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Standard Guide for Blast Furnace and Steel Furnace Slag as Produced During the Manufacture of Iron and Steel[1]

This standard is issued under the fixed designation D8021; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard is intended to provide guidance as to the appropriate/typical mineralogy observed when iron and steel slag, produced during the manufacture of iron and steel, is designated as a product. The included information covers the mineral properties of blast furnace slag and steel slag when they are manufactured in conjunction with the production of iron or steel, or both (Note 1).

NOTE 1—This guide is not intended to be used to determine the applicability of iron or steel slag, or both, for various applications. Terminology D8 designates steel slag as a product, while Terminology C125 designates blast furnace slag as a product. Its sole intent is to provide guidance as to the typical mineralogy when the iron or steel slag, or both, is designated as a product.

1.2 The values stated in SI units are to be regarded as standard. No other units are utilized in this standard.

1.3 The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) should not be considered as requirements of the specification.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates

C595/C595M Specification for Blended Hydraulic Cements

C702/C702M Practice for Reducing Samples of Aggregate to Testing Size

C989/C989M Specification for Slag Cement for Use in Concrete and Mortars

C1252 Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)

D8 Terminology Relating to Materials for Roads and Pavements

D75/D75M Practice for Sampling Aggregates

3. Terminology

3.1 *Definitions*—For the definitions of terms used in this standard, refer to Terminology D8.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *blast furnace slag, n*—see Terminology C125.

3.2.1.1 *Discussion*—Slag, ferrous metal, blast furnace (granulated, GBS or air-cooled, ABFS or ABF)—Blast furnace slag is formed in a continuous process by the fusion of limestone (or dolomite, or a combination thereof) and other fluxes with the residues from the carbon source and the non-metallic components of the iron-bearing materials (for example, iron ore, iron sinter). Blast furnace slag is generated at temperatures above 1500 °C. Dependent on the manner of cooling of the liquid slag, it can be distinguished between crystalline, air-cooled blast furnace slag and glassy, granulated blast furnace slag. Various cooling processes are defined in Terminology C125.

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[1] This guide is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.99 on Sustainable Asphalt Pavement Materials and Construction.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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3.2.2 *slag, steelmaking, n*—steelmaking slags (SMS) are generated as products during the refining/modification of steel in the production process.

3.2.2.1 *Discussion*—Steelmaking slag is formed (for example, from the conversion of hot metal to steel) from the melting of scrap in an electric arc furnace or from the subsequent treatments of various refinements/modifications of the crude steel, or both. The composition of the slags varies depending on the process step in which they are produced. The molten slag which has tapping temperatures of around 1600 °C is discharged into pots or pits where it cools and solidifies to provide an artificial aggregate having a crystalline structure. They are sometimes referred to as ladle modification or caster slags.

3.2.3 *steel slag, BOF/converter, n*—a product of the conversion of liquid iron (hot metal) into steel during a batch process in a basic oxygen furnace.

3.2.3.1 *Discussion*—BOF/converter slag is generated by the addition of fluxes, such as limestone, dolomite, or both, during the blowing of oxygen into the melt. Due to the oxidizing conditions, some elements (like Fe and Mn) are partly oxidized and contribute to the formation of the slag. Furthermore, some components are either oxidized to gas (like carbon) or are chemically bound in the slag (like silicon or phosphorus). The liquid slag which has tapping temperatures of around 1600 °C is air cooled under controlled conditions in pits forming crystalline slag.

3.2.4 *steel slag, EAF C, n*—electric arc furnace slag generated during carbon steel production is a product of melting steel scrap in an electric arc furnace.

3.2.4.1 *Discussion*—Steel slag, EAF C (carbon steel production) is generated by the addition of fluxes, such as limestone, dolomite, or both. Furthermore, some elements of the melt are oxidized and contribute to the formation of the slag. The liquid slag which has tapping temperatures of around 1600 °C is typically air cooled (possibly applying small amounts of water) under controlled conditions in pots or pits forming crystalline slag.

3.2.5 *steel slag, EAF S, n*—electric arc furnace slag generated during stainless steel or high-alloy steel production.

3.2.5.1 *Discussion*—Steel slag, EAF S (stainless/high-alloy steel production) is generated by the addition of fluxes and reducing agents, for example lime or dolomite (or a combination thereof), silicon compounds, or aluminum. The liquid slag which has tapping temperatures of around 1600 °C is controlled and treated, if necessary, to improve the properties of the slag. Then, the slag is cooled under controlled conditions in pots or pits forming crystalline slag.

4. Significance and Use

4.1 This guide provides guidance as to the appropriate/typical mineralogy observed when iron and steel slag is produced during a variety of processes in the manufacture of iron and steel.

