Mechanical and leaching characteristics of inert waste landfills

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ABSTRACT

The composition of inert waste landfill is important from the geotechnical and geoenvironmental point of view, as the concrete and rock wastes help in increasing the bearing capacity and the fibrous fractions can act as reinforcement to increase the volume of the inert waste landfill. In contrast, the presence of fibrous fractions may cause the storage of water inside the inert waste landfill and there are also some possibilities of presence of toxic and degradable matters in the inert waste materials. In this paper, the results from the field tests such as composition analysis, basic physical properties, angle of repose, CASPOL impact value test and in-situ direct shear test are discussed to evaluate the change in mechanical characteristics and basic physical parameters (in situ density etc.) of inert wastes. Change in the strength parameters are observed with respect to change in different components of the inert waste and age after reclamations. The results show that the density and impact value decrease for increase in fibrous content under 20%. For direct shear test, shear stress increases with increase in high fibrous content. In the laboratory column leaching test, the change in the leachate behavior is observed due to 2% and 10% fibrous content. The water storage and EC are found lower for the column with 10% fibrous content than that of 2% fibrous content. TOC is found higher for 2% fibrous content but the values are found to be within the standard limit.

Keywords: inert waste landfill, mechanical characteristics, laboratory column leaching test

1 INTRODUCTION

Inert wastes such as construction and demolition waste, rock, glass, metals, plastics, woods etc. are being disposed at the inert waste landfills in Japan. According to Yamawaki et al. (2017), presently, there are more than 1000 numbers of inert waste landfills in Japan which follow the design instructions of the municipal solid waste (MSW) landfills in Japan due to the unavailability of design instructions for the inert waste landfills. The MSW design instructions are considered as too conservative for the inert waste landfills, because the composition of the inert waste landfills is different than the municipal solid waste. Inert waste materials are important from geotechnical point of view (Monier et al., 2011); the concrete, rock etc. help increasing the bearing capacity of the landfill and the fibrous fractions can act as a reinforcement by providing tensile resistance to the landfill (Koelsch, 2009; Zekkos et al., 2010 and Takai et al., 2017). Although inert waste should contain chemically inert materials, still there are some possibilities of presence of biodegradable materials (Morotomi et al., 2018) or contaminants in the inert waste and there is a possibility of storage of leachate by the fibrous fractions inside the inert waste landfill, thus enhancing the risk of contamination. Considering these issues, in this paper, the mechanical and leaching characteristics of the inert waste materials are discussed. To know the mechanical characteristics, field tests are conducted at 14 locations in Kanto (A), Tohoku (B), Chubu (C) and Chiba (D) landfills in Japan. For these locations, the ages after reclamation vary from 0 to 19 years. For the mechanical testes, the variation in strength parameters and in basic physical parameters (such as density, percentage air voids etc.) with respect to different components of the inert waste and age after reclamation are discussed. The mechanical characteristics of inert waste are important to discuss the future possibility of increasing the volume by increasing the slope of the landfill. For the leaching test, laboratory columns are selected because we can simulate the field conditions in column tests (Naka et al. 2016) and it is easier to control the test environment (Kosson et al., 2014). For laboratory column test, two columns are prepared with inert waste (≤5 cm) collected from Chiba landfill by adjusting 2%
and 10% fibrous content in the inert waste. Moisture sensors are installed inside the column to check water storage due to variation in fibrous content. The presence of organic contents or contaminants due to variation in fibrous contents are checked. The relevant findings are useful to design safer and steeper inert waste landfills.

2 METHODOLOGY

2.1 Field tests
Composition analysis is conducted and basic physical parameters such as in situ density, percentage air voids etc. are measured at the 14 locations of the four landfills. To know the mechanical parameters, CASPOL impact value test, repose angle and direct shear test are also conducted at those locations. Figure 1 shows some field tests conducted at the 14 locations in the four inert waste landfills in Japan.

![Field tests conducted in the inert waste landfills in Japan](image)

Fig. 1. Field tests conducted in the inert waste landfills in Japan.

