High Strength Concrete Incorporating Ground Granulated Blast Furnace Slag and Steel Fibres: A Review

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***Abstract*—This paper describes a review of the potential use of High Strength Incorporating Ground Granulated Blast Furnace Slag and Steel Fiber Reinforced Concrete used in construction industry to improve the structural strength and reduce steel reinforcements requirements. Blast furnace slag (GGBS) has been used as a supplementary material along with the cement. It helps in increasing the durability and strength of the concrete. The experimental work done was reviewed which mainly deals with Mechanical and durability properties of high strength concrete reinforced with metallic (steel) fibres based upon normal curing.**

***Index Terms*—ground granulated blast furnace slag, steel fiber, durability, high strength**

I. Introduction

Concrete is the most widely used construction material due to its high and early compressive strength and low cost. It is the backbone of infrastructural development of whole world. But it is very brittle due to weak tension, flexure and impact strength and has low resistance against cracking. Concrete has capacity to enhance its properties with the help of other suitable constituents. Today, the industrial and agricultural waste by products such as Ground Granulated Blast – furnace Slag (GGBS), fly ash, rice husk ash, silica fume, etc. are used as Supplementary Cementitious materials in concrete. The incorporation of Supplementary Cementitious materials improve the mechanical and durability properties of concrete and also reduce the cement consumption by replacing part of cement with these pozzolanic material. To improve the brittle behavior of the concrete is the addition of small fibers in concrete with randomly distributed.

Concrete so reinforced is called Fiber Reinforced Concrete (FRC). The main reason for incorporating fibers into a cement matrix is to increase the tensile strength, the energy absorption capacity, toughness, flexural strength of concrete and also it improves the cracking deformation characteristics of the concrete composite.

A. Ground Granulated Blast Furnace Slag

The American Society of Testing and Materials (C 125 Definition of Terms Relating to Concrete and Concrete Aggregate) defines blast furnace slag as "the non-metallic product consisting essentially of silicates and alumino silicates of calcium and other bases, that is developed in a molten condition simultaneously with iron in a blast furnace."

In the production of iron, the blast furnace as shown in Fig. 1 is charged with iron ore, flux stone (limestone and/or dolomite) and coke for fuel. Two products are obtained from the furnace: molten iron and slag. The slag consists primarily of the silica and alumina from the original iron ore combined with calcium and magnesium oxides from the flux stone. It comes from the furnace as a liquid at temperatures about 2700 F, resembling molten lava. Dependent upon the manner in which the molten slag is cooled and solidified, three distinct types of blast furnace slag can be produced: air-cooled, expanded and granulated.

Figure. 1 Ground granulated blast furnace slag

Ground granulated blast-furnace slag (GGBFS): Hydraulic cement formed when granulated blast-furnace slag is ground to a suitable fineness commonly referred to as slag cement, or GGBFS.In India, annual productions of pig iron is 70-80 million tons and corresponding blast furnace slag are about 21-24 million tons. The blast furnace slag could be used for the cement raw material, the roadbed material, the mineral admixture for concrete and aggregate for concrete, etc.

B. Steel Fibres

Steel Fibre is a small piece of reinforcing material used as secondary reinforcement. They can be circular or flat. The fibre is often described by a convenient

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parameter called aspect ratio. The aspect ratio of the fiber is the ratio of its length to its diameter. Steel fibres will reduce steel reinforcement requirements, improve ductility, structural strength, reduce crack widths and control the crack widths tightly thus improve durability, improve impact & abrasion resistance, and improve freeze-thaw resistance. There are different types of Steel Fibres used in structural applications. They are Straight, Hooked and Crimped as shown in Fig. 2. Table I shows the typical properties of steel fibres.

