INDIAN SLAGS AS AGGREGATE FOR LIGHTWEIGHT CONCRETE

by S. K. CHOPRA and KISHAN LAL*

AMONGST aggregates used for lightweight concrete in other countries, expanded (or foamed) and granulated slags seem to find the maximum usage[1]. In U.S.A. alone, one out of every five lightweight concrete masonry blocks is produced from either of these aggregates[2]. Though India has yet to produce lightweight slag aggregates on a commercial scale, some exploratory work was undertaken by the Central Building Research Institute, Roorkee, in order to determine the suitability of slag concrete as a building material in India and to create an interest in the steel industry for the production of these aggregates at both the existing as well as the new steel plants.

Aggregates

The chemical analysis of expanded and granulated slags is given in *Table* 1. The expanded slag sample which was received in the form of lumps was crushed in the laboratory to particles of different sizes and the unit weights of different fractions of the slag showed only small variations. For example, the fractions (— 1½ in + ¾ in), (— ¾ in + ⅜ in), and (— ⅜ in + 3/16 in) were found to have unit weights of 42·1, 42·4 and 43·1 lb/ft^3, respectively, whilst the specified limit for coarse aggregates is 55 lb/ft^3. The unit weight of the granulated slag was found to be 61 lb/ft^3 which is within the permissible limit of 75 lb/ft^3 for fine aggregates[3].

TABLE 1. Chemical analysis of slag aggregates

Chemical constituent	Percentage content of constituent in	
	Expanded slag	Granulated slag
Silicon dioxide (SiO_2) ..	35·557	33·42
Iron and aluminium oxides (R_2O_3)	32·44	24·44
Calcium oxide (CaO) ..	30·66	37·34
Magnesium oxide (MgO)	2·652	3·46
Manganese oxide (MnO)	Traces	1·22
Soluble sulphates ..	Nil	Traces
Total sulphur	Traces	0·89

The aggregates were tested for the presence of deleterious substances according to the method recommended in ASTM Designation C 331–53T and passed the standard specifications laid down. The test for the presence of staining materials in the slag aggregates gave stain index values ranging between 0 to 20, which is well within the specified limits and shows that there is no likelihood of their staining masonry due to iron and iron compounds.

The accelerated sulphate soundness test[4] for testing the durability of the expanded slag aggregate was also carried out and the results given in *Table* 2 show a total loss of 8·3 per cent against the permissible limit of 15·0 per cent for coarse dense aggregate.

The mortar strength test as specified in ASTM Designation C 130–42T was performed to test the suitability of the expanded slag aggregate for making lightweight concrete. The results given in *Table* 3 show that mortars prepared with expanded slag developed strengths greater than the minimum specified in the standard, *i.e.* not less than 7 per cent of the strengths of the mortar prepared with graded standard (Ennore) sand.

TABLE 2. Sulphate soundness of expanded slag

Particle size		Grading of sample before test	Actual loss after test
Passing sieve	Retained on sieve	(per cent)	(per cent)
¾ in	½ in	51·5	3·4
½ in	⅜ in	25·4	3·1
⅜ in	3/16 in	23·1	1·8
			Total 8·3

TABLE 3. Mortar strength test

Material	Compressive strength (lb/in^2)	
	7 days	28 days
Standard sand mortar ..	3244	5194
Expanded slag mortar ..	2815	4233

Expanded slag concrete

The grading of the lightweight aggregate affects the weight and strength of the masonry units, the texture of the exposed surfaces, the insulating and sound absorbing properties, etc.[6] Though the grading requirements for lightweight aggregates for masonry units are specified in ASTM Designation C 331–53T, in practice, some experimentation is necessary for a particular production job in order to arrive at the best grading of the combined fine and coarse aggregates. The grading of the combined expanded slag aggregate used in the present study was fixed after several trials and is given in *Table* 4, together with the gradings that have been used successfully elsewhere[5] in the commercial production of concrete masonry units. The grading of the granulated slag sample is also given in *Table* 4.

Since the application of the water-cement ratio law for designing mixes and controlling the strength of lightweight concrete has not been found practical in the majority of cases, the proportioning of the lightweight concrete was done in the light of published data[6] on the relationship between compressive strength and cement content for expanded slag concrete. The proportion of cement to aggregate for a given strength depends upon the water absorption, grading and crushing strength of the aggregate, and also on the quantity of water used for mixing the cement and aggregate. The latter in turn depends on the consistency desired. According to Carlson[5], for any particular block mix, an attempt should be made to use as much mixing

*Central Building Research Institute, Roorkee.

