Performance Evaluation of Slag as a Cementitious Material in Concrete Production – Strength and Durability Properties

G. Ganesh Prabhu, J. Rajamurugadoss, K. Rajkumar

Abstract: The present study determine the influence of GGBS as a SCMs on strength and serviceability properties of concrete. The cement content of the concrete were substituted by GGBS with the replacement rate of 7.5%, 15%, 22.5% and 30% and the cement was replaced by SCMs in weight fraction. Slump cone test was executed to examine the influence of GGBS on fresh state properties of blended concrete. The study impact of GGBS on the strength properties of concrete compressive, flexural and split tensile strength tests were performed. RCPT test was made to study the chloride ion penetration in concrete and the penetration was determined through electrical conductance of concrete. Since the GGBS particles are smooth and spherical in shape, efficiently dispersed in the concrete mixture and exhibited a slump value relatively equal to the control/reference concrete. Even though the existence of GGBS reduced the concrete strength at the early eternities, as the curative time protracted, the increase in strength of the GGBS blended concrete mixtures was relatively upper than the control mixtures. In addition, the pozzolonic reaction and finess of the GGBS filled and densify the aperture structure of the concrete, thus, led to the increase in the chloride penetration resistance.

Keywords: GGBS, Concrete, Strength properties, Durability properties, SCMs

I. INTRODUCTION

In recent years, the governments of India started to pay more attention on building materials extraction and their effects on the environmental concerns. Over the past several decades, the Ordinary Portland cement is a solely one, used as a binding material in the concrete production. The clinker production of OPC led to significant emission of CO2, causing extensively affect the environment and widely contribute the conception of greenhouse effect [1]. So the increased OPC utilization led to the global forming escalation. It is documented that relatively a ton of CO_2 released to the environment to produce one ton of OPC, in addition, the CO_2 emission from the fabrication of OPC is relatively 8% of the total emission of CO2 in worldwide [2]. Furthermore, the quarrying of lime ore for the production of OPC destructed the habitats of wildlife. Past several decades, the replacement/substitution of OPC with supplementary binding materials (fly ash (FA), GGBS and silica fume) is in practice. Among the various SCMs used in worldwide, the inclusion of FA and GGBS has been successfully used in the concrete production over the 60years [3]. The glassy and crystalline phases of fly ash and GGBS improved the cementitious and hydration properties of the binding material. Lane and Best [4] confirmed that the strength properties of the conventional concrete has been increased up to 20% using fly ash substitution. In addition, the upturn in the replacement level of binding material using GGBS improved the shrinkage strain properties of the concrete [3]. The influences of GGBS in ultra-high performance concrete (UPHC) are very significant and the performance of UPHC up to 40% replacement is relatively equal to the conventional concrete. Puertas et al. [5] found that using alkali-activated slag/fly ash, reduced the sulfate damage of concrete and alkali-silica reaction. In addition the water permeability of the GGBS concrete are less than that of conventional concrete [6]. Since the presence of unreacted GGBS at higher level replacement, not enhanced the strength properties of the concrete, instead, acting as a filler material and improved the permeability properties of the concrete [7]. The test results of Cheewaket et al. [8] demonstrated that the chloride tie value of the fly ash concrete was nonlinear for the duration of 4years, after that the value was constant. The test results of Martin O'Connell et al. (2012) [9] documented that the resistance to the sulfate attack of the conventional concrete can be enhanced by means of GGBS in higher replacement level. The experimental investigation of Rami A. Hawileh et al. (2016) [10] exhibited that the higher level replacement (up to 70%) of cement using GGBS can be made and the higher level replacement not compromise the performance of the concrete in structural application. Researches performed so far have examined the strength and serviceability properties of the GGBS and fly ash blended concrete and in majority of the research the SCMs were neither GGBS nor fly ash. Only few of the researches were performed on multiple combination of SCMs in blended cement concrete production. Kazim Turk (2012) [11] found that the strength performance blended concrete developed using binary combination SCMs was relatively equal to the reference mixture. The combination of fly ash and palm oil fuel ash on concrete production significantly enhanced the microstructural properties of the concrete [12].Among the various researches performed related with SCMs in blended cement concrete, the research