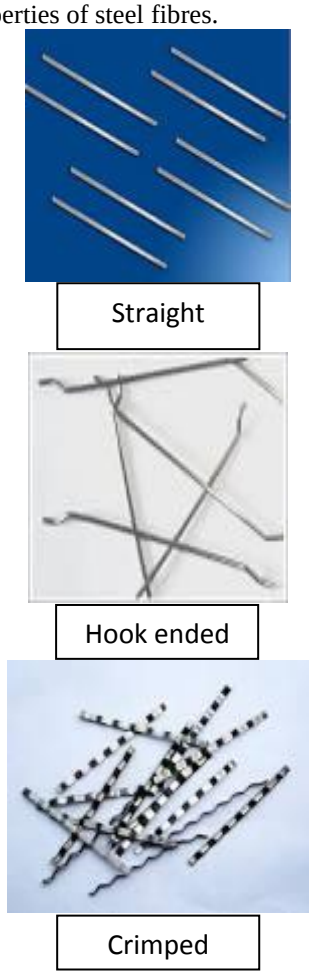

Figure. 2 Types of fibres

TABLE I: PROPERTIES OF STEEL FIBERS

Steel Fiber	
Tensile strength(Mpa)	275 – 2758
Young's modulus(10^3 Mpa)	200
Ultimate elongations (%)	0.5 – 35
Specific gravity	7.86

C. *Application of Steel Fiber Reinforced Concrete (S.F.R.C)*

The applications of S.F.R.C. are as follows for construction of different structural components:

- Refractories
- Pavements and overlays
- Manhole covers
- Patching and repair works
- Thin precast roofing and flooring and flooring elements
- Mine and tunnel supports and linings.
- Pipes, poles
- Machine foundations and structures resisting high impact load.
- Industrial flooring
- Rock slope stabilisation
- Wall panels
- Rapid dome construction
- Blast resistant structures
- Earthquake resistant structures
- Lining of steep incline of canals.

II. EXPERIMENTAL WORK DONE USING GGBS AND STEEL FIBRES

The investigation was carried out by Adams Joe M. and Maria Rajesh A. (2014) on characteristics of M40 concrete with different parameters of Ground Granulated Blast furnace Slag (GGBS) and 1% of steel fibre. The water binder ratio was 0.35 and super plasticizer CONPLAST SP-430 was use and cement was replaced with 0%, 10%, 20%, 30%, 40% & 50% of GGBS and 1% steel fibre. The investigation showed that by replacing the GGBS upto 40%, compressive, split tensile, flexural, and pullout strengths are increased and then it decreases. An experimental work was done by Yun Yeau K et.al (2005) on corrosion resistance of concrete containing ground granulate blast-furnace slag (GGBS) and ASTM Type I or ASTM Type V cement. The concrete was tested for rapid chloride permeability test, accelerated chloride-ion diffusion test, accelerated steel corrosion test and half-cell potential tests. Results showed that all concrete mixed with GGBS exhibited lower diffusion coefficient compared to GGBS free concrete. GGBS with 40% & more performs better. Oner A Akyuz S (2007) investigated to find the optimum level of optimum level of ground granulated blast-furnace slag (GGBS) on the compressive strength of concrete. Test concretes were made by adding GGBS to concretes in an amount equivalent to approximately 0%, 15%, 30%, 50%, 70%, 90% and 110% of cement contents of control concretes with 250, 300, 350 and 400 kg/m^3 dosages. All specimens were moist cured for 7, 14, 28, 63, 119, 180 and 365 days. The results indicated that the optimum level was obtained at about 55 – 59% of total binder content after that it decreases. Escalante-Garcia J.I. et.al investigated the cementious performance of coarse ground granulated blast furnace slag in concrete. First the cement was replaced by 30%, 50% and 70% with slag, and results showed that the strength decreased as the amount of slag increased. Second, the same amount of cement was replaced with slag which was alkali activated with sodium silicate (moduli 1.7 and 2) at 4%, 6% and 8% %Na2O, the strength increased with the amount of slag in the concrete and developed faster as %Na2O increased. Susanto Teng et.al (2013) investigated the mechanical and durability properties of high strength

