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EXPERIMENTAL INVESTIGATIONS ON STRENGTH CHARACTERISTICS OF STEEL FIBRE REINFORCED CONCRETE

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Abstract— It is now well established that one of the important properties of Steel Fibre Reinforced Concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particularly under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fibre composite pronounced post cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading. The real contribution of the fibres is to increase the toughness of the concrete. The fibres tend to increase the strain at peak load, and provide a great deal of energy absorption in post-peak portion of the load-deflection curve. This report presents a laboratory investigation on the strength characteristics of steel fibre reinforced concrete. Tests were conducted by adding Ground Granulated Blast furnace Slag (GGBS) and steel fibres to concrete in an amount equivalent to approximately 0%, 20%, 40%, 60% and 80% to the weight of cement content and that for steel fibres from 0 to 2% with an increment of 0.5%. The test results proved that the compressive strength of concrete increases with per cent increase in GGBS up to 40%. Beyond 40%, there is marginal decrease in strength of concrete. In addition, tests were conducted, taking the combinations of GGBS and steel fibres. From the test results, it was found that there is improvement in the strength of concrete by addition of GGBS and steel fibres.

Index Terms— steel fibre reinforced concrete, Ground Granulated Blast furnace Slag, compressive strength, split tensile strength,steel fibres, aspect ratio, concrete.

1 INTRODUCTION

Concrete is the most widely used man-made building material in the world, owing to its versatility and relatively low cost. Historically, concrete is weak in tension, porous and brittle when compared to steel. Concrete has also become the material of choice for the construction of structures exposed to extreme conditions (Lomborg, 2001). Furthermore, sustainability has become an increasingly important characteristic for concrete infrastructure, as the production of Portland cement (the most common binder in concrete) is an energy-intensive process that accounts for a significant portion of global carbon dioxide emissions and other greenhouse gases (Mehta, 2001) and (Van Dam and Smartz 2010). As such, even slight improvements in the design, production, construction, maintenance, and materials performance of concrete can have enormous social, economic and environmental impacts. As strength of concrete increases, material is more homogeneous, however it also becomes more brittle. To minimize this increased brittleness, fibres are added. Fibre reinforcement substantially enhances the toughness and durability of concrete.Fibre reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres. Fibres are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage

Some of the early research works were done using different pozzolanic materials with the replacement of cement using GGBS for the development in performance of concrete. Many researchers have used GGBS to improve cement-based materials properties, and have achieved great successes. GGBS is a pozzolanic material which can be used as a cementitious ingredient in both cement and concrete composites. This supplementary material improves many of the performance characteristics of the concrete. Oner and Akyuz (2007) studied on optimum level of GGBS on compressive strength of concrete. The test results proved that the compressive strength of concrete mixtures containing GGBS increases as the amount of GGBS increase. After an optimum point, at around 55% of the total binder content, the addition of GGBS does not improve the compressive strength. This can be explained by the presence of unreacted GGBS, acting as a filler material in the paste. Ganesan et al (2007) studied on the experimental results of ten steel fibre reinforced high performance concrete (SFRHPC) exterior beam-column joints under cyclic loading. Volume fraction of the fibres used in this study varied from 0 to 1% with an increment of 0.25%. Joints were tested under positive cyclic loading, and the results were evaluated with respect to strength, ductility and stiffness degradation. Test results indicate that the provision of SFRHPC in beam-column joints enhances the strength, ductility and stiffness, and is one of the possible alternative solutions for reducing the congestion of transverse reinforcement in beam column joints.

