Reprinted from N.B.O. Journal October 1962 issue.

A Light Weight Aggregate from the Durgapur Slag

by S.K. CHOPRA AND C.A. TANEJA
Central Building Research Institute, Roorkee

ON treating molten slag with a limited quantity of water under controlled conditions an expanded or "foamed slag" is formed. This product is being produced commercially in several countries and is commonly used as a lightweight aggregate. Among the latter type expanded slag is probably the simplest and cheapest to manufacture.

Some work on samples of expanded slag from the two old Steel Plants has already been reported[1,2]. Trials on the foamability of the slag from the two blast furnaces at the Durgapur Iron & Steel Plant were carried out in April, 1961 with the cooperation and help of the management. This report gives a brief account of the trials and the main findings.

General :

The main factors which control the properties of expanded or foamed slag are chemical composition, temperature and viscosity of the molten slag, and the method and speed of quenching etc. Blast furnace slags are mainly composed of calcium oxide, magnesium oxide, alumina and silica with small amounts of sulphur, iron oxide, titanic and manganic oxides. Generally speaking, at a particular temperature the viscosity increases with increasing contents of silica and alumina.[3] Magnesia increases mobility and has affinity for sulphur[4]. A slag which is cold does not foam satisfactorily while a very hot slag may foam to such an extent that the final product is much too glassy and friable.

Foamability of the Durgapur Slag

A simple way of testing the foamability of a slag is by the 'Spoon and Bucket Method' in which a spoonful of molten slag is poured into an ordinary mild steel bucket containing water up to a depth of about 2 in. (Any slag sampling spoon can be used for this purpose). The spoon is heated sufficiently before taking the slag sample and is emptied in the bucket with one jerk. After one minute the bucket is turned over to discharge the foamed slag 'core' which is left glowing undisturbed for 10-15 minutes. This allows the core of the product to harden. The desired quantity of sample is produced by repeating the process. The sample thus collected is then crushed to suitable sizes and tested for its suitability as an aggregate.

Trials were first carried out with the slag from the furnace No. 1, i.e. Kasturba, slag being taken from the runner. The flushing temperature of the slag as measured with the help of an optical pyrometer varied from 1360° to 1420°C. When the depth of water in the bucket was 2 inches or even 1 inch, the slag showed a tendency to granulate instead of expanding. The quantity of water in the bucket was therefore reduced to ½ inch. The sample produced was of a weak, frothy and friable nature usually known as 'feather weight slag'. In view of this 1 in. of sand was placed at the bottom of the bucket and saturated with water so as to leave about a ¼ in. sheet of water on top of the sand. The foamed slag produced was still weak and friable. Finally a 1 in. layer of saturated sand alone gave a strong product though the structure was not uniform. It was concluded that this slag required a smaller quantity of water to produce a strong tough variety of foamed slag.

In view of these results another set of trials was made with the quantity of water in the bucket being reduced by steps from 100 c.c. to 10 c.c. On the basis of a visual examination of the products obtained, it was decided to collect two samples of expanded slag i.e. A. & B prepared with 15 and 30 c.c. of water respectively.

Similarly two samples C & D were prepared from the slag from the furnace No. 2 i.e. Kamala.

Properties of Foamed Slag Aggregate

The properties of these trial samples of expanded slag were tested according to the procedures specified in ASTM Designation: C331-53 T for Lightweight Aggregates Concrete Masonry Units. The unit weights of the various samples are reported in Table 1 and pass the unit weight requirements laid down in the standard.

Typical chemical analysis (Table No. 2) of the slags from the two furnaces at Durgapur was provided by the Control Laboratories at the Steel Plant. The chemical composition of expanded slag is similar to that of molten slag except that the total amount of combined sulphur may be lower. During the foaming process, the action of water on sulphide in slag causes an evolution of sulphur dioxide and hydrogen sulphide with a consequent reduction in the quantity of sulphur.

The trial samples of foamed slags (A & C) were gray to black in colour and poorly crystalline in character. The X-ray powder diffraction pattern of the powdered sample indicated mainly the presence of gehlinite. The average refractive index was 1.653 that of pure well crystallised gehlinite being 1.665. The lighter varieties (samples B & D) had white encrustations over the grey aggregate. The encrustation is weak and frothy in character. It is glassy in nature and has an average refractive index of 1.636—1.638 which is very close to that of glass of a composition of gehlinite.

Foamed slag is a very clean lightweight aggregate and seldom contains any deleterious materials. It is also an inert aggregate. When used in concrete, the finer fractions have a certain amount of hydraulic activity which increases the strength of a concrete of which they are constituents.

A staining test was also performed to check the presence of any staining materials. The intensity of stains was very light, thus meeting the standard specifications.

Though the standard does not include crushing strength, samples of the foamed slag were subjected to this test. A cylindrical mould was filled with the course fraction (3/8 in. to No. 4) and load applied so that the crushed material passing 14 mesh was 10 per cent. The load applied was taken as the crushing strength of the aggregate. This test indicates the relative resistance of aggregates to attrition and breakage during mixing and predicts to some extent the strength property of lightweight aggregate in concrete. The results reported in the Table No. 3 show that the crushing strength is higher for the heavier product. The results also show that in general the trial samples of foamed slag are suitable for use as lightweight aggregates.

Properties of Foamed Slag Concrete.

Foamed slag is used principally as an

aggregate in the manufacture of concrete masonry units[4]. The strength of the blocks depends mainly on the grading and crushing strength of the aggregate, the proportion of cement to aggregate and on the quantity of water. The grading of the aggregate also affects the texture of the exposed surfaces and the insulating and sound absorbing properties of the blocks.

