

# **Application of Processed Blast Furnace Slag as Fine Aggregates in Mortar and Plastering**

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**ABSTRACT:** Solid wastes in steel plants are essential by-products generated during various processing steps involved in the production of iron and steel. Solid wastes generated by integrated iron and steel works cause environmental pollution and therefore must be discarded. Until the last decade, the slag, dust and sludge generated by integrated steel plants was called “waste”, but now this term has been replaced with “by-product” due to intensive re-utilization of these wastes. Waste management is one of the most common and challenging problems in the world. Blast furnace slag is a residue obtained during the production of steel. Construction Industry plays a crucial role in the economic development of any country. In India Construction industry is the second largest after agriculture, contributes about 11% in the GDP. Sand is a major material used for preparation of mortar, concrete and plaster and plays an important role in mix design. Sand is required about two times the volume of cement used in concrete construction. Hence the demand of natural sand is very high in developing countries to satisfy the rapid infrastructure growth. As demand of natural sand is increasing day by day there is a need to find the new alternative material to replace the river sand, such that excess river erosion and harm to environment is prevented. Blast furnace slag, since being produced in very large quantities during steel production and pose as environmental liability, were evaluated for their suitability of replacing natural sand. A small percentage of it is used by cement industries to manufacture cement but major portion is not being used and is stock piled or discarded as landfills. This paper deals with processing of Blast Furnace slag and its implementation as an effective replacement for natural sand as fine aggregate in Mortar and Plastering. The processing of the Granulated Slag is done by passing it through Vertical Shaft Impactor (VSI) mill and then through Vibrator Sieves for fine tuning of product size. From the results obtained, the processed granulated blast furnace slag is assessed for its degree of usability.

**KEYWORDS:** Blast Furnace Slag, Natural sand, Slag Processing, Fine Aggregates, Mortar, Plaster sand, Vertical Shaft Impactor, Compressive Strength.

## **I. INTRODUCTION**

Steel industry in general, produces large amounts of solid wastes while processing materials through its various processes. These solid wastes have many valuable products, which can be reused if recovered economically. Process chains within the industry are long. Many different technologies are applied and the industry has a significant impact on the environment. One of the major concerns of world steel industry is the disposal of wastes generated at various stages of processing. Because of natural drive to be cost-effective, there is a growing trend of adopting such waste recovery technologies which convert wastes into wealth, thereby treating wastes as by-products. This has led to aiming

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at development of zero-waste technologies. The technologies developed to economically convert wastes of steel plants into wealth also provide new business opportunities for prospective entrepreneurs.

The Construction Industry is very large consumer of natural resources like sand, gravel, crushed rock, etc. as building material. Aggregate is the main constituent of concrete, occupying more than 70% of the concrete matrix. The global consumption of natural sand is very high, due to the extensive use of concrete, mortar and plastering material. Environmental restrictions of sand extraction from river beds have resulted in search for alternative sources of fine aggregate, particularly near the larger metropolitan areas. In past decade variable cost of natural sand used as fine aggregate in concrete increased the cost of construction. In this situation research began for inexpensive and easily available alternative material to natural sand. Present experimental research study explores the possibility of using processed granular slag as replacement of natural sand in mortar (Masonry & plastering applications).

Impact size reduction incorporates striking to pulverize material. The primary types of impact crushers include horizontal shaft impactors (HSI), cage mill pulverizers, and vertical shaft impactors (VSI). A VSI is a mill that comminutes particles of material into smaller (finer) particles by throwing them against a hard surface inside the mill (called the wear plate). Any hard or friable materials can be ground with low value of metal waste.

## II. OBJECTIVE OF WORK

Conduct laboratory experimental investigations for mortar and plaster to evaluate effect of replacing natural sand produced cement mix with processed slag sand completely (by weight). A comparison of this mix's property was studied with reference to 100% natural sand mix. Conduct field trial by building a trial wall in a construction site and plastering the same after 28 days of curing period to assess the performance of mix in fresh as well as hardened properties.

