Possible Environmental Risks Associated with Steel Slag: A Batch Study

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1 Introduction

The management of mining, power plant, and metallurgical wastes/by-products is of a great challenge as well as an opportunity to create something good out of it. Quantity wise numbers are surging every year. Along with regulation of these outputs as environmental concerns are growing, push toward recycling and reusing is also gaining popularity—moreover, it is a need of the hour. Overburden, fly ash, iron slag, steel slag, and many such materials are used by different sectors such as construction, cement, roads, and agriculture. A highly alkaline, porous, crystalline, heterogeneous, and non-hazardous (Matei 2007; Proctor et al. 2000; Ziemkiewicz 1998) by-product from steelmaking plant is basic oxygen furnace (BOF)/steel/Linz-Donawitz (LD) slag. Every tonne of steel generates 150–200 kg of steel slag, and most of it ends up in storage yards due to low market value and demand and high hauling costs (Drissen et al. 2009; Kumar et al. 2010). Expansive nature of slag due to free lime restricts its usage in cement and construction industries.

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Synthetic soil or artificial soil is one such possibility where by-products from different industries are blended together to create a topsoil (Yellishetty et al. 2014). The main purpose of this topsoil would be to replace the natural soil with synthetic (top) soil for rehabilitation and restoration works such as: for mine rehabilitation, landfill cover, road median, and public gardens. Slag, when used as soil, would get exposed to different environmental conditions imparted mainly by water, organic matter or humic substances, acidic wastes/saline wastes.

Organic waste compost in an amendment made to slag to build synthetic (top) soil. Compost provides carbon, nitrogen, microbes as well as readily available inorganic ions such as Fe, Zn, K, Na, and others. Compost increases water holding capacity, provides above-mentioned nutrients, and enhances soil structure. Also, high concentrations of Na and K in compost would result in high conductivity. Environmentally, harmful trace metals such as Pb, Zn, Cr, and others are found in soluble phase under acidic conditions. Organic acids and humic acids present/generated would develop acidic conditions as well. Hence, the right approach would be to study the behavior of slag under acidic and saline conditions. In the current study, these environmental conditions are simulated using 0.11 M acetic acid and a mixture of 0.128 M sodium dithionite, 0.3 M sodium citrate, and 0.1 M sodium bicarbonate solutions (Shivpuri et al. 2012). The main objective is to measure the amount of inorganic ions extracted under acidic and saline conditions.

2 Materials

Linz-Donawitz (LD) slag was supplied by JSW Vijaynagar plant, Toranagallu, Karnataka, India. Two extraction fluids (1) 0.11 M acetic acid and (2) a mixture of 0.128 M sodium dithionite, 0.3 M sodium citrate, and 0.1 M sodium bicarbonate extraction solutions were prepared using analytical grade reagents. Milli-Q water was used for dilution.

3 Experimental Methodology

A series of nine 100 mL centrifuge tubes having 0.5 g (size $< 150\ \mu$) fresh LD slag was filled with 50 mL of extraction fluid (Shivpuri 2012). Tubes were placed on the end-over-end mixer (Make: Trishul Equipments, Mumbai). Sampling was done at regular intervals such as 1, 2, 4, 8, 12, 18, 24, 30, 36, and 48 h. Extraction fluid was filtered with a glass filter, acidified with 2% nitric acid for inductively coupled plasma atomic emission spectroscopy (ICP-AES) analysis (Make: SPECTRO Analytical Instruments GmbH, Germany). All experiments were performed in duplicates.

4 Results and Discussions

Cumulative metal concentrations (mg/kg) with time extracted using 0.11 M acetic acid and a mixture of 0.128 M sodium dithionite, 0.3 M sodium citrate, and 0.1 M sodium bicarbonate extraction solution are shown in Figs. 1 and 2. The rapid desorption of metal ions present on the surfaces of porous, heterogeneous, and crystalline slag was restricted to initial five hours for most of the metals when slag got exposed to the 0.11 M acetic acid solution. It took five hours for readily available metal ions like Al, Cd, Ni, and Zn to reach equilibrium conditions. In first five hours, ions present on an outer surface, mainly macropores, started coming out of solid phase into the solution phase quickly under acidic conditions (initial pH of 0.11 M acetic acid was 2.93). However, it was not the same for ions like Ca and Pb —which reached equilibrium slowly (Fig. 1). As contact time between slag and solution increased, Ca and Pb concentrations were steadily increased throughout 48 h. Indicating desorption of Ca and Pb from meso- and micropores throughout the experiment period.

