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Mechanical Properties of Ternary Blended Concrete: An Experimental Study

Choppala Samuel James Abhishek 1,Dr. Dumpa Venkateswarlu2

[1]P.G Scholar, Department of Civil Engineering, Godavari Institute of Engineering & Technology (A),Rajahmundry, Andhra Pradesh, India

[2]Professor & Head of the Department, Department of Civil Engineering, Godavari Institute of Engineering & Technology (A), Rajahmundry, Andhra Pradesh, India

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ABSTRACT:
Concrete has become part of civil engineering world and every structural development is more or less dependent on concrete. The increased concrete usage is resulting in higher cement productions which is significantly leading to CO2 emissions. We can only reduce carbon emissions when if we could cut the usage of cement and hence, replacement of cement with other durable substances is so far, the best found solution and hence blended concrete has come into picture for the past few years. Sustainable developments leading to circular economy is the key factor in finding alternative binders to concrete production that could possibly minimize the carbon dioxide emission volume. Also, the river sand is becoming scarce and hence utilization of manufactured sand with a visibly good results in strength as well as durability properties are being experimented. The present study experimented on the industrial end products i.e., Supplementary Cementitious Materials (SCMs) namely, Metakaolin, fly ash, Silica Fume, GGBS, etc which we use to replace the cement as far as possible. The effective usage of these materials as substitutes to cement is hereby analyzed with certain variations in the proportion of addition of these materials. Rather than utilizing the SCMs directly, the concept of dissolution is experimented in order to analyze the best results. The thesis work highlights on analyzing the mechanical properties of concrete namely Compressive Strength, Split Tensile Strength and Flexural Strength in blended mixes to that of conventional concrete.

INTRODUCTION

Concrete is considered as the most widely used artificial material in existence and also considered as a major contributor to the climate crisis. The major greenhouse gases viz., methane and carbon dioxide, the latter being the major product of concrete manufacturing, are considered threat to life existence on Earth. The production of concrete has become so high in the recent past that, if concrete were a country, it would be the third largest emitter of carbon dioxide leaving China and the United States for the prime. Also, around 8 to 10 percent of total CO_2 in the entire world is being emitted during the manufacture of cement.The present study deals with determining the mechanical properties of concrete by replacing cement partially with GGBS and fly ash in various proportions.

Literature Review

Faisal Hussainet.al [2020] framed a detailed report on GGBS as cement replacement and investigated on effect of GGBS on concrete properties such as hydration, setting time, workability, compressive strength, flexural strength, microstructure, modulus of elasticity and durability.

Mohan Aetal. [2020] investigated on sustainable replacement of cement with GGBS and Silica Fume where in varying GGBS i.e 40%, 50%, 60% against 10% silica fume are added as preferential supplant to cement and achieved. The results show that replacement of cement by upto 40% showed evidently good strengths but addition of 50% of GGBS and Silica Fume resulted in slightly lesser strengths when compared to controlled specimens.

Naga Venkat G etal. [2020] made a comparative study on improving strength of concrete using pozzolanic materials such as silica fuma, metakaoline, and GGBS as partial replacements to weight of cement. The results showed that, addition of 10% of Silica Fume, Metakaoline, GGBS and M-Sand gave higher compressive and tensile strengths. Out of all the additions, cement replaced with Silica Fume at 10% yielded higher compressive strength (57.5 MPa) where as Metakaoline gave 56 MPa and GGBS 53.5 MPa. Similarly, split tensile strengths are also better when cement is replaced by 10% with Silica Fume (5.6 MPa), Metakaoline (5.53 MPa) and GGBS (5.29 MPa).

Chinyere O. Nwankwo etal. [2020] discussed the high-volume replacement of Portand cement with industrial wastes like fly ash and GGBS, municipal wastes like glass powder and ceramic waste powder and agricultural wastes like palm oil fuel ash and derived their impacts on hydration mechanism, environmental impact on its usage and its relation to alkali cement. The study derived that replacement of cement by fly ash at 40% with W/C ratio as 0.47 gave higher 28 and 90 days strength and GGBS at 40% with W/C ratio 0.35 gave higher 28 and 90 days strengths.

Vijaya Bhaskar Reddy S etal. [2020] have investigated on optimum usage of Micro Silica (MS) and Ground Granulated Blast Furnace Slag (GGBS) wherein they recommended that, Compressive strength of ternary blended concrete at the ages of 7, 28, 60, 90 days for various combinations of Micro Silica and GGBS mixes were investigated. Micro silica of 0%, 5%,10% and 15% along with GGBS was replaced by 20%, 30%, 40% and 50%. All the mixes were studied at w/c ratio of 0.45.

