International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.9, pp 994-1003, 2017

Studies on Strength Properties of High Strength Concrete with Ground Granulated Blast Furnace Slag

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Abstract : Low cost concrete production by replacement of cement by ground granulated blast furnace slag (GGBS) and sand by waste foundry sand (WFS) is a new trend and reduces the disposal problem and decreases the environmental pollution. Ground blast furnace slag is the byproduct of steel and iron making process. It is obtained by quenching molten iron slag from a blast furnace in water or steam, to produce glassy. Waste foundry sand is the byproduct of ferrous and nonferrous metal casting industry. The ground granulated blast furnace slag and Waste foundry sand was partially replaced with cement and fine aggregate with 10%, 20%, 30%, 40%,50% replacement and results compared with referral mix. The grade of concrete is M40. The concrete works were conducted and testing was done for compressive strength, split tensile strength and sorptivity of concrete. The tests were conducted for 7days, 28 days, 56 days and 90 days, compressive strength and split tensile strength was evaluated. The compressive and spilt tensile strength is increased up to 20% replacement of Ground blast furnace slag and Waste foundry sand, after optimum dosage the compressive strength and split tensile strength decreased with increasing percentage. Sorptivity of concrete is maximum for 10% replacement. The workability of concrete increased with increasing percentage of replacement.
Key words : Ground granulated blast furnace slag(GGBS), Waste foundry sand(WFS), Compressive strength, Split tensile strength, Workability, sorptivity.

Introduction

Concrete's versatility, durability, sustainability, and economy have made it the world's most widely used construction material and it is a man-made product, fundamentally consists of cement, aggregates, water and admixtures. Every year four tons of concrete are produced per person worldwide. Concrete is being the most popular and most economical construction material has a major shortcoming in terms of embedded energy and is also one of the major causes of greenhouse gas effect. The cement industry is the primary producers of carbon dioxide; it is a major greenhouse gas. One ton of carbon dioxide gets released by the production of one ton of cement clinker [1]. So as to reduce the emission of carbon dioxide concerning the production of cement, we must reduce the use, and also the demand of Portland cement.

Sand is also the major material is used for the production of concrete. The consumption of natural sand is very high due to the large use of mortar and concrete [1]. Therefore the demand of the natural sand is very high in developing countries like INDIA to satisfy the rapid infrastructure growth [2, 3]. The developing countries facing scarcity of natural sand, natural sand deposits used up and effects environment as well as the society [2]. Rapid excavation of river sand affects the river bed and also causes the problems like losing water retaining soil strata, deepening of the river beds and causing bank slides, loss of vegetation on the bank of rivers and also disturbs the aquatic life by lowering the water table. Because of high demand in the construction industry, the research work has been started to search for alternative fine materials to natural sand.

Ground granulated blast furnace slag is a by product of iron and steel making process. It is obtained by quenching molten iron slag from a blast furnace in water or steam, to produce glassy. The product is then dried and ground into fine powder. The viscosity of the slag is low because ore and coke contain silicate and aluminate impurities are combined in the blast furnace slag. The slag float on the top of iron in the blast furnace and pours out for the separation. The composition of molten slag is approximately silicon dioxide (SiO_2) - 30% to 40%, calcium oxide (CaO) - 40%. The composition of Portland cement is close to this [6]. The GGBS concrete enhances lower heat of hydration and reduces thermal cracking. The GGBS improves durability and workability of concrete which in turn reduces permeability and higher resistance to external chemical agencies.

Waste foundry sand is a byproduct of the ferrous and nonferrous metal casting industry, where sand has been used for centuries as a molding material because of its unique engineering properties [7]. Waste foundry sand contains high quality silica sand. The physical and chemical properties of the waste foundry sand depend on the type of casting and process and industries. Depending upon the type of binder system it is classified as

I. **Clay bonded sands (green sand).**
II. **Chemically bonded sands.**

Clay bonded sand are the composition of naturally occurring substances blended together. High quality silica sand (85-95%) and bentonite clay (4-10%) acts as a binder material, and also carbonaceous additives (2-10%) and water is (2-5%) improves the surface finish of the moulds. Due to the presence of carbon content the color of the clay bonded sand is black. High temperature will resist by the silica sand while the coating of clay binds the sand together. Water maintains the plasticity. Fusing of sand into the casting surface is prevented by carbonaceous additives [8].

