial moisture content of the sample amounted to 74.09% (% of wet weight). In this variant of the test, the compaction of the paper sample was not done, but just smoothing it. Density of the sample at the end of the test rose to 0.8994 ton/m^3, while the moisture content of the sample after the test completed was 69.64% (% wet weight). The leachate out of the cell compression as much as 4,470 ml. Settlement on $Paper_{MD}$ was greater than $Paper_{HD}$, as shown in Figure 2.

3.1.3 Test on compost with a medium density (CompostMD)

Air temperature when the test is done at 24 - 26°C. The weight of the sample put into the mold was 27.7 kg, filling the space in the mold of the compression cell for 38,465 cm^3. This indicated that the initial density of 0.7198 tonnes/m^3 (at medium density conditions, according to [10]). The initial moisture content of the sample was 63.07% (% of wet weight). In this variant of the test, the composts were not solidified, but just do smoothing. Density of the sample at the end of the test rose to 0.7686 tonnes/m^3, while the moisture content of the sample was not changed. There was no leachate out of the compression cell. The relationship between time and deformation of $Compost_{MD}$ shown in Figure 2.

In the original plan, there are five times of the addition of stress, from an initial stress of 2.05 kPa to achieve a final stress of 10.25 kPa, where the ultimate stress is five times from the initial stress (ASTM D2435), so this design has met the standard addition of the stress (final stress of 10.25 kPa was five times greater than initial stress of 2.05 kPa). However, on $Paper_{HD}$ and $Compost_{MD}$, the addition of stress only up to three and four times (Figures 2). This is because the load plate that nearly hit the caliper, and it is impossible to add more load plate.

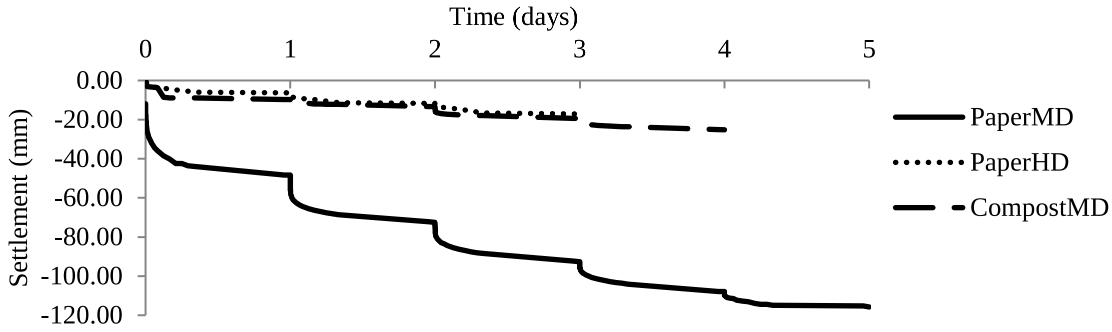

Fig. 2 The trend of the time versus settlement of $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$

3.2. Determination of Immediate Compression Ratio (Cc')

Due to the principles of soil mechanics for saturated soil can not be used for MSW samples which are in unsaturated [4], the detection of ε_{EOI} was done using by first-order rate equation (FORE), which was introduced by [7]. Figure 3 shows a graph of cumulative strain (%) versus time (hours) that is used to detect ε_{EOI} of $Paper_{MD}$ at a stress of 2.05 kPa, which ε_{EOI} detected by 0.11 m/m during the sixth hour. Secondary settlement, settlement mechanism are bound by time, started at this moment, when the graph has a linear decrease with time.

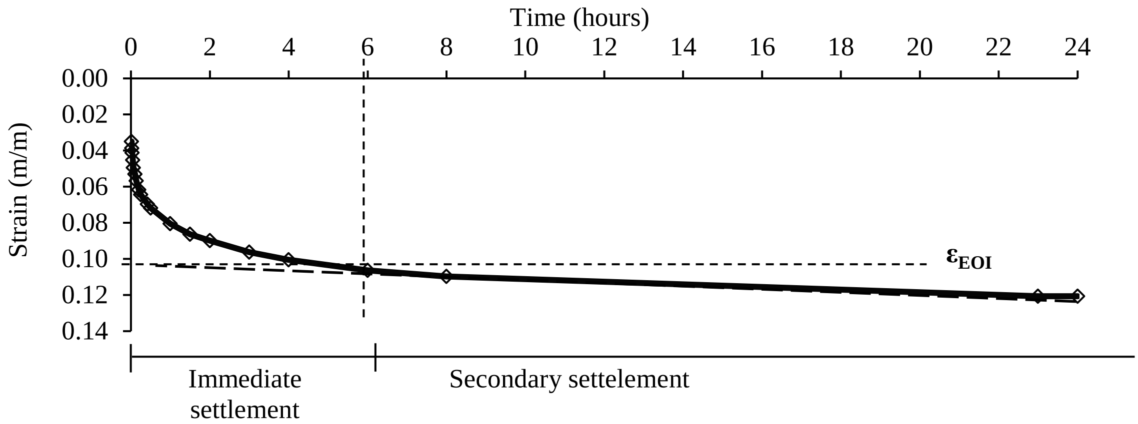

Fig. 3 Determination of ε_{EOI} of $Paper_{MD}$ at a stress of 2.04 kPa.

