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Water characteristic curve and permeability function of steel slag

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ABSTRACT: Waste arising from construction and demolition constitutes one of the largest waste streams globally. Construction and maintenance of roads require a large volume of aggregates for use as base and sub-base material. Because of the cost of virgin aggregates, government and local companies are encouraging the use of recycled material in old pavement and construction material. One type of recycled material, steel slag could be used for several construction purposes, such as concrete, road subgrade, and railway ballast materials. In order to utilize steel slag in these constructions, the engineers need to understand the properties of material appropriately including its unsaturated properties. The objective of this project is to study the soil-water characteristic curve, unsaturated permeability and unsaturated shear strength of steel slag. Advanced laboratory testing was conducted to obtain these unsaturated properties. The results of study indicated that the steel slag has the same unsaturated properties as natural aggregate or gravel.

1 INTRODUCTION

One of the main waste streams in the EU and many other countries is waste produced during construction and demolition (C & D). For instance, it is estimated that core C&D waste, defined as items originating from demolished structures or civil engineering infrastructure, amounts to about 180 million tons annually, or 480 kg per person, in Europe (Aggregates Advisory Service-UK, May 1999). Aggregates are needed in huge quantities for base and sub-base material during road construction and maintenance. Because of the cost of virgin aggregates, government and local companies are encouraging the use of recycled material in old pavement and construction materials.

Recycling of material is the process of turning used construction or industrial waste into raw materials that are suitable to be reused again. Natural resource preservation and pollution reduction are its primary goals. Recycling also lowers energy use because it often requires less energy to make a product through recycling than it does to create a new one. Similar to how recycling conserves raw materials and produces less pollution than producing new products. Additionally, less waste is disposed away or burned in incinerators. The term "water content" describes how much water is contained in a material's pores. The amount of water in unsaturated soil depends on the soil's suction. The soil-water characteristic curve (SWCC), which depicts the change of water storage capacity inside the micro and macro pores of the soil with respect to soil suction, can be used to show the relationship between water content and suction.

The properties of recycled materials in saturated conditions have been the subject of numerous studies. However, there haven't been many studies done on the permeability of recycled materials and the water characteristic curve in unsaturated conditions. The shear strength of recycled materials in unsaturated environments has also not been thoroughly studied. Thus, this project aims to investigate the unsaturated permeability and soil-water characteristic curve of steel slag.

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2 STEEL SLAG

Researchers found that steel slag might be utilized for a variety of construction purposes, including the production of concrete, road subgrade, and railroad ballast materials (Koh et al., 2018). Li et al. (2022) provided a description of the steel slag's characteristics and talked about how they affected the properties and microstructure of cement concrete. Their research indicates that the volume stability and workability of concrete are adversely affected by steel slag. It improves compressive strength, frost resistance, and wear resistance, although its effects on flexural strength and permeability are questionable. Meanwhile, steel slag can be utilized in road construction since it has qualities that are compatible with unbound and asphalt layers (Motz and Geiseler, 2001). Steel slag may create high-quality aggregates of a level that is comparable to natural aggregates, making its use in road construction plausible due to its great strength and durability. Additionally, characteristics like its high abrasion and rough texture make it appropriate for hydraulic construction (Yi et al., 2012). In their analysis, Yi et al. (2012) note that the Nippon Slag Association in Japan has been investigating the use of steelmaking slag as a material for ground improvement in port and harbour construction since 1993. The study of powdered steel slag was done by Akinwumi (2014). Related experimental results show that it was effectively applied to improve the drainage, plasticity, and uncured strength of lateritic soil without exhibiting any unfavourable swell behaviour.

3 LABORATORY TESTING

Grain size examination of the specimen was performed in accordance with ASTM D422-63. A water pycnometer was used in the test by ASTM D854-06 to estimate the specific gravity. A triaxial permeameter with two back pressure systems was used to obtain the saturated coefficients of permeability from the constant head permeability test (Head, 1986). The best method for figuring out slow flow rates is to do a constant head triaxial permeability test. This test may be executed under real confining stress at pore pressures that are relevant to the site circumstances, and a variety of hydraulic gradients can be applied and precisely quantified.

Three stages—saturation, consolidation, and permeability—of the triaxial test were used to determine the specimen's permeability. The saturated permeability test applied back pressure and water pressure to the specimen while it was inside a specific cell. Water would flow when the drainage intake was opened because of the pressure difference caused by the water pressure that was applied. The water volume change and the passing of time were gauged as the water passed through the specimen. Darcy's Law can then be used to compute the saturated permeability (ks).

An average value of the ks was then determined after several saturated permeability tests under various water pressures.

Using a typical 250 ml sample ring, the HYPROP fully automated laboratory apparatus (Figure 1) can be used to obtain unsaturated hydraulic parameters of soil samples, such as SWCC and unsaturated hydraulic conductivity. When using HYPROP equipment, the phases of the experimental technique include saturating the soil sample, setting up the device with the specimen inside, starting the measurement, and analyzing the results (Satyanaga et al., 2019).

Effective cohesion (c') and effective friction angle (') of soils are measured using the Consolidated-Drained (CD) Triaxial Test. It's a compression test where the sample is allowed to consolidate to its equilibrium moisture content during the application of the cell pressure prior to shearing and the drainage taps are opened during shearing where water is free to flow out of or into the test specimen (Powrie, 2004). Drainage is allowed throughout the test to ensure that consolidation happens fully under the all-around load and that there is no buildup of pore pressure when the deviator stress is applied (Bishop and Henkel, 1962).