Jemimah Carmichael M etal. [2021] investigated on the properties of compressive and tensile strengths of Permeable concrete by replacing cement with variable proportions of fly ash. In this work, the author adopted Cement to Coarse aggregate mix ratios as 1:4, 1:6 and 1:8 with respect to water binder ratios 0.32,0.33 and 0.34. The cement for these ratios is replaced by 0% to 50% of fly ash. The results deduce that, 1:6 ratio mix with 0.34 water binder ratio and 40% fly ash replacement gave optimum values.

Materials

Fly Ash

Fly ash is a fine powder that is a byproduct of burning pulverized coal in electric generation power plants. Fly ash is a pozzolan, a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, it forms a compound like Portland cement. This makes it suitable as a prime material in blended cement, mosaic tiles and hollow blocks, among other building materials.

Ground Granulated Blast Furnace Slag(GGBS)

Ground Granulated Blast Furnace Slag is obtained as a byproduct from the blast furnaces used to make iron. These operate at a temperature of about 1500°and are fed with a carefully controlled mixture of iron ore, coal, 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 must be rapidly quenched in large volumes of water.

Cement

The cement is to be tested in the laboratory for its quality requirement limitations as per Indian Standards. The cement used was ordinary Portland cement of OPC 43 grade (SAGAR) confirming to IS: 12269-2013.

Fine Aggregate

The Fine aggregate utilized in this project is crushed stone sand also known as M-Sand. This is usually used vastly in areas where natural river sand is not available in abundant.

Coarse Aggregate

Aggregate which are retained on the 4.75mm IS Sieve is called coarse aggregate. The function of Coarse

Journal of Chemical Health Risks

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JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

Aggregate is to act as the main load – bearing component of the concrete. According to IS 383 – 1970, Coarse Aggregate used in this present study confirms to single-sized aggregate. Locally available Coarse Aggregate having the maximum size of 20mm and 10 mm as shown in figures 9 and 10 are used in the present study

EXPERIMENTAL WORK

MIX DESIGN

Grade designation	Cement (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)	Water (kg/m^3)	W/C	Target strength (MPa)
M 40	421	641.92	1329.43	151.60	0.36	48.25

Mixture Proportions

The above conventional mix of M40 grade concrete is altered by adding 2.5% dissolved GGBS along with 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% of fly ash as cement replacement to study the mechanical properties

Preparation of Testing Specimens

Mixing

In the present work, tilting type concrete mixer is used. The individual mix ingredients are weighed with their proportions exactly and then the materials hand loaded into the mixer. The mixer is initially run with all the materials in dry condition for assuring the uniform mix after adding the water.

Casting of Specimens

In the present study, the cubes, prisms and cylinders are cast for testing Compressive, Flexural and Split Tensile Strengths of chosen concrete mix. Cast iron molds are cleaned of dust particles and applied with oil on all sides before concrete is poured into the molds. The molds are placed on a level platform. The well mixed green concrete is filled in to the molds by vibration with needle vibrator.

Compaction of Concrete

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In the process of mixing and placing of concrete in the molds, air is likely to get entrapped in the concrete. If air is not removed fully, the concrete loses strength considerably.In order to achieve full compaction and maximum density table vibrator is used in this experiment.

Curing of test specimens

After casting, the molded specimens are stored in laboratory in room temperature for 24 hours. After checking the proper setting of concrete in the molds, the specimens are demolded carefully without damaging the edges and are immediately submerged in clean, fresh water curing tank for required period as per IS 516-1969. In the present study, the specimens are cured strength test of specimens at 7 days, 28 days and 90 days.

Testing of Hardened Concrete

Compressive Strength Test

The test set up for conducting cube compressive strength test is shown in figure 12.Compression test on cubes is conducted on the cubes on 300Tons compression testing machine. The cube is completely air dried after removing the specimens duly completing their curing period, from the curing tank. Once the cubes are ready, they are placed one by one in the compression testing machine and the load on the individual cube is applied at constant rate of 2.5kN/sec until the failure of the specimen happens and the ultimate load is noted. The cube compressive strength of the concrete mix is then computed.

