Some Laboratory Scale Tests on An Australian Coal Tailings Sample

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ABSTRACT

As a country with rich mineral resources, Australia, is amongst the top five world’s leading exporter of minerals. As such, coal tailings, one of the by-products of mineral exploration, pose ample challenge for its handling, management and disposal in tailings dams. These usually are encountered with high moisture content. In order to avert the risk of fluidization and associated failures of coal tailing dams, dewatering is necessary to be applied for reducing their water content. With this in mind, some laboratory experiments based on a local coal tailings sample has been presented in this manuscript. The coal tailing sample has been characterized by conducting the liquid limit test, plastic limit test and shrinkage limit test. Sieve analysis and hydrometer test have been conducted to establish the gradational property of the material. Modified compaction test and one-dimension consolidation test have been performed and the load-deformation response of the material is described in detail. Also, the vane shear test has been conducted to figure out the relationship between gravimetric moisture content and shear strength. Furthermore, hydraulic and volume change response of the sample subjected to changing moisture content have been studied through soil-water retention curve (SWRC) and soil shrinkage characteristic curve (SSCC).

Keywords: coal tailings, dewatering, characterization, load, deformation, shear strength, SWRC, SCC

1 INTRODUCTION

As a country with rich mineral resources, Australia, is amongst the top five world’s leading producer of minerals (Roarty 2010). Eastern states have a large number of coal mines and western states have a number of gold, nickel, and iron ore mines (Basu and Baafi 1999). Since 2005, mining investment has increased from 12.5% to 25% and mining is more capital intensive than other industries in Australia (Jonathan and Philip 2011). Furthermore, mining in Australia is a key component of the economy. Mining Technology Services (MTS) sector contributed AU$3120 million to Australia’s gross domestic product in 2000-2001 and AU$1.9 billion in 2005-2006 (Martinez-Fernandez 2010). Since during extraction and processing of minerals, such as alumina, ilmenite and zircon, by-products are generated that need to be handled. All Australian coal for export is washed, coarse rejects and coal tailings are produced at the washery site (Duffy et al. 1981).

As a consequence, coal tailings are produced in this washing process to meet the market specifications, such as reduction of ash content (Shokouhi and Williams 2017). The coal tailings are usually high in water content, which results in lower shear strength and capacity of the material. Coal tailings with high moisture contents may liquefy leading to tailings dam failure (Jeyapalan et al. 1983).

To dewater the coal tailings, three conventional methods, vacuum consolidation, electrokinetic treatment and wick drain with surcharge, are widely used (Alam et al. 2011). In order to fully understand the dewatering efficiency of a local coal tailings sample, the present paper pertains to the characterisation and evaluation of mechanical, hydraulic and volume change behaviour of the material under changing moisture content.

2 CHARACTERIZATIONS OF MATERIAL

The coal tailings used in these tests were collected from Jeebropilly Coal Mine which is in the Ipswich Coalfields, south-eastern Queensland, Australia.

The liquid limit and plastic limit tests have been conducted as per ASTM D4318 (2010). When water content of the soil decreases, at plastic limit it gains about 100 times shear strength than that at the liquid
limit (Mishra et al. 2018a). For the specific gravity test, the sample was sieved through a 425μm sieve and oven dried for 24 hours. Helium gas displacement pycnometry method was used for this test (Mishra et al. 2018b). Table 1 presents the results of these characterizations.

Table 1. Characterizations of coal tailings.

| Identifications             | Result          |
|-----------------------------|-----------------|
| Liquid limit (LL)           | 39.8 %          |
| Plastic limit (PL)          | 25.5 %          |
| Specific gravity (G)        | 1.796           |

The particle size distribution test has been completed according to ASTM D422 (2007). Sample preparation was done by wet sieving to prepare the sample in a fraction for the hydrometer test and conventional sieving analyze. The coarser material fraction (greater than 75μm) was dried (60°C) for at least 24 hours before sieving. Figure 1 presents the particle size distribution curve obtained for the hydrometer test and sieve analysis. It is observed that the coal tailings are rich in sand-size material.

![Particle size distribution curves of coal tailings.](image)

From the result above, $D_{10}=0.008\text{mm}$, $D_{30}=0.11\text{mm}$ and $D_{60}=0.32\text{mm}$ for the sample. Coefficient of uniformity, $Cu$, and coefficient of curvature, $Cc$, are 40 and 4.73, respectively. Hence, the classification of coal tailings is clayey sand.

3 MECHANICAL BEHAVIOR

3.1 Compaction test

For the individual test, all samples have been prepared in the same way to ensure comparability of the results. The sample was oven dried (60°C) for at least 24 hours and passed through a 4.75mm sieve, before mixing it uniformly with deionized water at different moisture content for several groups. Each group of soil was compacted in a 1000 cm$^3$ compaction mould for 5 layers and 25 drops of the hammer were applied on each layer. This test was performed in accordance with ASTM D1557 (2012).

![Modified compaction curve for coal tailings.](image)

Figure 2 shows the relation between water content and dry density. The optimum moisture content is 21% and the maximum dry density is 1.03g/cm$^3$.

3.2 One-dimensional consolidation test

One-dimensional consolidation test was performed in accordance with ASTM D2435 (2011).

The sample used in this test was oven dried (60°C) and mixed with deionized water to reach 60% moisture content. To maintain the full saturation of the sample in the specimen ring, it was necessary to keep the sample free of air bubble by shaking and tapping the ring when filling the sample. Two porous disks were placed on the top and bottom of the sample respectively for drainage. Furthermore, the sample was submerged underwater during the whole test to keep it fully saturated. Table 2 presents the parameters for the specimen before the test.

