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# Granular Slag - Potential Sustainable Material Alternative to Fine Aggregate in Construction Applications

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**ABSTRACT**

The objective of present investigation was to study utilization of the granular slag (a waste industrial product) as fine aggregate in masonry construction and plastering applications. In this study, cement mortar mix proportions ranging from 1:3, 1:4, 1:5 & 1:6 by volume were selected for 0, 25, 50, 75 & 100 % replacement levels with w/c ratios of 0.60, 0.65, 0.70 & 0.72. These mixes were studied for properties like density, water absorption, compressive, joint crushing & adhesion strengths. The study concluded that granular slag could be effectively utilize as fine aggregate in masonry construction and plastering applications work economically.

**Key words:** *Granular slag, joint crushing strength, compressive & adhesion strength,*

## 1. INTRODUCTION

The world steel industry produces about 780 Million Tonnes of crude steel and simultaneously approximately 300 Million Tonnes of solid wastes. Thus an average of about 200 to 400 Kg of solid by product is generated per tonne of crude steel. Major share of this (70-80%) consists of BF Slags and basic Oxygen furnace Slags which are an ecological hazard. The total steel production in India is about 25 Million Tonnes and the waste generated annually is around 10 Million Tonnes (considerably higher than the world average) but hardly 25 % are being used mostly in cement production. Technologies have been developed in most of the developed nations of the world for utilization of the generated wastes and there are nations which have total utilization of these wastes. In India, though utilization of wastes has begun, it is still quite some time before there is total utilization.

In the production of iron and steel, fluxes (limestone and/or dolomite) are charged into blast furnace along with coke for fuel. The coke is combusted to produce carbon monoxide, which reduces the iron ore into a molten iron product. Fluxing agents separate impurities and Slag is produced during separation of molten steel. BF slag is a nonmetallic inert co-product primarily consists of silicates, aluminosilicates, and calcium-alumina-silicates. The molten slag which absorbs much of the sulfur from the charge, comprises about 20 percent by mass of iron production.

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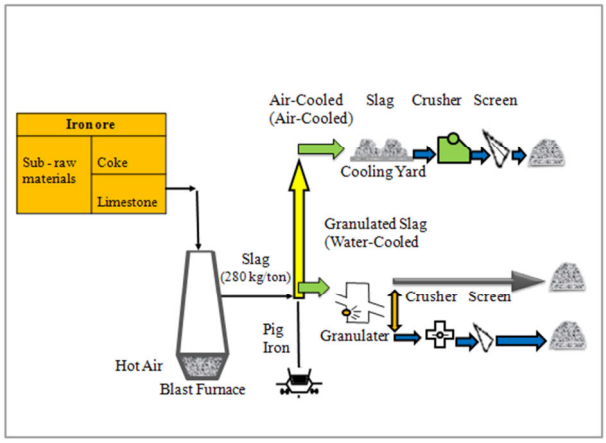



Figure 1. General Schematic view of blast furnace operation and Slag production

## 2. LITERATURE REVIEW

It is reported that a little or a very few research work is carried out pertaining to present research work. Hence some selected reviews of allied literature available are presented as below.

- Lun Yunxia[4], et.al.,-2008, worked on to find suitable methods for enhancing the volume stability of steel slag utilized as fine Aggregate in China. The effects of steam treatment at 100 $^0$C and autoclave treatment under 2.0 MPa. on the soundness of steel slag sand were investigated by means of powder ratio, linear expansion, compressive and flexural strength. Ethylene glycol methods were employed to analyze both the treated slags and susceptible expansion grains. After steel slag was treated under different conditions, powder ratio was carried out. It could be seen that steam and autoclave treatment reduced the powder ratio. Increasing the steam-treatment time from 8 to 12 hour, the change of powder ratio was not obvious. Powder ratio of autoclave treated steel slag was the lowest among them. It was concluded that the steam and autoclave treatment methods could lower the content of free lime and improve the volume stability of steel slag fine aggregate. Though the content of autoclave treated was the smallest, steam treatment lasting for 8 h was most effective in terms of reduced range. Autoclave treatment method, for 3 h under 2.0 MPa, at 215 $^0$C, significantly improved the volume stability of steel slag as fine aggregate.