## III. SLAG GRANULATION AND COMPOSITION

The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800 °C in order to prevent the crystallization of merwinite and melilite. To cool and fragment the slag a granulation process can be applied in which molten slag is subjected to jet streams of water or air under pressure. Alternatively, in the pelletization process the liquid slag is partially cooled with water and subsequently projected into the air by a rotating drum.

The main components of blast furnace slag are CaO (30-50%), SiO<sub>2</sub> (28-38%), Al<sub>2</sub>O<sub>3</sub> (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al<sub>2</sub>O<sub>3</sub> content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. Several compositional ratios or so-called hydraulic indices have been used to correlate slag composition with hydraulic activity; the latter being mostly expressed as the binder compressive strength.

The glass content of slag typically varies between 90-100% and depends on the cooling method and the temperature at which cooling is initiated. The glass structure of the quenched glass largely depends on the proportions of network-forming elements such as Si and Al over network-modifiers such as Ca, Mg and to a lesser extent Al. Increased amounts of network-modifiers lead to higher degrees of network depolymerization and reactivity.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015



Fig. 1: Natural River Sand Fig. 2: Raw Granulated Blast Furnace Slag

## IV. SAND CLASSIFICATION

Sand provides the structure of plaster, and the quality of sand can make the difference between success and failure. In general, good plaster sand should be sharp, with a diversity of particle sizes, and clean.

Sand should be sharp and angular, not worn and rounded. Unfortunately this means that many natural sands are poor plaster sand. Beach sand in particular should be avoided, because waves have often been rounding the sand grains for thousands of years.

Particle size diversity is important to create good structure, and to reduce the amount of binder needed. Ideally it should have a mix of nearly every grain size so that there are few large voids left; this creates a structure that resists movement, and also requires less binder to fill all those voids. Less binder equates to less cracking, and shrinkage cracks are one of the plasterer's number one enemies.

Sand should not, however, contain silt – which is the particle size below sand, slightly coarser than clay. Silt fills the voids in place of the binder, resulting in weak plasters. Clay can also cause serious problems in lime-based plasters. Salt also can lead to plaster failure, as well as causing rusting of metal lath or any other metal used in plaster preparation. So when considered sand as being clean, it means free of fine particles, and unwanted salt, chemicals or organic matter.

As a conservative rule the largest particles in your sand should be no more than half the thickness of your plaster, but preferably would be at least one quarter the thickness of your plaster (larger aggregate can provide better structure, resulting in a stronger plaster with less cracking. There are several types of sand that are widely available. Unfortunately the definition of sand types allows huge variability. As a rough guideline the main sand types generally known are concrete sand, masonry sand and plaster sand.

**Concrete sand:** Concrete sand (technically “fine aggregate”) has a maximum particle size of 3/8 inch (9.5 mm), and five percent should fall between 3/16 and 3/8 inch (4.75 – 9.5 mm). It also must have a variety of mid-size particles, and up to 5% can be finer than 100 mesh. Even though the 3/8 inch maximum is a little more than we'd like for most plasters, concrete sand may be a good choice for a plaster coat that will be applied at 1/2 inch or more. Large aggregate doesn't necessarily interfere with a nice finish, as it tends to push to the back. However it makes finishing extremely difficult and frustrating if the largest aggregate is about the same size as the depth of the finish coat.

**Masonry sand:** Masonry sand has a maximum particle size of 3/16 inch (4.75 mm), which could mean that it is a nearly ideal sand for many base coats, and particularly for lime and cement-lime body coats which are typically applied at a depth of about 3/8 inch. Unfortunately, using the Indian Standards IS 2116 - 1980 for particle size distribution (see Table below), anywhere from 70 to 100% of the sand can be less than 3/64 inch (1.18 mm). Brick sand can be a synonym for masonry sand, often a relatively fine version of masonry sand.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

IS Sieve Designation	Percentage Passing by Mass
4.75 mm	100
2.36 mm	90 to 100
1.18 mm	70 to 100
600 micron	40 to 100
300 micron	5 to 70
150 micron	0 to 15

Table 1: Masonry sand gradation (IS 2116 – 1980)

**Plaster sand:** Plaster sand is the type of sand wanted for plastering internal wall, external wall or ceiling. It's similar to Masonry sand, with a maximum particle size of 3/16 inch, but is required to have a greater proportion of large particles, and less very fine sand. A large amount of variability is also allowed in plaster sand, but because it is formulated for plaster it's more likely to have a desirable gradation. Plaster sand is ideal for anything but thin finish coats, however it is far less widely available than masonry or concrete sand.