Chemically bonded sand are used where high strength are required to withstand the heat of molten metal in core making process and in mold making. It consists of silica (93-99%) and chemical binder (1-3%). Silica sand is mixed with chemicals. Curing and hardening of mass is occurred by catalyst initiations.Chemical binder systems used in the chemically bonded sand are phenolic-urethanes, epoxy-resins, furfyl-alchohol, and sodium silicates. Clay bonded sand are darker than chemically bonded sand[6].

In modern foundry practice, sand is typically recycled and reused through many production cycles. Industry estimates are that approximately 100 million tons of sand are used in production annually. Of that, four to seven million tons are discarded annually and are available to be recycled into other products and industries. In INDIA nearby vacant areas of the foundries are filled with waste foundry sand. This affects the environment, during rainy season the waste product from the dumping areas will flow along with water and contaminate the water sources.

Materials and properties

Cement:

Ordinary Portland cement 53 grade of brand name Ultratech is to be used for the investigation. It is available in local market. The cement was used fresh without lumps and dust. The properties of cement was confirmed according to the specifications as per IS 12269-1987[14]. Table 1 shows the physical properties of cement.

Table 1 Physical properties of OPC 53 cement

S.No	Property	Test results
1	Normal consistency	29.5%
2	Specific gravity	3.10
3	Initial setting time	110 minutes
4	Final setting time	270 minutes

Coarse aggregate:

The coarse aggregates are used in this investigation is 20mm and 10mm size aggregate are locally available crushed stone obtained from quarries. The coarse aggregates are used for the experimental investigation is angular in size, uniformly graded. The specific gravity of the aggregate is 2.71. The specifications for coarse aggregate are include in IS 383:1970[9].The physical properties of coarse aggregate shown in table 2.

Table 2 Physical properties of coarse aggregate

S.No	Properties	Results
1	Specific gravity(20mm)	2.71
2	Specific gravity(10mm)	2.66
3	Fineness modulus	3.75%
4	Water absorption	0.4%

Fine aggregate:

Locally available river sand is used for the investigation. The sand is well graded and which is passing through 4.75mm sieve confirming to Zone- II. Specific gravity of fine aggregate is 2.6. The sand is free from organic matters. Specification of the properties of fine aggregate as per IS 383:1970[10].Table 3 shows the properties of fine aggregate.

Table 3 Physical properties of Fine aggregate

S.No	Properties	Results
1	Specific gravity	2.6
2	Fineness modulus	2.6
3	Water absorption	0.8%

Ground granulated blast furnace slag (GGBS):

Ground blast furnace slag is obtained from JSW cement limited. The color of the GGBS is white. The Specific gravity of GGBS is 2.88. The specification of GGBS as per BS: 6699[15]. Physical and chemical properties of GGBS shown in Table 4.

Table 4 physical and chemical properties of GGBS

S.No	Characteristics	Requirement as per BS:6699	Test result
1	Fineness (m^2/kg)	275(Min)	400
2	Specific gravity		2.88
3	45 Micron (Residue) (%)		7.70
4	Insoluble Residue (%)	1.5(Max)	0.49
5	Magnesia content (%)	14.0(Max)	7.91
6	SulphideSulphar (%)	2.00(Max)	0.52
7	Sulphite content (%)	2.20(Max)	0.45
8	Loss on ignition (%)	3.00(Max)	0.25
9	Manganese content (%)	2.00(Max)	0.12
10	Chloride content (%)	0.10(Max)	0.008
11	Glass content (%)	67(Min)	93
12	Moisture content (%)	1.0(Max)	0.13
13	$CaO+MgO+SiO_2$	66.66(Min)	76.97
14	$(CaO+MgO)/ SiO_2$	>1.0	1.39
15	CaO/ SiO_2	<1.40	1.14

Waste foundry sand (WFS):

The waste foundry sand is obtained from lamina foundries limited Nitte, Karkala. The WFS is passing through 4.75mm sieve. The color of the WFS is black. Specific gravity is 2.27 and water absorption is 7.7%. Testing were done as per IS:2386 (part III) – 1963(Reaffirmed – 2011). The properties of WFS confirmed as per IS: 383-2016. Table 5 and 6 shows the physical and chemical properties of WFS.