concrete incorporating ultra fine GGBFS. Two concrete mixes with 450 and 550 kg/m^3 of ordinary Portland cement and two more mixes of equivalent total cementious material with 30% UFGGBS replacement was cast. The test performed were Compressive strength, flexural strength, modulus of elasticity, chloride migration, electrical resistivity and drying test. Results showed that the mechanical and durability properties of UFGGBS blended concrete were improved significantly. Al-Otaibi S (2008) had performed the durability tests on concrete containing GGBS activated by water – glass. Two types of water glass with different silicate modulus were used. One in solution form (Ms = 1.65) and other in a solid granular form (Ms = 1). All the mixes had the same binder content and w/b = 0.48. Results showed that Alkali Activated Slag (AAS) concrete with higher dosage of Na_2O gives higher strength and with higher silicates modulus of activator resulting in higher strength. Moreover the durability of AAS concrete was good compared to OPC concrete. The research was carried out by Arribas I et.al (2014) on the durability of Electric – Arc furnace slag (EAF) aggregate as a substitute for the conventional aggregate and their resistance to both physical (freeze – thaw, high temperature and relative humidity) and chemical degradation (sulfate attack, alkali aggregate reaction and marine environment) and as well as their resistance to the corrosion of steel reinforcement bars embedded in the concrete matrix. Results found that concrete with EAF slag performed better to freeze/thaw effect, to high temperature and relative humidity and resistance to sulphate attack compared to normal concrete. Topcu I B *et al.* (2007) had performed experiments to study the effect of replacement of cement with different percentage of flyash and effects of addition of steel and polypropylene fibres. The results showed that by adding fibres, workability decreases but with flyash addition it is maintained. Thus adding flyash and fibres to concrete its performance increases and cost decreases. Kaikea A *et al.* (2014) investigated the mechanical properties of high performance fibre reinforced concrete. The main parameters that varied were the fiber volume content and the types of mineral addition. Results showed that by adding steel fibres and blast furnace slag the compressive, flexural, toughness and shrinkage properties can be improved significantly. Holschemacher K *et al.* (2010) investigated influence of steel fibre types and amounts on flexural tensile strength, fracture behaviour and workability of steel bar reinforced high-strength concrete beams. Different bar reinforcements (2ϕ6 mm and 2ϕ12 mm) and three types of fibres configurations (two straight with end hooks with different ultimate tensile strength and one corrugated) were used. The results showed that strength and geometry of fibres have a direct influence on the load bearing capacity of HSSFRC beams without bar reinforcement. High strength fibres showed better ductile behaviour and higher load levels in the post cracking range. Bernal S A *et al.* (2012) studied the effects of activation conditions on the engineering properties of alkali-activated slag/metakaolin blends. Results showed that at high activator concentration, compressive strengths at early age was enhanced by the inclusion of metakaolin in the binder. A similar effect was observed in the flexural strength of the concretes, as dissolution and reaction of metakaolin was favoured under higher-alkalinity activation conditions. Increased metakaolin contents and higher activator concentrations also lead in most cases to reduced water sorptivity and lower chloride permeability. Vejmelkova E. *et al.* (2009) investigated a wide set of parameters of concrete containing 10% of ground granulated blast furnace slag as Portland cement replacement involving basic material characteristics, mechanical and fracture-mechanical properties, durability characteristics, hydric and thermal properties and chloride binding characteristics was determined and compared with the parameters of reference Portland cement concrete with otherwise the same composition. The results showed that the replacement of Portland cement by even such a low amount of ground granulated blast furnace slag as environmental more friendly and still valuable alternative binder affects positively. Higgins D D (2003) had done experiment to study the increased sulphate resistance of GGBS in presence of carbonate. Three test methods were employed. First cubes were immersed in magnesium and sodium sulphate solutions and monitored for corner-loss and strength-loss, over six years. Second mortar was sieved from fresh concrete and used to make prisms. These prisms were immersed in magnesium and sodium sulphate solutions and their expansions monitored for up to six years. Third in accordance with a draft of a European Standard for sulphate resistance, mortar prisms were prepared and monitored for expansion for one year. The experimental study was done by addition of small percentages of either calcium carbonate or calcium sulphate and GGBS concrete improved the resistance to sulphate attack. Qiang W et.al (2013) investigated the influence of steel slag on the compressive strength, drying shrinkage, permeability to chloride, and carbonation resistance of concrete under two different conditions: constant W/B and constant 28 days' compressive strength. The effects were (1) Under the condition of constant W/B, increasing the steel slag content tends to decrease the compressive strength especially the early strength of the concrete. At high W/B (0.50), the late compressive strength of the concrete with more than 30% steel slag is significantly lower than that of the pure cement concrete. But at low W/B (0.35), the late compressive strength of the high volume steel slag concrete is much closer to that of the pure cement concrete. The negative effect of steel slag on the strength of concrete is less obvious at lower W/B. (2) At high W/B, the drying shrinkage of the concrete with steel slag develops faster at the early ages than that of the pure cement concrete, but their ultimate shrinkages at 90 days are very close to each other. At low W/B, steel slag has little influence on the drying shrinkage of the concrete. (3) Under the condition of constant W/B, increasing the steel slag content tends to increase the permeability to chloride ion of the concrete at 28 days. At high W/B, the permeability of the high volume steel slag concrete is