IS Sieve Designation	Percentage Passing by Mass
100 mm	100
4.75 mm	95 to 100
2.36 mm	95 to 100
1.18 mm	90 to 100
600 micron	80 to 100
300 micron	20 to 65
150 micron	0 to 15

Table 2: Plaster sand gradation (IS 1542 – 1992)



Fig. 3: Plaster sand

## V. COMPARISON OF PHYSICAL PROPERTIES OF NATURAL SAND TO SLAG

**Natural Sand:** Locally available natural sand was tested for its suitability as fine aggregate as per IS: 383-1970. Results of the tests are as summarized in Table 3.

Properties	Values	Range as per code IS: 383-1970
Specific gravity	2.72	2.30-2.90
Bulk density (kg/m <sup>3</sup> )	1509	1280-1920
Fineness Modulus	2.80	2.10-3.20
Water absorption (%)	1.28	0-8

Table 3: Physical properties of natural sand

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

**Granulated Blast Furnace:** A sample BF slag was collected from JSW Plant, located at Toranagallu, Bellary Dist., Karnataka for processing into plaster sand. The physical properties of blast furnace slag is shown in Table 4.

Properties	Values	Range as per code IS: 383-1970
Specific gravity	2.60	2.30-2.90
Bulk density (kg/m <sup>3</sup> )	1320	1280-1920
Fineness Modulus	2.40	2.10-3.20
Water absorption (%)	2.59	0-8

Table 4: Physical properties of BF slag

## VI. VERTICAL SHAFT IMPACTOR

Vertical Shaft Impactor is an improved version of 'Rock on Rock' to 'Rock on Metal' configuration. This machine consists of parts such as top chute, material tube, feeding device, rotor assembly, crushing chamber, shaft assembly, drive unit attached to motor and a heavy base frame.

During the design process of VSI mill, the complexity of three dimensional collision forces are considered and the projectile of the material is investigated by taking into account five major physical components:

1. Free fall of a body with variable mass and geometrical configuration;
2. Conversion of energy and momentum;
3. Internal and external ballistic properties including the projectile's initial velocity and impact force over time;
4. Conversion of the physical properties of solid bodies into a fluid model and replacing the classical Newtonian physics with Bernoulli's dynamic kinematics of fluids;
5. Friction.

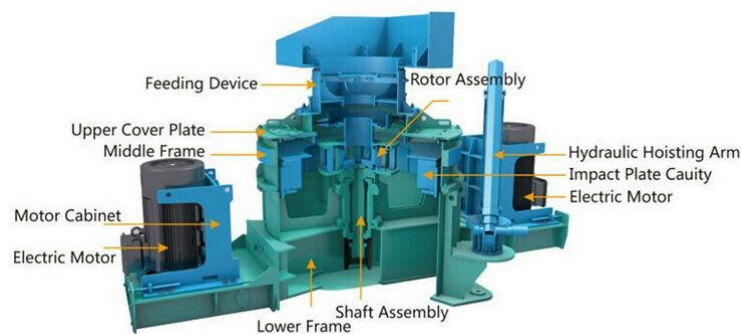


Fig. 4: A cross section view of VSI mill

## VII. PRINCIPLE BEHIND VSI CRUSHING

The principle in Vertical Shaft Impactor (VSI) crushing is based on the fundamental principle of conservation of energy and centrifugal force. The material to be crushed is dropped on top chute & goes through material tube on to