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related with GGBS are very minimum. Since the two different phase of the GGBS are crystalline and glassy, the glassy phase improve the cementitious properties of the GGBS and the crystalline progress the hydration process of the concrete. The present research investigate the feasibility and influence of GGBS as a SCMs in concrete production. The experimental parameters were replacement rate of GGBS. The OPC of the concrete mixtures were replaced by GGBS with the replacement rate of 7.5%, 15%, 22.5% and 30% and the cement was replaced by SCMs in weight fraction. Slump cone test was executed to examine the influence of GGBS on fresh state properties of blended concrete. The study impact of GGBS on the strength properties of concrete compressive, flexural and split tensile strength tests were performed. RCPT test was made to study the chloride ion penetration in concrete and the penetration was determined through electrical conductance of concrete.

II. EXPERIMENTAL INVESTIGATION

A. *Materials and mixture proportions*

OPC confirming to IS: 8112-1989 was used as a binding material in this study. Since the research focused on cement replacement using SCMs, the chemical analysis of cement has been performed. The determined specific gravity of the cement was 3.12. Natural river and the blue metal jelly (19mm size) obtained from local quarry was utilized in this investigation as a fine and coarse aggregate, repectively. According to the methodology mentioned in IS 2386 (3):1963, both fine and coarse aggregate was tested for specific gravity and the obtained value was about 2.47 and 2.66, respectively. In addition to that, sieve analysis also performed on both coarse and fine aggregate. First grade GGBS received from steel plant located near to Chennai was used. The specific gravity of the GGBS was 2.76gram/cm^3 and the GGBS passing through 45 micron sieve was used to prepare the mixtures. The M30 concrete mix proportions was considered in this study and the mix proportion was designed according to the procedure recommended in IS 10262. The designed proportion is 1:1.76:3.61. A W/C ratio of 0.50 was adopted.

B. *Mixtures and specimen preparation*

To prepare the concrete mixture, binding material, coarse and fine aggregate were taken in dry condition and the portable mixer was used to mix the mixtures. Since the GGBS is very fine powder, the slump cone workability test was conducted to test the influence of GGBS on workability. The cylinders and cubes were fabricated to measure the tensile and compressive strength, respectively. Prism with the size of 100x100x500mm was fabricated to measure the flexural strength. The cubes, cylinders and prisms were filled by concrete and compacted by portable vibrator. After 24 hours, the molds were removed and the specimen were immersed in water tank up to the age of testing. A compression testing machine was used to test the cubes and cylinders. Flexural machine was used to test the prisms. RCPT was done to measure the influence of GGBS on the serviceability properties of concrete. The test was performed according the methodology recommended in ASTM C1202-97. For that, a concrete disc with the size of 5.1cm thickness and 10.2cm diameter was fabricated and cured until the age of testing. Followed by, the both ends of the disc was sealed with cell and filled with 0.3NNaOH and 3%NaCl solution. Across the two cells, 60V potential difference was maintained and the charge passing to the cell was observed for the interval of 6 hrs.

III. RESULTS AND DISCUSSIONS

A. *Slump loss*

The slump cone test was done to measure the influence of GGBS on workability of concrete and the obtained result was presented in Figure 1.

