Section: Research Paper

STUDY ON PARTIAL REPLACEMENT OF FINE AGGREGATE IN HIGH PERFORMANCE CONCRETE

MS. NEELAM PETKAR[1], DR. MOHAN MURUDI[2]& DR. VISHAL THOMBARE[3]

[1]Civil Engineering Department, Sardar Patel college of Engineering (SPCE), Andheri (West), Mumbai - 400 058
[2]Civil Engineering Department, Sardar Patel college of Engineering (SPCE), Andheri (West), Mumbai – 400 058
[3]Executive engineer Municipal Corporation of Greater Mumbai

ABSTRACT

Nowadays, sustainability is crucial in preserving and promoting enduring environmental conditions for the benefit of humanity's well-being. The purpose of this paper is to present anidea on use of artificial replacement for fines so as to declare it as alternative to natural sand and also to fit the line of increasing demand for high performance concrete. With growing needs of finding substitute for fines, cement industry has already raised the beneficial use of supplementary cementitious materials in various combinations and its effect on requiremental aspects of concrete. This paper emphasizes the use of cementitious materials i.e. silica fume and GGBS in trial evolved proportion in combination with natural sand, crushed sand and processed slag sand. With the increasing need of natural cement, the need of evolving the use of steel slag has come in picture. The evolution for sustainability is the need of hour. The Indian standard code permits the use of recycled aggregates in some percent but with the changing environmental conditions this has to be changed.

Keywords— Fine aggregate, high performance concrete, silica fume, GGBS, compressive strength

INTRODUCTION

With the increasing need to use a cement substitute, the evolution of tailor-made materials has increased to a great extent. The use of cementitious materials then came into the picture such that the entire cement industry shifted the focus onto the use of the same and the proportion in which this could be cast off in varying site conditions, grade of concrete, workability and durability of concrete. Vahid Afroughsabet [17], examined the utilization of calcium sulfoaluminate cement as a complete or partial substitute for ordinary portland cement in combination with GGBS (grinded granulated blast furnace slag) and analyzed it for compressive strength, electrical resistivity and SEM images. He also concluded that using solely CSA ettringite crystals in the experiment resulted in an increase in concrete strength. The use of GGBS helped in reducing the cracking potential, stress rate and cracking potential in the high-performance concrete by using GGBS in varying proportions of 0%, 20%, 35% and 50%. Increased dosages of silica fume increase tensile creep and autogenous shrinkage, cracking stress but decreased cracking resistance at early stage in the high-performance concrete by using GGBS in varying proportions of 10%, 15% and 20% [5].

When using a binary blend of concrete incorporating crushed granulated blast furnace slag (GGBS), the desired strength can be attained by replacing up to 50% of cement with GGBS, with comparable carbonation characteristics observed over several weeks. However, if the GGBS proportion exceeds 50%, the depth of carbonation increases. Conversely, when the GGBS ratio is below 25%, the depth of chloride penetration decreases [10].

Utilizing supplementary cementitious materials (SCMs) not only enhances the concrete structure, but also promotes the formation of the C-(A)-S-H phase, resulting in superior strength and durability performance of the concrete [2]. When the replacement of fine aggregate with steel slag was about 20% or 80% high compressive strength and toughness was obtained in normal strength concrete but when the same replacement was 30% the compressive strength and toughness was superior in case of high strength concrete [18]. If silica fume is replaced up to 10 % the tensile strength increased by 26%, compressive strength by 13% and 5% modulus of elasticity but with all this when the replacement goes beyond 10% the concrete became brittle so it was recommended that not to use silica fume beyond 10% [15]. Similarly, many researchers have experimented the various proportions of these cement substitutes and the studied its effects on various properties of the concrete in terms of performance and durability [4], [3], [11], [9].

The tailored material is defined to be the one which can be developed by the unproductive product such that it acts as a sustainable option for the environment. Among these materials the most common ones used are silica fume and ground granulated blast furnace slag (GGBS) as discussed above.

