

SOIL WATER RETENTION CURVE OF A COMPACTED IRON ORE TAILING OBTAINED BY VARIOUS METHODS.

CURVA DE RETENÇÃO DE ÁGUA NO SOLO DE UM REJEITO DE MINÉRIO DE FERRO COMPACTADO OBTIDO POR DIVERSOS MÉTODOS

Michelli H. de Jesus

Department of Sedimentary and Environmental Geology, MSc Student at Institute of Geoscience, Brazil, [Presenter's email address]

João Paulo de S. Silva

Mineral Development Centre, Engineer at VALE S.A, Brazil.

Fernando A. M. Marinho

Department of Sedimentary and Environmental Geology, Associate professor at University of São Paulo, Brazil

ABSTRACT: With the current trend of depositing mining tailings in compacted stacks, the material's initial condition is unsaturated and must predominantly remain in this state. To assess its actual mechanical and hydraulic behavior, flow studies are essential for evaluating the medium- and long-term stability of these tailings' embankments. These studies not only allow for the assessment of saturation levels but also aid in the placement of monitoring systems. The soil water retention curve (SWRC) of compacted tailings is a crucial property for these investigations. Based on the unified classification, these mining tailings are categorized as sandy silt and are non-plastic. This study aims to present the drying path of the soil water retention curve (SWRC) for this iron ore tailing obtained from the flotation process. The SWRC was determined using various methods, including filter paper, suction plate, pressure plate, and WP4C, with specimens prepared under different compaction conditions. The limitations of these methodologies will be discussed. The results indicate that the SWRC definitions obtained through the employed methods are similar. However, it is important to exercise caution in both the filter paper method and WP4C regarding the chosen methodology and the measured suction levels.

KEYWORDS: Tailing, Soil water retention curve, unsaturated, suction

1 INTRODUCTION.

The iron ore tailings are a material resulting from the iron ore beneficiation process, composed of minerals still without economic value. The increasing global demand for mineral goods leads to a rise in mineral production and, consequently, a significant increase in tailings production. Currently, the mining industry is seeking to develop new technologies and techniques for the disposal of this material, ensuring safety and reducing environmental impacts. Stacking of filtered material and dams are the most common structures for tailings disposal.

In recent years, environmental disasters resulting from dam failures have marked society at large, causing environmental and economic damage and loss of human lives (e.g., Santamarina, 1919). In this scenario, it has become necessary to more thoroughly understand the hydraulic behavior of tailings subjected to the effects of the weather. Therefore, interpreting the behavior of tailings in their unsaturated condition is important, especially for a primary prediction of the hydraulic behavior of the material.

The Soil Water Retention Curve (SWRC) is used for predicting parameters and behavior of unsaturated soils. The soil water retention curve is represented by the relationship between amount of water (gravimetric water content, volumetric water content,

and/or saturation degree) and suction (total, matric, or osmotic). Several studies show that the SWRC is influenced by structure, texture, aggregation, soil type, mineralogy, void ratios, stress history, and compaction method, as well as the material's grain size distribution (e.g., Fredlund & Xing, 1994, Vanapalli et al., 2001, among others).

Currently, studies on the behavior of mining tailings and even ores require characterizing the hydraulic properties of tailings in the unsaturated condition. Literature provides SWRC data on ore tailings and sterile (waste rock) materials (e.g., Veyera and Martin, 1983; Swanson and Barbour, 1991; Aubertin et al., 1998; Swanson et al., 1999; Qiu & Sego, 2001; Satyanaga et al., 2021; Bella, 2021, 2023). These authors confirm the variables that affect the shape of the SWRC. Additionally, soil structure disturbance also alters water retention in the soil (Cronley & Coleman, 1954; Young & Dixon, 1966; Unger, 1975; Klute, 1982; Unger & Cassel, 1991; Tuli et al., 2005). According to Cronley & Coleman (1954), the SWRC of undisturbed and disturbed samples have an intersection point marking an increase or reduction in suction at the failure. This aspect will not be addressed in this paper.