- Chen Meizhu[5], et.al., – 2007, developed new kind of mortar made of GGBS slag, gypsum, clinker and steel slag sand (<4.75 mm). The ratio of steel slag sand to GGBFS was 1:1 and the amount of gypsum was 4% by weight while the dosage of clinker ranged from 0% to 24%. The optimization formulation of such mortar was studied. The content of steel slag sand should be less than 50% according to the volume stability of blended mortar, and the dosage of clinker was about 10% based on the strength development. Besides strength, the hydration heat, pore structure and micro pattern of blended mortar were also determined. It was found that reactivity of steel slag sand was not lowered after 100$^0$C steam treatment for 4 hours and the stability of mortar was good upto the dosages of 50%. The strength of samples increased when the clinker content was less than 10%. The study concluded that application of steel slag sand reduces dosages of clinker with further improvement of micro structure.

- M H Ozkul[12],-1996 studied two types of concrete one had natural river sand and coarse aggregate while the other one consisted of all Slag. Compressive, flexural strength, abrasion resistance of these concretes were obtained upto ½ year age. Also investigated was the effect of wetting and drying on the dynamic modulus and volume expansion of mortar with and without fine slag were measured. The mix prepared with natural sand and one with fine slag gave quite similar results and they were reasonably in the same range of natural aggregate concretes. The dynamic moduli of concretes determined after 20 cycles of wetting and drying was about 3% of initial values which was quite small.

## 3. RESEARCH SIGNIFICANCE IN INDIAN CONTEXT

Presently, use of slag in India is to the tune of 15 to 20 % by cement industry rest is mostly unused. The use of industrial by-products in concrete and mortar not only helps in reducing green house gases but helps in making environmental friendly material. Fine aggregates are part of all the three major applications of construction namely masonry, plastering & concreting which is used to the tune of 25 to 40 % by total volume of aggregates and hence provides great opportunity to utilise slag – a waste material in big volume.. Research study explores the possibility of using granular slag, steel production waste byproduct as replacement of natural sand in mortar (Masonry & plastering applications).

## 4. EXPERIMENTAL INVESTIGATION

### 4.1. Raw materials

In the present investigation, Granular slag from the local steel making plant, natural sand from the local Kanhan river and Portland Pozzolana cement were used . All the chemical & physical properties of the materials are given in the Table No.1

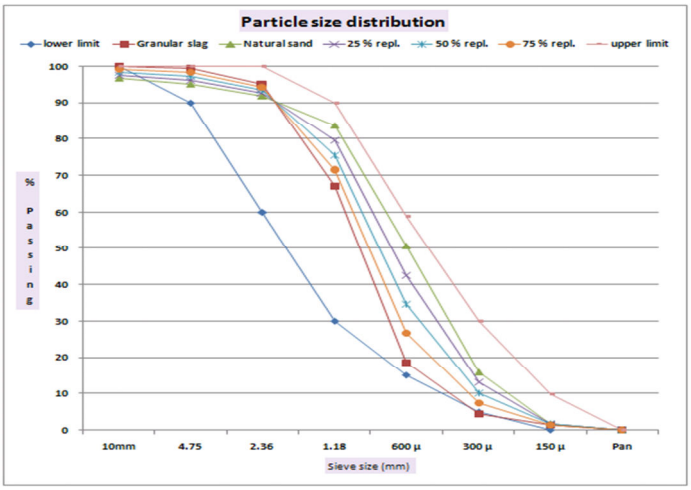
Table 1. Physical & Chemical Properties of Materials

| **Slag** | | | | **Natural Sand** |
|---|---|---|---|---|
| **Chemical Analysis** | | **Physical Properties** | | **Physical Properties** |
| Constituents | (%) | Specific Gravity | 2.38 | 2.65 |
| LOI | 1.80 | Water Absorption | 0.39% | 0.65% |
| Silica | 30.20 | DLBD | 1058 Kg/cum | 1468 Kg/cum |
| $R_2O_3$ | 20.20 | Soundness | 0.90% | 0.90% |
| $Fe_2O_3$ | 0.60 | F.M. | 3.14 | 2.64 |
| $Al_2O_3$ | 19.60 | Zone | I | II |
| Cao | 32.40 | Silt (Volume) | 1.38 % | 2% |
| MgO | 9.26 | | | - |
| $SO_2$ | 0.27 | | | - |
| Insoluble matters | 0.80 | | | - |