TABLE 4. Recommended grading of slag aggregates as compared with standard aggregate for masonry units

Aggregate	Per cent (by weight) passing sieves						
	⅜ in	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100
Standard (fine)* ..	–	97	76	55	39	25	16
Standard (coarse)* ..	92	27	15	13	13	10	7
Granulated slag ..	–	97·42	89·17	58·4	22·45	8·92	5·02
Expanded slag	100	90·00	65·00	–	–	25·00	15·00

* As recommended by Carlson.

water as is possible, short of slumping or loss of desired open face shell texture (smearing). Generally, the maximum water content is determined by the tendency to produce smeared surfaces on freshly moulded units.

For the moulding of blocks the vibration (with pressure) type of machine was preferred over the tamper type because the former is known[5] to be more efficient and productive. In the present study a Winget block vibrating machine, was used for making the blocks.

Trials of moulding hollow blocks (dimensions 4½ × 9 × 17⅝ in with core volume 22·5 per cent) on the Winget machine from cement expanded slag mixes showed that mixes leaner than 1:5 by volume did not yield blocks of satisfactory surface texture and quality. A 1:6 mix required more water than a 1:5 mix and on vibration some segregation of materials was found to take place in the former case. A reduction in the quantity of fines in a 1:6 mix was also tried but this increased the harshness of the mix and introduced some honeycombing on vibration. A 1:5 mix was, therefore, selected. The properties of the concrete made from it and cured under wet gunny bags are as follows:

Bulk density .. .. 84 lb/ft³

Compressive strength:
- at 28 days .. .. 2,562 lb/in²
- at 90 days .. .. 3,178 lb/in²

Flexural strength:
- at 28 days .. .. 622 lb/in²
- at 90 days .. .. 753 lb/in²

Drying shrinkage:
- at 28 days .. .. 0·029 per cent
- at 90 days .. .. 0·053 per cent

The strength results show that concrete made with Indian expanded slag possesses strengths comparable to those reported elsewhere[5,6,7] and is suitable not only for making masonry units but also for structural concrete.

Granulated slag concrete

The moulding of hollow masonry blocks of 4½ × 9 × 17⅝ in size from wet mixes of Portland cement and granulated slag was not found practical on the Winget machine because of the poor moulding and cohesive qualities of the mixes and the poor resistance of freshly moulded units to cracking when handled. However, slag bricks of 9 × 4½ × 4 in could be made by pressing wet mixes of cement and granulated slag in a manually operated brick pressing machine[8].

Cement slag mixes of 1:6, 1:9 and 1:12 by volume were used for preparing the bricks. The optimum quantity of water required for moulding the bricks from these mixes was fixed by trial, and was found to be 20·0, 14·5, 11·0 per cent, respectively of the dry weight of the mix.

The freshly moulded bricks required 24 to 96 hours of hardening in 90 per cent humidity before being cured under wet gunny bags. Although curing under water was found to result in slightly higher strengths (see *Table* 5), continuous curing under wet gunny bags was adopted because the latter is more commonly employed in the field and also because moist-cured concrete is known to possess greater immunity to cracking for a high degree of restraint.[9]

TABLE 5. Effect of curing conditions on strength of 1:6 cement-slag mix

Curing condition	Compressive strength (lb/in²) at			
	7 days	14 days	28 days	90 days
Under wet gunny bag only	534	–	713	743
Under wet gunny bag for 7 days and then under water	–	579	851	885

TABLE 6. Properties of slag bricks

Mix proportion (by volume)	Bulk density (lb/ft³)	7 days water absorption (per cent)	Drying shrinkage (per cent)	Compressive strength (lb/in²) at		
				7 days	28 days	90 days
1:6 cement-slag	89·2	13·62	0·023	921	1,349	1,608
1:9 cement-slag	88·4	18·32	0·054	534	713	742
1:12 cement-slag	83·1	21·93	0·043	431	524	713
1:6 cement-slag (with greater quantities of water)	61·3	34·10	0·114	294	525	774
1:5 lime-slag	87·1	16·65	0·044	348	896	995

TABLE 7. Physical requirements of hollow load bearing and non-load bearing masonry units