Materials Used

The materials used in the experimental investigation include:

1. Cement
2. Fine and coarse aggregates
3. Ground granulated blast furnace slag
4. Steel fibres

Cement

Ordinary Portland Cement (53 grade) was used for the investigation. Initial experiments like initial and final setting times and fineness tests were conducted. The results are shown in Table 1

Table 1 Physical properties of cement

S. No	Property	Value
1	Specific gravity	3.10
2	Fineness	7.5
3	Initial setting time	35 min
4	Final setting time	450 min

Fine and coarse aggregates

The fine aggregate used was river sand passing through 2.36 mm IS sieve with fineness modulus of 2.46 and specific gravity 2.74. Crushed granite stones retained on 20 mm and 12.5 mm and having a fineness modulus of 6.89 and specific gravity of 2.8 were used for coarse aggregates.

Ground granulated blast furnace slag (GGBS)

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. These operate at a temperature of about 1,500 degrees centigrade and are fed with a carefully controlled mixture of iron-ore, coke and limestone. The iron ore is reduced to iron and the remaining materials form a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be used for the manufacture of GGBS it has to be rapidly quenched in large volumes of water. The quenching, optimises the cementitious properties and produces granules similar to a coarse sand. This 'granulated' slag is then dried and ground to a fine powder. The composition of minerals and physical properties of GGBS are shown in Table 2. In the present study, the percentages of GGBS used are 20, 40, 60 and 80 to the weight of cement.

Table 2 Chemical composition and physical properties of GGBS

Chemical composition		Physical properties	
Calcium oxide	40%	Colour	off-white
Silica	35%	Specific gravity	2.9
Alumina	13%	Bulk density	1200 kg/m3
Magnesia	8%	Fineness	>350m2/kg

Steel Fibres

Fibre is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fibre is often described by a convenient 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, improve freeze-thaw resistance Steel fibres cut to size 50 mm are used in this investigation. The properties of steel fibre used are presented in Table 3

Table 3 Properties of steel fibre

Length	50mm
Diameter	1mm
Appearance	Clear and Bright
Tensile strength	800-2500mpa
Aspect ratio	50

Results and Discussion

A total of 13 mixtures were prepared, in which one is taken as control mix, four were prepared by partial replacement of GGBS (20%, 40%, 60%, 80%), four mixes were prepared by adding steel fibres to the total binder content (0.5%, 1%, 1.5%, 2%). With the optimum value of GGBS and at different percentages of steel fibres, remaining four mixes were prepared. The compressive strength testing is done for 7, 14 and 28 days, whereas split-tensile strength testing is done for 7 and 28 days.

Effect of GGBS on Strength Parameters

The percentages of GGBS considered for the study are 0, 20, 40, 60 and 80 % respectively. From the results, it is observed that the early age strength values of GGBS concrete mixtures are lower than the control mixtures. The variation of compressive strength with number of days is plotted in Fig.1. Fig. 2 shows the variation of split tensile strength of concrete with different percentages of GGBS. As the curing period is extended, the strength values of the GGBS concrete mixtures increase more than the control mixtures. Since the pozzolanic reaction is slow and depends on the calcium hydroxide availability, the strength gain takes longer time for the GGBS concrete. The pozzolanic reaction of the Portland cement is expressed as follows (Oner and Akyuz 2007).

Cement (C_3S, C_2S) + H_2O (H) → CSH–gel + $Ca(OH)_2$ (CH)

The pozzolanic reaction is:

$Ca(OH)_2$ (CH) + SiO_2 (S) + H_2O (H) →CSH–gel

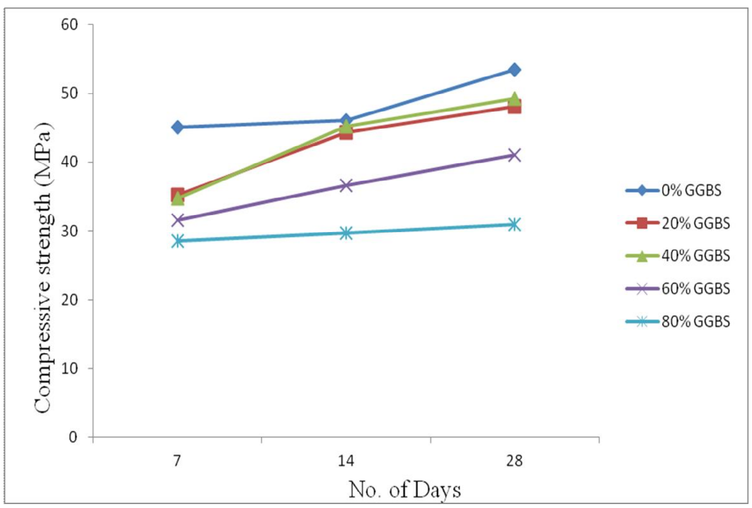

Fig.1 Variation of Compressive strength of Concrete with different percentage of GGBS

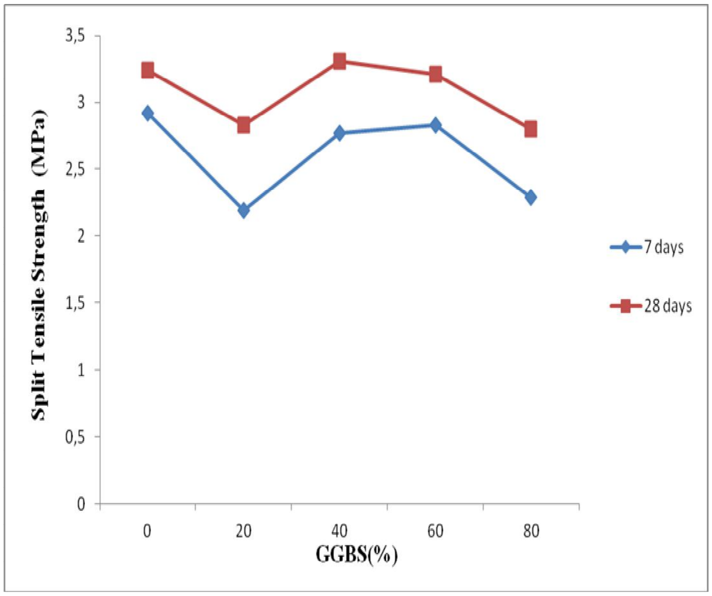

Fig.2 Variation of Split tensile strength of Concrete with different percentages of GGBS

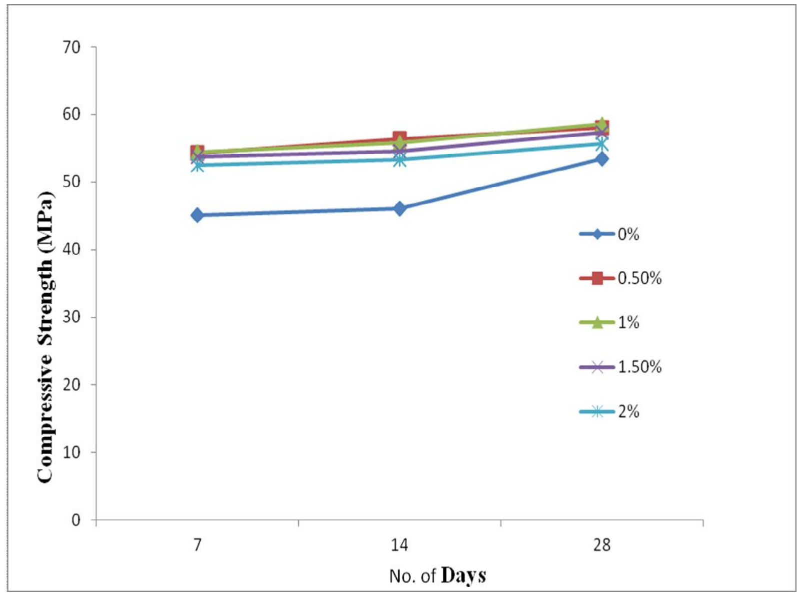

Fig. 3 Variation of Compressive strength of Concrete with different percentages of steel fibres

Effect of Steel Fibres on Strength Parameters

The percentages of steel fibres considered for the study are 0, 0.5, 1, 1.5 and 2 % respectively. From the test results, it is observed that compressive strength and spilt tensile strength are higher than the normal mix and increases up to 1% and starts decreasing gradually with increase in fibre volume fraction. The results were presented in Table 4 and variation of compressive strength with number of days is plotted in Fig.3 Fig.4 shows the variation of split tensile strength of concrete with different percentages of steel fibres. The main purpose of adding steel fibres is to reduce the brittleness of concrete and increase in strength.