obviously higher than that of the pure cement concrete at the late ages. But at low W/B, the high volume steel slag concrete can get permeability close to the pure cement concrete at the late ages.

The negative effect of steel slag on the permeability of concrete is weaker at lower W/B. (4) Under the condition of constant W/B, a small steel slag replacement has little influence on the carbonation resistance of the concrete. A large steel slag replacement tends to significantly weaken the carbonation resistance of the concrete. The negative effect of steel slag on the carbonation resistance of the concrete is weaker at lower W/B and with longer initial standard curing period. (5) Under the condition of constant 28 days' compressive strength, the concrete with steel slag exhibits lower early strength but higher late strength than the pure cement concrete. The ultimate drying shrinkage at 90 days of the concrete with steel slag is close to that of the pure cement concrete. The concrete with steel slag can get permeability to chloride ion and carbonation resistance similar to the pure cement concrete. Johari Megat M. A. et.al (2011) had studied the influence of supplementary cementitious materials (SCMs), namely silica fume, metakaolin, fly ash and ground granulated blast-furnace slag, on the engineering properties of high strength concrete (HSC). Workability, compressive strength, elastic modulus, porosity and pore size distribution were assessed in order to quantify the effects of the different materials. The observations were: 1. The use of SF at a replacement level of up to 10% tends to improve the workability of HSC. From the literature, this scenario has been observed only in concrete produced with low water/binder ratio in conjunction with the use of superplasticiser. The effect of MK is to reduce the workability of HSC with greater reducing effects at higher replacement levels. The influence of FA and GGBS on the workability of HSC is the same as that observed in normal strength concrete, which is to improve the workability. Greater effects were observed at higher replacement levels. 2. The inclusion of the different SCMs significantly influences the compressive strength of the HSC mixes. The effect of SF is to enhance the compressive strength of the concretes at all ages, particularly between the ages of 28 and 90 days. Similarly, the general effect of MK is to enhance the strength of the HSC, except for the MK15, concrete at the age of 1 day. At a replacement level of 5%, the maximum contribution of MK to the HSC strength occurs at the age of 1 day, while at higher replacement levels of 10% and 15%, the maximum contribution to strength takes place between the ages of 14 and 28 days. Due to the slower reactivity of FA and GGBS, as well as the dilution effect, their inclusion reduces the early strength of the concrete, particularly at higher replacement levels. While the FA enhances the later age strength of the HSC, the GGBS gives maximum strength between the ages of 28 and 90 days. For each mineral admixture, SF, MK, FA and GGBS, maximum long-term strength was obtained at replacement levels of 15%, 10%, 30% and 20%, respectively. 3. The general effect of the different SCMs on elastic modulus of HSC is nominal compared to their effect on strength. The static modulus of elasticity of the HSC at the age of 28 days can be expressed as a function of compressive strength. The EC 2 and ACI 209 models give good estimates of static modulus of elasticity. The equation given in BS8110 tends to slightly underestimate the static modulus of elasticity, while the ACI 363 tends to underestimate static modulus of elasticity with higher error coefficient. 4. The dynamic modulus of elasticity of the HSC can be expressed as a function of the cube compressive strength raised to the power of 0.5. The general relation between static and dynamic moduli of elasticity, as given in BS 8110, could be applicable to the HSC, with or without SCMs. 5. The effect of SCM is to reduce the porosity of mortar measured using the MIP apparatus, while the mean and average pore sizes are significantly reduced for all mortars containing SCMs. SF and MK seem to have greater influences in reducing the porosity and pore size of mortar. 6. The effect of the SCMs is to increase the volume of mesopores in the ranges of <15 nm and 15–30 nm, but to significantly reduce the percentage of macropores. The mortars containing SF and MK, as well as the GGBS60 mortar, show significant increase in the percentage of mesopores in the range of <15 nm, with the MK15 mortar exhibiting the greatest increase. Kumar S et – al (2008) used mechanically activated granulated blast furnace slag (GBFS) in the range of 50–95% to replace clinker in portland slag cement (PSC). The slag and clinker were activated separately using an attrition mill and mixed to prepare cement formulations. The strength of the sample containing 80–85% slag was comparable to the commercial cement used as a reference. The hydrated cement samples were characterised using powder X-ray diffraction (XRD), scanning electron microscopy with X-ray microanalysis (SEM-EDS) and simultaneous thermogravimetry and differential thermal analysis (TG/DTA). The effects were: 1. Mechanical activation of the slag had a beneficial effect on the early strength development. Low early strength development has been a major handicap in increasing the proportion of slag in conventional portland slag cement. 2. In the PSC prepared using mechanically activated clinker and slag, it was found that up to 85% replacement of clinker by slag is possible without impairing the strength vis-a-vis a commercial cement containing 40% slag of the same origin. 3. Unlike the ball milled slag, where strength decreases at early ages, both 1-day and 28-day strength increased with increasing amount of activated slag up to 70% 4. The fineness of the slag was found to be more critical than that of the clinker from the point of view of strength development. 5. Mechanical activation results in following changes in the evolution of microstructure during the hydration (a) increased hydration of C3S in clinker and hydration of slag due to the increase in its reactivity. Elahi A et.al (2010) investigated the mechanical and durability properties of high performance concretes containing supplementary cementitious materials in both binary and ternary systems. The mechanical properties were assessed from the compressive strength, whilst the durability characteristics