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

center of closed rotor. An accelerator rotates with a high speed at about tip speed of 80m/s to 120m/s and particles increase their speed by centrifugal force. Material from rotor gets thrown with high centrifugal force as the rotor rotates on high rpm. When this material hits inside the Rock chamber (crushing chamber) where anvil assembly is attached, a high speed impact leads to destruction of particles into pieces of different size. A majority portion of the material gets shaped due to impact & depending on inertia of the material cubical shaped products falls freely due to gravity through the bottom chute. The high velocity impact crusher in VSI enhances the shape of the aggregate, reduces the product moisture, resulting in superior shaped products. Other particles (less than 1 mm) lift by air stream into a classifier where blades make rotating dust flow. Middle size particles shift to wall by centrifugal force in a big chamber of a classifier and fall down to cone and later they move into an accelerator. Small particles move by air stream to outlet. Fine tune of a product size is achieved by changing of blade angle.

### VIII. ACCELERATOR

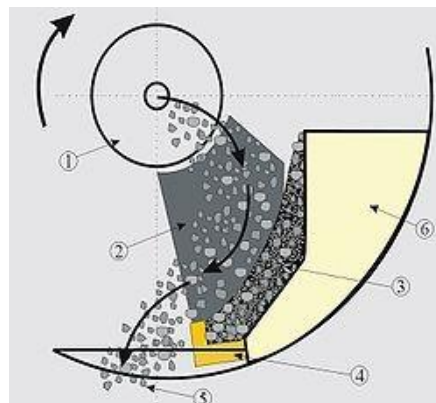


Fig. 5: A schematic drawing of the accelerator in a VSI mill

A schematic drawing of a VSI mill accelerator is shown at Fig. 5. Very high speed of particle motion needs to obtain good grinding but high speed must lead to high metal waste. Really it doesn't happen because in an accelerator particles move along same material in special inwall area (3) which is bounded by accelerator body and hard metal blade (4). Material in such region holds by centrifugal force. Wear plates (2) and cone (1) use also to avoid wear and tear of an accelerator body.

Benefits of using processed slag as a replacement as of natural sand:

- Cubical shaped product.
- Reduces "slabby" or slivered material.
- Consistent product in a tight gradation range
- Presence of intermediates and fines
- Low cost
- Environmental friendly.
- Higher utilisation of industrial wastes.

### IX. RESULTS OF COMPRESSIVE STRENGTH OF MORTAR WITH NATURAL SAND AND PROCESSED BF SLAG

For determining the Compressive strength, first the standard cubes of mortar (7.07 cm) size were casted with the natural sand. Table 5 show the 3 and 7 days strength of mortar cubes of 1:4 proportions casted with 0.85 W/C ratios of natural sand and blast furnace slag.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

Combination	C/S Proportion	BFS Compressive Strength, (Mpa)	
		3 Days	7 Days
0% PGBS +100% NS	1:4	2.94	4.12
25% PGBS+ 75% NS	1:4	3.25	3.84
50% PGBS + 50% NS	1:4	3.53	4.36
75% PGBS + 25% NS	1:4	2.91	3.44
100% PGBS + 0% NS	1:4	2.28	3.21

Table 5: Comparison of mortar strength of blast furnace slag with natural sand.

\*PGBS - Processed Granulated Blast furnace Slag

\*NS - Natural Sand



Fig. 6: Processed Granulated Blast Furnace Slag

## X. CONCLUSION

The substitution of natural sand with processed slag sand has positive impact on workability, compressive strength and durability. The high glass content with sharp particles have been nullified during the 'Rock on Metal' impacting process due to which workability and handling of GBS has been drastically increased without the risk of wounding. The mix of 50% replacement level was found increasing the compressive strength by about 6% compared to 100% natural sand mix. The replacements of natural sand with processed slag by 50% to 75% improved mortar joint crushing strength by about 10% in all the mix proportions. The Processed Granulated Blast Furnace Slag and Natural Sand blended mortar laboratory trial experiments were carried out and case study of actual mortar supplied at construction site shows that PGBS can be used as alternative to fine aggregate for various civil engineering works with blend of Natural sand. The study concluded that granular slag could be utilized as alternative construction material for natural sand in masonry & plastering applications either partially or fully. The results of the present study also indicates that consumption of natural sand can be reduced considerably in construction activity and hence achieving environmental sustainability.

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