Journal of Chemical Health Risks

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JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

Split Tensile Strength Test

The split tensile strength is usually performed to analyze the tension in concrete. The concrete is cast into cylinders and thus obtained cylinders are used for the proposed test. In the present study, 150x300 mm size molds are casted with desired concrete mix and the cylinders are tested after 7 days, 28 days and 90 days of curing. The procedure for conducting the split tensile strength is similar to that of cube compression strength test. The same testing machine is used as shown in Figure 4.4. The split tensile strength is evaluated by the formula

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

Where ft= Split tensile Strength
P= Load in KN
D= Diameter of the Cylinder i.e., 150 mm
L= Length of the Cylinder i.e., 300 mm

Flexural Strength Test

The flexural strength test is performed on the concrete casted into prisms to analyze the flexural strength of the concrete. The test is performed using a universal testing machine. The concrete prisms of size 100x100x500 are casted and cured for the desired period. Once the curing period is over, the prisms are removed from the curing tank and air dried. Thus, prepared prisms are marked on ant two faces by drawing lines perpendicular to the face of the prism at a distance of 5 cm and 13.33 cm correspondingly from the two edges of the prism

RESULTS AND DISCUSSIONS

5.1 Compressive Strength of M40 Grade Concrete

The Compressive Strength of M40 Grade Concrete with 2.5% GGBS dissolved in water for 1 hour and varied percentages of fly ash replaced partially with volume of Cement. The results of compressive strength at various ages of concrete, i.e., 7 days, 28 days and 90 days are detailed in the following Tables correspondingly.

Table 1 Compressive Strength for ternary blended mix at 7 days

Sl. No	Grade of Concrete	% Replacement of GGBS (D)	% Replacement of Fly Ash	Average density (kg/m^3)	Average Compressive Strength (N/mm^2)
1	M40	2.5%	0%	2792.59	46.07
2	M40	2.5%	5%	2736.30	43.11
3	M40	2.5%	10%	2706.67	41.48
4	M40	2.5%	15%	2654.81	37.19
5	M40	2.5%	20%	2650.67	37.18
6	M40	2.5%	25%	2660.74	39.25
7	M40	2.5%	30%	2657.78	32.66
8	M40	2.5%	35%	2577.19	30.07
9	M40	2.5%	40%	2562.96	26.96
10	M40	Control Mix		2794.07	39.18

Table 2 Compressive Strength for ternary blended mix at 28 days

Journal of Chemical Health Risks

www.jchr.org

JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

Sl. No	Grade of Concrete	% Replacement of GGBS (D)	% Replacement of Fly Ash	Average density (kg/m3)	Average Compressive Strength (N/mm^2)
1	M40	2.5%	0%	2788.15	65.77
2	M40	2.5%	5%	2758.52	56.30
3	M40	2.5%	10%	2752.59	54.02
4	M40	2.5%	15%	2734.81	53.04
5	M40	2.5%	20%	2648.89	52.88
6	M40	2.5%	25%	2755.56	54.44
7	M40	2.5%	30%	2696.30	46.41
8	M40	2.5%	35%	2637.04	43.70
9	M40	2.5%	40%	2628.15	40.40
10	M40	Control Mix		2791.11	52.66

Table 3 Compressive Strength for ternary blended mix at 90 days

Sl. No	Grade of Concrete	% Replacement of GGBS (D)	% Replacement of Fly Ash	Average density (kg/m3)	Average Compressive Strength (N/mm^2)
1	M40	2.5%	0%	2797.04	68.44
2	M40	2.5%	5%	2764.44	54.22
3	M40	2.5%	10%	2734.81	49.77
4	M40	2.5%	15%	2746.67	53.33
5	M40	2.5%	20%	2776.30	55.66
6	M40	2.5%	25%	2800.00	61.33
7	M40	2.5%	30%	2604.44	48.66
8	M40	2.5%	35%	2622.22	56.00
9	M40	2.5%	40%	2610.37	52.88
10	M40	Control Mix		2817.78	58.32

Figure 5.1 shows the graphical representation of compressive strength values of concrete at various ages of curing and at varied percentages of fly ash combined with GGBS as replacement of cement in concrete.