| **Cement-Portland Pozzolana Cement –IS 1489 –(Part 1) 1991** | | | |
|---|---|---|---|
| **Physical Properties** | | **Chemical Properties** | |
| Specific Surface | 380 $m^2$/kg | Total Loss on Ignition | 1.40% |
| Setting time – Initial | 195 minutes | Magnesia | 1.40% |
| Final | 280 minutes | Sulphuric Anhydride | 2.06% |
| Soundness-Le-chatelier | 0.50% | Insoluble residue | 26.0% |
| Auto Clave | 0.06% | | |
| Compressive strength – 3day | 34.9 Mpa | | |
| 7 days | 44.2 Mpa | | |
| 28 days | 61.4 Mpa | | |
| Chloride | 0.04% | | |
| Fly ash | 28% | | |

Figure 2. View of Granular slag sand & natural sand

The particle size distribution of natural sand, granular slag with 25, 50 & 75 % replacements and upper & lower limit of % passing from various sieves as per IS 383-1993 are shown in the Figure No. 3.




| Equivalent seives | |
|---|---|
| ASTM C 33 | IS 383 (mm) |
| 3/8" | 9.5 |
| #4 | 4.75 |
| #8 | 2.36 |
| #16 | 1.18 |
| #30 | 0.600 |
| #50 | 0.300 |
| #100 | 0.150 |
| #200 | 0.075 |
| PAN | |

Figure 3. Particle size distribution of natural sand and granular slag with ASTM equivalent sieves

### 4.2. Experimental set-up

The study was done to find out comparative results with natural sand and granular slag for mortar compressive strength, mortar joint crushing & adhesion strength, mortar water absorption, mortar flow, density. The whole study was done for 1:3, 1:4, 1:5 & 1:6 mix proportions by replacing natural sand with granular slag by 0% (Standard mix), 25%, 50%, 75%, & 100%. The experimental set-ups are described in detail as below,

#### 4.2.a. Flow test set-up

Based on the targeted standard flow of 100±5 mm for standard mix of 100 % natural sand, w/c ratio was found out for 1:3, 1:4, 1:5 & 1:6 mixes tabulated in the Table no 2.

Table 2. Flow table results

| W/C Ratio for standarad flow of 100+_5 mm flow | |
|---|---|
| Mix proportions | W/c Ratio |
| 1:3 | 0.6 |
| 1:4 | 0.65 |
| 1:5 | 0.7 |
| 1:6 | 0.72 |

Figure 4. Flow table test set-up

#### 4.2b. Cement mortar compressive strengths

The cement mortar mix proportions ranging from 1:3, 1:4, 1:5 & 1:6 by volume were selected for 0, 25, 50, 75 & 100 % replacement with W/C ratios of 0.60, 0.65, 0.70 & 0.72 respectively for a targeted standard flow of 100 ± 5 mm.

Table 3. Mix proportions with respect to replacement

| Mix No. | Proportions | Natural Sand (%) | Slag Sand (%) | 50 mm$^2$ cube |
|---|---|---|---|---|
| Mix I, II,III, IV, | 1:3, 1:4, 1:5, 1:6 | 100 | 0 | 30 |
| | | 75 | 25 | 30 |
| | | 50 | 50 | 30 |
| | | 25 | 75 | 30 |
| | | 0 | 100 | 30 |
| * Set of 3 moulds ecah for compressive & split strengths | | | Total | 120 |

For each of the four mixes i.e. 1:3, 1:4, 1:5 & 1:6, set of 3 cubes of 50 mm$^2$ area were cast and tested for compressive strength after 28 days time in CTM. For getting the compressive strength, failure load was divided with the mortar cube area in contact.

