DEPARTMENT OF COMMERCE

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BLAST FURNACE SLAG AS CONCRETE AGGREGATE

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In the latter part of 1919 a brief summary of tests on crushed blast furnace slag as aggregate for concrete was prepared by the Bureau, chiefly for the purpose of facilitating replies to individual inquiries for information on this subject. In revising this summary for further distribution it seemed desirable to include somewhat more general information concerning blast furnace slag, as well as the results of additional tests. The information presented herewith is compiled from various sources, but the results of tests are confined to those obtained in the Bureau's laboratories. Other tests are reported in some of the articles listed in the appended bibliography.

WHAT SLAG IS

The following concise statement regarding the composition and production of blast furnace slag is quoted from an article by H. J. Love in "The Engineering World", August 15, 1919.

"Blast furnace slags are essentially silicates of alumina and lime. Stand an elongated steel barrel 90 to 100 ft. long and from 25 to 35 ft. in diameter on end, line it with fire-brick at the upper end and with hollow bronze blocks, water-cooled, at the base, and under the bottom place a fire-brick basin. Arrange for an intensely hot blast of air to be introduced at a point near the bottom; fill the barrel with alternate layers of coke, limestone and iron ore and start the fuel burning. After the fires are started and the blast turned on, the temperature in this stack will vary from approximately 300°F near the top to 3500°F at the bottom, with the following results as the process is continued.

The iron in the ore is originally combined with silica and alumina through well-defined chemical laws; however, this silica and alumina possess a greater affinity for lime than they do for the iron, and in the presence of such intense heat as is present in a blast furnace, become free from the ore and combine with the limestone. This new union forms a substance possessing enough difference in specific gravity from that of the freed iron to cause it to float on the surface of the material in the basin at the bottom of the barrel. The new combination is called 'Blast Furnace Slag.'

There are two openings in the base of a blast furnace, and the slag is drawn off by means of the one above the level of the molten iron by gravity to either pits immediately adjoining the furnace, or, if room is not available at that point, into ladles on standard railway trucks and hauled to some point where land is available, where it is poured out onto 'banks' or modified 'pits', where it is allowed to cool."

PREPARATION OF SLAG FOR CONCRETE AGGREGATE

The slag is removed from the banks by steam shovels, and conveyed to crushing and screening plants, where the processes of sizing and grading are essentially the same as for the preparation of stone aggregates. Typical blast furnace slag as prepared for concrete aggregate is of greyish color and weighs approximately 2000 lb. per cu. yd. The surfaces of the fragments are usually pitted due to the cellular structure of the mass.

The fine aggregate from slag corresponds to the screenings from a stone crushing plant, and like the latter tends to produce more harsh working concrete mixtures than ordinary bank or river sand on account of the roughness and sharpness of the grains. Attention should be called, however, to the fact that finely divided slag is sometimes produced by pouring molten slag into pits of water, thereby yielding a "granulated slag" which is quite different in its physical properties from the fine material produced by crushing and screening the air-cooled slag. Only the latter is recognized as suitable for fine aggregate in concrete.

EXTENT TO WHICH SLAG HAS BEEN USED AS CONCRETE AGGREGATE

Blast furnace slag has been used as concrete aggregate for many years in all types of construction. The earlier use of slag for this purpose naturally developed in the furnace districts, where the problem of waste disposal was acute, and where conditions were such as to warrant a trial of the material for any purpose to which it might prove adapted. Accordingly we find that slag concrete was used in the Birmingham district more than thirty years ago, first in plant and machinery foundations, and later for all kinds of concrete work. In the Lehigh district in eastern Pennsylvania, records show that slag concrete was used by the Philadelphia and Reading Railroad in 1890, and by the Atlas and other cement companies in 1895. In the Pittsburgh, Cleveland and Chicago districts also, the continuous use of slag concrete dates back to the early nineties. One of the earliest reinforced slag concrete buildings was erected in Philadelphia in 1897. When this building was torn down in 1913, both concrete and reinforcement were found to be in excellent condition. Railroad bridges and culverts have been built of slag concrete since the use of slag in reinforced concrete construction was first attempted. Two notable examples of slag concrete bridges are referred to in the appended bibliography. During the last decade slag concrete has been extensively used in road construction, and there are now in service in various parts of the country more than 100 miles of slag concrete roads.

TESTS OF SLAG AS CONCRETE AGGREGATE

Considerable work has been done to determine the value of crushed slag as concrete aggregate, and reports of numerous tests are cited in the bibliography at the end of this circular. The Bureau of Standards has completed tests of the product of four different slag companies. These tests are reported in the tables below.