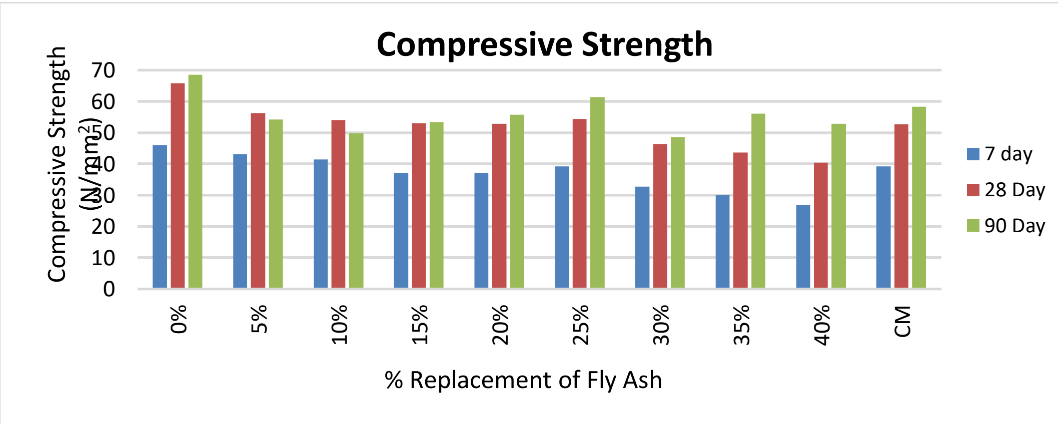

Figure 1. Compressive Strength (MPa) Vs Age of Concrete

Journal of Chemical Health Risks

www.jchr.org

JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

Table 4 Compressive Strength at 7 & 28 Days

Sl. No	Optimum % of Fly Ash	Age of Concrete	Average Compressive Strength (N/mm^2)
GGBS (ND) @ 2.5%			
1	25%	7 Days	38.96
2	25%	28 Days	44.00
3	25%	90 Days	52.00
GGBS (D) @ 2.5%			
4	25%	7 Days	39.25
5	25%	28 Days	54.44
6	25%	90 Days	61.33
7	Control Mix	7 Days	38.96
8	Control Mix	28 Days	52.66
9	Control Mix	90 Days	54.17

The study for comparison of GGBS (ND) and GGBS (D) with respects to conventional mix are made and the results are graphically represented as shown in Figure 5.3. From the figure it is observed thatspecimens under GGBS(D) attained more strength at the all the ages i.e., 7 days, 28 days and 90 days when compared to replacement under no dissolution condition.

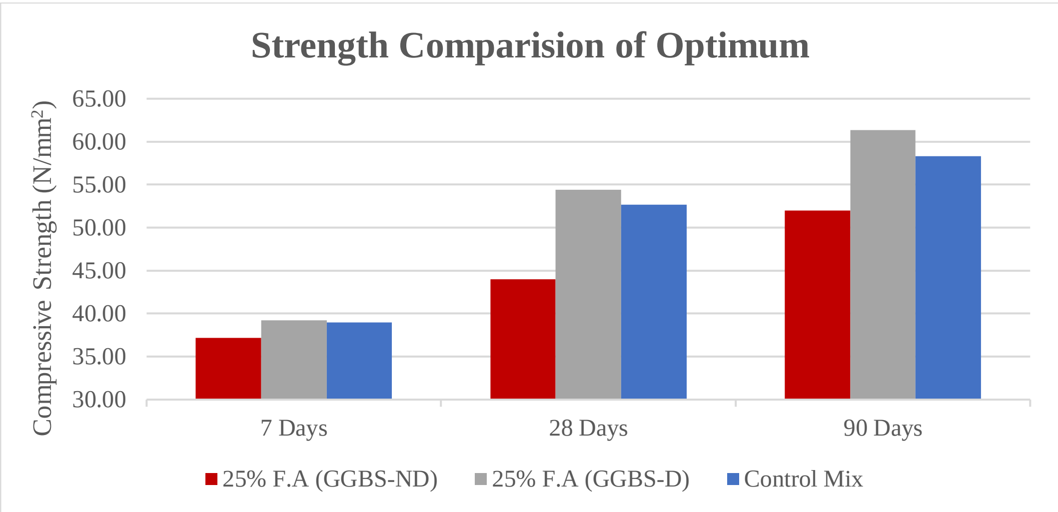

Figure Compressive Strength comparison for Optimum

Flexural Strength of M40 Grade Concrete

Table 5.5 Flexural Strength for ternary blended mix

Sl. No	Optimum % of Fly Ash	Age of Concrete	Average Compressive Strength (N/mm^2)
GGBS (ND) @ 2.5%			
1	25%	7 Days	7.21
2	25%	28 Days	7.98