Table 4 Effect of Steel fibres on Compressive strength of concrete

S.No	% Steel Fibres	Compressive Strength (MPa)		
		7 days	14 days	28 days
1	0	45.04	46.06	53.44
2	0.5	54.26	56.4	58.04
3	1	54.40	55.82	58.50
4	1.5	53.70	54.60	57.24
5	2	52.48	53.33	55.6

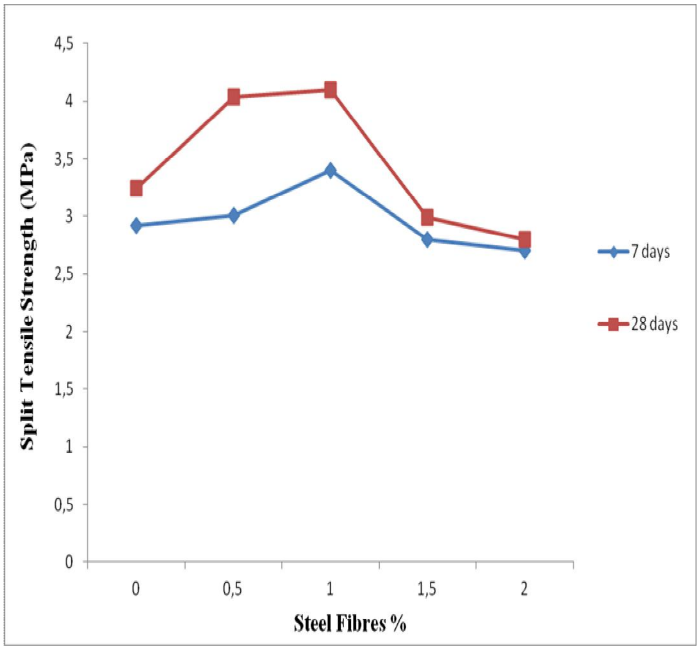

Fig.4 Variation of Split tensile strength of Concrete with different percentages of steel fibres

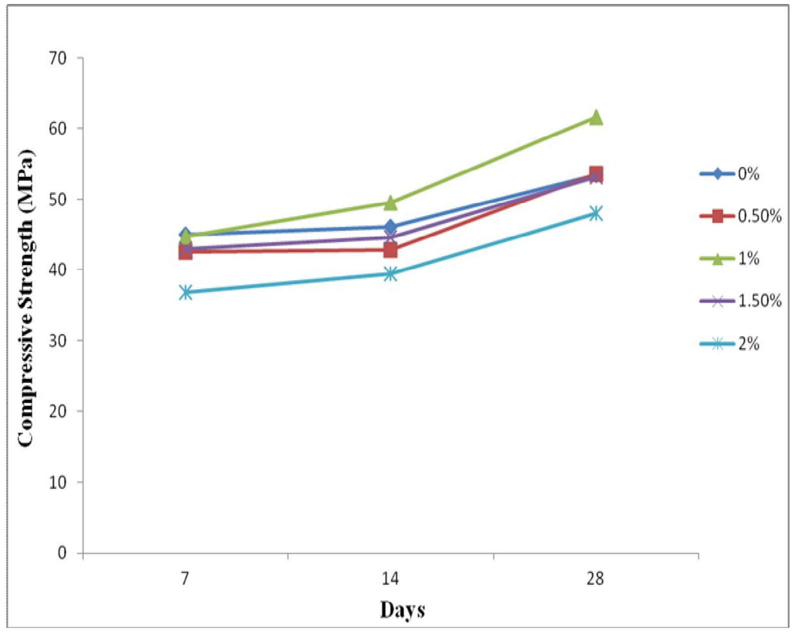

Fig.5 Variation of Compressive Strength of Concrete with Optimum GGBS of 40% at different percentages of steel fibres