Given the importance of the water retention curve, it is necessary to pay particular attention to the methods used for suction determination. This study has two objectives: To ascertain

the SWRC of statically compacted iron ore tailings under various compaction conditions and to assess the synergy of four methods for applying and measuring suction.

2 MATERIALS AND METHODS

2.1 The iron ore tailing

The study was conducted on iron ore flotation tailings from the *Quadrilátero Ferrífero* of Minas Gerais state, Brazil. Mineralogical characterization was performed through X-ray diffraction analysis (XRD). The tailings are predominantly composed of quartz and hematite, with 89.1% of their total composition being quartz. The dry unit weight of the material is 3.34.

From a granulometric perspective, the material is classified as silt (80%), with approximately 13% fine sand and 3% clay-sized

particles. The material exhibits non-plastic behavior. Figure 1 shows the compaction curve (Proctor standard energy) and the initial compaction conditions of the tested specimens. The values for maximum dry density and optimum water content were 2.015 g/cm³ and 11.9%, respectively. The specimens numbered 1 to 40 were all statically compacted. Table 1 presents the initial characteristics of each specimen and the experimental methods used. All specimens, except those for the WP4-C method, were placed on the suction plate for capillary saturation. It can be observed that the degree of saturation at the optimum point is around 60%, and the curve is quite flattened. The compaction of the specimens aimed to achieve compaction degrees of 90, 100, 105, and 110% for different water contents. As observed in Figure 1, the densities showed variations concerning the target, but this does not compromise the analysis because the goal is to evaluate variations in the methods and position related to the compaction curve.

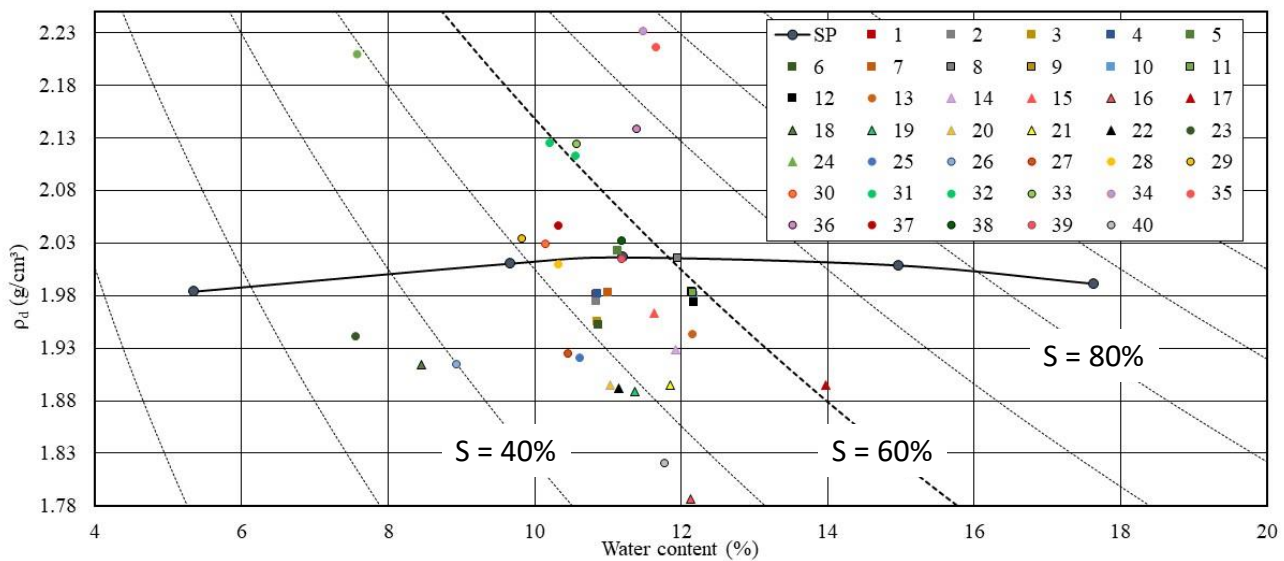


Figure 1. Compaction curve and position of compacted specimens.

