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Building materials from granulated blast furnace slag—Some new prospects

S K Malhotra* & S P Tehri
Central Building Research Institute, Roorkee 247 667, India
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A fairly large quantity of granulated blast furnace slag is being used in the manufacture of portland slag cement and supersulphated cement. Efforts have been made at this Institute to explore other possible ways to utilize the surplus slag in the development of cementitious binders suitable for masonry and building bricks. The properties of these materials have been found to be comparable in properties to the specifications of conventional materials. The production of these materials have potential for partial replacement of high energy consuming portland cement and burnt clay bricks.

The scarcity as well as the rising costs of conventional building materials in construction industry pose threats to the mass housing programme in the country. Thus, a substantive need to develop alternative and cheaper building materials has been identified. The search for such types of materials has led to the utilization of some industrial by-products. With the rapid pace of indigenous industrialization, the production of various by-products is also on the increase. The accumulation of these wastes is not only a burden on an industry, but also affects the environment adversely. Conversion of these by-products into some useful building materials has attracted world-wide attention in the recent past.

At present about 10 million tonnes of molten slag is being produced in the country, out of which about 2.5 million tonnes are being granulated. Several different possibilities exist for the utilisation of this slag to manufacture various types of building materials[1] and some are being practiced in India as well as in many industrially advanced countries.

Fairly good quantity of granulated slag is being used in the manufacture of slag cement[3] and supersulphated cement[4,5]. Efforts have been made at the Central Building Research Institute to explore alternative means to utilise the surplus amount of slag in the development of other useful building materials such as high slag masonry cement, lime-slag mixture and slag-lime-sand brick.

Granulated Blast Furnace Slag

During the process of manufacture of iron, granulated blast furnace slag is obtained as a by-product. The main constituents present in Indian slags are reported in Table 1. In general, the Indian slags are characterised by low CaO/SiO_2 and SiO_2/Al_2O_3 ratios. Granulated blast furnace slag is a glassy, non-crystalline material and possesses latent hydraulic property. The hydraulicity of the slag is ascribed to the presence of glass content which is directly related to its reactivity and is also dependent on the amount of lime, silica and alumina contents.

Formation of hydraulic products depend upon the hydraulic index of the granulated slag. Hydraulic index can be determined with the help of various formulae enlisted in the Indian standard IS:455-1989. Most of the Indian slags conform to the prescribed value of hydraulic index.

Slag as a Building Material

In view of the expected increase with the expansion programmes of iron and steel manufacture along with granulation facilities, the production of granulated slag will also increase. The following alternative building materials can be produced from the granulated slag.

Masonry cement

A large fraction of the cementitious binders, up to as high as 45 % is consumed as mortars and plasters. These are prepared by mixing cementitious binder with sand and water. The main purpose of the mortars and plasters is to provide good bond between the

Table 1—Chemical analysis of Indian slags

Constituents	Range, % (w/w)
Silica	28-38
Alumina	8-18
Calcium oxide	35-45
Magnesium oxide	0-16
Manganese oxide	0-5

*Author to whom correspondence should be addressed

building units and also to provide protection over the surface. These mixes are required to possess high workability, good water retention against the forces of suction exerted by the porous building units and maintain moisture in the mortar for hydraulic reactions to proceed.

Eventhough mortars prepared from portland cement harden rapidly and attain good early strength, they exhibit poor plasticity, low water retention, poor bond with the substrate, harsh to work, possess poor volume stability and high bleeding. Therefore, the cement based mortars are not very suitable for masonry work. On the other hand composite mortars, e.g., the mixture of cement-lime-sand are the most suitable materials for masonry, i.e., for brick laying and plastering work. But the non- availability of good quality lime, lack of proper mixing with cement and the risk of expansion due to the presence of small amount of unslaked lime or magnesia are factors responsible for scarce use of these mortars. Therefore, there is a substantial need for the development of alternative materials suitable for use as masonry mortars[6-8].

Attempts have been made in this institute to develop high slag masonry cement[9] bearing properties comparable to the requirements of masonry cements. According to the Indian standard IS: 3466-1988 masonry cement is a mixture of ordinary portland cement with inert materials such as limestone, dolomite or gypsum with an air entraining plasticizer.

In high slag masonry cement the slag content is kept high. This has two fold advantages, i.e, reduction in portland cement and a maximum utilisation of granulated slag available at relatively lower costs. Also due to the hydraulic nature of the slag it reacts with the finely ground portland cement and thus helps in further increasing the compressive strength of the masonry cement due to the formation of cementitious products. The masonry cement thus developed satisfies all the requirements given in the standard.