The detection of ε_{EOI} for $Paper_{MD}$ was done to stress 2.05-, 4.10-, 6.15-, 8.20- and 10.25 kPa, which produced five ε_{EOI} values for $Paper_{MD}$ at five different stress. Then, a linear equation was made by connecting the difference between ε_{EOI} ($\Delta\varepsilon_{EOI}$) and the difference in stress logarithm ($\Delta\log\sigma_v$) of each time the stress adding. The compression ratio (C_c') is the slope of the linear line between $\Delta\varepsilon_{EOI}$ versus $\Delta\log\sigma_v$. On $Paper_{MD}$, obtained a value of C_c' of 0.2949 (Figure 4). The same methodology was done for $Paper_{HD}$ and $Compost_{MD}$, to obtain the results as presented in Table 3.

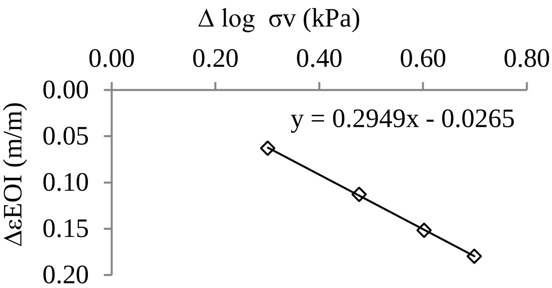

Fig. 4 Determination of C_c' on $Paper_{MD}$.

Table 3 Variations of $C_{c'}$ values of $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$.

Sample Code	Time at ε_{EOI} (hour)	C_c'
$Paper_{MD}$	6	0.2949
$Paper_{HD}$	4	0.0696
$Compost_{MD}$	4	0.0932

3.3. Determination of Secondary Compression Ratio

Secondary compression ratio (C_α) is a parameter that describes the settlement MSW dependent on time, is described by the equation: $\boldsymbol{C_\alpha = \frac{\frac{\Delta H}{H}}{\Delta log t}}$ [11]. $\boldsymbol{\frac{\Delta H}{H}}$ is a strain (settlement per initial high) and t is the time. [3] and [12] use the unit within days to the time parameters in the equation to estimate settlement in landfills. Thus, the value obtained from this study also used days as a unit of time parameters. For example, Figure 5 shows a graph $\frac{\boldsymbol{\Delta H}}{\boldsymbol{H}}$ vs $\Delta logt$, as a results of compression test on a sample of $Paper_{MD}$ at the initial stress (σ_v) of 2.05 kPa. Data were regressed from the time of the end of the immediate compression (ε_{EOI}). C_α is the gradient of the line generated, ie 0.0235. Table 4 presents the variation of the C_α to sample $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$.

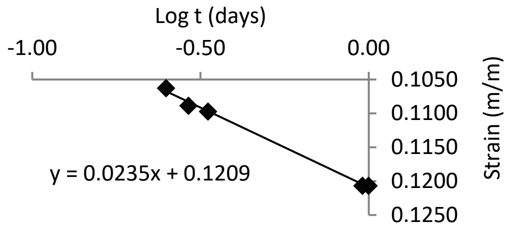

Fig. 5 Determination of C_α of $Paper_{MD}$ at the stress of 2.05 kPa.

Table 4 Value of C_α of $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$

Vertical stress, σ_v (kPa)	C_α		
	$Paper_{MD}$	$Paper_{HD}$	$Compost_{MD}$
2.05	0.0235	0.0055	0.0037
4.10	0.0198	0.0057	0.0055
6.15	0.0213	0.0156	0.0072
8.20	0.0196	*)	0.0074
10.25	0.0045	*)	*)

Note: *) Data not available.

C_α value tends to increase with the increase in vertical stress given. The use of a single C_α value will produce results that are unrealistic in estimating settlement in landfills [13]. C_α given value, must correspond with the leveling in the formation of landfill. [13] mentioned that the compressibility of MSW increases as the depth of MSW (where stress has also increased). However, the results of tests conducted by low addition of stress, the value of C_α seen not correlate with the additional stress exerted, and the single C_α value, which is obtained from the average value, can be used. For the record, the test is done with the addition of stress that is assumed to be the addition of a layer of 0.5 m landfill with MSW density of 0.4 tonnes/m^3.