Figure 5. Cement mortar compressive strength test set-up

**4.2c - Brick mortar joint crushing strength**

Cement mortar is used in masonry work for binding two masonry units. The primary object of masonry bond is to give strength to masonry unit but it may also be employed to create artistic effects when the brick work is exposed to view. The bond mainly takes compressive stresses due to load transferred by the above units. In this test set-up, the cement mortar layer of 10 mm thick was applied in-between two bricks and kept it for moist curing. A set of bricks (2 nos. cross bricks. - 3 sets) for the proportions of 1:3, 1:4, 1:5 & 1:6 with granular slag replacement of 0, 25, 50, 75 & 100 % were prepared and tested after 7 days time in CTM
.

Fig. 6. Brick mortar joint crushing strength test set-up

In this test set-up the set of bricks were laid in-between the CTM plates. The compression load was applied uniformly on the surface of brick and the load at which brick mortar joint gets crushed divided by the area of mortar gave mortar joint crushing strength.

**4.2d - Brick mortar joint adhesion strength**

In this test, mortar joint adhesion strength was tested by pulling apart two cross bricks. A set of cross bricks ( 2 nos. cross bricks – 3 sets) were made by applying 10 mm thick mortar layer in-between two bricks for proportions of 1:3, 1:4, 1:5 & 1:6 with granular slag replacement of 0, 25, 50, 75 & 100 % tested after 7 days of curing. Cross bricks were kept in-between the jaws of UTM by means of metal sling. Pull over load was applied till the cross bricks pull apart and separated completely from each other. The load at which brick joint fails divided by the mortar area in contact with both the bricks gave brick mortar adhesion strength tested as per the test set-up shown in the Figure No.8.

Figure 7. Brick mortar joint adhesion strength test set-up

**4.2e - Water absorption by mortar slates (Plaster surface)**

Plaster is defined as the lean mortar applied on the surface of masonry units used mainly as protective layer to masonry wall which gives protection against destructive attacks of the atmosphere like wind, rain, harmful industrial gases to masonry unit etc. Plaster also provides decorative leveled surface for applying painting coat. The most important property of plaster is to reduce ingress of rain water, normally used with a thickness of 12 to 20 mm. In order to study property of water absorption by the plaster surface, mortar slates of size 150 x 150 mm, 15 mm thick were prepared with the help of wooden mould for mix proportions of 1:3, 1:4, 1:5 & 1:6 proportions with granular slag replacement of 0, 25, 50, 75 & 100 %. The slates were tested after 7 & 28 days time for water absorption by keeping them in aerated oven at 105$^{o}$C temperature for 24 hours time.

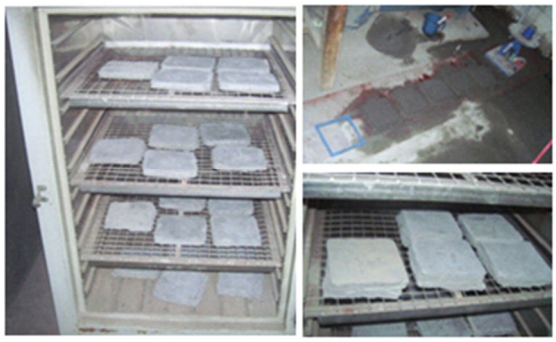


Figure 8. Sample of mortar slates in Oven

**5. RESULTS & DISCUSSION:**

**5.1. Mortar flow**

In the proportions of 1:3 & 1:4, it was observed that flow increases by 7 % upto slag replacement level of 75 % & 50 % respectively and at 100 % replacement level, it came down to 5% & 2 % respectively. In mix proportions of 1:5 & 1:6, flow increases upto the replacement level of 50 % by 2 & 1 % but later decreases 3 & 5 % at 100 % replacement level respectively. The study clearly indicated that in rich mixes with finer particles, granular slag reduced internal particle frictions which enhanced its flow properties at the same time with lesser cement content, flow decreased.