National Slag Company Series .- Tests were made in 1916. Slag came from plant of National Slag Company, (Offices Widener Building, Philadelphia, Pa.), at South Bethlehem, Pa. Slag was referred to as "granulated" in correspondence, but it was a crushed air-cooled bank slag.

Birmingham Slag Company Series.- The basic or "furnace" slag that was used in these tests, made in 1917 and 1918, came from the crushing plant of the Birmingham Slag Company, (Birmingham, Ala.), at Ensley, Ala., and the sand was their No. 7, 1/4 in. to 0 in. slag sand. The acid or "foundry" slag also used in the tests was produced at another pit.

New England Slag Company Series.- The slag used in the New England Slag Company series, made in 1917 and 1918, was the output of the Barnum Richardson Iron Company. It was crushed, however, by the New England Slag Company, East Canaan Conn. Charcoal fuel, native ore, and local limestone were used in the production of the slag, and both the coarse and fine aggregates were furnished crushed.

Wight and Company Series.- The slag used in the tests of Wight and Company materials, made in 1920, was crushed material out of their pits at Longdale, Va.

Contents of Tables

Table I. gives the gradation of the aggregates used in the four series. In all cases the sand and gravel came from the Potomac River. Table II. reports detailed chemical analyses of the slags of the first three series, and strength tests are reported in detail in Table III.

TABLE 1.- Gradation and Unit Weight of Aggregates

Coarse Aggregates

Size of opening, in.	Per cent Passing Sieves 1.5	1.0	.75	.50	.25	.187	Weight cu.ft.1
Nat'l Slag Company							
Coarse slag	100.0	86.0	55.2	12.5	0.6	--	72.0
Medium slag	100.0	100.0	100.0	100.0	57.4	6.2	71.6
Potomac gravel	100.0	98.4	92.1	62.6	4.1	--	103.0
Birmingham Slag Co.							
Crushed furnace slag	100.0	90.5	68.8	23.0	2.6	--	76.9
Crushed foundry slag	100.0	94.5	84.9	44.3	6.8	--	98.8
Potomac gravel	100.0	89.9	46.3	21.2	1.4	--	103.0
New England Slag Co							
Crushed slag	100 0	98.8	87.4	33.7	4.0	--	89.6
Potomac gravel	100.0	69.9	46.3	21.2	1.4		103 0
Wight & Co.							
Crushed slag	100.0	----	25.5	----	2.0	--	85.0
Potomac gravel	100.0	----	25.0	---	0 0	--	109.0

Fine Aggregates

	Per cent Passing U.S. Standard Sieves						Weight
Number	4	8	16	30	50	100	cu.ft
Size of opening	.187	.094	.047	.0234	.0117	.0059	lb.
Nat'l Slag Co.							
Slag sand	100.0	66.0	40.8	24.6	14.2	7.3	86.7
Potomac sand	99.5	86.4	72.1	49.4	21.3	6.0	98.0
Birmingham Slag Co.							
Slag sand	94.3	65.0	36.8	17.7	9.7	6.3	85.5
Potomac sand	100.0	97.7	92.2	70.1	28.1	8.0	98.0
New England Slag Co							
Slag sand	97.6	74.5	55.7	40.1	27.7	16.5	104.5
Potomac sand	100.0	97.7	92.2	70.1	28.1	8.0	98.0
Wight & Co.							
Potomac sand	97 3	79.6	61.9	44.9	15.9	3.3	114.0

TABLE II.- Chemical Analyses of Slag Aggregates

Aggregate	SiO_2	Al_2O_3	Fe O	CaO	MgO	SO_3	Sulphide Sulphur
Nat'l Slag Company							
Coarse furnace slag*	31.41	12.76	1.10	36.24	12.86	0.95	1.16
Medium furnace slag	35.02	12.98	0.80	36.46	12.41	0.66	1.31
Slag sand **	35.78	13.11	0.73	35.60	9.20	0.99	1.43
Birmingham Slag Co.							
Crushed furnace slag	34.96	12.29	0.86	41.59	7.68	1.01	0.59
Crushed foundry slag	37.22	14.32	0.54	44.68	1.58	0.09	1.08
Slag sand	33.84	12.48	1.24	40.36	7.45	0.74	0.58
New England Slag Co							
Crushed slag	45.82	16.58	3.08	18.78	13.93	0.12	0.06
Slag sand ***	49.20	14.94	3.70	17.04	12.01	0.10	0.04

