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Studies on High Strength Concrete Using GGBS, GBS and Tio_2

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ABSTRACT

Concrete is the most versatile construction material because it can be designed to withstand the harshest environments while taking on the most inspirational forms. Engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixtures and supplementary cementitious materials. Nowadays, most concrete mixture contains supplementary cementitious material which forms part of the cementitious component. These materials are majority byproducts from other processes. The main benefits of SCMs are their ability to replace certain amount of cement and still able to display cementitious property, thus reducing the cost of using Portland cement. The fast growth in industrialization has resulted in tons and tons of byproduct or waste materials, which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag, steel slag etc. The use of these byproducts not only helps to utilize these waste materials but also enhances the properties of concrete in fresh and hydrated states. Slag cement and fly ash are the two most common SCMs used in concrete. Most concrete produced today includes one or both of these materials. For this reason their properties are frequently compared to each other by mix designers seeking to optimize concrete mixtures. Perhaps the most successful SCM is silica fume because it improves both strength and durability of concrete to such extent that modern design rules call for the addition of silica fume for design of high strength concrete. To design high strength concrete good quality aggregates is also required. Steel slag is an industrial byproduct obtained from the steel manufacturing industry. This can be used as aggregate in concrete. It is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial byproduct more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides hence steel slag aggregates are not used in concrete making. Proper weathering treatment and use of pozzolanic materials like silica fume with steel slag is reported to reduce the expansion of the concrete. However, all these materials have certain shortfalls but a proper combination of them can compensate each other's drawbacks which may result in a good matrix product with enhance overall quality.

INTRODUCTION

Concrete is a composite material [1] composed mainly of cement, aggregate and water. It is a widely used construction material for various types of structures due to its structural stability and strength. Increasing the construction challenges in combinations with the new innovations in materials and production techniques have provide new basis for producing high performance concrete structures. These days concrete is being used for wide varieties of purposes to make it suitable in different conditions. In these conditions ordinary concrete may fail to exhibit the required quality performance or durability. In such cases, pozzolanic [2] or mineral admixtures are used to modify the properties of ordinary concrete.

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The word 'Pozzolana' was derived from pozzuolu, a town in Italy, a few miles from Naples and mount vacuous. The materials are of volcanic region containing various fragments of pumice, obsidian, feldspars, and quartz etc. The name 'Pozzolana' was first applied exclusively to this material. But the term has been extended later to diatomaceous earth, highly siliceous rocks and other artificial products. Thus, the pozzolanic materials are natural or artificial having nearly the same composition as that of volcanic tuffs or ash found at pozzuolu [3].

Pozzolanic materials are siliceous or siliceous and aluminous material, which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature, to form compounds, possessing cementitious properties. On the hydration of tri-calcium silicate and di-calcium silicate, calcium hydroxide is formed as one of the products of hydration. This compound has no cementitious value and it is soluble in water and may be leached out by the percolating water. The siliceous or aluminous compound in a finely divided form react with the calcium hydroxide to form highly stable cementitious substances of complex composition involving water, calcium and silica. Generally amorphous silicate reacts much more rapidly than the crystalline form. It is pointed out that calcium hydroxide is converted in to insoluble cementitious material by the reaction of pozzolanic materials [4].

Concrete is an artificial material in which the aggregates both fine and coarse are bonded together by the cement when mixed with water. Concrete has unlimited opportunities for innovative applications, design and construction techniques. It exhibits great versatility and relative economy in filling wide range of needs which by other means has been made itself as competitive building material [5].

With the advancement of technology and increased field of applications of concrete and mortars, the strength, workability, durability and other characteristics of the ordinary concrete need modifications to make it suitable for challenging needs for construction environment(Added to this is the necessity to combat the increasing cost and scarcity of cement). Under these circumstances the use of admixtures is found to be an important alternative solution.