The determination of points on the water retention curve was carried out using the following methods: suction plate (PS), pressure plate (PP), filter paper (FP), and dew point method (WP4C). The curve was obtained during the drying trajectory by evaporation of the specimens at room temperature (approximately 21°C). The techniques used to obtain the water retention curve of the material are described below.

2.2 Experimental Techniques

2.2.1 Suction plate and pressure plate

The suction plate, also known as the Haines funnel, is a method of inducing suction ranging from 0 to 70 kPa. However, for practical reasons, suctions up to 30 kPa are applied. This method is crucial for defining the SWRC in the initial range, playing a

significant role in the overall interpretation of the material's behavior.

The pressure plate employs the axis translation technique (e.g., Marinho et al., 2009). The technique induces an increase in air pressure, which is no longer atmospheric, as in the suction plate test, and simultaneously controls or measures the water pore pressure.

In this study, the suction plate was used to define the initial range from 0 to 25 kPa, and the pressure plate induced matrix suction from 25 to 500 kPa. Specimens for these methodologies were molded using a PVC mold with a diameter of 37 mm and a height of 20.3 mm. They were shaped by a custom-made wooden tamper and statically compacted using a manual press. For both methods, variations in the water quantity were continuously imposed, and the water content and degree of saturation were determined at the end after drying in an oven.

Table 1. Initial conditions of the specimens tested.

Specimen	ρ_{di} g/cm ³	w_i %	S_i %	DC %	e_i	Method
1	1.981	10.8	52.4	98	0.69	SP
2	1.975	10.8	52.1	98	0.69	SP
3	1.955	10.9	51.3	97	0.71	SP.
4	1.981	10.9	52.9	98	0.69	SP
5	2.023	11.1	56.8	100	0.65	SP.
6	1.951	10.9	51.0	97	0.72	SP/PP.
7	1.983	11.0	53.5	98	0.69	SP/PP.
8	2.015	12.0	60.8	100	0.66	SP.
9	1.984	12.1	59.0	98	0.69	SP.
10	1.980	12.2	59.2	98	0.69	SP.
11	1.983	12.2	59.4	98	0.69	SP.
12	1.973	12.2	58.7	98	0.70	SP.
13	1.943	12.2	56.5	96	0.72	SP.
14	1.929	11.9	54.2	96	0.73	SP/FP.
15	1.963	11.6	55.1	97	0.70	SP/FP.
16	1.786	12.1	46.3	89	0.87	SP/FP.
17	1.895	14.0	61.2	94	0.77	SP/FP.
18	1.914	8.5	38.0	95	0.75	SP/FP.
19	1.889	11.4	49.4	94	0.77	FP.
20	1.894	11.0	48.0	94	0.77	FP.
21	1.895	11.8	51.6	94	0.77	FP.
22	1.891	11.2	48.7	94	0.77	FP.
23	1.941	7.6	35.1	96	0.72	FP.
24	2.209	7.6	49.4	110	0.51	FP.
25	1.920	10.6	47.7	95	0.74	WP4C
26	1.914	8.9	39.8	95	0.75	WP4C
27	1.925	10.5	47.6	96	0.74	WP4C
28	2.009	10.3	51.8	100	0.67	WP4C
29	2.034	9.8	50.8	101	0.65	WP4C
30	2.028	10.1	52.0	101	0.65	WP4C
31	2.124	10.2	59.3	105	0.58	WP4C
32	2.112	10.6	60.7	105	0.58	WP4C
33	2.123	10.6	61.6	105	0.58	WP4C
34	2.230	11.5	76.9	111	0.50	WP4C
35	2.216	11.7	76.8	110	0.51	WP4C
36	2.138	11.4	67.5	106	0.57	WP4C
37	2.046	10.3	54.2	102	0.64	WP4C
38	2.032	11.2	57.9	101	0.65	WP4C
39	2.015	11.2	56.7	100	0.66	WP4C
40	1.820	11.8	47.1	90	0.84	WP4C

SP – Suction Plate; PP – Pressure Plate; FP – Filter Paper; WP4C – Dew point method. DC – Degree of Compaction

For a better visualization of the initial conditions of the specimens, the values of void ratio, gravimetric water content, and degree of saturation are presented in Figure 2.