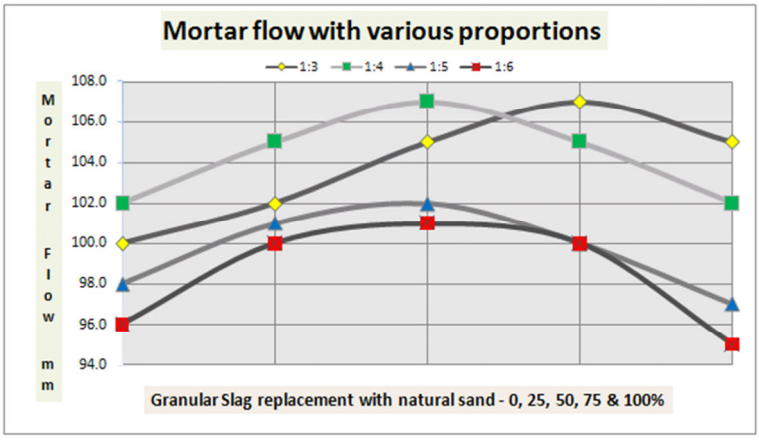



Figure 9. Mortar Flow with respect to proportions & granular slag replacement

### 5.2 - Mortar compressive strength

It was observed that in the mix proportions of 1:3 & 1:4, compressive strength increased upto the replacement level of 75 % by 14.66 & 16.42 % respectively and in 1:5 & 1: 6 mix proportions the increase in strength was observed to the tune of 11.19 & 11.7 % at 50 % replacement level. It was also observed that in case of 1:3, 1:4 and 1:5 proportions though the compressive strength decreased at 100% replacement level but not below the level of 0 % replacement level. The increase in strengths at 100 % replacement was noted as 5.41, 6.9 & 1.09 % in 1:3, 1:4 & 1:5 mix proportions and in 1:6 it was below 0.82 % compare to 0 % replacements.

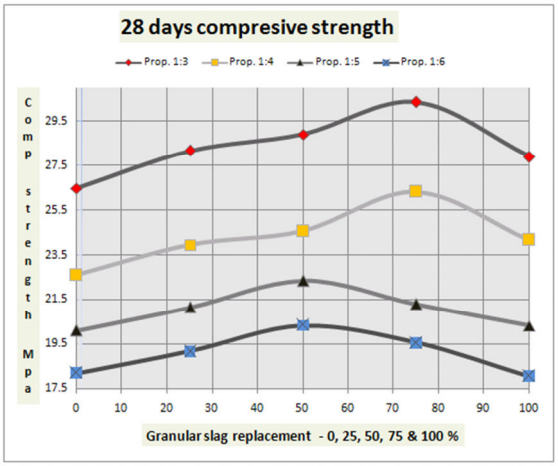



Figure 10. Mortar compressive strength

### 5.3 - Brick mortar joint crushing strength

The brick mortar crushing strength in 1:3 & 1:4 proportions increased at 75 % replacement level by 9.11 & 10.43 % respectively compare to 0 % replacement on the other hand in 1:5 & 1:6 proportions, the strength was increased at 50 % replacement level by 9.11 & 10.43 % respectively. It was also observed that in the proportions 1:3, 1:4, the strengths at 100 % replacement was found as 6.08, 5.06 % and in 1: 5 & 1:6 mix proportions it decreased by 0.78 & 1.5 % compare to 0 % replacements.

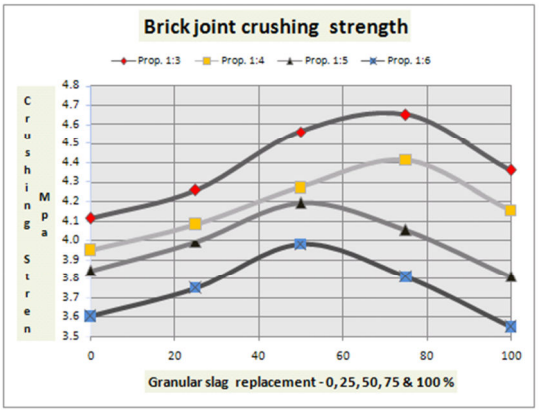



Figure 11. Brick mortar joint crushing strength

### 5.4 - Brick mortar adhesion strength

The brick mortar adhesion strength increased at 75 % replacement in 1:3 & 1:4 mix proportions by 12.97 & 12.21 % and in 1:5 & 1:6 mix proportions, 50 % replacement level gave increase in strength by 10.19 & 11.98 % respectively. It was also observed that even though in 1:3, 1:4 mix proportions, the adhesion strength decreased after 75 % replacement level but it was higher by 2.17 & 0.54 % respectively, similarly in 1:5 & 1: 6 mix proportions it decreased by 1.98 & 1.36 % at 100 % replacements level compare with 0 % replacements.