For $Paper_{MD}$, the value of C_α at 10.25 kPa vertical stress excluded from the calculation of the average, because the R^2 value of the equation that generates the value of the C_α only 0.8070, far below the value of R^2 of equation to produce another C_α (above 0.9900), so the average C_α for $Paper_{MD}$ is 0.0211. For $Paper_{HD}$, taken from the average value of two nearest C_α values, that is equal to 0.0056, where the value C_α on vertical pressure 6.15 kPa are far different than the other two C_α values. For $Compost_{MD}$, taken from the average value of the four values of C_α, that is equal to 0.0060.

3.4. Early Indications of the Correlation between the Compressibility with the Physical – Hydraulic Properties of Waste

3.4.1 The decline in moisture content and compressibility of paper waste

The moisture content in the $Paper_{MD}$ decreased by 4.45% (% of wet weight). Reduction of moisture content showed a reduction of 4,219 ml of water in a compression cell (assuming density of leachate = 1 kg/liter), based on the initial weight and moisture content of the sample was 28.8 kg and 74.09% (% of wet weight). These estimates were in accordance with the water coming out of the compression cell of 4,470 ml. While the moisture content at the $Paper_{HD}$ did not decline (initial moisture content = 72.04%, and the final moisture content = 72.61%, in % of wet weight). However, there was leachate out of 1,990 ml. If it was assumed that there was a subjective fault when taking a sample of the moisture content, the actual moisture content at the end of the test was estimated at 70.65%, where the moisture content of the sample was estimated to be reduced by 1.39% (assuming a density of leachate = 1 kg/liter).

The decrease of moisture content at the $Paper_{MD}$ was higher than $Paper_{HD}$ (3.2 times), demonstrating the ability of $Paper_{MD}$ to drain the water was higher than $Paper_{HD}$. Along with these results, the compressibility of $Paper_{MD}$ was also higher than $Paper_{HD}$ ($Paper_{MD}$ was more compressible than $Paper_{HD}$, see Table 3 and Table 4). $Compost_{MD}$ has compressibility characteristics similar to $Paper_{HD}$, and there is no change in the moisture content. There is no water coming out of the compression cell at the time of this test. Similar observation was found with $Paper_{HD}$, the compression ratio of $Compost_{MD}$ is also much smaller than the $Paper_{MD}$ (see Table 5).

Table 5 Moisture content and compressibility

	$Paper_{MD}$	$Paper_{HD}$	$Compost_{MD}$
Change in moisture content (% of wet weight)	-4.45	-1.39%	0.00%
Immediate compression ratio, Cc’	0.2949	0.0696	0.0932
Secondary compression ratio, Cα	0.0211	0.0056	0.0060

3.4.2 An increase of density and compressibility

The $Paper_{HD}$ tested only up to 6.15 kPa, during 3 x 24 hours. At a stress of 6.15 kPa, $Paper_{MD}$ (initial density = 0.75 tonnes/m^3) decreased by 23.17%, while $Paper_{HD}$ (initial density = 1.09 tonnes/m^3) only fell by 4.29 %, and $Compost_{MD}$ (initial density = 0.72 tonnes/m^3) only fell by 4.86%. This is in accordance with the compressibility of $Paper_{MD}$ that higher than $Paper_{HD}$ and $Compost_{MD}$. The comparison of the initial density, density at the time of stress 6.15 kPa, settlement/strain and compressibility are presented in Table 6. The increase of the bulk density occured on $Paper_{MD}$ and $Compost_{MD}$, each amounting to 20.12% and 6.77% respectively. While on $Paper_{HD}$ with no increase of the bulk density. Changes in the density of the dry weight of the samples, to detect the compaction of the dry matter of the sample, presented in Figure 6 and Figure 7, where the largest settlement and increase in dry density occurred on the $Paper_{MD}$ which has the lowest initial density. The results correspond with the results obtained by [2] which states that MSW with higher (initial) dry density had a smaller compressibility.

Settlement/strain was found more extreme on $Paper_{MD}$ (five times larger than the other samples, see Figure 6), compared to the increasing of the dry density. $Paper_{MD}$ was compacted almost the same with the other samples. Figure 7 shows that the effect of flowing water, out of compression cell may be more dominant than mechanical settlement of solid component of MSW.