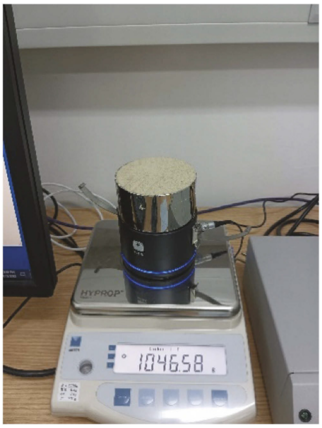

Figure 1. Measurement of SWCC using Hyprop.

4 RESULTS AND DISCUSSION

Based on the grain size analysis, steel slag appeared to have 98.11% of gravel content larger than 4.75 mm. A complete composition can be seen in Table 1, which shows the index properties of the steel slag.

Table 1. Index properties of Steel slag.

	Steel Slag
USCS Classification	GP (Poorly-graded gravel)
Specific gravity, G_s	3.5
Gravel content,% (more than 4.75mm)	98.11
Sand content, %	1.89
Fines content, % (Less than 0.075mm)	0
Saturated permeability, k_s (m/s)	0.98

From the conducted laboratory works, SWCC of steel slag was generated. Accordingly, the relationship between volumetric water content and matric suction can be observed in Figure 2. Equation (1) was used to fit the experimental data of SWCC best. The best fitting parameters of Equation (1) can be seen in Table 2.

Table 2. Best fitting parameters of Satyanaga et al. (2022) equation.

θ_s=	0.27
θ_r=	0
ψ_m=	1.034308
σ=	1.601103
ψ_{aev}=	0.3
ψ_r=	137489.9
r2	0.992052

In order to use Equation (1) for modelling SWCC, each parameter must have a proper initial value (Satyanaga et al. 2017). To best fit the laboratory data of the SWCC, all the parameters can be adjusted via an iterative non-linear regression approach offered in the Microsoft Excel software (Satyanaga et al. 2019b; Dodge and Stinson, 2007). Eventually, SWCC data are applied in subsequent seepage analyses.

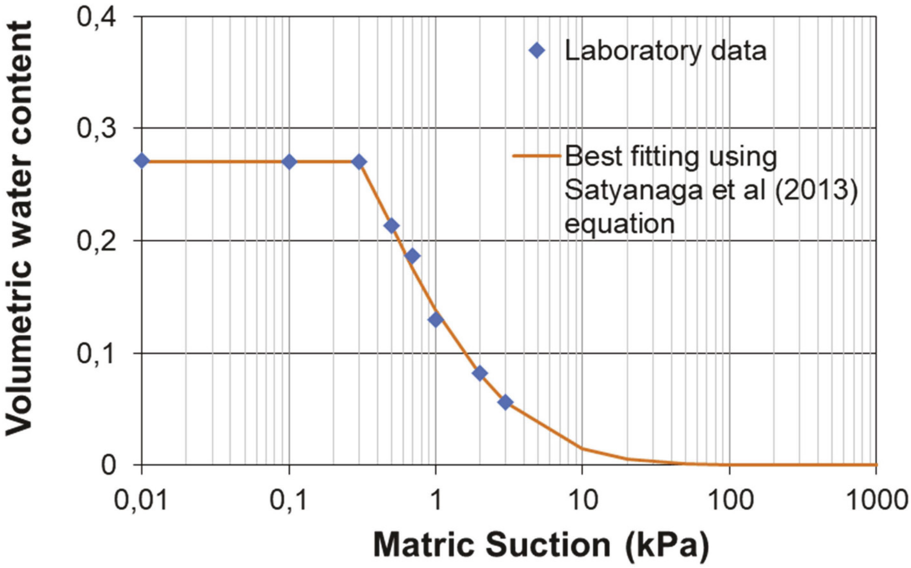

Figure 2. SWCC of Steel Slag.

The permeability function of steel slag was determined from SWCC and saturated permeability using the statistical method following the procedure explained by Satyanaga et al. (2022b) (Figure 3). The permeability function was also incorporated in the numerical analysis together with the best fitted SWCC data.

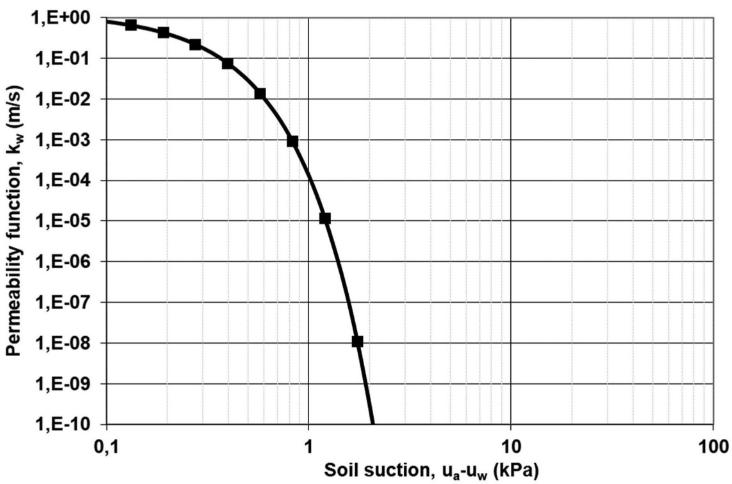

Figure 3. Unsaturated permeability of Steel Slag.

5 CONCLUSIONS

The results of the study indicated that the properties of steel slag are similar to gravel. The air-entry value of steel is 3 kPa which is corresponding to its saturated permeability (1 m/s).

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