2.2.2 Filter paper

The technique involves the use of calibrated Whatman 42 filter papers for quantifying the matric and/or total suction of the soil. For this study, matric suction was measured by placing the filter paper in contact with the water from the specimen (e.g., Chandler et al., 1992; Marinho & Oliveira, 2006; Marinho et al., 2015). The suction was determined using calibration curves presented by Chandler et al., 1992. The equilibrium time used was 7 days, as suggested by Marinho & Oliveira, 2006.

For this method, specimens were statically molded using a manual press in a tripartite steel mold with a diameter of 38 mm and a height of 80.5 mm, in three successive layers.

In the case of the iron ore tailings used, it was necessary to use a protective filter paper as an intermediary between the Whatman

42 filter paper and the specimen. Contamination of the measurement paper significantly alters the readings. After each measurement, the specimens were air-dried until suctions reached approximately 20,000 kPa.

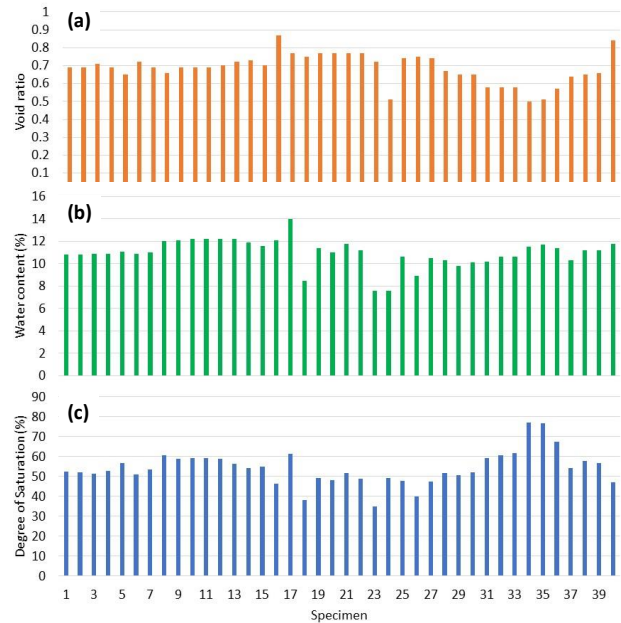


Figure 2. Initial compacted condition of the tested specimens.

2.2.3 WP4C

The WP4C is an equipment that determines the dew point and, through correlations with the air's relative humidity in the same specimen environment, allows inference of suction using thermodynamic correlations. Manufactured and marketed by Meter Group Inc., the equipment determines the total suction of the soil. The operating principle can be found in ASTM D6836 (2006). It is important to note that the total suction value is the same as the matric suction for materials that do not have osmotic suction, as is the case with the present material.

According to the manufacturer, the equipment can measure suctions from 0.1 to 300 MPa with an accuracy of ± 0.05 MPa in readings from 0 to -5 MPa. However, according to studies by Campbell et al. (2007), the device is not recommended for suction measurements below 1 MPa.

For this methodology, cylindrical metal molds provided by the WP4C device manufacturer were used. The mold has a diameter of 40 mm and a height of 10 mm. The compacted samples were prepared using a custom-made wooden tamper with the same dimensions as the metal mold, except for a height limiter of 5 mm, ensuring a final specimen height of 5 mm. This arrangement allows for an air gap as specified by the manufacturer.

Measurements were taken 30 minutes after compaction and again 24 hours later. This procedure aimed to assess the equilibrium of the specimens. The material drying process was carried out until a suction close to -70 MPa was reached. In this method (WP4C), only the specimens 34, 35, 37, and 38 were saturated after molding.