Table 6 Density and compressibility

	$Paper_{MD}$	$Paper_{HD}$	$Compost_{MD}$
Strain (at σ_v= 6,15 kPa) %	23.17	4.29	4.86
An increase of density (*bulk*) %	20.12	-0.47 (≈ 0)	6.77
Increase of density (dry) %	26.29	4.09	5.03
Immediate compression ratio, Cc’	0.2949	0.0696	0.0932
Secondary compression ratio, Cα	0.0211	0.0056	0.0060

3.4.3 Composition and compressibility

Compared with other samples prepared under conditions of moderate density ($Paper_{MD}$), strain in $Compost_{MD}$ was much smaller. The strain in $Compost_{MD}$ was similar to settlement on Paper - HD, where the value of the compression ratio of the two samples were almost the same. It is estimated that, compressibility of $Compost_{MD}$ is more like the character of the soil that is more compact. Organic waste that become compost, has finer pore structure and pore size smaller [14].

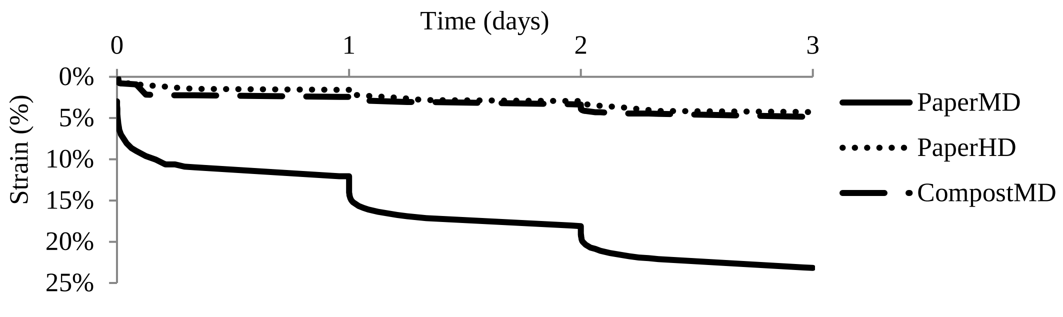

Fig. 6 Settlement on $Paper_{MD}$, $Paper_{HD}$ and $Compost_{MD}$.

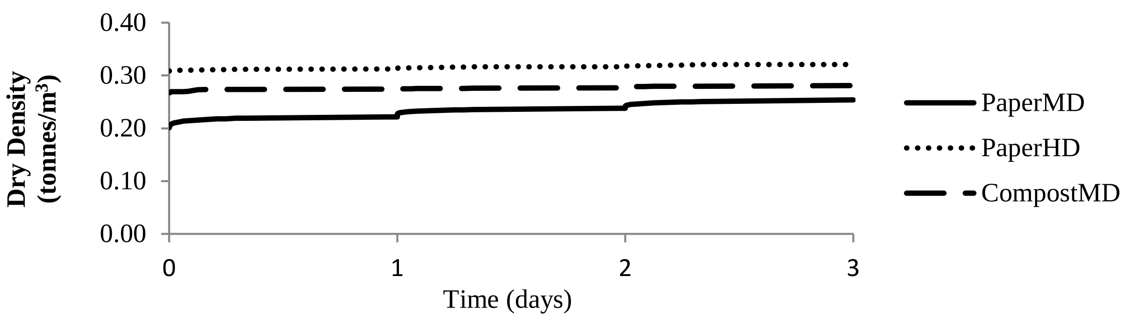

Fig. 7 Changes in dry density of the sample.

4. CONCLUSION

From these research, it can be concluded that paper waste at medium density ($Paper_{MD}$) was the most compressible samples, which have the highest value of the immediate compression ratio (C_c') and the secondary compression ratio (C_α). Meanwhile, compost, although in a state of medium density ($Compost_{MD}$), had a lower compressibility, because it has finer pore structure and has characteristics which was more similar to the soil. The decline of moisture content of $Paper_{MD}$ was greater than the other samples, showed the ability of $Paper_{MD}$ to drain more water than that of $Paper_{HD}$ and $Compost_{MD}$. On the other hand, compressibility of $Paper_{MD}$ was also greater than $Paper_{HD}$ and $Compost_{MD}$, indicated there is a relationship between the ability to drain the water with compressibility of synthetic MSW samples. A significant reduction occurred on $Paper_{MD}$ (5 times larger than the other samples) compared to the addition of the dry density ($Paper_{MD}$ solidified almost almost the same as the other samples), showing that the effect of the flow of water out of the compression cell may be more dominant than mechanical settlement of components solid from the samples. A significant difference of compression ratio between $Paper_{MD}$ and $Compost_{MD}$, each represented the fresh and degraded MSW, illustrated that the compressibility of MSW is strongly related to the age of waste.

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