The composition analysis is important because it gives us the idea about the ratio of different materials present in the waste which in turn may have significant effect in the strength characterization. For the composition analysis, the inert waste materials are divided into three main components as soil-like material (≤20 mm), granular materials (>20 mm) and fibrous waste materials (>20 mm). Granular materials are again manually subdivided as rocks and glass & pottery. In fibrous materials, two sub divisions are plastic and other fibrous fractions. To determine the in-situ density, the water replacement method is used. For percentage air voids test, the cut-out waste is placed in a water filled container and water level increment is measured. The details of the procedures for these tests are explained in Yamawaki et al. (2017). The relationship between mechanical characteristics of the waste materials and the basic parameters can be considered for a better reclamation method.

The CASPOL impact test is a quick test which indicates the bearing capacity of the waste ground. In this test, the CASPOL instrument developed by the Kinki Construction Engineering Office (1996) is used. The instrument is first properly levelled in the ground and then a rammer of diameter 50 mm and mass 4.5 kg is dropped from a height of 45 cm from the ground surface. The accelerometer attached to the rammer measures the impact acceleration value. The maximum value of impact acceleration is considered as impact value (I). Repose angle test is performed to determine the repose angle which is related to the slope stability of the waste layers. To measure the angle of repose, inert waste is first excavated from the landfill and then a heap is made using a backhoe. When the maximum slope angle of the heap exceeds, then an avalanche occurs. The slope angle of the heap after avalanche is taken as the repose angle.

For in situ direct shear test, a large sized direct shear test apparatus developed by Omine et al. (2014) is used. First, a specimen with dimensions of 30 cm × 30 cm × 15 cm is cut out from the solid waste deposit in such a way that the bottom part of the specimen is still connected to the waste landfill and undisturbed. Fibrous materials on the sides of the block specimen are cut by a grinder. After shaping, the shear box of the in situ direct shear test apparatus is fitted around the specimen. The shear box and specimen both have the same size. After fixing the direct shear test apparatus, the specimens are sheared with a shearing rate of 1.0 mm/min under three vertical stress of 0.96 and 20.8 kN/m². In case of no clear peak strength, the strength at a horizontal displacement of 35 mm is used to calculate the shear parameters.

2.2 Laboratory column leaching tests

![Laboratory column leaching test](image)

Fig. 2. Laboratory column leaching test.
The laboratory column leaching test is conducted to check the water storage and possibility of presence of contamination in leachate due to variation in fibrous content. Figure 2 shows the diagram for the laboratory column leaching test.

For this test, two columns with fibrous content of 2% and 10% are prepared. The inert waste materials for the columns are collected from location D1 in Chiba landfill. The columns are having a diameter of 30 cm and a height of 100 cm. First the fibrous fractions are separated from the inert waste. The waste materials are then sieved with a 5 cm × 5 cm size sieve because of the size restriction of the columns. After sieving, waste materials are thoroughly mixed to confirm the reproducibility in both the columns. After mixing, two samples are prepared by adding fibrous fractions of 2% and 10% with size ≤ 5 cm to the mixer of inert wastes. The two columns are then filled with the two samples in 4 numbers of layers with equal compaction energy. To check the water storage, moisture sensors are installed at two points of 25 cm and 55 cm from the top waste layers for both the columns. Thermometers are also installed at the same points to check the temperature variation. As in the landfills, where we use soil layers for reclamation, in these columns, an additional soil layer of 10 cm at the bottoms of the columns are provided to make the leachate quality better. The soil layer is made of with decomposed granite soil sieved with size 2 mm. The design parameters for laboratory column leaching test are shown in Table 1.