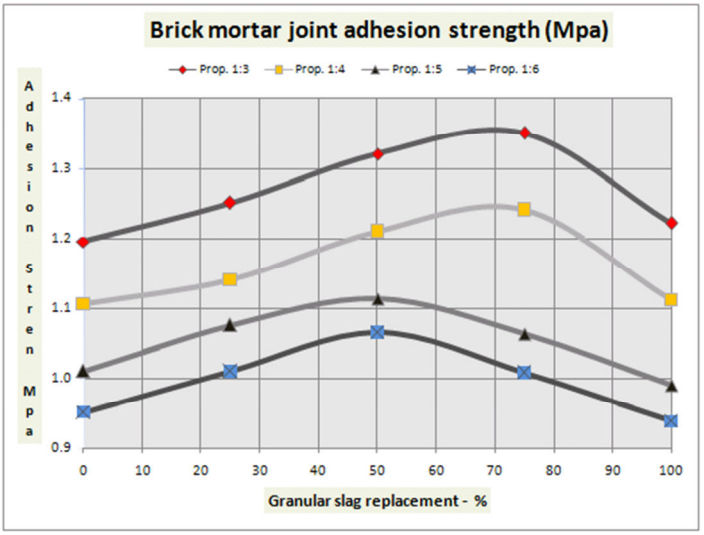



Figure 12. Mortar joint adhesion strength

**5.5 -Water absorption by mortar slates (Plaster surface)**

**5.5 a - 7 days water absorption**

The water absorption after 7 days time was observed in mix proportions 1:3, 1:4, 1:5 & 1:6 at 0, 25, 50, 75 & 100 replacement levels in the range of 2.62 to 5.40 %. The reduction in water absorption 1:3 & 1:4 mix proportions at 50 % replacement level was 10.90 & 13.60 % respectively and in 1:5 & 1:6 mix proportions, reduction in water absorption at 25 % replacement level was 7.2 & 2.9 % respectively compare to 0 % replacements. It was also observed that water absorption increase from 1:3 to 1:6 mix proportions in a range of 34.7 to 43.0 % , maximum at 50 % replacement level of 1: 6 mix proportions.

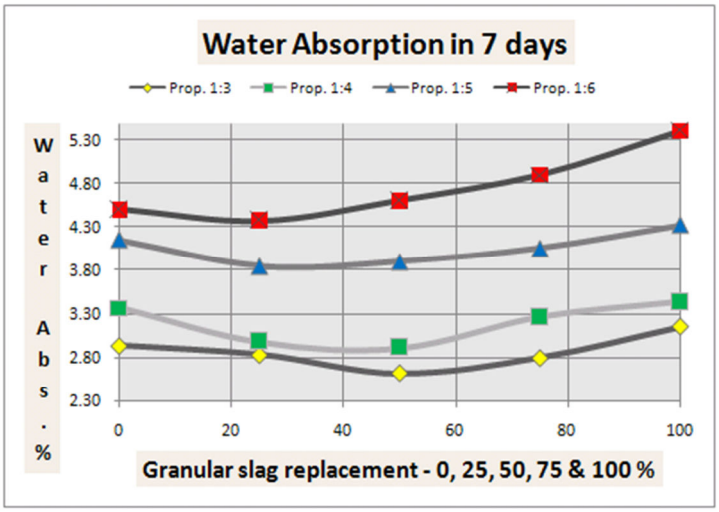



Figure 13. Water absorption of mortar slates at 7 days duration

**5.5b - 28 days water absorption**

The water absorption after 28 days time was observed in mix proportions 1:3, 1:4, 1:5 & 1:6 at 0, 25, 50, 75 & 100 replacement levels in the range of 2.0 to 3.95 %. The water absorption reduced in 1:3 & 1:4 mix proportions at 50 % granular slag replacement by 11.90 & 8.90 % respectively and in 1:5 & 1:6 mix proportions, reduction in water absorption was observed at 25 % replacement by 14.60 & 6.70 % compare to 0 % replacements. It was also observed that water absorption increase from 1:3 to 1:6 mix proportions in a range of 27.90 to 40.30 % , maximum at 50 % replacement level of 1: 6 mix proportions.