4.2 Slag can be considered a product based on the mineralogy of samples that are tested using X-ray diffraction, phase recognition and characterization, powdered XRD-Rietveld analysis, and SEM-PARC results, using this guide.

5. Classification

5.1 Slag, ferrous metal, blast furnace (granulated, GBS or air-cooled, ABFS).

5.2 Slag, steelmaking, and converter—BOF.

5.3 Slag, steelmaking, and electric arc furnace—EAF C (carbon steel production).

5.4 Slag, steelmaking, electric arc furnace—EAF S (stainless/high-alloy steel production).

5.5 Slag, steelmaking—SMS.

6. Properties

6.1 *Mineral Constituents:*

6.1.1 Granulated blast furnace slag (GBS) typically contains up to 100 w/w% of glassy (vitreous) material (Specification C989/C989M). In some cases where a minor mineral component is detected, it is usually in the form of melilite (calcium-magnesium-silicate). Since the mineral component is usually minor, no characteristic mineral constituents can be given.

6.1.2 All other iron and steel slags exist predominantly in a crystalline form. Many are considered air cooled, although the process does allow for a water addition during cooling. The typical tables for ABFS, BOF, and EAF C include major primary mineral constituents which are characteristic for the fresh slag. The table for EAF S contains typical major mineral constituents (primary and secondary), and for SMS slags the most common mineral constituents are listed. Other mineral phases can occur, because the slags are UVCB[3] substances. The XRD[4] diagrams of all slags can show secondary mineral phases, for example hydroxides and carbonates, which are a result of weathering and aging of the slags. This is the case especially for EAF S slags and a large quantity of SMS slags, which are mostly soaked directly after the production.

6.1.3 Sometimes impurities, for example sand (quartz), can occur due to sampling, processing, or loading. In that case the quartz is not a fine-grained respirable crystalline silica, but granules, and therefore is considered to have no adverse health effects. The slag itself generally does not include crystalline quartz.

6.1.4 Slag, ferrous metal, blast furnace (granulated)—GBS, CAS[5] No. 65996-69-2. Mineral constituents: glass (amorphous).

6.1.5 Slag, ferrous metal, blast furnace (air-cooled)—ABS, CAS No. 65996-69-2 (Table 1, Note 2).

NOTE 2—Air-cooled blast furnace slag from some steel plants may also contain a certain amount of glass.

6.1.6 Slag, steelmaking, converter—BOF, CAS No. 91722-09-7 (Table 2).

6.1.7 Slag, steelmaking, electric furnace (carbon steel production)—EAF C, CAS No. 91722-10-0 (Table 3).

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[3] UVCB: unknown or variable composition, complex reaction products, and biological materials.

[4] XRD: X-ray powder diffraction.

[5] CAS: Chemical Abstracts Service.

TABLE 1 Slag, Ferrous Metal, Blast Furnace (Air-Cooled)

Major Primary Mineral Constituents	Molecular and Structural Formula
Melilite (solid solution between akermanite and gehlenite), calcium-aluminum-magnesium-silicate	$Ca_2MgSi_2O_7$ – $Ca_2Al_2SiO_7$
Merwinite, calcium-magnesium-silicate	$Ca_3MgSi_2O_8$
Pseudowollastonite, calcium-silicate	$CaSiO_3$
Monticellite	$CaMgSiO_4$
Amorphous	. . .

TABLE 2 Slag, Steelmaking, Converter—BOF

Major Primary Mineral Constituents	Molecular and Structural Formula
Larnite, beta-dicalcium-silicate	beta-Ca_2SiO_4
Srebrodolskite, calcium-iron-oxide	$Ca_2Fe_2O_5$
Hatrurite, tricalcium-silicate	Ca_3SiO_5
Spinel	$Me^{2+}Me^{3+}{}_2O_4$
Wuestite, solid solution of iron(II)-oxide with MgO and MnO	$(Fe_{1-x-y}, Mg_x, Mn_y)O_z$
Free lime, calcium oxide	CaO
Amorphous	. . .

TABLE 3 Slag, Steelmaking, Electric Furnace (Carbon Steel Production)—EAF C

Major Primary Mineral Constituents	Molecular and Structural Formula
Larnite, beta-dicalcium-silicate	beta-Ca_2SiO_4
Srebrodolskite, calcium-iron-oxide	$Ca_2Fe_2O_5$
Brownmillerite, calcium-aluminum-iron oxide	Ca_2AlFeO_5
Spinel	$Me^{2+}Me^{3+}{}_2O_4$
Wuestite, solid solution of iron(II)-oxide with MgO and MnO	$(Fe_{1-x-y}, Mg_x, Mn_y)O_z$
Gehlenite, calcium-aluminum-silicate	$Ca_2Al_2SiO_7$
Bredigite, calcium-magnesium-silicate	$Ca_{14}Mg_2Si_8O_{32}$
Amorphous	. . .