Table 1. Design parameters for laboratory columns.

| Parameters       | Column 1  | Column 2 |
|------------------|-----------|----------|
| Waste fibrous content | 2%        | 10%      |
| Soil layer       | 10 cm     | 10 cm    |
| Waste density    | 1.38 g/cm³| 0.92 g/cm³|
| Soil density     | 1.88 g/cm³| 1.88 g/cm³|
| Rainfall         | 1530 mm/year | 1530 mm/year |

Water is applied on the top of the column and quantity of the water is taken as the average annual rainfall in Japan (1530 mm). Leachates are collected at the bottom of the column and analyzed for pH, EC, Eh, total organic carbon (TOC) and other ions and metals. Total Organic Carbon Analyzer (TOC-5050A) is used to measure the total organic carbon in the leachate. To measure the ions and metals in the leachate, ICP-OES series 700 and Atomic Absorption Spectrophotometer (AA-6800) are used.

3 FIELD TEST RESULTS

For the field tests, the results from the composition analysis, basic physical parameters and the variation of mechanical parameters with respect to the fibrous content are discussed in this paper.

3.1 Composition and density

The compositions of all the locations and their average are shown in Fig. 3. Wide variety in composition are found for three main components which are: fibrous content (>20 mm) with a range of 3.6 to 54%, granular content (>20 mm) 13 to 45% and soil content (≤20 mm) 43 to 74%. Among all the components, the fibrous content is found as the lowest with an average value of 16%. The inert waste materials contain significant amount of soil contents with an average value of 59% which is the maximum among all the three components. There is one exception at B3 location, where no soil component is found. The average granular content is found as 25%.

![Fig. 3. Compositions at the 14 locations of inert waste landfill.](image)

The density of the waste for the 14 locations varied from 1.08 to 1.79 g/cm³. With increase in fibrous content up to 30%, the density decreases. The decrease in density with increase in fibrous content is may be due to two reasons. Firstly, for the same volume, particle density of fibrous content is lower than the granular or soil content and this low particle density makes the waste density lower. Secondly, the presence of fibrous content restricts the compaction of the waste thus decreases the density. Figure 4 shows the change in density with increase in fibrous content.

![Fig. 4. Change in density with increase in fibrous content.](image)
3.2 Impact value and repose angle

Figure 5 shows the change in impact value with increase in fibrous content. Impact value decreases with increase in fibrous content below 20%. It is confirmed that for lower fibrous content, density is higher and bearing capacity becomes more. Impact value is lower for older landfills. Decomposition of biodegradable waste and water penetration through the landfill with time are considered to be the reason for the lower impact value in older inert waste landfills. Therefore, new landfills with less fibrous content are having better bearing capacity.

![Fig. 5. Change in impact value with respect to fibrous content.](image)

In case of repose angle, with increase in fibrous content, repose angle first increase and then decreases. Maximum repose angle is found with around 10-20% fibrous content. With increase in fibrous content, the heap of the repose angle become loosen. Therefore, the slope angle after avalanche or repose angle is lower. Repose angle is found higher for older landfills. The decomposition of older waste and higher water content which gives more binding effect is considered to be the reason for higher value of repose angle. Figure 6 demonstrates the change in repose angle with increase in fibrous content.

3.3 Direct shear test

The direct shear tests were not successful at all the locations. The results of the successful tests are taken to calculate the c values and \( \phi \) values of the locations. Figure 7 shows the shear stress vs horizontal displacement in direct shear test. The shear stress increases with increase in normal stress. Shear stress values are also found higher for high fibrous content. For high fibrous content, when we apply a higher normal stress, the shear stress keeps increasing without showing a clear peak value. The change in shear stress with respect to normal stress is shown in Fig. 8. From the data, the average shear stresses with respect to the normal stresses are plotted and the trend line is drawn. Finally, the average cohesion is calculated as 12 kN/m² and the average internal angle of friction is calculated as 45.47° for these six locations of inert waste landfills.

![Fig. 7. Shear stress vs horizontal displacement in direct shear test.](image)

![Fig. 8. Change in shear stress with respect to normal stress.](image)
4 COLUMN LEACHING TEST RESULTS

In the laboratory column leaching test, the change in the leachate behavior is observed due to 2% fibrous content and 10% fibrous content in the waste materials. The storage of water and some parameters related to leachate quality are discussed in this paper.