Increasing the usage of cement is the main problem that causing more emission of carbon dioxide (co2). So, researchers have been studying to improve the mechanical properties of concrete by incorporation of mineral admixture [6].

The use of pozzolanic materials in cement concrete paved a solution for

- Modifying the properties of the concrete
- Controlling the concrete production cost
- To overcome the scarcity of cement
- The economic advantageous disposal of industrial wastes

HIGH STRENGTH CONCRETE:

High strength concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementitious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usuall a super plasticizer. The term 'high strength' is somewhat pretentious because the essential feature of this concrete is that it's ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence High strength concrete [7] is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhance the strength, durability and workability qualities to a very high extent.

High strength concrete works out to be economical, even though it initial cost is higher than that of conventional concrete because the use of High strength concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs [8].

Concrete is a durable and versatile construction material. It is not only Strong, economical and takes the shape of the form in which it is placed, but it is also aesthetically satisfying. However experience has shown that concrete is vulnerable to deterioration, unless precautionary measures are taken during the design and production. For this we need to understand the influence of components on the behavior of concrete and to produce a concrete mix within closely controlled tolerances.

The conventional Portland cement concrete is found deficient in respect of:

- Durability in severe environs (shorter service life and frequent maintenance)
- Time of construction (slower gain of strength)
- Energy absorption capacity (for earthquake resistant structures)
- Repair and retrofitting jobs.

Hence it has been increasingly realized that besides strength, there are other equally important criteria such as durability, workability and toughness. And hence we talk about ‘High strength concrete’ where strength requirements can be different than high strength and can vary from application to application. High strength Concrete can be designed to give optimized strength characteristics for a given set of load, usage and exposure conditions consistent with the requirements of cost, service life and durability. The high strength concrete does not require special ingredients or special equipments except careful design and production. High strength concrete has several advantages like improved durability characteristics and much lesser micro cracking than normal strength concrete [9].

NANOTECHNOLOGY

Nanotechnology is the use of very small pieces of material by themselves or their manipulation to create new large scale materials. The particle size is a critical factor. At the nano scale (anything from one hundred or more down to a few nano meters, or 10-9 nm) material properties are altered from that of larger scales [10]. There is a sudden change in situation and this is what happens at the scale of nanotechnology. As particles become nano-sized, the proportion of atoms on the surface will increase and this results in modification within the properties. Knowledge at the nano scale of the structure and characteristics of materials (otherwise known as characterization) will promote the development of new applications and new products to repair or improve the properties of construction materials. For example, the structure of the fundamental Calcium-silicate-hydrate (C-S-H) gel which is responsible for the mechanical and post-selfing physical properties of cement pastes, like shrinkage, creep, porosity, permeability can be improved to obtain better durability characteristics of concrete [11].

Nano Titanium dioxide:

Research work has been done to study the effect of nano TiO_2 in concrete mixes. As TiO_2 is an inert material it will not participate in the reaction within the cement paste but the rate as well as the peak of hydration of concrete has shown to be increased. Nano TiO_2 improves compressive, flexural strengths and enhance the abrasion resistance of concrete. Incorporating of TiO_2 nanoparticles has been addressed in some of the works considering the properties of normal vibrated concrete [12].

Flexural fatigue performance of concretes containing TiO_2 nano particles is improved significantly and the sensitivity of their fatigue lives to the change of stress is also increased. In addition, the theoretic fatigue lives of concretes containing TiO_2 nano particles are enhanced in different extent. With increasing stress level, the enhanced extent of theoretic fatigue number is increased. The abrasion resistance of concrete containing TiO_2 nanoparticles for pavement has been experimentally studied. The abrasion resistance of concretes containing TiO_2 nanoparticles is significantly improved. The enhanced extent of the abrasion resistance of concrete is decreased by increasing the content of TiO_2 nanoparticles. The hydration kinetics of titania-bearing tricalcium silicate phase has been studied. Nano-TiO_2-doped tricalcium silicate (C_3S) [13] was obtained by repeated firing of calcium carbonate and quartz in the stoichiometric ratio of 3:1 in the presence of varying amounts of titanium dioxide from 0.5 to 6% by weight. The study revealed that the presence of up to 2% TiO_2 has an inhibiting effect on the rate of hydration of C_3S. They are three types of nano titanium dioxide:

They are:

- Anstase
- Rutile
- Brookite

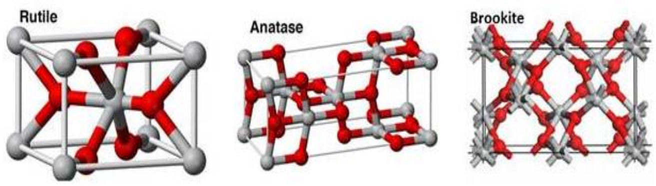

Fig 2: Anatase, rutile, brookite structures

Anatase is one among three mineral forms of titanium dioxide, the other two being brookite and rutile. It is always found as small, isolated and sharply developed crystals, and like rutile, a more commonly occurring modification of titanium dioxide, it crystallizes in the tetragonal system; but, although the degree of symmetry is the same for both, there is no relation between the interfacial angles of the two minerals, except in the prism-zone of 45° and 90°.

Rutile is one of three forms of titanium dioxide (TiO_2). It occurs in crystals, often in twins or rosettes, and is typically brownish red, although there are black varieties. Rutile is found in igneous and metamorphic rocks, chiefly in Switzerland, Norway, Brazil, and parts of the United States. Rutile is found naturally occurring in small quantities as impurities in iron oxide, chromium oxide and vanadium oxide [14].

Since, nano materials improve mechanical properties of concrete and increase compressive strength they are used in UHPC mix. These give high compressive strength when compared to normal concrete mix.

MATERIALS USED AND THEIR PROPERTIES

Different type of materials used in this work are cement,silica fume, quartz powder, quartz sand, steel fibres,nano titanium dioxide,super plasticizer, Ground granulated blast furnance, water. Physical and chemical properties of materials used in this investigation are mentioned below

Table 1: Selection parameters for Ultra high performance concrete components

Components	Selection Parameters	Function	Particle Size	Types
Sand	Good hardness readily available and low cost	Give strength, Aggregate	150µm– 600 µm	Natural, Crushed
Cement	C_3S : 60%; C_2S : 22%; C_3A : 3.8%; C_4AF : 7.4%	Binding material, Production of Primary hydrates	1µm-100 µm	OPC Medium fineness
Steel Fibers	Good aspect ratio	Improve Ductility	L :13-25mm, Dia:0.15-0.5mm	Corrugated
Super-plasticizer	Less retarding characteristic	Reduce water to cement ratios	--	Polyacrylate-based (or) polycarboxylate based
GBS				
GGBS			0.01µm-3500 µm	

Ground-granulated blast-furnace slag:

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder [15]. The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of

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an assemblage of Ca-Al-Mg silicates. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800 °C in order to prevent the crystallization of merwinite and melilite. To cool and fragment the slag a granulation process can be applied in which molten slag is subjected to jet streams of water or air under pressure. Alternatively, in the pelletization process the liquid slag is partially cooled with water and subsequently projected into the air by a rotating drum. In order to obtain a suitable reactivity, the obtained fragments are ground to reach the same fineness as Portland cement.

The main components of blast furnace slag are CaO (30-50%), SiO2 (28-38%), Al2O3 (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al2O3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. Several compositional ratios or so-called hydraulic indices have been used to correlate slag composition with hydraulic activity; the latter being mostly expressed as the binder compressive strength.

Granulated Blast Slag:

Granulated blast slag (GBS) [16] is manufactured from molten blastfurnace slag, a coproduct produced simultaneously with iron. Rapid chilling with water or air forms a glassy granular material with latenthydraulic properties. It is used for cement, concrete, mortar, grout and aggregates.