Table 5 Physical properties of WFS

S.No	Properties	Results
1	Specific gravity	2.27
2	Moisture content	0.401%
3	Fineness modulus	1.95
4	Water absorption(%)	7.7

Table 6 Chemical properties of WFS

S.No	Properties	Results
1	Aluminium oxide(Al_2O_3) ,% by mass(min)	6.63
2	Iron oxide(Fe_2O_3),% by mass(min)	7.11
3	Silicon dioxide(SiO_2),% by mass(min)	78.52
4	Magnesium oxide(MgO),% by mass(min)	1.06
5	Total Sulphur as Sulphur trioxide(SO_3),% by mass (max)	0.06
6	Loss of ignition,% by mass (max)	1.87
7	Calcium oxide(CaO),% by mass	1.20
8	Total chlorides,% by mass	0.024

Water:

The water to be used for mix and curing is potable water free from suspended solids and organic materials, which may affect the properties of the fresh and hardened concrete.

Superplasticizer:

Use of superplasticizer in the concrete reduces the amount of water content without reducing the workability and also improves the strength and quality. Conplast SP430 is a superplasticizer is used in the investigation. ConplastSP430(G) complies with IS:9103:1999 and BS:5075 Part 3 and ASTM-C-494. Table 7 shows the properties of superplasticizer.

Table 7 Properties of Superplasticizer

S.No	Properties	Results
1	Specific gravity	1.20
2	Chloride content	Nil. as per IS:9103-1999 and BS:5075
3	Air entrainment	Approx. 1% additional air over control

Mix design:

The mix design is carried for M40 grade of concrete as per IS: 10262-2009 [7]. The mix proportion obtained shown in Table 8.

Table 8 Mix proportion of M40 Grade concrete

W/C ratio	cement	Fine aggregate	Coarse aggregate
0.39	450	623.12	1178.949
	1	1.38	2.61

Experimental

Testing of specimen

Compressive strength:

Compressive strength of specimen were determined at 7days, 28 days, 56 days, 90 days of the curing using compression testing machine (CTM) of capacity 2000KN as per IS:516(1959)[11] code practice.

Fig 1 Demolded specimen

The compressive strength of specimens calculated using following formula

Compressive strength = P/A
Where,
P = Failure compression load in KN, A = Area of the specimen in mm^2

Table 9 Compressive strength of 7 days, 28 days, 56 days, 90days

Mix designation	Compressive strength of cubes in MPa			
	7 days	28 days	56 days	90 days
Referral mix	39.9	53.5	59	62
10% GGBS+10%WFS	26.4	55.3	61.3	64.2
20% GGBS+20%WFS	29.2	60.3	66.4	68.3
30% GGBS+30%WFS	26.0	57.6	62.5	63.1
40% GGBS+40%WFS	22.8	54.9	58.6	60.5
50% GGBS+50%WFS	19.6	52.2	54.7	58.6

Split tensile strength:

Split tensile strength of concrete is determined for all replacements and compared with referral mix. Split tensile strength of concrete is determined as per IS:516(1959)[11] code practice capacity of 2000KN.

Fig 2 Testing of specimen

The split tensile strength is calculated using following formula,

Split tensile strength = 2P/ (pi*D*L)
Where,
P = Applied load in KN, D = Diameter of the specimen in mm, L = Length of the specimen mm

Table 10 Split tensile strength of 7 days, 28 days, 56 days, 90 days

Mix designation	Split Tensile strength of cylinder in MPa			
	7 days	**28 days**	**56 days**	**90 days**
Referral mix	3.1	3.9	4.0	4.3
10% GGBS+10%WFS	3.4	4.3	4.6	4.7
20% GGBS+20%WFS	3.9	4.4	4.9	5.1
30% GGBS+30%WFS	3.5	4.2	4.4	4.7
40% GGBS+40%WFS	3.1	4.0	4.2	4.6
50% GGBS+50%WFS	2.7	3.8	4.0	4.3

Sorptivity of concrete:

Sorptivity is nothing but measurement of capillary rise water absorption on homogeneous material, also the ability of water absorption of material by capillary action. In this investigation water was used as test fluid. The specimen is immersed in water. The size of the specimen used for the investigation is 150mm*150mm. The specimen is oven dried for 24hrs at 100^0c after taking out from the curing tank. The specimen is covered with nonabsorbent material silicone sealant. The specimen is maintained with 15mm of water. The dry weight is measured. The weight of the specimen is weighed every 30minutes of immersion. The excess water is wiped using dampened tissue. Sorptivity is a property of a material characteristic of porous material to absorb the water by capillary action. The following formula is used to calculate sorptivity,