4.1 Storage of water

The water storage inside the column is checked by moisture sensors. Figure 9 demonstrates the change in volumetric water contents with change in time for the columns with 2% fibrous content and 10% fibrous content. The water storage is lesser for the column with higher fibrous content (10%). The high fibrous content makes the density of the waste material lower inside the column. There are more voids which are connected to each other thus making the flow of water faster and more. The water storage above the fibers is considered to be less due to the small size of the fibrous fractions (5 cm x 5 cm).

![Volumetric Water Content Graph](image)

**Fig. 9.** Change in volumetric water contents with change in time.

4.2 Leachate quality

The leachate collected below the soil layer is analyzed for pH, electrical conductivity (EC), redox potential (Eh), total organic carbon (TOC), ions and other metals. The leachate is slightly alkaline in nature with pH range up to 7.8. The waste is found as moderately reduced with Eh range of 300-400 mV. Figure 10 shows the change in electrical conductivity (EC) with increase in L/S ratio. From the graph, we can see that at first, the EC for the column with 2% fibrous content is higher than EC of 10% fibrous content. In case of 10% fibrous content, due to the less density of the waste material, the flow is higher making the water contact time lesser. Therefore, the leachate from 10% fibrous content column contains lesser ions. When L/S ratio is greater than 1.12, the EC of leachate for column with 2% fibrous content becomes lower than 10% fibrous content. Due to longer contact time of water with the waste, for 2% fibrous content, the ions present in the waste materials are precipitated or absorbed at the soil layer. Whether in case of 10% fibrous content, the ions do not get much time to have sorption in the soil layer or to get precipitated due to the high flow rate of water and less water contact time.

![EC Graph](image)

**Fig. 10.** Change in EC with increase in L/S ratio.

Figure 11 shows the change in TOC with L/S ratio for column with 2% fibrous content and for column with 10% fibrous content. Although the TOC confirms the presence of biodegradable material in the inert waste, the limit of TOC is found to be far lower than the standard limit. From the graph, it can be observed that at first, the TOC for the column with high fibrous content (10%) is lesser than the TOC from the column with less fibrous content (2%). It means, the waste materials other than fibrous fractions contains more biodegradable materials. The high flow rate and less contact time of water are other reasons of lesser TOC value in case of higher fibrous content (10%).

![TOC Graph](image)

**Fig. 11.** Change in TOC with increase in L/S ratio.
5 CONCLUSIONS

In this paper, field tests such as composition analysis, basic physical properties, angle of repose, CASPOL impact acceleration test and in-situ direct shear test are conducted to evaluate the mechanical characteristics of inert waste landfills in Japan. In the composition analysis, wide variety in composition are found for three main components which are: fibrous content (>20 mm) with a range of 3.6 to 54%, granular content (>20 mm) 13 to 45% and soil content (≤20 mm) 43 to 74%. Density and impact value decrease with increase in fibrous content up to 20%. Repose angle are found higher for older landfills. The decomposition of older waste and higher water content which gives more binding effect are considered to be the reason for the increase in the repose angle. Maximum repose angle is found at around 10-20% fibrous content. For direct shear test, shear stress increases with increase in normal stress. Shear stress values are also found higher for high fibrous content.

Laboratory column leaching tests are also conducted with columns having 2% and 10% fibrous content to know leaching characteristics of inert waste landfills due to variation in fibrous content. The water storage and EC are lower for the column with 10% fibrous content than that of 2% fibrous content. The presence of organic matters is confirmed from the TOC test but the value is found to be within the standard limit. From the leaching test, it is confirmed that the higher fibrous content in the waste materials does not store leachate if they are smaller in size. Moreover, the TOC and other contaminant etc. are also lesser in case of high fibrous inert waste materials. With high fibrous content, the density becomes lower which makes the flow rate higher and water contact time lesser.

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