In this study, supplementary cementitious materials, namely silica fume and pulverized blast furnace slag, are added to treated slag sand to partially replace natural and crushed sand as fine aggregate. These materials were used in varying proportions but the optimum mix in relation to the processed slag sand was yet to be investigated. This processed slag sand added an advantage as fine aggregate, the properties are identical to that of natural sand and as per codal provisions. Extensive research has been conducted on different ratios of swapping cement with silica fume and granulated blast furnace slag (GGBS) in various combinations from 5%, 10%, 15%, 20% up to 60%. Along with the increasing need of cement replacement the need of replacing natural sand also came into existence. But the sudden ban on the drenching of natural sand made it compulsory to shift to manufactured sand alternatively known as crushed sand or tailored made sand. This research conducted a comparative analysis of the behavior of crushed sand and natural or river sand, examining their effects on the compressive strength and flowability of high-performance concrete with a grade of M60. The trials were carried out using silica fume and GGBS with varying replacement percentage as 5%, 10%, 15% and 30%, 40%, 50% respectively.

PROPOSED FRAMEWORK

The experiments were conducted on M60 grade concrete through a water-cement ratio of 0.27 and different proportions of supplementary cementitious materials. In the initial stage, the optimal amount of silica fume and GGBS was determined, meeting the necessary design criteria. The effects of silica fume and GGBS was studied with respective to strength and workability. The trials with various proportion of 5%, 10%, 15% of silica fume and 30%, 40%, 50% of GGBS in combination with natural sand, crushed sand and processed slag sand.

Materials Used

Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) of 53 grade was used for all trials. The cement was tested for specific gravity, initial setting time and final setting time for basic specifications.

Silica Fume

Silica fume is a form of amorphous silicon dioxide, characterized by its fine particle size and high surface area, which can range up to approximately 20,000 m2/kg. The particles are roughly one-hundredth the size of a normal cement particle. It reduces the permeability of concrete, thereby improving its durability. However, in regions with high temperatures, it should be used with caution and in an optimized manner to avoid an increased rate of early age shrinkage cracks in the concrete structure (14).

Ground granulated blast furnace slag (GGBS)

Ground Granulated Blast furnace slag (GGBS) is anoutgrowthof pig iron production that is obtained by rapidly cooling molten slag. The processed slag exhibits hydraulic properties similar to those of cement, making it suitable for use as a pozzolanic material (14). The need to reduce carbon emission in the atmosphere with massive production of cement, it has become a necessity of an hour to use such supplementary cementitious materials for production of concrete.

Processed slag sand

The processed slag sand is prepared on-site by passing it through a vertical shaft impact machine assembly, which crushes it and alters its particle shape. This process is primarily intended to enhance the bulk density of the processed slag sand and create a more spherical shape. The figure below gives an over view of particle size distribution for all the kinds of fine aggregates used in the experimentation.

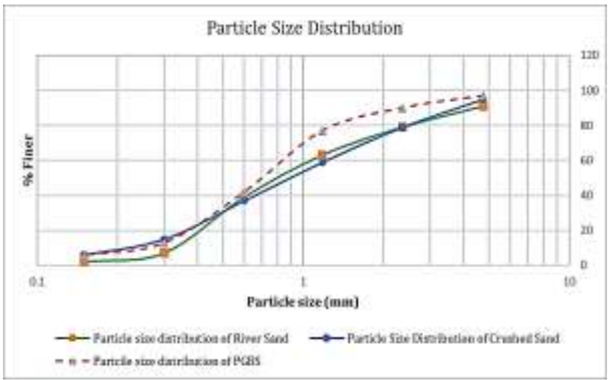

Fig.1. Distinctive particle size distribution of fines aggregate used in experimentation

PROPOSED METHODOLOGY

This research involves casting concrete cubes of standard dimension 150x150x150 mm, with different combination of fine aggregate, PGBS being 25% replaced in river sand and crushed sand for M60 grade of concrete in combination with 5%,10%,15% and 30%,40%,50% of silica fume and GGBS. The cube moulds were filled with concrete in 3 layers, compacting each layer by tamping rod and thereafter placing them on vibrator table so as to remove all the entrapped air and obtained a finish concrete surface on hardening. There was total 180 cubes casted during this process. They were further immersed in water for curing and then tested for 3 days, 7 days and 28 days. For each proportion trail, the workability of the concrete was checked so as to satisfy the clause of being pump-able along with high strength. The results of each in the graphical representation is shown further. Various materials used are listed below