Journal of Chemical Health Risks
www.jchr.org
JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

GGBS (D) @ 2.5%			
3	25%	7 Days	7.36
4	25%	28 Days	9.90
5	Control Mix	7 Days	7.33
6	Control Mix	28 Days	9.35

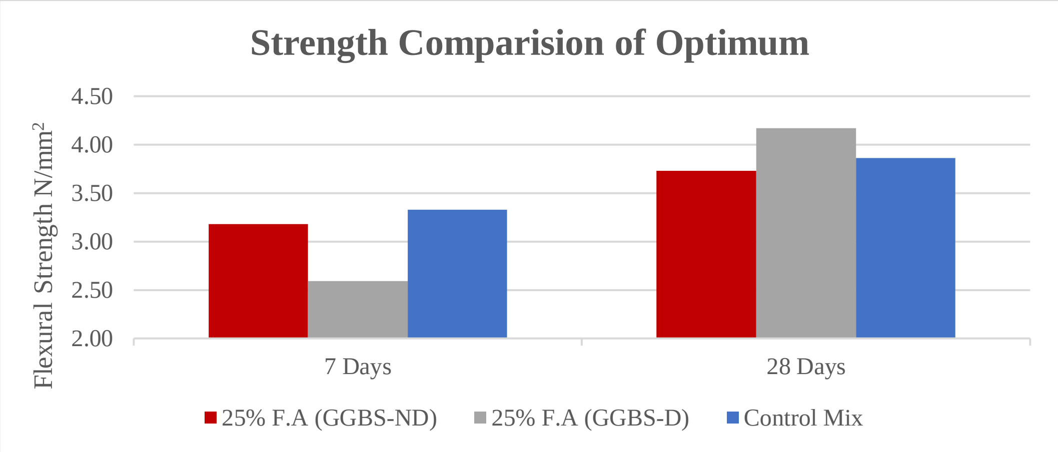

Figure 5.4 Flexural Strength Comparison with Age

The flexural strength at 28 days strength of concrete as a function of their corresponding compressive strength for mixes with 25% F.A (GGBS-ND), 25% (GGBS-D) and control mix is analyzed in Figure 5.5. The linear relationship between the compressive strengths and flexural strengths was established in the graph with a correlation coefficient (R^2)of 0.765.

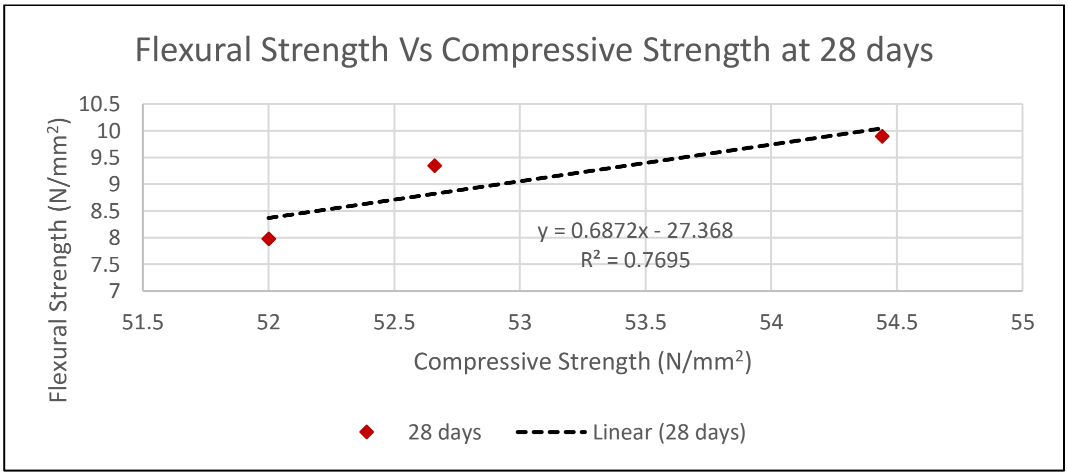

Figure 5.5 Flexural strength as a function of Compressive strength

An attempt is made to develop the relation between flexural strength and compressive strength both in theoretical and experimental conditions. Hence, as per IS 456-2000 a correlation is been established between the strengths in terms of flexure as well as compression of 25% F.A (GGBS-ND), 25% (GGBS-D) and control mix specimens at the age of 28 days. The correlation achieved R^2 values closely equal to 1.