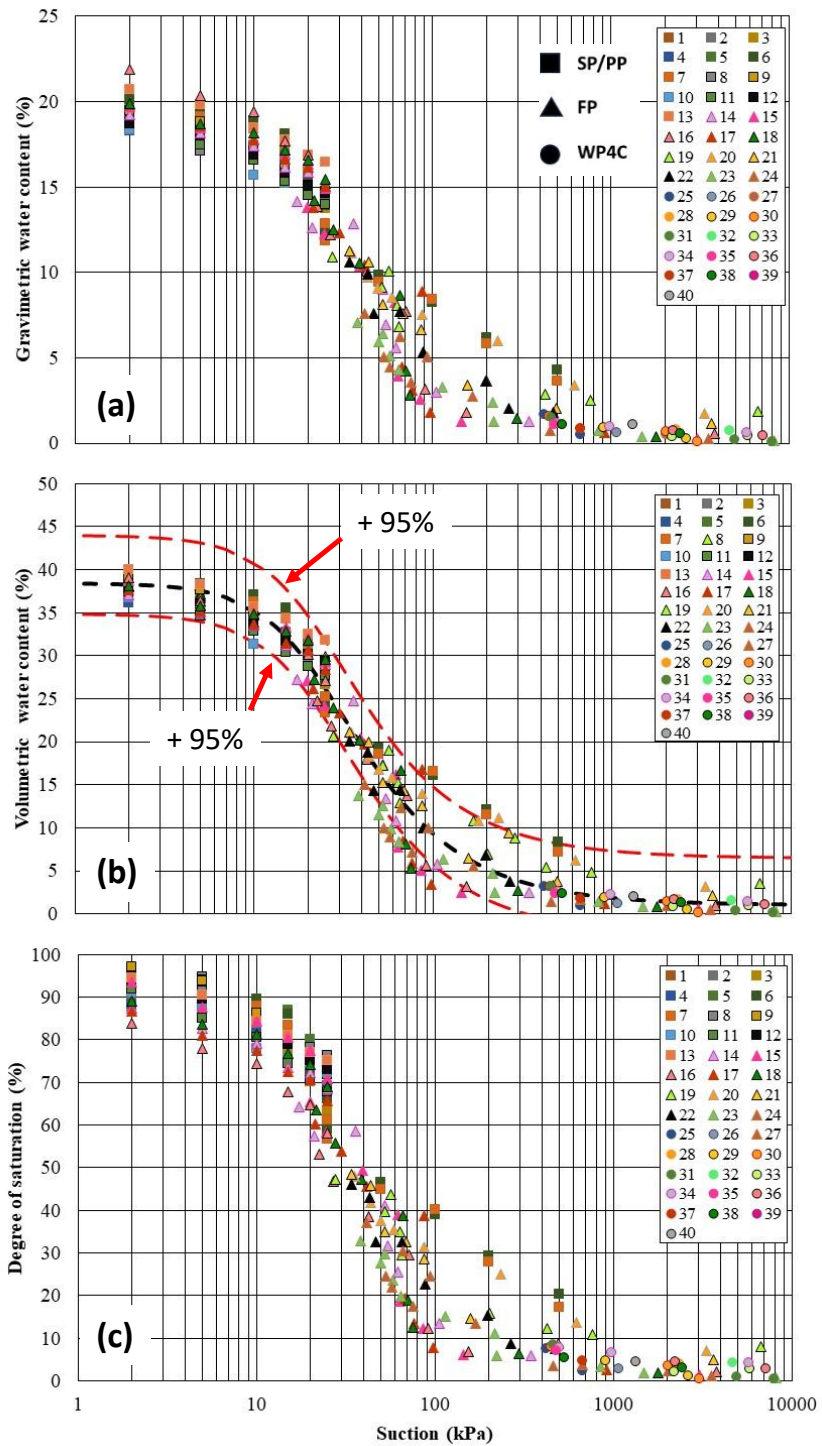


Figure 3. Soil water retention curve in terms of (a) gravimetric water content (b) Volumetric water content (c) Degree of saturation.