I=S.t½
Therefore S=I/ t½
I=Δw/Ad
Where
S = sorptivity in mm, t = time in minutes
Δw= change in weight, Δw = W2-W1
W1 = Oven dry weight of specimen in grams, W2 = Weight of cylinder after30 minutes capillary suction of water in grams.
A= surface area of the specimen through which water penetrated, d= density of water

Fig3Non absorbent material applied to the mould Fig4 Specimen kept for sorptivity test Table

11 Sorptivity of concrete at 30 minutes

Sl.N	**Mix designation**	**Dry weight in grams (W_1)**	**Wet weight in grams (W_2)**	**Sorptivity value in 10^{-5}mm/min$^{0.5}$**
1	Referral mix	8516	8517	0.82
2	10% GGBS+10%WFS	8492	8501	7.30
3	20% GGBS+20%WFS	8720	8727	5.67
4	30% GGBS+30%WFS	8520	8522	1.62
5	40% GGBS+40%WFS	8120	8121	0.93
6	50% GGBS+50%WFS	7320	7292	0.78

Table 12 Sorptivity of concrete at 1hour

Sl.N	**Mix designation**	**Dry weight in grams (W_1)**	**Wet weight in grams (W_2)**	**Sorptivity value in 10^{-5}mm/min$^{0.5}$**
1	Referral mix	8516	8520	3.25
2	10% GGBS+10%WFS	8492	8504	9.74
3	20% GGBS+20%WFS	8720	8730	8.12
4	30% GGBS+30%WFS	8520	8528	6.49
5	40% GGBS+40%WFS	8120	8126	4.86
6	50% GGBS+50%WFS	7320	7324	3.23

Table 13Sorptivity of concrete at 1hour 30 minutes

Sl.N	**Mix designation**	**Dry weight in grams (W_1)**	**Wet weight in grams (W_2)**	**Sorptivity value in 10^{-5}mm/min$^{0.5}$**
1	Referral mix	8516	8525	7.31
2	10% GGBS+10%WFS	8492	8506	11.4
3	20% GGBS+20%WFS	8720	8730	8.12
4	30% GGBS+30%WFS	8520	8529	7.30
5	40% GGBS+40%WFS	8120	8128	6.48
6	50% GGBS+50%WFS	7320	7327	5.66

Table 14 Sorptivity of concrete at 24hours

Sl.N	Mix designation	Dry weight in grams (W_1)	Wet weight in grams (W_2)	Sorptivity value in 10^{-5}mm/min$^{0.5}$
1	Referral mix	8516	8525	7.30
2	10% GGBS+10%WFS	8492	8511	15.42
3	20% GGBS+20%WFS	8720	8732	9.74
4	30% GGBS+30%WFS	8520	8530	8.11
5	40% GGBS+40%WFS	8120	8128	6.49
6	50% GGBS+50%WFS	7320	7327	4.88

