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Research Initiative on the Use of Steel Slag in Concrete and Cement

Office of the Assistant Secretary for Science and Technology (OST-R)

Industry Assessment

Technical Brief

Variation of Physical and Chemical Properties of Different Slag Types for Concrete Use

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Overview

This technical brief discusses the physical and chemical properties of different slag types for use in concrete. While the focus of this project is on steel slag it is important to note that steel slag differs from iron slag. Iron slag is commonly used in concrete production and is widely known as ground granulated blast-furnace slag (GGBFS), or slag cement, which is used as a supplementary cementitious material (SCM) to replace portland cement. Steel slag is less commonly used in the concrete industry and is more often considered as a potential aggregate replacement. This brief discusses the differences in the physical and chemical properties of steel slag compared with iron slag and identifies opportunities to modify these properties for use as a cementing material, potentially increasing its commercial value.

Key Takeaways

- Steel slags differ from iron slags (i.e., GGBFS) in chemical composition and reactivity. Users in the concrete industry need to be aware of these differences to avoid confusion and misuse.
- The reactivity of slag in concrete is important. Slags are not pozzolanic, so current pozzolanic reactivity testing does not apply. A new method is needed.
- The physical and chemical properties of steel slag can be modified to increase reactivity. Thermodynamic modeling can be useful in this process.

Typical Types of Slag and the Associated Properties

Iron Slag – The concrete industry is a major user of iron slag produced by blast furnace ironmaking. Blast furnace slag (BFS) is a byproduct of iron manufacture that is composed mainly of silicates and aluminosilicates. When rapidly cooled (i.e., quenched) and finely ground (mean particle size of 10 to 25 microns), GGBFS is hydraulically reactive and serves as a partial replacement for cement clinker. According to the USGS, in 2024, 16 million tons of GGBFS was sold in the US, of which 11% was imported from Japan, 53% from China, and 23% from Brazil.

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Physical and Chemical Properties of Steel Slag for Concrete Use

Steel slag – Steel slag differs from iron slag. Steel slag is a byproduct of the steel production process. The concrete industry does not widely use steel slag as a cementitious material; however, it may be used as an aggregate. Steel slags are rich in CaO (similar to GGBFS) and tend to have lower silicate and aluminosilicate contents. While GGBFS tends to be more uniform in composition, steel slags can vary more in MgO, Al_2O_3, and SiO_2 content, depending on the manufacturing process and ladle fluxing. Steel slags may also contain minor FeO/Fe_2O_3 components, and in stainless/alloy slags, oxides like Cr_2O_3 or Ni oxides. Figure 1 shows relative chemical compositions of different slags.

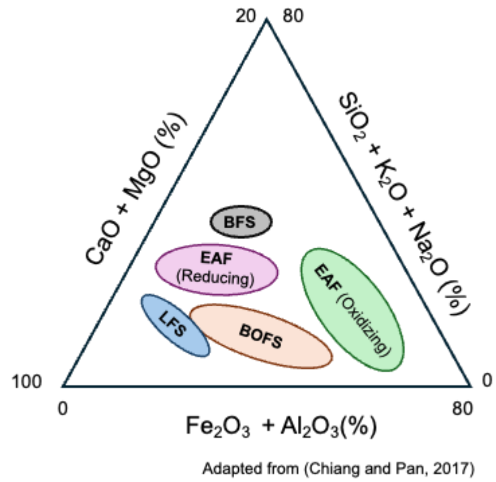

Figure 1: Range of chemical constituents of slag products

While iron slag is most commonly produced using a blast furnace, steel slag can be produced through a variety of processes including:

- Basic Oxygen Furnace Slag (BOFS) – In this process, scrap and molten iron are combined with flux consisting of lime and silica-rich materials. The impurities separate from the steel slag and float. This may be known as BOFS or Linz-Donawitz (LD) slag.
- Electric Arc Furnace slag (EAFS) – In this steelmaking process, scrap steel is processed in an electric arc furnace (EAF). EAFS is composed of fluxes and impurities.
- Ladle slag (LS) – Results from ladle refining steel from BOF and EAF processes; they are often richer in alumina and silica with a specific CaO/SiO_2 to optimize desulfurization and alloying reactions and low in Fe_xO_y.

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- Stainless and specialty steelmaking slags – Stainless steels or nickel-based alloys slags can be richer in Cr_2O_3, MnO, FeO, SiO_2, and other oxides. This type of slag can vary and be specialized depending on the production process.

While the chemical compositions of steel slags are in some ways similar to those of iron slags, they contain lower silica and aluminosilicate phases, making them less reactive. Opportunities exist to alter these phases chemically and physically to improve performance.

Typical chemical compositions of all slags are shown in Table 1.

Table 1: Typical composition of slag by-products

	Steel Slags				Iron Slags
	BOF / LD	EAF Slag	Ladle Slag	Stainless / Specialty	BFS
CaO	10–60	18–60	40–60	*Varies | richer in Cr_2O_3, MnO, FeO, SiO_2*	18-50
SiO_2	5–40	4–40	0–25		16-42
Al_2O_3	0–20	0–20	0–40		3-24
MgO	5–15	0–20	0–12		1-18
Fe_xO_y	0–40	0–60	0–6		-

Factors Impacting Reactivity

While chemical composition is important, the reactivity of slag depends largely on the rate at which slag is cooled (i.e., granulation) as this affects the portion of the material that crystallizes. The fineness to which the material is ground also impacts the reactivity with more finely ground particles reacting more rapidly. Many iron slags are granulated for rapid cooling before being ground into GGBFS, which makes them more reactive for cementitious use. Currently, many steel slags are not rapidly cooled, contributing to their low reactivity. Modifications to the cooling process of steel slags and their impact on reactivity still need to be explored.

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This brief summarizes findings on the Physical & Chemical Properties of Steel Slag for Concrete Use as part of the Industry Assessment for USDOT-SLAG, "Research Initiative on the Use of Steel Slag in Concrete and Cement" under cooperative agreement 693JK42550005. Information supporting these findings can be found at: https://cait.rutgers.edu/usdotsteelslag/publications/. Inquiries about this work can be sent to: usdotsteelslaginitiative@rutgers.edu