Hydraulic Conductivity of Steel Slag and Potential Influence of Leaching on Groundwater Alkalinity

Rituraj Devrani, Anant Aishwarya Dubey, K. Ravi, and Clint Thankachan

Abstract Steel slag is a coarse industrial solid waste obtained from steel manufacturing industries as by-product. The steel slag acquired from Tata Steel, Jamshedpur, India is investigated in this study. Recent studies have reported its potential for utilization as coarse aggregate in asphalt mixtures, embankments, landfills and sub-base material of highways & railways. This study emphasis on the assessment of saturated hydraulic conductivity with different proportions of sand mixtures and alkalinity exchange behaviour of steel slag through water outflow test. The steel slag obtained is observed to be heavy granular material and highly alkaline in nature. This study reports decrease in the hydraulic conductivity of sand from $(15.70 \pm 0.66) \times 10^{-5}$ m/s to $(4.505 \pm 0.17) \times 10^{-5}$ m/s with addition of 25% by weight of steel slag. This study also recommends for chemical treatment of the steel slag prior to its utilization in geotechnical applications as it may cause drastic change in the alkalinity of ground water.

Keywords Steel slag · Industrial waste · Hydraulic conductivity · Alkaline ex-change behaviour · Leaching

1 Introduction

Over the last few years, the functions and improvements in process technologies have led to a significant reduction in the volume of industrial waste generated. Also, the utilization of these by-products led us to the significant reduction of stress on the environment. The production of granulated slag is close to 10 million tonnes per annum from its existing steel plants [6]. Steel slag is the solid industrial waste produced during the separation of molten steel from impurities in steel-making furnaces during the production of steel. The slag is a complex solution of silicates and

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oxides that solidifies upon cooling. The generation of steel slag will remain inevitable and emphasis on its recycling will remain one of the major concerns. These granular industrial waste materials may be utilized in large quantity in geotechnical applications as geo-material, however the major concern in its utilization as geo-material, is the environmental impact. Therefore, an efficient method of utilization of slag is necessary for sustainable development.

Several studies recommend utilization of steel slag in various engineering applications. Kandhal and Hoffman [11] incorporated the steel slag aggregates into the asphalt concrete. Chesner et al. [4] recommended to avoid any contamination of slag aggregate produced for its efficient utilization for sub-grade or sub-base construction in highway and pavement construction. Poh et al. [15] investigated the potential of utilization of steel slag in soil stabilization and it was reported that use of Blast oxygen steel (BOS) slag improves the strength, durability and reduces in the linear expansion. This study also suggested that a high percentage (15–20 %) of BOS slag and a long curing period are required for significant improvement. Asi et al. [2] recommended in their study that replacement of 75 % of limestone coarse aggregate with Steel Slag Aggregate (SSA) improved the mechanical properties of the asphalt mixes and suggested replacement of 25% Steel Slag Aggregate (SSA). Montenegro et al. [13] studied the expansive behaviour of ladle furnace slag in the construction of embankments. Anastasiou et al. [1] proposed the utilization of steel slag, fly ash in production of concrete and suggested the use of concrete produced for low-grade applications. Aziz et al. [3] indicated that the steel slag has hydrophobic property which provides good adhesion with bitumen binder and may help in resisting against stripping and other defects of roads. The steel slags are also employed as aggregates in road and pavement mixtures. Oluwasola et al. [14] introduced the electric arc furnace slag and copper mine tailings in asphalt mixes for road construction and observed increase in the performance of asphalt mixtures. Yildirim and Prezzi [16] reported that the utilization of both fresh and aged basic oxygen furnace (BOF) steel slag manifested superior strength and stiffness characteristics to conventional friction materials. Furthermore, the long-term swelling of fresh and aged basic oxygen furnace (BOF) steel slag when exposed to water, is due to the presence of free lime and magnesia. The application of fresh and aged steel slag as a railway ballast material was investigated by Koh et al. [12] and the study suggested that it can be used in place of natural crushed stone aggregate. Dubey et al. [5] discussed about the calcium leaching potential and high alkalinity behaviour of steel slag. The utilization of steel slag in geotechnical engineering applications without evaluation of its environmental aspects brings a concern for to the sub-surface environment. Limited studies have been done on the leaching potential of steel slag after its utilization with soil for geotechnical applications. This study investigates the basic geotechnical characterization, alkalinity exchange behaviour and hydraulic conductivity behaviour of steel slag.