Steel slag exposure to freshly prepared Na rich solution also showed a similar kind of trend. Except for Al, Ca, and Fe, all other metal ions reached equilibrium in less than five hours of contact between slag and extraction solution. However, Al, Ca, and Fe continued to release into the solution throughout the contact period. Indicating enhanced release of ions under saline conditions (initial conductivity of solution was 60.6 mS/cm).

Table 1 describes percentage increase in metal extraction under saline and acidic conditions. Al, Ba, Cr, Cu, Fe, Mn, and Zn extraction was 680.09, 164.71, 187.41, 137.04, 2066.79, 191.01, and 281.48%, respectively, times more in saline conditions than in acidic conditions. Extraction of Pb was 17.78% less in saline conditions compared to acidic conditions. This implies care should be taken while using highly saline organic waste compost as an amendment to steel slag to build an artificial/synthetic soil. To predict the release of metals in future, long-term leaching studies should be performed with actual artificial soils.

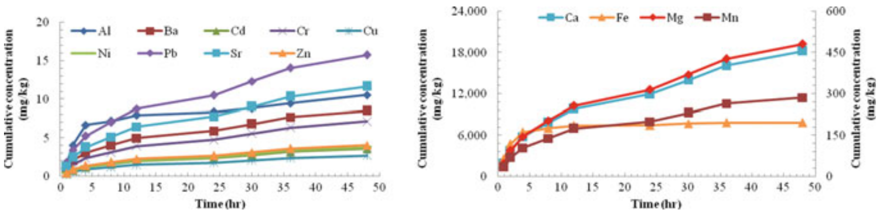

Fig. 1 Cumulative concentration of metals extracted using 0.11 M acetic acid with time

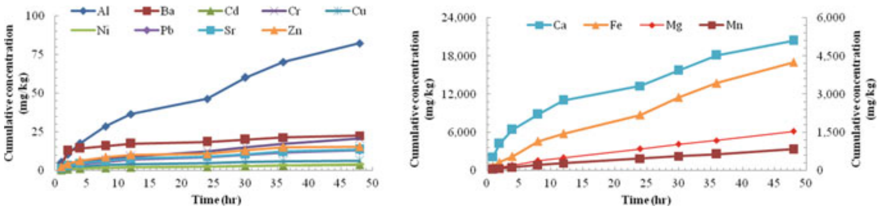

Fig. 2 Cumulative concentration of metals extracted using a mixture of 0.128 M sodium dithionite, 0.3 M sodium citrate, and 0.1 M sodium bicarbonate extraction solution with time

Table 1 Percentage increase in metal extracted at the end of 48 h

Metal	A (mg/kg)	B (mg/kg)	% increase (B-A)/A × 100
Al	10.55	82.30	680.09
Ba	8.50	22.50	164.71
Ca	18188.55	20415.95	12.25
Cd	3.60	3.60	0.00
Cr	7.15	20.55	187.41
Cu	2.70	6.40	137.04
Fe	196.50	4257.75	2066.79
Mg	480.65	1532.95	218.93
Mn	285.80	831.70	191.01
Ni	3.80	3.80	0.00
Pb	15.75	12.95	−17.78
Sr	11.65	13.55	16.31
Zn	4.05	15.45	281.48

Note A: Cumulative concentration of metal extracted using 0.11 M acetic acid after 48 h. **B**: Cumulative concentration of metal extracted using a mixture of 0.128 M sodium dithionite, 0.3 M sodium citrate, and 0.1 M sodium bicarbonate extraction solution after 48 h

5 Conclusions

The utilization of industrial wastes and municipal waste in individual or together would definitely help to reduce the burden on land and would also curb the pollution level to a certain extent. However, the change that can happen in future cannot be neglected. The outcomes of batch extraction study on steel slag can be summarized as follows:

1. Steel slag as synthetic soil would be exposed to acidic and saline conditions. The result showed that metal extraction was more with saline extraction conditions.

2. Al, Ba, Cr, Cu, Fe, Mn and Zn extraction was 680.09, 164.71, 187.41, 137.04, 2066.79, 191.01, and 281.48%, respectively, more in saline conditions than in acidic conditions.
3. Extraction of Pb was 17.78% less in saline conditions compared to acidic conditions.
4. Care should be taken while using highly saline (Na rich) compost as an amendment to alkaline steel slag to make synthetic soil, as it could enhance the trace metal leaching.

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