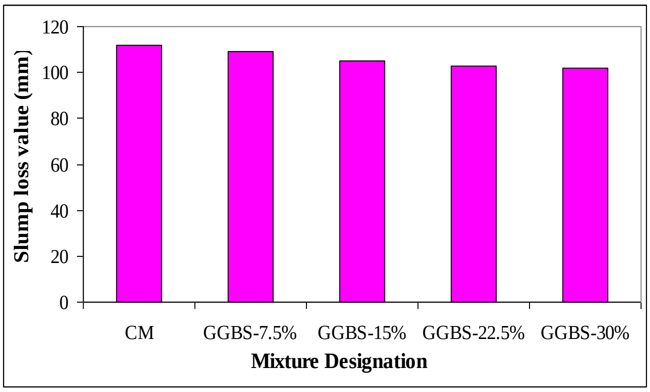

Figure 1 Influence of GGBS in workability of concrete

The replacement of cement using GGBS did not affect the slump value, in addition, the increase in the replacement rate also not significantly affected the slump value. Compared to reference mixture, the mixtures Con-GGBS-7.5%, Con-GGBS-15%, Con- GGBS-22.5% and Con-GGBS-30% showed 2.75%, 6.66%, 8.73% and 9.82%, respectively, decrease in slump value and this decrease in slump is not significant. It is expected that the particle size of the GGBS may decrease the slump of the concrete mixtures significantly. Conversely, the GGBS with the replacement rate up to 30% showed relatively equal slump value of control mixture. This is may be due to the surface smoothness and spherical shape of the GGBS. In addition, the dense powder properties of the GGBS efficiently dispersed in the concrete mixture, consequently, exhibited relatively equal slump value of CM.

B. *Compressive strength*

The 7, 28 and 90days compressive strength values are graphically presented in Figure 2. The test results of this study revealed that in all ages, the replacement of cement by GGBS combination reduced the compressive strength, however, the decrease in the strength was not significant. At 28days, with respect to CM, the mixtures Con-GGBS-7.5%, Con-GGBS-15%, Con- GGBS-22.5% and Con-GGBS-30% decreased its strength by 3.41%, 7.79%, 12.24% and 16.48%, respectively. Even though compressive strength decreased with the increase in GGBS replacement rate, the compressive strength value of the mixture Con-GGBS-22.5% was comparatively equivalent to the control mixture. At 28days, Con-GGBS-22.5% achieved a compressive strength of 35.12N/mm2, whereas the control mixture achieved a strength of 39.42N/mm2, which is 12.24% only higher than the Con- GGBS-22.5% and this difference is not significantly high.

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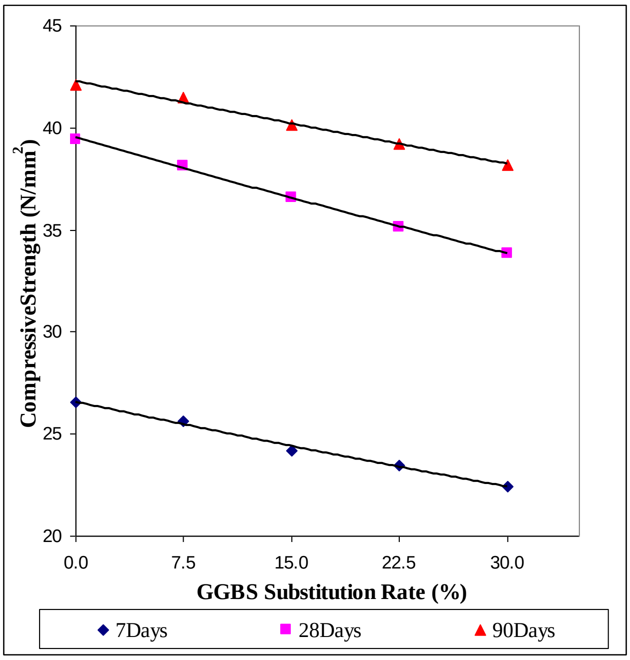

Figure 2 Influence of GGBS on compressive strength

The reduction in compressive strength may credited to the slow pozzolanic reaction owing to the demand of $Ca(OH)_2$. Since the replacement of cement by GGBS reduced the Ca(OH)2 formation, the GGBS participated in the pozzolanic reaction was reduced. Hence, the strength reduced with the escalation in the replacement amount of GGBS. However, from Figure 2, indicated that the strength enhancement of GGBS blended mixtures was relatively higher than the control mixtures, as the curing time protracted. At the age of 90days, the control mixtures exhibited 6.8% strength enhancement when compared to the 28days strength. Whereas the mixture Con- GGBS-7.5%, Con- GGBS-15%, Con- GGBS-22.5% showed 8.89%, 9.71% and 11.64%, respectively strength enhancement when compared to the 28days strength. Since the pozzolanic reaction of GGBS will occur only after the hydration process starts, the available GGBS contributed in the pozzolanic reaction and exhibited improved strength over the period.