Table 2. The parameters of specimen.

| Parameters                          | Value          |
|-------------------------------------|----------------|
| Sample diameter                     | 7.5 cm         |
| Sample height                       | 2.0 cm         |
| Sample weight                       | 113.59 g       |
| Sample cross section area           | 44.18 cm$^2$   |
| Assumed sample moisture content     | 58.5 %         |
| Actual sample moisture content      | 58.12 %        |

The vertical load on the specimen was doubled after the settlement of the specimen attained a constant value under a specific load. The loads applied on the sample was 10kPa, 20kPa, 40kPa, 80kPa, 160kPa, 320kPa and 640kPa. From Figure 3, it can be observed that the void ratio decreases while increasing the load on top of the specimen. At the beginning of the test, the void ratio was 0.895, however, after the final load applied on the specimen, the void ratio reached 0.705. And the average value for the coefficient of consolidation was 55.75 m$^2$/year in the range from 10kPa to 640kPa. In Figure 4, it can be detected that the trend line of the hydraulic conductivity of coal tailings was decreasing when the vertical effective stress kept increased. Initially, it was 2.5E-10m/s at 20kPa, and finally it dropped to nearly 0m/s at 640kPa.
3.3 Vane shear test

Before conducting vane shear test, the sample needs to be placed in the oven for drying (60°C) at least 24 hours. The samples were mixed with deionized water to achieve the following gravimetric moisture contents: 18%, 22%, 26%, 32%, 36%, 42% and 45%.

The test was performed in a cylindrical mould (6.5 cm diameter and 4.2 cm height) using a motorized vane shear test machine with a four-bladed vane (12.7mm diameter and 25.4mm length). This test was performed employing ASTM D4648 (2010).

Figure 5 presents the relationship between peak undrained shear strength ($S_u$) and moisture content. A trend line represents the associated relationship with the following equation:

$$S_u = 137.3 \times e^{-0.063w}$$

(1)

4 HYDRAULIC BEHAVIOR

SWRC test was performed by using a Fredlund SWCC Device (Figure 6). The initial gravimetric water content of the sample used in this test was 60% and initial bulk density of the sample was 1.5g/cm$^3$. When placing the sample into the mould of device, it is important to make sure that no leakage between each pipe connections and valves. When applying the pressure, some water would escape from the sample into drainage tubes. Water level in the drainage tubes was recorded once a day and pressure was increased when the drainage tube readings did not change for 24 hours. The set of incremental pressure applied were: 10kPa, 20kPa, 40kPa, 80kPa, 160kPa, 320kPa and 500kPa.

The relationship curve between soil suction and water content can be predicted by fitting with the Fredlund and Xing equation (Fredlund and Xing 1994). The equation and graph (Figure 7) for this fit is
presented below:

\[
w(\psi) = \left[ 1 - \frac{\ln \left( 1 + \frac{\psi}{\psi_r} \right)}{\ln \left( 1 + \frac{10^{\text{e}}}{\psi_r} \right)} \right] \left[ \frac{w_s}{\ln \left( e + \left( \frac{\psi}{\psi_r} \right)^m \right)} \right]
\]

(2)

where:

- \( \psi \) = total soil suction (kPa)
- \( \psi_r \) = total suction corresponding to the residual water content, 266.53 kPa
- \( e \) = natural number
- \( a_f \) = a soil parameter which is related to the air entry value of the soil, 8.4483 kPa
- \( n_f \) = a soil parameter that controls the slope at the inflection point in the soil-water characteristic curve, 0.9645
- \( m_f \) = a soil parameter that is related to the residual water content of the soil, 0.8638
- \( w_s \) = gravimetric water content at saturation, 0.60

\[ (\psi)^6 + \ln(\psi) - 1 = 0 \]

5 VOLUME CHANGE BEHAVIOR

Shrinkage test is performed to figure out the connection between gravimetric moisture content and void ratio of the sample undergoing evaporative dewatering (Mishra et al. 2018c,d).

The sample used in this test has been dried in an oven (60°C) for at least 24 hours and mixed with deionized water to achieve 60% of gravimetric water content.

Before filling the sample into the ring, coating with vaseline was necessary to ensure uniform shrinkage. When filling the sample, shaking and tapping was helpful to release air bubbles from the sample. After preparation, the sample was evaporatively dewatered in laboratory conditions for 10 days with intermittent measurement of the volume and weight of the sample twice a day. Figure 8 shows the top view of the sample before and after the test.

Figure 9 presents the result of the relationship between void ratio and water content under the impact of evaporation. Initially, the void ratio was around 0.85 and it decreased gradually to about 0.7 at the end of the test. Additionally, when gravimetric water content decreased to 14%, there is no more volume change taking place with further drying. Therefore, the shrinkage limit can be identified as 14%.

6 CONCLUSIONS

The presented observations above focused on the characterization of the mechanical and hydraulic behavior of a coal tailings sample from the Jeebropilly Coal Mine, Australia. Although rich in the sand fraction, the coal tailings sample shows distinct changes in void
ratio, suction and undrained shear strength with changing moisture content. The gain in shear strength with reducing moisture content is a manifestation of the content of fines in the soil. It needs to be evaluated and analyzed to which degree the saturation and how the influence of section plays a role here. Although, the content of coarse fraction is relatively high, the compaction due to desiccation is similar to the compaction due to consolidation using a load of 640kPa. The results of this study highlight the potential of evaporative methods for compacting soils.

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