Lime-slag mixture

Studies conducted on the activation of granulated blast furnace slag indicated that alkaline activators contribute towards strength development and such binders can be used as masonry cements. Investigations carried out at this Institute revealed that good quality lime-slag mixture[11] with a small amount of gypsum can be produced.

The process of alkali activation of granulated slag proceeds as follows - when slag is brought in contact with water, initially it reacts very fast and then the reaction ceases because of the formation of extremely thin surface film of silica rich gel, which acts as barrier for further reaction of water with the slag. On adding alkali, however, the structure of gel is broken thereby facilitating the formation of the usual hydraulic products similar to portland cement.

Experimental technique—Granulated slag sample was ground to a fineness of about 5000 cm^2/g in a laboratory ball mill. Experiments were carried out to determine the optimum amount of hydrated lime conforming to class "C" grade for the activation of slag. The compressive strength of slag with varying amounts of lime are reported in Table 2.

The effect of the addition of a small amount of gypsum on the early strength development was also studied. As a result of the above findings, the mixture of slag with 15 % lime and 4 % gypsum was found to be the optimum. The detailed properties of the mortars prepared from this mixture were determined according to IS:10772-1983, i.e., specifications for quick setting lime pozzolana mixture. The results are reported in Table 3.

Lime-slag bricks

Clay brick is one of the basic building materials used in construction activities. With the increasing demand of the bricks, the reserves of good quality soils are depleting steadily. In addition, the production of clay bricks consumes a considerable amount of energy during firing. In view of the non-availability of suitable soils, a need to find some alternative raw

Table 2—Compressive strength* of lime slag mixture

Mix production, %		Water, %	Compressive strength kg/cm^2	
Lime	Slag		7 days	28 days
10	90	33.5	128	168
15	85	34.0	180	180
20	80	36.0	115	170

*Determined on 25 mm cubes at normal consistency

Table 3—Physical properties of lime-slag-gypsum mortars

Property	Results	IS:Requirements (IS:10772-1983)
Fineness, cm^2/g Blains	5250	5000 (min)
Setting time, min		
Initial	205	30 (min)
Final	480	1440 (max)
Compressive Strength kg/cm^2		
7 days	56.3	25 (min)
28 days	105.7	50 (min)
90 days	110.9	80 (min)
Soundness, mm Le-chatelier's Expansion	1.0	10 (max)
Water retention (%)	62.5	70 (min)

Table 4—Compressive strength of slag-lime-sand bricks

Mix No.	Composition, % (by weight)		Compressive strength kg/cm²
	Slag-lime mix.	Sand	
1	50	50	150
2	40	60	134
3	30	70	121
4	20	80	80

materials for making bricks has been identified. Efforts were made to manufacture bricks using different types of mining/industrial wastes in the recent past. Based on the preliminary studies[12] carried out at this institute on the prospects for producing bricks from granulated slag, good quality bricks can be prepared from lime-slag mixture and sand. These bricks can be used as an alternative to burnt clay bricks. The production of bricks from slag will help in saving energy and also spare land for agriculture and housing.

Experimental technique—Stipulated proportions of lime-slag mixture and sand were taken and mixed thoroughly. Sufficient amount of water is then added to have a semi-dry mixture. The bricks of 19 × 9 × 9 cm size were prepared by compressing the mixture at a pressure of 50 kg/cm² by a hydraulic press. After demoulding, the bricks were cured at 95 % relative humidity at a temperature of 27 ± 1°C till the time of testing. The cured bricks were tested for compressive strength after 28 days in a saturated condition. The results are reported in Table 4.

Conclusions

High slag masonry cement and lime-slag mixture can be produced by utilising a high proportion of granulated slag. Both the binders satisfy the specific requirements for masonry cement and quick setting lime pozzolana mixture. Production of these types of cements has a special significance as the cost involved and energy consumption will be lower compared to the conventional binder, i.e., the ordinary portland cement.

Good quality bricks can also be produced from lime-slag mixture and sand. The manufacturing process of the bricks is simple and does not require firing, therefore, the energy consumption will be less compared to that for the conventional burnt clay bricks. Production of bricks from slag will also help in solving the problem of quick depletion of good quality soils and preserve for agriculture and building construction.

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