C. Flexural and split tensile strength

Figure 3 and 4 exhibit the flexural and split tensile strength test results at the phase of 7, 28 and 90days. The obtained results were exhibited a similar trend of compressive strength and it can be evident from Figure 3 and 4. Like compressive strength, at the stage of 7, 28days, the presence of GGBS abridged the flexural and split tensile strength, in addition, the increase in the replacement rate of GGBS reduced the flexural and split tensile strength further. However, the reduction was not significant, in addition, the flexural and split tensile strength value of mixture Con- GGBS-22.5% was comparatively equivalent to the control mixture. Compared to CM, the mixture Con- GGBS-22.5% showed 7.95% and 8.56% decrease in flexural and split tensile strength, respectively.

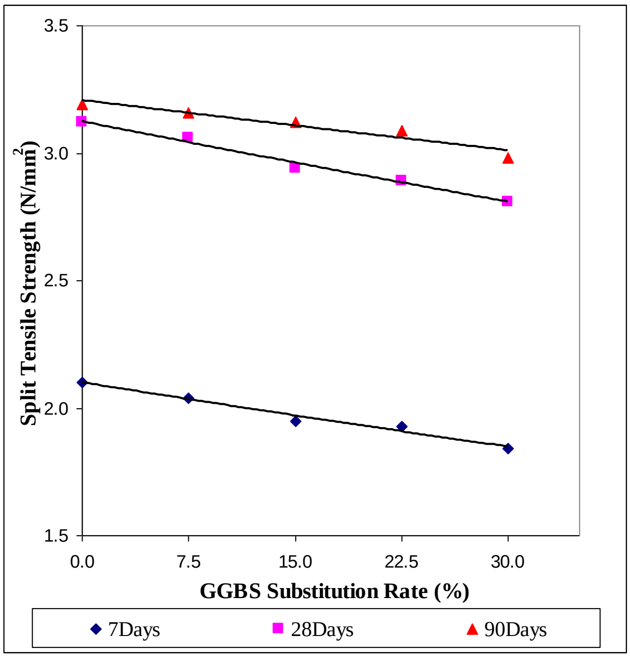

Figure 3 Influence of GGBS on split tensile strength at various ages

As discussed earlier, the demand of Ca(OH)2, caused slow pozzolanic reaction, led to the reduction in the strength. Since the increase in the replacement rate of GGBS increased the demand of Ca(OH)2, the increase in replacement decreased the strength. However, the 90days compressive strength of mixture produced with GGBS were shown comparatively equivalent to the CM strength.