TABLE 4 Slag, Steelmaking, Electric Furnace (Stainless/High-Alloy Steel Production)—EAF S

Major Primary Mineral Constituents	Molecular and Structural Formula
Bredigite, calcium-magnesium-silicate	$Ca_{14}Mg_2Si_8O_{32}$
Larnite, beta-dicalcium-silicate	beta-Ca_2SiO_4
Gamma-dicalcium-silicate	gamma-Ca_2SiO_4
Merwinite, calcium-magnesium-silicate	$Ca_3MgSi_2O_8$
Cuspidine, calcium-fluoride-silicate	$Ca_4F_2Si_2O_7$
Wuestite, solid solution of iron(II)-oxide with MgO and MnO	$(Fe_{1-x-y}, Mg_x, Mn_y)O_z$
Periclase, magnesium oxide	MgO
Spinel	$Me^{2+}Me^{3+}{}_2O_4$
Mayenite, calcium-aluminum-oxide	$Ca_{12}Al_{14}O_{33}$
Portlandite, calcium hydroxide	$Ca(OH)_2$
Calcite, calcium carbonate	$CaCO_3$
Amorphous	. . .

6.1.8 Slag, steelmaking, electric furnace (stainless/high-alloy steel production)—EAF S, CAS No. 91722-10-0 (Table 4).

6.1.9 Slag, steelmaking—SMS, CAS No. 65996-71-6 (Table 5).

7. Criteria

7.1 The slag should meet the following criteria in order to be designated as a product:

7.1.1 *Definition*—The production of the molten material should be similar to the one of those outlined in Section 5 for the type of slag being addressed.

TABLE 5 Slag, Steelmaking—SMS

Major Primary Mineral Constituents	Molecular and Structural Formula
Gamma-dicalcium-silicate	gamma-Ca_2SiO_4
Larnite, beta-dicalcium-silicate	beta-Ca_2SiO_4
Bredigite, calcium-magnesium-silicate	$Ca_{14}Mg_2Si_8O_{32}$
Mayenite, calcium-aluminum-oxide	$Ca_{12}Al_{14}O_{33}$
Cuspidine, calcium-fluoride-silicate	$Ca_4F_2Si_2O_7$
Spinel	$Me^{2+}Me^{3+}{}_2O_4$
Free lime, calcium-oxide	CaO
Periclase, magnesium-oxide	MgO
Gehlenite, calcium-aluminum-silicate	$Ca_2Al_2SiO_7$
Merwinite, calcium-magnesium-silicate	$Ca_3MgSi_2O_8$
Srebrodolskite, calcium-iron-oxide	$Ca_2Fe_2O_5$
Brownmillerite, calcium-aluminum-iron oxide	Ca_2AlFeO_5
Wuestite, solid solution of iron(II)-oxide with MgO and MnO	$(Fe_{1-x-y}, Mg_x, Mn_y)O_z$
Hatrurite, tricalcium-silicate	Ca_3SiO_5
Portlandite, calcium hydroxide	$Ca(OH)_2$
Calcite, calcium carbonate	$CaCO_3$
Brucite	$Mg(OH)_2$
Amorphous	. . .

7.1.2 Frequently found mineral components that are usually identified in iron and steel slags are given in Section 6. When samples are analyzed by the techniques discussed in 8.2.1, the major mineral constituents, items constituting greater than 10 % of the sample, should correspond with the appropriate table in 6.1 (Note 3).

NOTE 3—The amorphous portion of a slag XRD can exceed 10 % when air cooled.

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7.1.3 *Environmental*—The material should meet all applicable environmental regulations of the local governmental agencies in effect at the time of use.

8. Sampling and Testing

8.1 *Sampling:*

8.1.1 Sample the material in accordance with Practice D75/D75M. The slag sample can be obtained immediately after the material is removed from the cooling area or after/during processing.

8.1.2 Samples should be reduced to the appropriate size for testing in accordance with Practice C702/C702M.

8.2 *Testing:*

8.2.1 The combination of XRD (X-ray diffraction)[6] (bulk analysis) and PARC (phase recognition and characterization)[7] microanalysis can provide an accurate tool for mineralogical characterization of steel slag. (See Note 4.)

8.2.1.1 Powdered XRD-Rietveld analysis[8] is used for crystalline phase identification and corresponding phase amounts.

8.2.1.2 SEM-PARC results in amounts and chemical composition of individual crystalline and amorphous phases.

NOTE 4—The XRD, Rietveld, and PARC techniques are utilized for determining quantitative values of the mineral components for the characterization of slag in the European Reach program. The data

[6] *Methods and Practices in X-Ray Powder Diffraction*, 3rd ed., International Centre for Diffraction Data, Newtown Square, PA, 1989.