It is desirable that blocks should be light in weight and provide good thermal insulation. These properties were therefore determined. The foamed slag samples A and B were mixed and crushed to obtain various sizes of the aggregate which were combined according to the grading given in the Table No. 4.

Four inch concrete cubes were cast using 1 part of cement to 7 parts of mixed aggregate by volume. The most suitable water content was determined by the tendency of the mix to produce a smeared surface on the freshly moulded cubes. The water cement ratio thus chosen was 0.92.

Slag and water were mixed together for one minute. Cement was then immediately dusted over the surface of the wet slag and the mixing was continued for one more minute. Cubes were then cast by vibration, demoulded after 24 hours, cured in not less than 90 per cent relative humidity for 28 days and crushed for compressive strength.

The drying shrinkage of the above mix was determined by consolidating it in steel moulds of 2″×2″×11″ dimensions curing the test specimens for 7 days at a relative humidity of 95—100 per cent when initial measurements were taken. The specimens were then stored at 81°F at about 50% relative humidity for the duration of the test. The results are reported in Table No. 5.

A minimum compressive strength of 400 p. s. i. has been specified in B.S. 2028/1953 for blocks to be used for external walls, when protected by a rendering. The data in table No. 5 shows that lightweight concrete blocks meeting the requirements of B.S. 2028 : 1953 can be prepared with the trial foamed slag aggregates. However, if the specifications laid down by the ASTM in their Designation are to be satisfied a richer concrete mix will have to be used. The properties of concretes prepared with samples C and D will be similar to those prepared with the above aggregate A & B.

Uses of Foamed Slag Concrete Blocks

Foamed slag blocks have long been recognized as a reliable product and have been incorporated in thousands of structures in U.S.A., U.K. and Continental countries. They are used not only for partitions and the inner leaf of external cavity walls but also for external load bearing walls. Rendering is, however, essential.

The general practice in U.K. is to use 18″×9″×9″ hollow blocks which can be erected at about three times the speed of comparable areas of brickwork, thus reducing overhead charges. Blocks have a high degree of thermal insulation, fire resistance and sound absorbing properties.

Foamed slag of higher density has been used in U.K. and in Europe for the construction of reinforced beams and floor and roof slabs in multistoreyed buildings.

Although from the present study it is not possible to make definite recommendations regarding the most suitable manufacturing process, Mr. W. Kinniburgh, Colombo Plan Expert on Lightweight Aggregate, has recommended foaming bed technique for consideration on account of its simplicity, low capital investment, low cost of production etc. The equipment required for the manufacture of this aggregate by this technique will be mostly indigenous. The selling price of this aggregate is estimated at Rs 16 per 100 cu. ft. which is quite attractive.

Conclusion

A study of the foamability of Durgapur slag indicates that the slag is suitable for the manufacture of foamed aggregate for use in concrete masonry blocks for two storeyed buildings. It is also suitable for in-situ concrete constructions.

Acknowledgements

The authors are grateful to the management and staff of the Durgapur Steel Plant for affording facilities for carrying out the trials on the foamability of the slag; and to Dr. G.P. Chatterji, Chief Metallurgist, for his keen interest and active cooperation. They are obliged to Mr. W. Kinniburgh, Colombo Plan Expert from U.K., for his helpful suggestions and some of the information made use of in this paper. They record their appreciation for the help of Shri Krishan Lal in carrying out trials at Durgapur.

This paper is being published with the permission of the Director, Central Building Research Institute, Roorkee.

References

1. Chopra S.K. and Lal, K. "Indian Slags as aggregate for lightweight concrete". The Indian Concrete Journal, Aug., 1959 bb. 2.4.

2. Chopra, S.K. Report on 'Investigations into the utilization of Indian Blast Furnace Slag in the Building Industry' Central Building Research Institute, Roorkee, 1961.

3. Machin, J.S. & Tin Boo Yee "Viscosity Studies of System CaO-Al_2O_3-SiO_2— Journal Amer. Cer. Soc. (1948), 31, pp. 200-204.

4. Sattele, L.F., 'Effect of Magnesia and low alumina in blast furnace slags on furnace operation and desulphurisation —Journal of Iron & Steel Institute, No. 2, 1940, P. 209A.

TABLE No. 1

Furnace	Sample	Density in lbs. per cu. ft.	
		3/8"—No. 4	No. 4 to dust
Kasturba	A	44—49	61—72
"	B	38—43	52—59
Kamala	C	43—50	50—55
"	D	34—35	50—52

TABLE No. 2

	Furnace No. 1 (Kasturba)				Furnace No. 2 (Kamala)
SiO_2	31.2	29.8	30.0	29.9	31.2
Al_2O_3	26.6	25.0	25.4	26.4	26.0
FeO	0.50	0.76	0.72	0.68	0.73
MnO	1.04	1.10	1.14	1.22	1.68
CaO	35.7	37.0	36.5	35.4	35.4
MgO	4.5	5.6	5.4	5.6	3.8
S	0.76	0.82	0.76	0.70	0.70

TABLE No. 3

Sample	Unit weight lbs./cu. ft.	Crushing strength in tons.
A	45	2.75
B	38	1.75
C	43	2.25
D	34	1.60

TABLE No. 4

Size Designation	Percentage	(by weight)	Passing sieves having square opening					
	¾ in.	½ in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 100
As per ASTM ½ in. to 0.	100	95 to 100	--	50 to 80	—	—	5 to 20	2 to 15
3/8 in to 0.		100	90 to 100	65 to 90	35 to 65	—	10 to 25	5 to 15
as used			100	90	65	—	25	15

TABLE No. 5

Sample	Density of Concrete in lbs./cu. ft.	Compressive Strength lbs./sq. in	Flexural Strength lbs./sq. in	Drying Shrinkage per cent
A	100	996	239	.035
B	95	916	164	.039