Comparison of theoretical strengths of flexure to that of laboratory results is also observed. The theoretical flexural strength as per IS 456-2000 clause 6.2.2 is calculated for the optimum mixes under dissolution and no dissolution as well as control mix and tabulated as shown in Table 5.6.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

Table 5.6 Comparison of theoretical and experimental results

	Theoretical (f_{cr}=0.7√f_{ck})	**Experimental**
GGBS(D)	5.16	9.90
GGBS (ND)	5.05	7.98
CONTROL MIX	5.08	9.35

The values clearly depict the higher indent of experimental results than that of theoretical results and same comparison is graphically represented as shown in Figure 5.6.

5.5 Split Tensile Strength of M40 Grade

Under this section, the results of the split tensile strength of concrete under the condition of 2.5% GGBS without dissolution along with 25% fly ash replacement to cement are analyzed. For the convenience of comparison, the set of cylinders with conventional mix are also tested. The results are as tabulated in the Table 5.6.

Table 5.6 Split Tensile Strength for ternary blended mix

Sl. No	Optimum % of Fly Ash	Age of Concrete	Average Compressive Strength (N/mm^2)
GGBS (Non-Dissolution) @ 2.5%			
1	25%	7 Days	3.18
2	25%	28 Days	3.73
GGBS (Dissolution) @ 2.5%			
3	25%	7 Days	3.43
4	25%	28 Days	4.17
5	Control Mix	7 Days	3.33
6	Control Mix	28 Days	3.86

From the above table, it can be inferred that the tensile strength is attained on higher sides for both dissolution and non-dissolution condition when compared to the conventional mix. Also, the strength of the GGBS (D) at the age of 28 days attained higher value when compared to the GGBS (ND) as well as conventional mix. The same comparison is graphically depicted as shown in Figure 5.7. Hence, it can be concluded that the GGBS (D) at 25% fly ash combination is achieving higher results in all aspects.

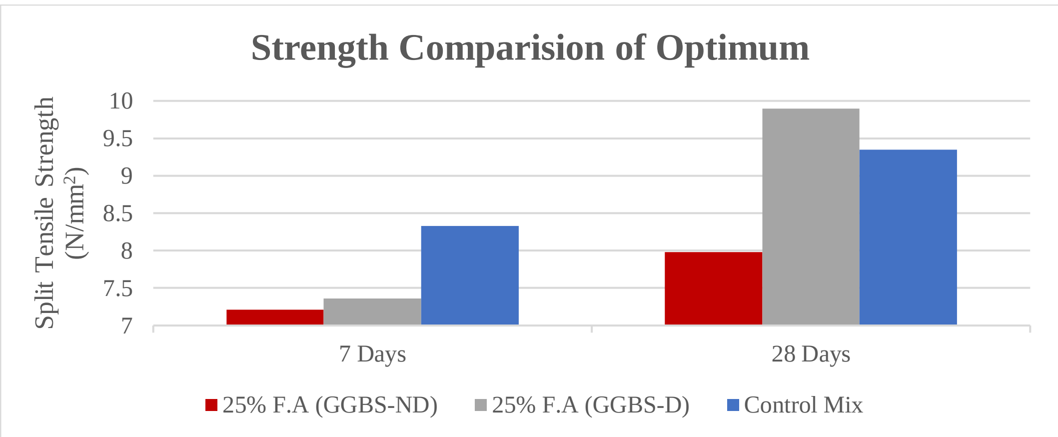

Figure 5.7 Split Tensile Strength Vs Age

Journal of Chemical Health Risks
www.jchr.org
JCHR (2023) 13(6), 706-716 | ISSN:2251-6727

Similar to the compressive strength, split tensile strength also followed the same trending and figure 5.8 plots the split tensile strength for 28 days strength of concrete as a function of their corresponding compressive strength for mixes with 25% F.A (GGBS-ND), 25% (GGBS-D) and control mix. A good linear relationship is found between compressive strength and split tensile strength with a correlation coefficient (R^2) of 0.999.