3 RESULTS AND DISCUSSION

The use of three methods to obtain experimental data of the SWRC indicates good consistency among them, with a smooth transition between the methods. Figure 3 presents the results obtained in terms of gravimetric water content, volumetric water content, and degree of saturation. The WP4C data used in this figure were limited to a minimum suction value of 500 kPa, and this aspect will be discussed further. Some specimens experienced slight expansion during the saturation process, which was not recovered during drying. This expansion is attributed to a mechanical rather than mineralogical process. In Figure 3, it is observed that specimens 6 (P.P.), 7 (P.P.), 19 (F.P) and 20 (F.P.) positioned themselves above the other data points in the range between 100 kPa and 1000 kPa. The reason for this behavior could not be identified. It is important to highlight that the SWRC can change according to the load applied to the material.

It is noted that in some specimens, degrees of saturation above 90% could not be achieved during saturation procedure. Variations in SWRC behavior due to density variations could not be attributed. Variations in the SWRC due to specimen density could not be identified. The WP4C, due to employing a principle that is highly imprecise for low suctions, is limited to suctions greater than 500 kPa. To highlight the consequences of using WP4-C for suctions lower than 500 kPa, Figure 4 presents all data obtained with the WP4C, showing a sort of limit near a suction of 500 kPa. These data pertain to statically compacted specimens with densities exceeding 1.79 g/cm³.

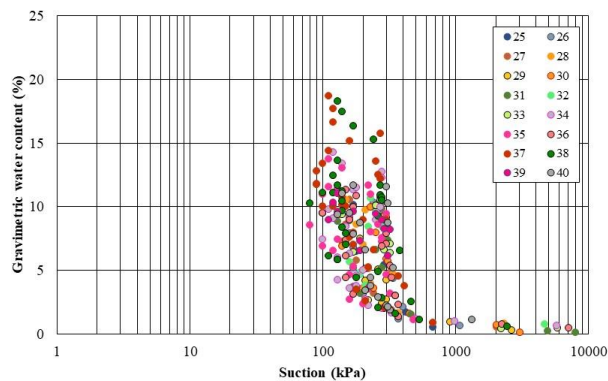


Figure 4. Soil water retention curve using WP4C with specimen statically compacted.

3 CONCLUSIONS

Tailing stacks (or piles) are structures generally built above the water table with adequately compacted material. However, there is concern about the material becoming saturated due to rising groundwater or capillarity, or through infiltration from the top and slopes of the stack. This infiltration will necessarily occur under unsaturated conditions, requiring flow analysis under these conditions. Therefore, one of the critical parameters to be included in numerical analyses is the SWRC (Soil Water Retention Curve) and the permeability function. The use of SWRC in stability and flow studies is becoming increasingly common. For SWRC to be

adopted more systematically, it is essential to understand the phenomena involved in the processes of infiltration and evaporation in porous media. This understanding will enhance the accuracy of stability assessments and improve the design and monitoring of tailing stacks. The techniques of suction plate, pressure plate, filter paper, and determination of suction through equilibrium relative humidity with the specimen (WP4C) were tested on 40 statically compacted specimens of iron ore tailings. The compaction curve of the tested tailings appeared very flat, indicating little variation in density with changing water content. The specimens were prepared with void ratios ranging from 0.5 to 0.84 and a water content deviation between +2.1 and -4.3. The specimens did not achieve complete saturation, and the SWRCs appeared to be approximately parallel with respect to the degree of saturation.

All methods used demonstrated that the curves were consistent with each other, showing a smooth transition between the methods. Some specimens (6, 7, 19, and 20) exhibited the SWRC above the main curve between suctions of 100 to 1000 kPa. No relationship with the measurement method was observed.

The WP4C method has a reading limitation for suction values below 500 kPa, which is the wettest range, and is therefore restricted to suctions above 500 kPa.

As a general conclusion regarding the use of the various methods in conjunction and continuously, it can be stated that all methods, respecting their individual limits, allow for the precise determination of the SWRC. These limits can be established as follows: suction plate (0 to 30 kPa), pressure plate (30 kPa to 500 kPa), filter paper (30 kPa to 10 MPa), and WP4C (suctions higher than 500 kPa).

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