Type	Minimum face shell thickness (in)	Minimum compressive strength (lb/in^2)		Maximum water absorption (lb/ft^3)	Maximum moisture content (per cent)
		Average of 5 units	Individual unit		
Load bearing	1¼ or over				
	Grade A *	1,000	800	15	40
	Grade B **	700	600	–	40
	Under 1¼ and over ¾	1,000	800	15	40
Non-load bearing		350	300	–	40

* For use in exterior walls below grade and for unprotected exterior walls above grade.
** For general use above grade where protected from the weather with two coats of Portland cement paint or other satisfactory waterproofing treatment by the purc

The physical and strength properties of the bricks are given in *Table* 6. The slag bricks have a bulk density much lower than that of dense concrete and considerably lower than that of burnt clay bricks. The water absorption of the slag bricks even after 7 days immersion in water is of the magnitude usually associated with lightweight concretes[10]. In all cases except one, the drying shrinkage is within the specified limit of 0·10 per cent and comparable to British slag concrete[11].

The physical requirements of hollow load bearing and non-load bearing masonry units are given in *Table* 7. The strengths at 28 days of the slag bricks (*Table* 6) show that while bricks made from mixes 1 : 6 and 1 : 9 are suitable for making load bearing masonry units, the bricks made from 1 : 12 mix are suitable only for non-load bearing purposes.

Though further reduction in the unit weight of the cement slag brick could be achieved by using greater quantities of water for mixing the constituents and moulding the bricks without any pressure, the bricks thus produced were not entirely satisfactory because of the considerable increase in water absorption and the drying shrinkage of the bricks thus obtained (*Table* 6).

The preparation of slag bricks from mixes of lime and slag was also tried and a volumetric mix of 1 : 5 was found suitable. The properties of these bricks (see *Table* 6) show that they are comparable to bricks from 1 : 9 cement-slag mix except that the strength at 7 days of the former is lower. In view of the general practice of using only 28 days cured units in the field, the lower strength at 7 days is not considered serious.

Conclusions

The expanded and granulated slag test samples from Indian iron and steel plants were found suitable as aggregates for making lightweight concretes, and they possess the requisite strength and other properties specified by the American Society of Testing Materials for load bearing and non-load bearing purposes. Therefore, the development of lightweight slag concrete products from Indian slags is recommended.

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References

1. Chopra, S. K., and Patwardhan, N. K. "Development of lightweight concrete in India." *Proceedings of the Symposium on Housing and Building Materials*, Vol. 2. National Building Organisation, New Delhi, 1956.
2. —— "Slag concrete masonry units." National Slag Association, Washington, 1954.
3. —— "Tentative specification for lightweight aggregates for structural concrete." ASTM Designation C 330-53 T. American Society for Testing Materials, Philadelphia, 1955.
4. "Method of test for soundness of aggregates by use of sodium sulfate or magnesium sulfate." ASTM Designation C 88-56 T. American Society for Testing Materials, Philadelphia.
5. Carlson, C. C. "Lightweight aggregates for concrete masonry units." *Journal of the American Concrete Institute*, November 1956, Vol. 28, No. 5, pp. 491–508.
6. Kluge, R. W. "Structural lightweight-aggregate concrete." *Journal of the American Concrete Institute*, October 1956, Vol. 28, No. 4, pp. 383–402.
7. Washa, G. W. "Properties of lightweight aggregates and lightweight concrete." *Journal of the American Concrete Institute*, October 1956, Vol. 28, No. 4, pp. 375–382.
8. Mohan, D. and Mani, D. R. "A study of brick and block making machines." Report issued by Central Building Research Institute, Roorkee.
9. Washa, G. W., Saemann, J. C., and Warren, C. "Effect of curing on the properties affecting shrinkage cracking of concrete block." *Journal of the American Concrete Institute*, May 1955, Vol. 26, No. 9, pp. 833-852.
10. —— "Specifications for lightweight aggregates for concrete masonry units." ASTM Designation C 331–53 T. American Society for Testing Materials, Philadelphia.
11. —— "Concrete made with lightweight aggregate." Digest No. 32. Building Research Station, Watford. July 1951.
12. —— "Specification for hollow load-bearing concrete masonry units." ASTM Designation C 90–52. American Society for Testing Materials, Philadelphia.
13. —— "Specification for hollow non-load-bearing concrete masonry units." ASTM Designation C 129–52. American Society for Testing Materials, Philadelphia.

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