Effect of both GGBS and Steel Fibres on Strength Parameters

With the optimum value of GGBS, that is 40 %, different percentages of steel fibres are used. The percentages of steel fibres considered are 0, 0.5, 1, 1.5 and 2 % respectively. From the test results, it is observed that compressive strength and spilt tensile strength are higher than the normal mix and increases up to 1% for compressive strength, 1.5% for split tensile strength and it starts decreasing gradually with increase in fibre volume fraction. The results were presented in Table 5 and variation of compressive strength with number of days is plotted in Fig.5. Fig.6 shows the variation of split tensile strength of concrete with optimum GGBS with different percentages of steel fibres.

Table 5 Effect of both GGBS and Steel fibres on Compressive strength of concrete

S.No	% Steel Fibres	Compressive Strength (MPa)		
		7 days	14 days	28 days
1	0	45.04	46.06	53.44
2	0.5	42.62	42.80	53.60
3	1	44.80	49.53	61.60
4	1.5	42.97	44.60	53.2
5	2	36.88	39.51	48.08

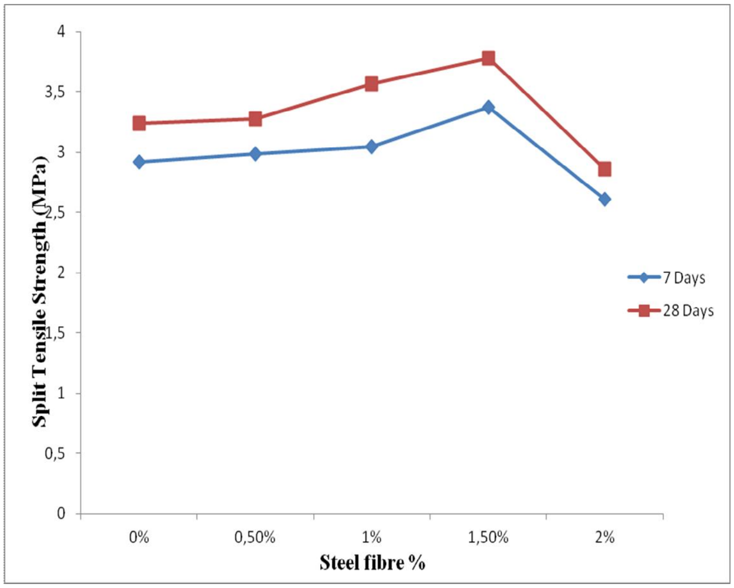

Fig.6 Variation of Split Tensile Strength of Concrete with Optimum GGBS of 40% at different percentages of steel fibres

Conclusions

The following conclusions are made from the present investigations

1. Compressive strength of concrete increases with per cent increase in GGBS up to 40%. Beyond 40% there is marginal decrease in strength of concrete. Hence 40% is taken as the optimum value of GGBS.
2. Replacing the cement with GGBS in concrete is one of the best solutions available to the problem of environmental impacts.
3. Compressive strength in concrete enhances up to 1% of steel fibre and then decreases gradually. Split tensile strength of concrete increases with per cent increase in steel fibre up to 1%. Beyond 1% there is a decrease in strength of concrete.
4. Compressive strength of concrete (combination of optimum value of GGBS at 40% and different percentages of steel) increases up to 1%. Beyond 1% there is a decrease in strength of concrete.
5. Split tensile strength of concrete (combination of optimum value of GGBS and cement) increases up to 1.5%. Beyond 1.5% there is a decrease in strength of concrete.

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