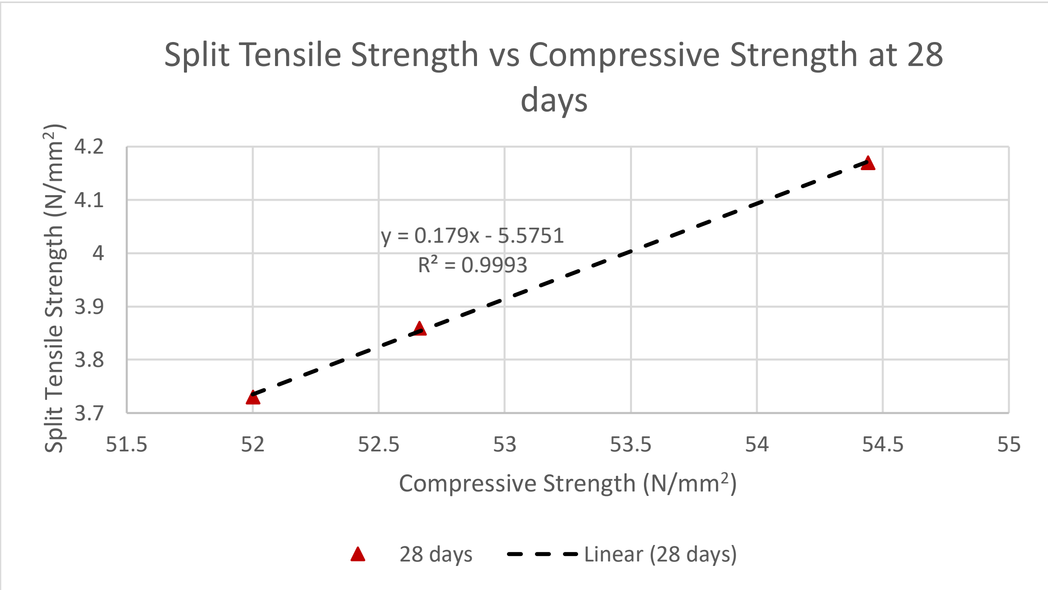

Figure 5.8 Split tensile strength as a function of compressive strength

CONCLUSIONS AND RECOMMENDATIONS

The results of the various tests on the hardened concrete and discussed in the previous chapter. The following conclusions are drawn from the observation of test results in concrete with 2.5% Dissolved GGBS and fly ash as replacement to Cement.

1. The compressive strength at the age of 7 days is increased by 18% when compared to the conventional mix in the case of dissolved GGBS replacement by cement. Also, the specimens with 5% F.A replacement and 10% F.A replacement along with 2.5% GGBS (D) showed an increase in compressive strength of around 10% and 6% respectively when compared to the conventional concrete specimens.
2. The compressive strength values for the specimens at the age of 28 days derived an increase of around 25% in comparison to the conventional concrete specimens when the case of replacement of cement by 2.5% GGBS under dissolved condition is concerned. Further, an increase of around 7% ,3% and 4% are observed for the mixes containing 5%, 10%, and 25%fly ash replacement in addition to 2.5% of GGBS (D). Overall, there is an increase trend in the strength values for the mixes with combinations of 0%, 5%, 10%, 15% & 20% and 25% fly ash. Also, it can be observed that the strength values attained more than the target strength for the blends containing fly ash up to 25% beyond which decline is observed.
3. The compressive strength values for the specimens at the 90 days curing period showed a similar increase of around 5% at 25% FA replacement, when compared to conventional concrete. Also, the strength values of blended mix of 0% FA and 2.5% GGBS (D) reported a higher indent than the conventional mix.
4. The flexural strength of concrete derived for 2.5% GGBS (D) and 25% fly ash combination yielded better results when compared to GGBS (ND) and fly ash mix.
5. The split tensile strength of concrete derived for 2.5% GGBS (D) and 25% fly ash combination also showed better results when compared to

GGBS (ND) mix.

6. The rate of strength attainment is higher at later ages of concrete than that of earlier concretes.
7. The study on the trend of densities at the age of 7 days analysed show that there is a sharp decrease and the values tent to decline to as low as 8% when compared to the conventional mix.
8. The relationship established between flexural strength and split tensile strength with their corresponding compressive strengths derived a good linear correlation.
9. The overall study based on strengths and densities prove that, GGBS and fly ash combination is a success and also the new technique of dissolution of GGBS derived positive results in terms of strengths in first place and also in achieving lighter concrete.
10. GGBS and fly ash both being the end products of industrial waste, using them effectively has satisfied the strength attaining phenomenon and also it is cost effective.

Future Scope

The study may be further extended to analyze other properties of concrete such as Water Absorption, Elastic Modulus, Acid Reaction, Drying Shrinkage and Sorptivity etc.

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