Steel fiber:

Steel fibres are filaments of wire, deformed and cut to lengths, for reinforcement of concrete, mortar and other composite materials. It is a cold drawn wire fibre with corrugated and flatted shape. It is often used to instead of Xorex steel fiber. Short fibers used in concrete can be characterized in different ways. First according to the fiber material: natural organic (such as cellulose, sisal, jute, bamboo, etc.); natural mineral (such as asbestos, rock-wool, etc.); man-made (such as steel, titanium, glass, carbon, polymers or synthetic, etc). Second, according to their physical/chemical properties: density, surface roughness, chemical stability, non-reactivity with the cement matrix, fire resistance or flammability, etc. Third according to their mechanical properties such as tensile strength, elastic modulus, stiffness, ductility, elongation to failure, surface adhesion property, etc. Moreover, once a fiber has been selected, an infinite combination of geometric properties related to its cross sectional shape, length, diameter or equivalent diameter, and surface deformation can be selected. The cross section of the fiber can be circular, rectangular, diamond, square, triangular, flat, polygonal, or any substantially polygonal shape. To develop better bond between the fiber and the matrix the fiber can be modified along its length by roughening its surface or by inducing mechanical deformations. Thus fibers can be smooth, indented, deformed, crimped, coiled, twisted, with end hooks, paddles, buttons, or other anchorage. In some fibers the surface is etched or plasma treated to improve bond at the microscopic level. Some other types of closed-loop steel fibers such as ring, annulus, or clip type fibers have also been used and shown to significantly enhance the toughness of concrete in compression; however, work on these fibers did not advance beyond the research level [7-13].

Fig 3:Different types of steel fibers

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Super plasticizer:

Superplasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation(gravel,coarse and fine sands), and to improve the flow characteristics of suspensions such as in concrete applications.Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement-superplasticizer incompatibilities. The addition of superplasticizer in the truck during transit is a fairly new development within the industry. Admixtures added in transit through automated slump management systems, such as Verifi, allows concrete producers to maintain slump until discharge without reducing concrete quality.

Since in UHPC, w/c ratio should be less so high range water reducer is used. To increase strength, water content should be reduced. Master Glenium sky 8233 formely B-233 which is poly-carboxylic ether based superplasticizer is used. It is brought from BASF India Ltd construction chemicals –Secundarabad.

Nano Titanium dioxide

Nano titanium dioxide is in the form of white powder. Particle size is 5 to 10nm. It is procured from sigma company, Hyderabad.

TESTS CONDUCTED ON STRENGTH PROPERTIES OF CONCRETE

Compressive Strength Test

This test is performed on 100mm×100mm×100mm size cube specimens to determine compressive strength of concrete at 28 days curing.

Apparatus: - Compressive Testing Machine (CTM)

The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified. The permissible error shall be not greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied.

Compressive strength of concrete is calculated using following

$$C = \frac{P}{A}$$

Where P is the maximum load at failure in N

A is the area of the Cube specimen in mm

Figure 7: Compressive strength test

Split Tensile Strength Test

This test is conducted on cylinder specimen to evaluate its split tensile strength of concrete at 28 days curing.

Apparatus: - Compressive Testing Machine (CTM)

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Compressive Testing Machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified. The permissible error shall be not greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied.

Split Tensile Strength of concrete is calculated using following

$$S = \frac{2P}{\pi DL}$$

Where P is the maximum load at failure in N
L and D are the length and diameter of the cylindrical specimen in mm

Figure 8: Split Tensile strength test

Flexural Strength Test

This test is performed on Beam specimens to determine Flexural strength of concrete for 28 days curing.
Apparatus: - Universal testing machine (UTM)

The test for flexural strength of concrete beams under middle point loading utilizes a beam testing machine which permits the load to be applied normal to the loaded surface of the beam. The specimen is tested on its side with respect to its molded position. The beam is centred on the bearing supports. The dial indicator of the proving ring is placed at the zero reading. The load is applied at a uniform rate and in a way to avoid shock. The load required to cause specimen failure is obtained from the dial indicator's final reading

Flexural strength of concrete is calculated using following

$$F = \frac{3Pa}{bd^2} \quad (a > 13.0\text{cm specimen})$$

$$F = \frac{Pl}{bd^2} \quad (a < 13.0\text{cm specimen})$$

Where P is the maximum load at failure in KN.
a is the length of crack in mm.
l is the supported length in mm
b and d are the breadth and width of the beam specimen in mm.