were investigated in terms of chloride diffusion, electrical resistivity, air permeability and water absorption. The test variables included the type and the amount of supplementary cementitious materials (silica fume, fly ash and ground granulated blast-furnace slag). Portland cement was replaced with fly ash up to 40%, silica fume up to 15% and GGBS up to a level of 70%. The observations were (1) With the w/b kept constant at 0.3, the compressive strength was detrimentally affected by the replacement of PC with both FA and GGBS at all ages up to 91 days. However, the compressive strength increased at all ages due to the use of SF at 7.5% replacement levels. There was a decrease in compressive strength at early ages when the SF content was increased from 7.5% to 15%. It was possible to enhance the long-term compressive strength of both FA and GGBS mixes with the addition of 7.5% of SF, but there was a decrease in compressive strength at early ages. (2) The results of the tests carried out on the HPC concretes containing SF, FA and GGBS in large volumes clearly illustrated that some mix combinations are superior to others for different properties presented in this paper. Clearly this would mean that HPCs for different exposure conditions could be designed and produced with a combination of different cementitious materials and the exact choice of these combinations should be based on the physical properties relevant to the durability and performance expected from the HPC. (3) There was a decrease in air permeability with age for all the mixes. No advantage was observed in adding SF to both the control mix (PC only) and binary mixes from the point of view of the air impermeability, except mixes SF15 and SF + FA20. The binary mixes with 40% FA showed a dramatic reduction in air permeability at 44 days, followed by 20% FA mix at 44 days. The control mix exhibited the lowest air permeability values at later ages, marginally above the mix with 40% FA at the same age. This means that HPCs with low air permeability could be obtained without the addition of any supplementary cementitious materials. However, these mixes may perform adequately only where air permeability is the criterion affecting its durability. (4) There was a decrease in sorptivity (water absorption) with age for all the mixes. SF was less pronounced in improving the sorptivity at 44 as well as 91 days. The 50% GGBS, both with and without SF, improved the water absorption at 44 and 91 days. Similarly, the 20% FA with and without SF improved the water absorption at 91 days. SF improved the GGBS concrete more than FA concrete. That is, in the case of sorptivity (water absorption), there was benefit with the addition of 20% FA and 50% GGBS compared to the control concrete. However, the improvement to sorptivity with the addition of SF was marginal. (5) All the mixes with cement replacement materials showed at least three times greater resistance to chloride diffusion than the control mix. Amongst all the binary mixes, SF mixes showed the best performance in improving the chloride resistance. Even the ternary mixes, achieved by the inclusion of SF in FA and GGBS concretes, exhibited increase in the resistance to chloride diffusion. (6) The type and content of binders had almost the