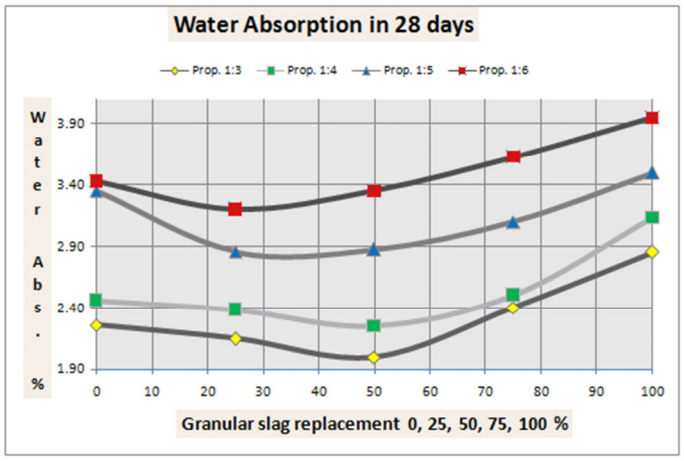



Figure 14. Water absorption of mortar slates at 28 days duration

### 5.6 - Mortar density

The mortar density reduced by 21.71 % max. from 0 % to 100 % replacement levels in 1:3, 1:4, 1:5 & 1:6 mix proportions compare to 0 % replacements more predominantly from 1:3 to 1:6 mix proportions by 3.5 to 7.49 %.

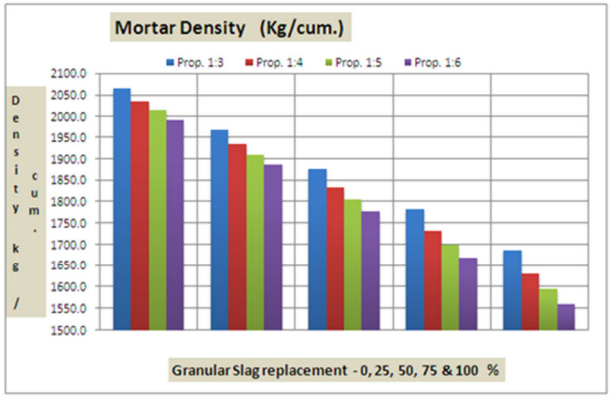



Figure 15. Mortar density

## 6. DISCUSSION & CONCLUSIONS

The experimental results obtained show that partial substitution of ordinary sand by granular slag gives better results over the verified range from 0, 25, 50, 75 & 100 % replacement. The conclusions are drawn as below,

1. In mortar, 50 to 75 % replacement was favourable to increase the flow properties by 7 % in 1:3 & 1:4 mix proportions and 2% in 1:5 & 1:6 mix proportions. The 100 % replacement affected positively by 3% flow increase in 1:3 & 1:4 mix proportions. However 100 % replacement level is not feasible in 1:5 & 1:6 mix proportions since it had reduced the flow by 4 %.

2. In general, the range of 50 to 75 % replacement level is helpful in increasing the mortar compressive strength of 1:3 & 1:4 and 1:5 & 1:6 mix proportions by about 15 & 11 % respectively.

3. The mortar joint crushing and adhesion strengths were increased by a range of 9 to 12 % at 50 to 75 % replacement level in all the mixes. It could also be said that mortar adhesion strength is about 27 % of mortar joint crushing strength.

4. The replacement level of 25 to 50 % is favourable for reducing water absorption of mortar slates by about 10 % in all the mixes. The same replacement level reduces the water absorption by about 21% from 7 to 28 days time.

5. The replacement level of 0 to 100 % could made cement mortar lighter by 38 %. This reduction is advantageous in reducing the

dead weight of structure as well as easy handling of mortar by labours and masons.

In respect of the above conclusions, it could be said that granular slag replacement level of 50 to 75 % had increased the packing density of mortar which resulted in reduced w/c ratio, increased strength properties of all mortar mixes. The rough spherical particles of granular slag had also improved the bond and adhesion strength. Hence it could be recommended that the granular slag could be effectively utilize as fine aggregate in masonry construction and plastering work economically in place of conventional cement mortar mixes with natural sand as fine aggregate.

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