* Insoluble residue 3.05
** Loss on ignition 2.90
*** Loss on ignition 0.77

TABLE III.- Concrete Strength Tests

National Slag Company Series

Combination No.	Aggregate Combinations: Fine	Coarse	1;1½;3 Mix: % Water	Compressive strength: 7 das.	28 das	6 mo.
1	Potomac sand	Potomac gravel	8.9	1093	1921	---
2	Potomac sand	Coarse slag	11.2	1925	2648	3918
3	Slag sand	Coarse slag	10.3	1208	1625	2465
4	Potomac sand	Medium slag	11.5	1404	2892	3280

Aggregate Combination No.	1;2;4 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.	1:3;6 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.
1	8.6	684	1191	---	7.7	594	1016	---
2	11.0	1555	1981	3135	10.7	920	1497	2148
3	12.0	915	1990	3332	11.6	587	1077	2058
4	---	---	----	----	12.5	622	730	1638

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Birmingham Slag Company Series

Combination No.	Aggregate Combinations: Fine	Coarse	1:1½:3 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.
1	Potomac sand	Potomac gravel	8.7	1778	2790	3750
2	Potomac sand	Foundry slag	9.6	1753	3020	4150
3	Slag sand	Foundry slag	9.0*	----	2690	3515
4	Potomac sand	Furnace slag	10.7	1933	2406	4400
5	Slag sand	Furnace slag	10.6	1973	2850	3270

Aggregate Combination No.	1:2:4 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.	1:3:6 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.
1	8.1	1194	1949	3890	7.6	649	1210	1915
2	8.7	1322	2689	3570	8.0	985	1937	2837
3	8.8*	953	1703	2248	7.4*	---	1060	1740
4	10.0	1396	2165	3395	9.8*	774	1328	2405
5	9.9*	864	1565	1800	10.0*	519	582	1547

New England Slag Co. Series

Combination No.	Aggregate combinations: Fine	Coarse	1:1½:3 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.
1	Potomac sand	Potomac gravel	7.9	2550	3365	4040
2	Potomac sand	Crushed slag	8.7	2563	3530	4165
3	Slag sand	Crushed slag	8.5	1860	3230	4835

Aggregate Combination No	1:2:4 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.	1:3:6 Mix: % Water	Compressive strength: 7 da.	28 da.	6 mo.
1	7.9	1730	3250	4180	7.3	1230	1640	2800
2	8.7	2280	2820	3910	8.1*	1280	1840	2360
3	8.3	1810	2210	3080	7.6*	1095	1300	2370

proper proportioning. Slag sand is harsh working because of its lack of fine material, and its working qualities can be improved by the addition of small amounts of fine sea sand, hydrated lime or other fine material, or by using a larger proportion of slag sand.

The tests are not extensive enough to determine the durability of slag concrete, but to the extent of the tests there were no signs of disintegration due to sulphide sulphur or other causes.

SPECIFICATIONS FOR SLAG

In the past there has been more or less hesitation on the part of engineers and architects to permit the use of slag aggregate in important concrete work without certain special limitations on the material, such, for example, as a minimum weight per cubic foot, or some restriction on the sulphur content. Experience has shown, however, that there is probably no greater need for such restrictions in the case of blast furnace slag than for other commonly used and acceptable aggregates. Experience with light weight aggregates during the war period indicated clearly that weight per cubic foot was no criterion of the suitability or unsuitability of a material as concrete aggregate, and examination of the reinforcing steel in numerous structures of slag concrete that have been demolished has been wholly reassuring so far as corrosive tendencies are concerned.

In this connection, however, attention should be called to certain cases recently reported, wherein structures of slag concrete, erected within the last two or three years, have developed "popping", not unlike that which sometimes occurs in lime plasters, but on a larger scale. Probably not more than half a dozen cases of this sort are on record, but the phenomenon has given rise to some question as to the "inertness" of slag and has aroused considerable interest on the part of engineers and others who are concerned with specifications for concrete aggregates. So far as they have gone, investigations have indicated that the trouble is not due to the slag, but to accidental inclusions of flux stone, which in the course of time have gradually "slaked", and by expansion have developed sufficient pressure to cause spalling. It is believed that these inclusions are traceable to careless operation of the furnaces and improper control of the molten slag which goes to the pits, and that the producers of slag are now fully aware of the precautions which are necessary to insure elimination of this material from their product.

In the present state of our knowledge, therefore, there are but two special restrictions that would seem to be justified in specifications for slag aggregate: one is that the slag shall be air-cooled, and the other is that it shall be free from flux stone. It is obvious, of course, that as laboratory tests of aggregate can not be relied upon to detect the presence or absence of occasional inclusions of this sort in many tons of slag, it is up to the producers to insure that these inclusions shall not occur.