2 Materials and Methods

The steel slag used in the study was acquired from TATA Steel Plant, located in Jamshedpur, Jharkhand, India and the sand utilized in the study was Brahmaputra river shore sand. The study includes the geotechnical characterization such as grain size distribution analysis and classified according to Unified soil classification system (USCS). The specific gravity of steel slag was evaluated using kerosene instead of water because kerosene is bipolar in nature and using water may give deceptive observations. The relative density test was performed to determine the maximum and minimum density of steel slag. After that, the influence on the hydraulic behaviour of the sand with addition of different proportion of slag was examined using Falling head permeability test. The samples for the tests were prepared using quartering and coning method. All the tests were performed on triplicate samples. The specific gravity, grain size distribution, relative density and the falling permeability test were performed as per bureau of Indian Standards IS 2720 (Part 3/Sec 2)-1980; IS 2720 (Part 4)-1985; IS 2720 (Part 17)-1986; IS 2720 (Part 14)-1983 respectively. This study also assessed the alkalinity exchange behaviour of the water leaching from the steel slag as during the rainy season, the rainwater may percolate through non-engineered openly dumped steel slag to sub-surface and influence the alkalinity of the groundwater. The study was performed by collecting and examining the change in the alkaline behaviour of inflow and outflow of the water. Figure 1 illustrates the setup for alkalinity exchange behaviour of inflow and outflow study of water. The distilled water having pH of 6.8 was used in this test.

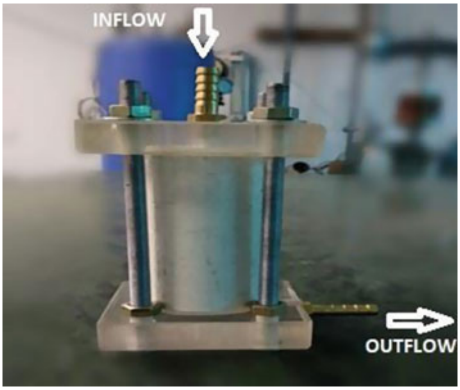

Fig. 1 Alkalinity exchange behaviour setup of inflow and outflow of water

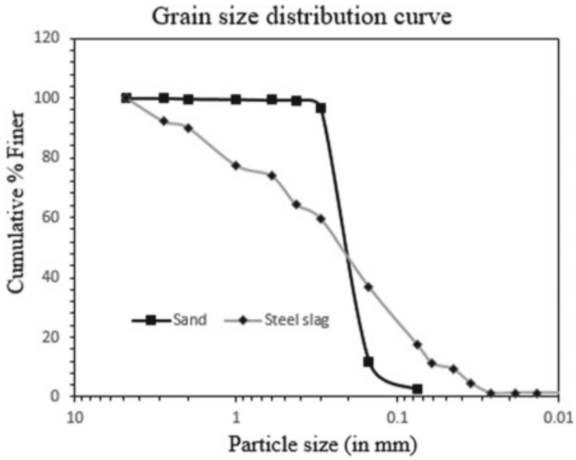

Fig. 2 Grain size distribution curves of steel slag and sand

Table 1 Grain size distribution measures of steel slag and sand

Gradation measures	Steel slag	Sand
Effective size, D_{10} (mm)	0.050	0.136
D_{30} (mm)	0.123	0.182
D_{60} (mm)	0.308	0.235
Coefficient of uniformity (Cu)	6.114	1.717
Coefficient of curvature (Cc)	0.982	1.032

3 Results

3.1 Grain Size Distribution Analysis

The grain size distribution curve of the Brahmaputra River shore sand and steel slag is shown in Figure 2. Steel slag was classified as Silty sand (SM) according to Unified Soil Classification System (USCS) as per ASTM D422-63, obtained is presented in Table 1. The grain size distribution based on dry sieve analysis classified Brahmaputra river shore sand as Poorly graded sand (SP) as per USCS with 2.4% of fine content. The gradation measures of sand are also presented in Table 1.

3.2 Specific Gravity

The specific gravity of the steel slag was 3.50 ± 0.021. Whereas, the specific gravity of Brahmaputra river shore sand was obtained as 2.75 ± 0.015.