Results

Compressive strength

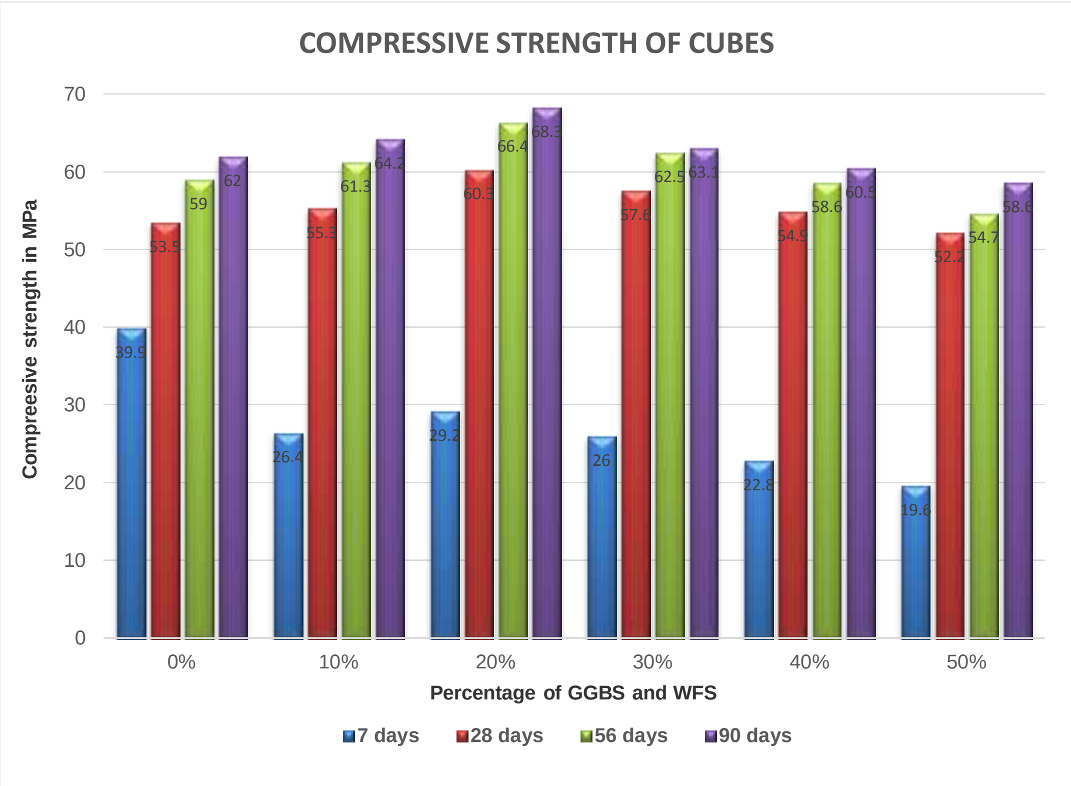

Fig5 graphical representation of compressive strength

Split tensile strength

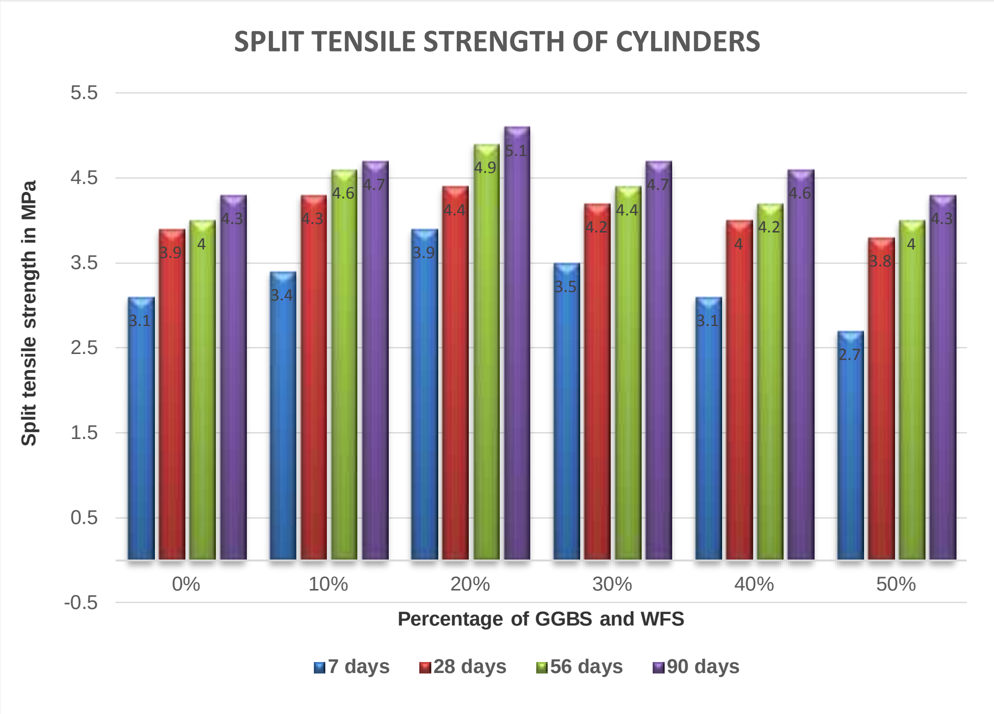

Fig6 Graphical representation of split tensile strength

Sorptivity of concrete

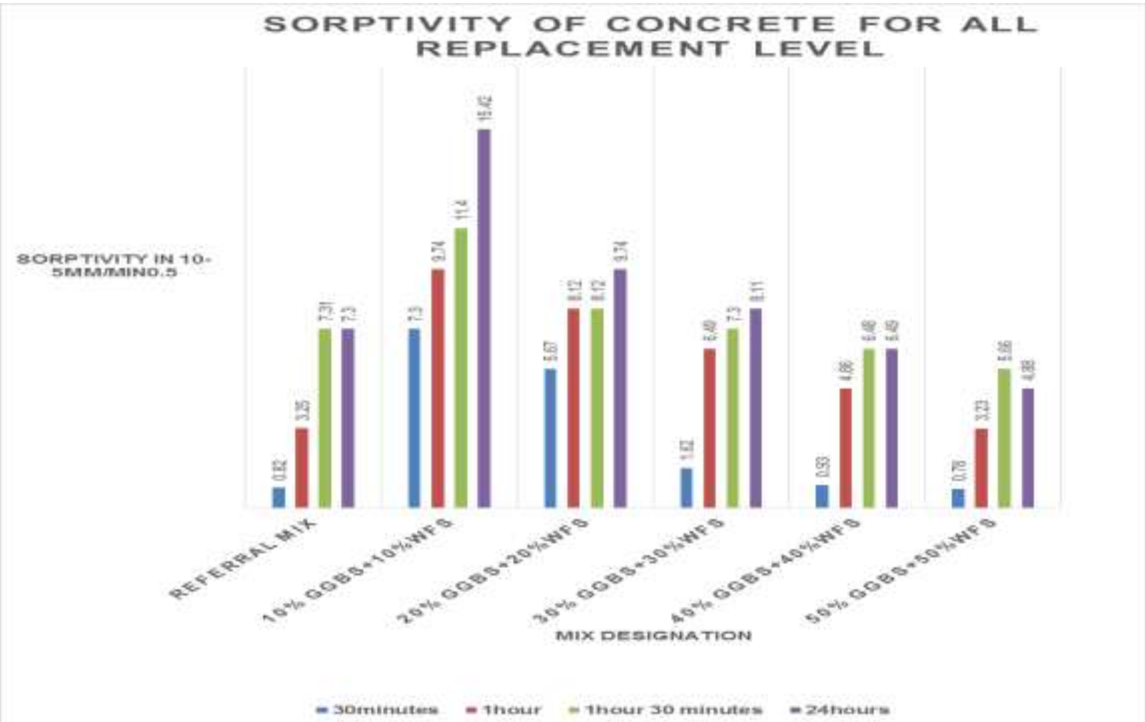

Fig 7 Sorptivity of concrete at 30 minutes, 1hour, 1hour 30minutes, 24 hours

Conclusion

- The workability of concrete increased with increasing percentage of GGBS and WFS.

- The 28 days compressive strength obtained is 53.5 N/mm^2 for a grade of M40 concrete. Also, the compressive strength obtained for 56 days and 90 days is 59 N/mm^2 and 62 N/mm^2 respectively. As the age of concrete increases the concrete compressive strength increases.
- For all replacement level of GGBS and WFS i.e., 0% 10%, 20%, 30%, 40%, 50%, the 28 days compressive strength are 55.3 N/mm^2, 60.3 N/mm^2, 57.6 N/mm^2, 54.9 N/mm^2 and 52.2 N/mm^2 respectively. It shows a maximum value of compressive strength at 20% replacement level of GGBS and WFS at 28 days. Beyond 20% replacement level the strength decreases with increasing percentage of GGBS and WFS. The percentage increase in compressive strength at 20% replacement level is 12.7% at 28 days, 12.5% at 56 days and 10.16% at 90 days when compared with referral mix. The optimum percentage of replacement will be 20%.
- The replacement of GGBS and WFS shows a decrease in the early age strength of concrete, but shows an increase in the strength at a later age.
- The split tensile strength achieved for 10%, 20%, 30%, 40%, 50% replacement level is 4.3 N/mm^{2,} 4.4 N/mm^2, 4.2N/mm^2, 4.0 N/mm^2, 3.8 N/mm^2 for 28 days of curing, which is higher than referral mix. At 56 days and 90 days, it shows an increase in the split tensile strength.
- Sorptivity is maximum for 10% replacement of GGBS and WFS and decreases when the percentage of GGBS and WFS increased.
- The sorptivity of concrete for all replacement level of GGBS and WFS is higher when compared to the referral mix.

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