- Cement: Ordinary Portland Cement 53 grade
- Coarse aggregate: Granite conforming IS: 383-2016
- Manufactured aggregate: Crushed sand of Zone II conforming IS: 383-2016
- Processed sand: Processed sand of Zone II conforming IS 383-2016
- Water: Portable water conforming IS 456: 2000
- Mineral Admixtures: Silica fume, Ground granulated blast furnace slag
- Chemical Admixture:CAC – Hyper fluid R 100 (M4)
- The basic test on materials is given in table no. 2 & table no. 3

Secondary part of this experiment included the usage of optimum mix i.e. using the determined percentage of silica fume and GBBS with 30% of processed slag sand in combination with natural sand and crushed sand. These combinations were examined for compressive strength and water penetration test for analysing the performance of concrete. The table below depicts preliminary trials

Table 1: Compressive strength test on cement

Compressive Strength of 3 days	29.5 N/mm^2
Compressive Strength in of 7 days	39.5 N/mm^2
Compressive Strength in of 28 days	53.42 N/mm^2

Table 2: Specific Gravity of materials

River Sand	2.70
Crushed Sand	2.89
Processed slag sand	2.47
Metal 1	2.77
Metal 2	2.81

Table 3: Preliminary trials

<table>
<tr><td>Trial 1 (T1)</td><td>100 % Natural sand</td><td rowspan="4">5% silica fume + 30% GGBS
5% silica fume + 40% GGBS
5% silica fume + 50% GGBS
10% silica fume + 40% GGBS
10% silica fume + 50% GGBS
10% silica fume + 60% GGBS</td></tr>
<tr><td>Trial 2 (T2)</td><td>100 % Crushed sand</td></tr>
<tr><td>Trial 3 (T3)</td><td>75% Natural sand + 25% PGBS</td></tr>
<tr><td>Trial 4 (T4)</td><td>75% Crushed sand + 25% PGBS</td></tr>
</table>

Table 4: Secondary trails

<table>
<tr><td>Trial 5 (T5)</td><td>75% Natural sand + 30% PGBS</td><td rowspan="2">10% silica fume + 30% GGBS</td></tr>
<tr><td>Trial 6 (T6)</td><td>75% Crushed sand + 30% PGBS</td></tr>
</table>

After determination of material property, the trials were conducted as mentioned in the table above to check the effect of silica fume and GGBS mixture combined with natural sand, crushed sand and processed slag sand on M60 grade of concrete.

IV. RESULT

The results of the trials done are shown below:

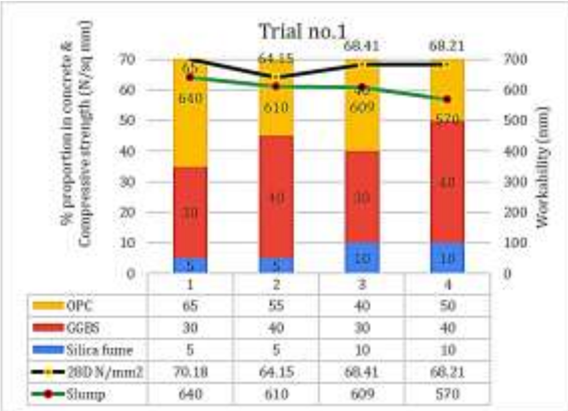

Fig.2. Results of Trial no.1

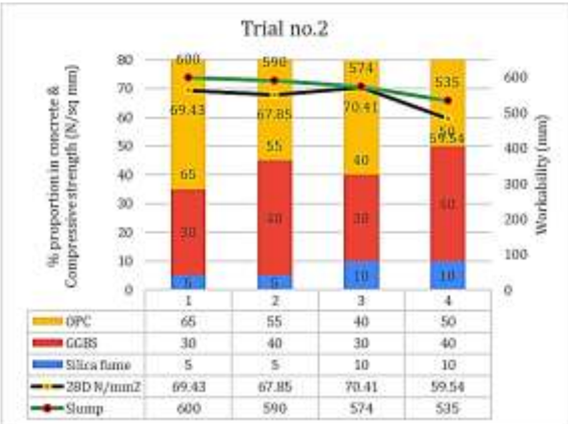

Fig.3. Results of Trial no.2

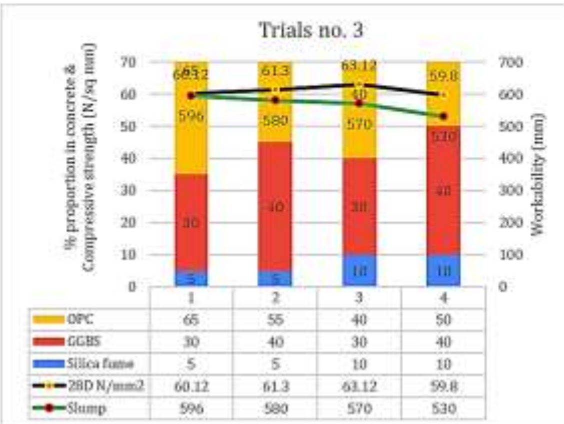

Fig.4. Results of Trial no.3

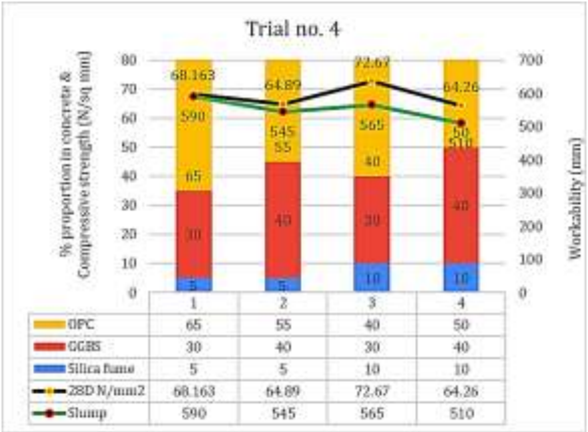

Fig.5. Results of Trial no.4

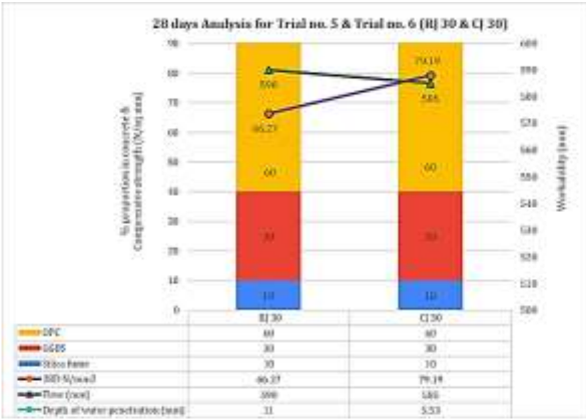

Fig.6. Results of trial 5 & trial 6

FUTURE SCOPE

As far as Indian scenario is concerned, the health of concrete is the most crucial aspect to be maintained in the coming future. In order to develop the solution for this, there needs to be research conducted in the field of construction industry with various combination of substitutes for cement as well as for the fine aggregate. Research needs to be conducted going beyond the codal provisions for replacement of fine aggregates or sand. In future the percentage of processed slag sand in combination of natural sand and crushed sand will be increased to analysis these trials for the behavioural aspect of concrete.

CONCLUSION

The behavioural modification in concrete is examined for various trials taking into account the processed slag sand as the partial replacement for fine aggregates along with natural sand and crushed sand. For the preliminary trials i.e., from trial no. 1 to trial no. 4, it has been observed that the trial in containing 10% silica fume and 30% GGBS combined satisfies this requirement of compressive strength and workability with natural sand, crushed sand and processed slag sand. This optimum proportion of supplementary cementitious material (SCM) was further analysed for durability aspects with increased percentage of processed slag sand from 25% to 30% used as partial replacement for natural sand and crushed sand. These results were interpreted for the compressive strength and water penetration test of concrete for comparing it with natural sand with respect to crushed sand. It was then observed that when crushed sand partially replaced with processed slag sand performs better than with river sand. The packing of concrete for this trail proves to be denser leading to less permeability of concrete and more compressive strength.

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