3.3 Relative Density

The density index of both sand and steel slag was determined. The maximum dry unit weight (γ_{d_max}) and minimum dry unit weight (γ_{d_min}) for sand were observed as 15.37 and 13.41 KN/m^3. The Maximum dry unit weight (γ_{d_max}) and minimum dry unit weight (γ_{d_min}) for steel slag were obtained as 20.05 KN/m^3 and 16.07 KN/m^3.

3.4 Saturated Hydraulic Conductivity

The saturated hydraulic conductivity of soil and steel slag are shown in Fig. 3. It also represents the rate of change in permeability with the incorporation of different ratio of steel slag with the sand. The saturated hydraulic conductivity of the bare sand was found as $(15.70 \pm 0.66) \times 10^{-5}$ m/sec and of bare steel slag as $(10.80 \pm 0.10) \times 10^{-5}$ m/s. The hydraulic conductivity was found to be decreased to $(4.50 \pm 0.17) \times 10^{-5}$ m/s with the addition of steel slag to 25% by weight. The hydraulic conductivity decreases with the increase in the proportion of steel slag. The proportion of steel slag is added in small quantity during the preparation of mould for performing the test, in order to maintain the relative density of the sand-steel slag mixture. The hydraulic conductivity may be reduced due to the adjustment fine particles of steel slag in between the pores of sand particles.

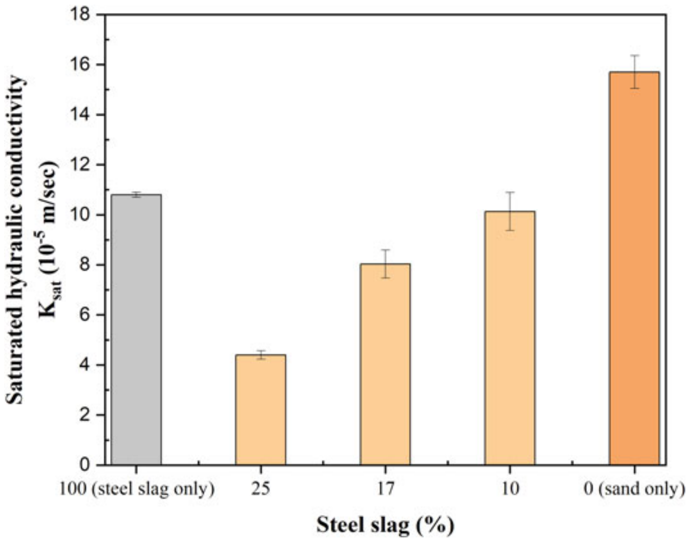

Fig. 3 Saturated hydraulic conductivity of sand, steel slag and their mixtures

3.5 Alkalinity Exchange Behaviour

It was observed that the pH of the distilled water (initial pH = 6.8) in inflow changes to (pH=11.84) in outflow through a sand column of 10 cm (diameter 3.8 cm). The results indicated that the utilization of steel slag in geotechnical applications without prior treatment may harm the ground water sources and nearby aquatic lives.

4 Conclusion

Steel slag is a coarse industrial waste obtained from steel production industries. The utilization of industrial granular waste in engineering applications aims to reduce the dumping of industrial waste in the geo-environment. The investigation of any industrial solid waste in environmental aspects is vital for sustainable development. This study helps to understand the alkalinity exchange capacity of steel slag due to leaching on the ground water pH. The drastic change in the alkalinity of ground water may affect the geo-environment adversely. Some of the major conclusions drawn from this study are reported as following-

- The hydraulic conductivity of the sand incorporated with different proportion of steel slag decreased with increase in steel slag proportion. This study also suggests that there are other factors which affect the hydraulic conductivity of the soil such as morphology of slag particles.
- The steel slag was observed to have significant alkaline exchange capacity as it changed the pH of the leaching water to highly alkaline (11.84) from neutral pH (6.8). The leaching of water through steel slag may affect the ground water sources adversely. This study suggests the treatment of steel slag prior to its use in the geotechnical applications such as in sub-base, sub-grade or in embankment construction.

The utilization of steel slag in the geotechnical applications must be considered as a sensitive issue as it can impact the geo-environment negatively. So, further investigation on the geo-environmental aspects of steel slag should be evaluated for better utility of slag as alternative geo-material.

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