Figure 9: Flexural strength test

RESULTS

Compressive strength

Compressive strength of M80 Grade concrete .Compressive strength results of all concrete mixtures determined at 28 and 56 days of curing are listed in Table 3 compressive strength was increased with

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increase of ggbs up to 20% and then decreased as compared with the control mixture. Maximum compressive strength obtained by M3 is 99.03 N/mm2 with is more than 5.54% at 28days and Maximum compressive strength obtained by M3 is 102.2 N/mm2 with is more than 5.996% at 56 days compared to control mix.

Table 17: show Variation of compressive strength for ggbs.

Concrete mixes	% of Ggbs	Compressive strength	
		28 days	56 days
M1	0%	94	96.48
M2	10%	96.83	98.09
M3	20%	99.03	102.2
M4	30%	97.51	100.31

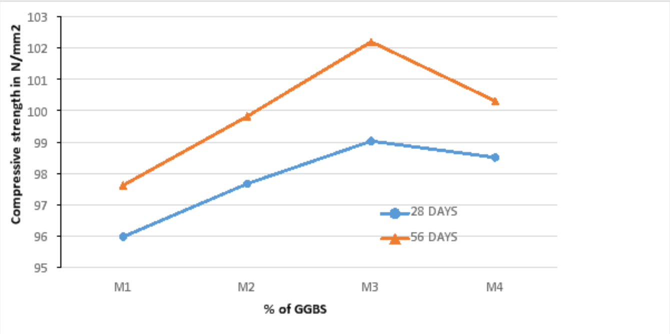

Fig 10:- Variation of compressive strength for different % of GGBS

Compressive strength were study with 10,30,50,70 and 90% with 20% of ggbs are shown table 4 .it was observed Maximum compressive strength obtained by M8 is 107.76 N/mm2 with is more than 14.32% at 28days and Maximum compressive strength obtained by M8 is 108.79 N/mm2 with is more than 15.32% at 56 days compared to control mix. Figure 2 show Variation of compressive strength for ggbs.

Table 18: Compressive strength of Gbs testing results

Concrete mixes	% of Ggbs	% of Gbs	Compressive strength	
			28 days	56 days
M5	20%	10%	101.02	102.98
M6	20%	30%	102.86	104.48
M7	20%	50%	105.05	105.98
M8	20%	70%	107.76	108.79
M9	20%	90%	106.06	107.28

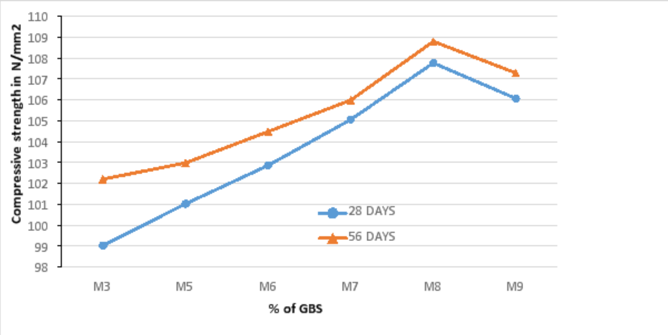

Fig 11:- Variations of compressive strength for different % of GBS

Compressive strength of M80 Grade concrete were study with 1, 2, 3 and 4% of tio2 and 70 % with 20% of ggbs are shown table 5. .it was observed Maximum compressive strength obtained by M12 is 113.06 N/mm2 with is more than 19.32% at 28days and Maximum compressive strength obtained by M12 is 114.56 N/mm2 with is more than 20.32% at 56 days compared to control mix. Figure 3 show Variation of compressive strength for Tio2.