[7] Van Hoek, C., Small, J., and Van der Laan, S., "Large-Area Phase Mapping Using PhAse Recognition and Characterization (PARC) Software," *Microscopy Today*, Vol 24, No. 5, 2016, pp. 12–21.

[8] *The Rietveld Method*, Young, R. A., Ed., Oxford University Press, 1993.

presented in this guide was determined using these techniques as well as ICP (inductively coupled plasma) and XRF (X-ray fluorescence).

9. Keywords

9.1 ACBF slag; blast furnace; BOF slag; EAF slag; electric furnace; slag; slag composition; steel furnace

APPENDIX

(Nonmandatory Information)

X1. TERMINOLOGY (DESCRIPTIONS)
(for reference purposes only)

X1.1 International Glossary of Terms – World of Iron and Steel Network 2020

X1.1.1 This glossary contains terms and phrases that are commonly used by those who are involved with the production, handling, management, storage, value add applications, and use of iron and steel slags (ISS) across the globe.

X1.1.2 Stakeholders within the iron and steel slags value chain have used these terms for many years, with other modern terms, for example, co-product, have been included over time which better define the essential role of slag production to the primary products of iron and steel.

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X1.1.3 The acronym ISS was first used in 2010 and subsequently globally adopted and encouraged through the World of Iron and Steel Slag Network (WoISS).

X1.1.4 This glossary of terms is an attempt to aid in future standardization, and reflect these terms in common usage across the industry. Additionally, some ASTM, allied products, environmental, and regulatory terms associated with ISS are included for comparison purposes. The ASTM terms and definitions utilized are related to Terminologies C125 and D8.

X1.1.5 Contributions, suggestions, corrections, and/or improvements to this living document are welcome. Please submit these to the Australasian (Iron & Steel) Slag Association (asa-inc.org.au), the National Slag Association (nationalslag.org), or EuroSlag (euroslag.com).

X1.2 Terminology

X1.2.1 *Definitions:*

X1.2.1.1 *aggregate*—material complying with the specified grading requirements for fine and coarse aggregates. It may be produced from rock, gravel, metallurgical slag, or artificial stone.

X1.2.1.2 *aggregate*—a granular material used as a construction material, meeting the requirements of road and paving applications. **D8**

X1.2.1.2.1 *Discussion*—Examples of aggregate include sand, gravel, shell, slag, and crushed stone. See *coarse aggregate* and *fine aggregate* for more information.

X1.2.1.3 *aggregate*—granular material such as sand, gravel, crushed stone, or iron blast-furnace slag, used with a cementing medium to form hydraulic-cement concrete or mortar. **C125**

X1.2.1.4 *air-cooled blast furnace slag (ABS)*—after separating from the heavier iron, the slag is typically tapped or poured onto ground bays to air cool to form a crystalline aggregate.

X1.2.1.5 *air cooling*—process where the slag is allowed to cool down slowly by leaving it in contact with ambient temperature air.

X1.2.1.6 *AOD process*—AOD stands for Argon Oxygen Decarburization, a refining process associated with the production of stainless steel. Most stainless steel is initially produced in an electric arc furnace before being transferred to a separate ladle furnace for refining to achieve the precise metallurgical content required, a process known as secondary metallurgy. In the AOD process, a mixture of argon and oxygen is blown through the molten steel in the ladle furnace, and the oxygen achieves the main objective of oxidizing unwanted carbon in the steel melt. But because the vital and expensive chromium contained in all stainless steels is also prone to oxidation and subsequent loss with the process slag, the argon is introduced to inhibit this reaction.

X1.2.1.7 *ash*—the solid residue from combustion processes. Industrial combustion processes mostly aim to extract energy from coal, oil, or even domestic waste. The primary aim is therefore not to obtain valuable materials, as it is in metallurgical processes, where the focus is on obtaining a metal.

X1.2.1.8 *basic oxygen furnace (BOF)*—also known as LD converter or Basic Oxygen System (BOS), is a steel making furnace in which hot metal from the blast furnace, with some amounts of steel scrap, is converted into steel. High-purity oxygen is blown through the molten bath to lower the carbon content. Fluxes are used to reduce other unwanted elements. Those fluxes combine with silicates and oxides to form liquid slag that floats on the surface of the hot metal. Also see Guide D8021 for further information.

X1.2.1.9 *basic oxygen furnace slag (BOF slag)*—also known as LD converter slag or Basic Oxygen System Slag (BOS) are slags from a steel making furnace which are defined as co-products. The slag is removed from the vessel after the exothermic refinement of molten iron and recycled steel in the presence of fluxes and oxygen. The slag is typically dark gray in color and characteristically harder than blast furnace slag