SHORT BIBLIOGRAPHY ON USE OF

BLAST FURNACE SLAG AS CONCRETE AGGREGATE

. Blast Furnace Slag as a Structural Material. J. A. Shinn.
Proc. Engr's Soc. of W. Pa. 20, 157-176, 1904.
Reviews uses to which slag has been applied, and gives references to earlier tests and articles

. Blast Furnace Slag as Aggregate in Concrete. W. A Aiken,
Proc. A. S. T. M., 14, Part 2, 282-297, 1914.
From an extensive series of tests, summarized in the paper, the author concludes that slag is in every way satisfactory for use as aggregate in concrete.

. German Utilization of Iron Furnace Slag. Commerce Reports
Feb. 10, 1914
Review of the uses of slag as a building material in Germany. Quotes from numerous reports and articles on the general subject.

. Ornamental Bridge at Akron Built of Slag Concrete.
Eng. News, 74, 769-70, Oct. 21, 1915.
Illustrated description of a slag concrete bridge 190 ft. high, containing 5000 cu. yd. of concrete, completed in 1915.

. Utilization of Iron and Steel Works' Slags. E C Brown.
Proc. Engr's Soc. of W. Pa. 31, 884-927, 1915
Valuable review of the uses of slag. The discussion of the paper contains much interesting testimony on experiences with slag as concrete aggregate during the past 25 years.

. Slag as Concrete Aggregate. S. E. Thompson.
Proc. Am. Conc. Inst. 13, 107-16, 1917
Presents results of tests showing very high strength of slag concrete. No authentic cases of deterioration of slag concrete, or of rusting of steel embedded in such concrete, have been discovered.

. Slag Used to Complete Bibb County, Georgia, Road Contract. Concrete Highway Magazine, October, 1918.
Supply of crushed grainite aggregate for this job gave out, and nearly a mile was completed with blast furnace slag. After a year's heavy traffic the slag concrete pavement was in excellent condition.

. Tests of Blast Furnace Slag as the Coarse Aggregate in Concrete. P. J. Freeman, Proc. Am. Conc. Inst. 14, 95-100, 1918
Gives results of compr ession tests on concretes made of slags from nine different sources, in comparison with six other aggregates. From tests up to one year, the slag concretes were superior to the others.

. Slag as an Aggregate for Concrete Ships. C. C. Meyers, Iron Age July 18, 1918.
Describes an extensive series of tests in which slag concrete was found to be superior to crushed stone concrete in compressive strength, bond strength and resistance to impact.

). Blast Furnace Slag in Concrete and Reinforced Concrete. J. E. Stead. Eng. World, 14; 36-38, Feb. 15, 1919; 14, 25-27, March 15, 1919.
Discusses the chemical composition of slag in relation to its suitability for concrete aggregate, and concludes that clean slag is superior to limestone, trap rock and pebbles for any kind of concrete.

1. Blast Furnace Slag. H J Love, Eng. World, 15, 29-31, Aug. 15, 1919.
Describes production of slag and its application to the building of roads and concrete structures.

2. Fire Tests of Concrete Columns. W. A. Hull, Proc. Am. Conc. Inst. 15, 89-107, 1919.
Among tests of various aggregates as to fire resistive properties, blast furnace slag makes favorable showing.

3. Versuche mit Hochofenschlacke (Tests with Blast Furnace Slag) H. Burchartz. Stahl u. Eisen, 41, 193-200, Feb. 10, 1921.
Concrete from blast furnace slag is said to harden as well in salt water as in fresh, and to be as durable as gravel concrete.

14. In Wrecked Slag Concrete Little Corrosion of Reinforcing is Shown. Concrete, 17, 128-9, March 1921.
Illustrated description of progress in wrecking the Ulmer Building, Cleveland, of which the frame was built of slag concrete in 1905-6. In general the reinforcing steel was found to be in excellent condition.
Reported also in Eng. News Rec. Feb 3, 1921.

15. Long Arch Bridge Built of Slag Concrete, W. C. Fry, Jr. Eng. News-Rec. 86, 840-844, May 19, 1921.
Describes construction at Reading Pa. of what is probably the largest slag concrete bridge in existence, involving 21,000 cu.yd. of concrete. Slag was selected as permitting maximum economy in design and construction.

16. A Study of the Composition of Blast Furnace Slags Suitable for Concrete Aggregate. L. G. Carmick. Proc. A. S. T. M. 1921.
Investigates the chemical composition of slags in relation to the property of spontaneous disintegration. The results are reassuring so far as commercial blast furnace slag is concerned.

17. General information on all phases of the slag industry is published in the Official Organ of the National Slag Association, H. J. Love, Secretary, Leader-News Bldg., Cleveland, Ohio.