Table 19 Compressive strength of TIO2 testing results

Concrete mixes	% of Ggbs	% of Gbs	% of Tio_2	Compressive strength	
				28 days	56 days
M10	20%	70%	1%	109.09	110.92
M11	20%	70%	2%	111.38	112.08
M12	20%	70%	3%	113.06	114.56
M13	20%	70%	4%	112.68	113.28

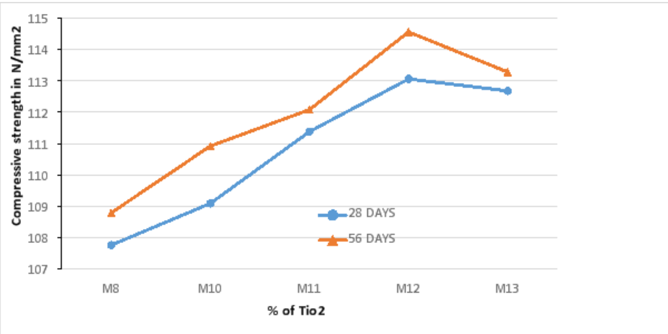

Fig:12:Variations of compressive strength for different % of Tio_2

Conclusion

1. Compressive strength of M3 (20% GGBS) is 87.6 N/mm2 with is more than 5.54% of Control mix (M1) at 28 days. Compressive strength of M3 (20% GGBS) is 88.8 N/mm2 more than 5.99% of control mix at 56 days.

2. Maximum compressive strength was obtained by M8 (20% GGBS and 70% GBS) is 94.89 N/mm2 which is 14.32% more than that at 28 days and Maximum compressive strength obtained by M8 is 96. 84 N/mm2 which is 15.32% more than that at 56 days compared to control mix.

3. Maximum compressive strength obtained by M12 (3% Tio2, 20% GGBS and 70% GBS) is 99. 03N/mm2 with is more than 19. 32% at 28days and Maximum compressive strength obtained by M12 is 102. 2 N/mm2with is more than 20. 32% at 56 days compared to all mixes.

4. Split Tensile strength of M3 (20% GGBS) is 7.28 N/mm2 with is more than 14.46 % of Control mix (M1) at 28 days. Split Tensile strength of M3 (20% GGBS) is 8.1 N/mm2 more than 16.54% of control mix at 56 days.

5. Maximum Split Tensile strength obtained by M8 (20% GGBS and 70% GBS) is 7. 6N/mm2 with is more than 19. 9% at 28days and Maximum Split Tensile strength obtained by M8 is 8. 35 N/mm2with is more than 15. 32% at 56 days compared to control mix.

6. Maximum Split Tensile strength obtained by M12 (3% Tio2, 20% GGBS and 70% GBS) is 7. 8N/mm2 with is more than 22. 62% at 28days and Maximum Split Tensile strength obtained by M12 is 8. 62 N/mm2with is more than 24. 028% at 56 days compared to all mixes.

7. Flexural strength of M3 (20% GGBS) is 5.42 N/mm2 with is more than 4.63% of Control mix (M1) at 28 days. Flexural strength of M3 is 88.8 N/mm2 more than 5.99% of control mix at 56 days.

8. Maximum Flexural strength obtained by M8 is 5. 82N/mm2 with is more than 12. 35% at 28days and Maximum Flexural strength obtained by M8 is 6.09 N/mm2with is more than 15. 34% at 56 days compared to control mix.

9. Maximum Flexural strength obtained by M12 is 6. 11N/mm2 with is more than 17. 95% at 28days and Maximum Flexural strength obtained by M12 is 6. 29 N/mm2with is more than 19. 12% at 56 days compared to control mix

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