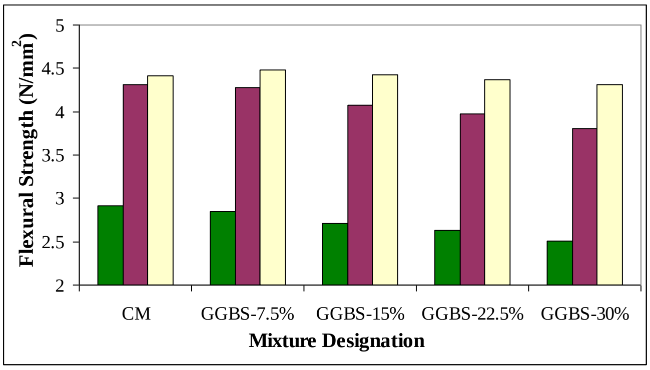

Figure 4 Influence of GGBS on flexural strength at various ages

IV. DURABILITY PROPERTIES

A. Rapid chloride ion penetration test (RCPT)

Since the serviceability criteria of the reinforced concrete structure chiefly depends upon the chloride penetration, for all mixtures, RCPT test made at the phase of 90 and 180days according to the methodology recommended in ASTMC1202-97 [24] and the obtained results were verified with the limits recommended in ASTMC1202- 97 [24]. Figure 5 shows the chloride penetration resistance of all mixtures with respect to the ages. From Figure 5 it can be implied that the replacement of cement using GGBS significantly enhanced the chloride penetration resistance of all mixtures, in addition, the chloride penetration resistance value was increased, while increasing the replacement rate. At the age of 90days, compared to CM, mixtures Con- GGBS-7.5%, Con-GGBS-15%, Con- GGBS-22.5% showed 14.84%, 23.31% and 34.85% enhancement in chloride penetration resistance. In addition, according to the category based on the limits provided in the ASTMC1202-97 [30], all the mixtures fall under very low category. The pozzolonic reaction and finess of the GGBS filled and densify the pore structure, thus, increased chloride penetration resistance. From Figure 5, it can be understood that the chloride penetration resistance of the mixture GGBS not deteriorated over the period of time. At the age of 180days, the chloride penetration value of CM was 642, which is 3.71% higher than the 90days value of CM. whereas the mixtures Con- GGBS-7.5%, Con- GGBS-15%, Con- GGBS-22.5% exhibited 0.55%, 0.79% and 1.74%, respectively, increase in chloride penetration resistance with respect to its 90days chloride penetration value. This is maybe due to the occurrence pozzolonic reaction over the period, densify the pore structure of the concrete. From the observation, it can be inferred that the increase in the GGBS improve the concrete chloride penetration resistance and chloride penetration resistance of concrete linearly proportional to the replacement rate of GGBS.

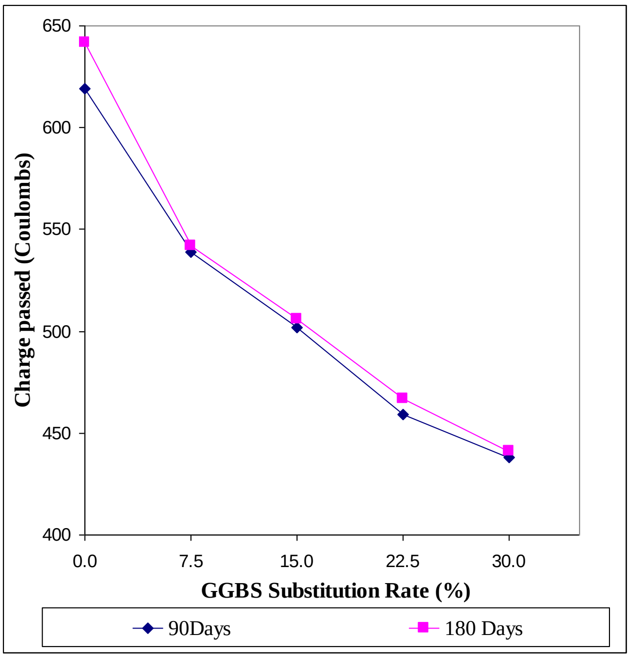

Figure 5 Influence of GGBS on RCPT values at various ages

V. CONCLUSION

The cement magnitude of the concrete were changed by GGBS by means of four different replacement rates and conclusions are:

1. Smooth and spherical in shape of the GGPS, efficiently dispersed in the concrete mixture and exhibited a slump value relatively equal to the control mixture. The mixture prepared with the replacement rate of 30% showed decrease in slump value than that of control mixture.
2. Even though the presence of GGBS decreased the compressive, split tensile and flexural strength, the strength value of the mixture Con-GGBS-22.5% was comparatively equivalent to the control concrete.
3. As the curative time protracted, increase in strength of the GGBS blended mixtures was comparatively higher with respect to control mixtures. At the age of 90days, the control mixtures exhibited 6.8% strength enhancement when compared to the 28days strength. Whereas the mixture Con- GGBS-7.5%, Con- GGBS-15%, Con-GGBS-22.5% showed 8.89%, 9.71% and 11.64%, respectively, strength enhancement when compared to the 28days strength.
4. The replacement of cement using GGBS significantly enhanced the chloride penetration resistance of all mixtures, in addition, the chloride penetration resistance value was increased as the GGBS rate increased.
5. At the phase of 90days, compared to CM, mixtures Con-GGBS-7.5%, Con- GGBS-15%, Con- GGBS-22.5% showed 14.84%, 23.31% and 34.85% enhancement in chloride penetration resistance.

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