same effect on penetration parameter and bulk resistivity as their effect on the resistance to chloride diffusion. Amongst the SCM blends, the highest resistivity was obtained for SF15 and the lowest for BS50. Generally the addition of SF increased the resistivity of FA and GGBS mixes. Song P S and Hwang S (2004) investigated the mechanical properties of high-strength steel fiber-reinforced concrete. The properties included compressive and splitting tensile strengths, modulus of rupture, and toughness index. The steel fibers were added at the volume fractions of 0.5%, 1.0%, 1.5%, and 2.0%. The effects were 1. The compressive strength of HSC improved with additions of steel fibers at various volume fractions. The strength showed a maximum at 1.5% fraction but a slight decrease at 2% fraction compared to 1.5%, still remaining 12.9% higher than before the fiber addition. 2. The splitting tensile strength and modulus of rupture of HSFRC both improved with increasing fiber volume fraction. The splitting tensile strength ranged from 19.0% to 98.3% higher for the fractions from 0.5% to 2.0%. And the modulus of rupture ranged from 28.1% to 126.6% higher for the fraction from 0.5% to 2.0%. 3. The strength-effectiveness showed at each volume fraction a maximum for modulus of rupture, followed by splitting tensile strength, and compressive strength. 4. The strength models developed for HSFRC predicts the compressive and splitting tensile strengths and modulus of rupture accurately. Bernal S (2010) investigated mechanical and permeability properties at early ages of an alkali-activated slag concrete (AASC) reinforced with steel fibers. The compressive, splitting tensile and flexural strengths, flexural notch sensitivity, pull-out and water absorption properties were evaluated. The results obtained were:

- The developed AASC present higher compressive strengths than the OPC reference concretes. A higher reduction of the compression strength in OPC concretes with the addition of fibers could be identified. The AASC exhibit better retention of this property.
- Splitting tensile strengths increase in both OPCC and the AASC concretes with the incorporation of fibers at 28 curing days; however, these increments were higher in AASC reinforced with steel fibers. The effect of steel fibers on flexural behaviour was notable. The deflection corresponding to the ultimate load was enhanced with the increase of fiber volume. Additionally, the modulus of rupture, of the fiber reinforced mixtures, were higher for AASC. A substantial improvement in load capacity as well as flexural toughness (understood as absorption of energy until failure slip) with increasing fiber volume was identified.
- The AASC reinforced with steel fibers present a three-fold increase in flexural toughness compared to OPCC at early ages of curing, both in continuous and in notched samples, being more significant in samples with notches.

III. Conclusion

Ground Granulated Blast Furnace Slag and steel fiber can be used in concrete as a suitable replacement of cement to make the concrete stronger in compression and tension, to make concrete more economical, and Proper utilization of industrial waste to reduce the impact on environment.

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