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An Experimental Investigation on the Strength Properties of Concrete by Partial Replacement of Fine Aggregate with Quarry Dust and Cement with GGBS and Nano-Silica

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ABSTRACT

Concrete is the most widely used construction material in civil engineering fields because of its high structural strength and stability. The concrete industry is constantly looking for supplementary cementations material with objective of reducing the solid waste disposal problem. Ground granulated blast furnace slage (GGBS) and Quarry dust are among the solid waste generated by industry. Natural sand is most commonly used fine aggregate in concrete increasing construction activities requires production of more and more quality of concrete, which needs more and more natural sand and coarse aggregate. Owing to acute shortage in many areas, cost and environmental factors, an alternative for the same is pondered, during the process of production of coarse aggregate in crushing plants, a huge quantity of quarry dust is produced which is considered worth less for any substantial use. The use of crushed fine aggregate in concrete as partial replacement of fine aggregate will be an alternative material up to some extent, besides helping in environment protection and disposal quarry dust in abundance.

Cement is the major component in making the concrete. Due to urbanization and industrialization, the production of concrete is increasing day by day. A recent survey shows that for production of every tone of Cement, around one tone of Carbon dioxide is liberated. So, in the present scenario it has become a matter of prime importance, to reduce the cement production and increase the use of substitute materials to the save the environment. In the present study Quarry Dust is used as partial replacement of fine aggregate by weight at varying percentage of 25%, 50%, 75% and 100% respectively. Cement is used as replacement of GGBS by weight at varying percentages of 20%, 40% and 60%, and Nano silica by weight at varying percentages of 3 %. The combined influence of quarry dust and GGBS, Nano Silica on Compressive strength, Split Tensile Strength and Flexural Strength of M40 grade of concrete investigation. The test results of concrete prepared using different combinations of quarry dust and GGBS, Nano-Silica are compared with that of controlled concrete. Based on the experimental investigation, the increase in the strength properties of the materials has been observed and the optimum replacement percentages of GGBS and Quarry Dust are 40% and 50% respectively.

INTRODUCTION

In India, the manufacturing of Portland cement was commenced around the year 1912. The beginning was not very promising and growth of cement industry was very slow. At the time of independence in 1947, the installed capacity of cement plants in India was approximately 4.5 million tons and actual production around 3.2 million tons per year. The large construction activity undertaken during the various 5 years plans

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necessitated the growth of cement industry. However, until the year 1982, the growth remained stinted due to the complete control exercised by the Government over the cement industry. The partial deep control in 1982 prompted various industrial houses to setup new cement plants in the country. The full decontrol on cement industry in 1988 further provided momentum for the growth.

Concrete is an artificial material in which the aggregates both fine and coarse are bonded together by the cement when mixed with water. The concrete has become so popular and indispensable because of its inherent, concrete brought a revolution in applications of concrete. Concrete has unlimited opportunities for innovative applications, design and construction techniques. Its great versatility and relative economy in filling wide range of needs has made it is very competitive building material.

With the advancement of technology and increased field of applications of concrete and mortars, the strength workability, durability and other characters of the ordinary concrete need modifications to make it more suitable for challenging (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.

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

There are wide variety and very large number of admixtures available in the construction market. The admixtures are classified mainly into following groups as according to the type of materials constituting the admixture or characteristic effect of the use.

- Air entraining agents
- Accelerators
- Retarders
- Pozzolanas
- Gas forming agents

FLY ASH

Fly ash is available in large quantities in India also. For every 100MW of power generation, nearly 0.2 million tones of fly ash is being produced. Recent data show that from more then 70 thermal power stations, nearly 40 million tones of fly ash is being produced every year in India. It is estimated that production of fly ash, by turn of the century, will be 100 million tones. About 6000tonnes of ash is being produced dial at present in Andhra Pradesh alone. Such vast quantities of fly ash are causing pollution hazards effecting the ecological balance and human habitat environment. The disposal of these huge fly ash quantities is incoming a grit problem day by day. Management of coal ash of this magnitude is a matter of grate concern in the years to come. In view of the above serious considerations on fly ash, lot of investigations is being carried out to make its use as an alternative building material in construction. Besides finding solution to disposal of fly ash, this would also save enormous amount of energy and scare raw materials in the construction industry. Increased awareness of environmental hazards, steep risen prices of building materials, non availability of space to stack the fly ash and other factors have generated interest among the research community to work on the gainful utilization of fly ash. Researchers all over world have proved that fly ash is suitable material for construction with many beneficial properties.It is disappointing fact the only 2% of the total generated fly and is now being utilized in India, despite the enormous research work on utilization of fly ash in construction industry in the past half century. France is using 58% of its fly ash production while the European countries are using 10-20% of their fly as production. The reason for this situation is, perhaps the lack of awareness on utility of fly ash at the root level of construction society.The technology on fly ash utilization has to be intensively taken to the doorstep of actual construction for its effective implementation thus increasing the use of fly ash. Confirmative experimental results on using fly ash as a partial replacement of cement especially in structural components at different levels in the construction society worked definitely in structural components at different levels in the construction society would definitely improve the use of fly ash.

SILICA FUME

Silica fume is a mineral admixture made up of very fine, solid glassy spheres and amorphous solids of silicon dioxide. It is a by-product obtained during the production of metallic silicon or Ferrosilicon alloys in electric arc furnaces. The silica content is as high as exceeding 98% as compared to about 38 to 48% in the case of fly ash. Because of extreme fineness, it is a very efficient pozzolanic material.

Silica fume is highly pozzzolanic. The amount of silica present, the super fineness, the high specific surface area up to 25000m2/kg are the main characters of silicafume which impart high strength to concrete with enhance qualities when mixed as a partial replacement to comment achieving economy. Silica fume is thus found a place to be in the group of pozzolanic admixtures and made a way for the research community to develop high strength concretes of the order up to M50 or more. The silica fume concretes (SFC) are found to posses improved permeability properties. The sulphate resistance of SFC is also considerably good.

METAKAOLIN

Metakaolin is obtained by calcinations of pure or refined kaolintic clay at a temperature between 650°C, and 850°C, followed by grinding to achieve a fineness of 700 to 900m2/kg. The resulting material has high pozzolanicity. Metakaolin is manufactured from pure raw material to strict quality standards. It is not a by-product. Other pozzolanic materials are currently available, but many are by products, which are available in chemical composition. They may also contain active components (such as sulphur compound, alkalis, carbon, reactive silica) which can undergo delayed reactions within the concrete and cause problems over long time periods.

GROUND GRANULATED BLAST FURNACE SLAG (GGBS)

Ground Granulated Blast Furnace Slag has been used in the construction industry for years as areplacement for Ordinary Portland Cement (OPC). GGBS is a by-product of the iron production process, and consists mostly of calcium silicates and aluminosilicates. These operate at a temperature of about 15000C 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 from the 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 optimizes the cementitious properties and produces granules similar to coarse sand. thisgranulatd slag is then dried and ground to a fine powder. This cementitious material has been toted for both its strength and durability enhancing characteristics when used in Concrete. The main problem is the original conventional materials are depleting and we are in hunt for alternative building materials which lands us here on the purpose of GGBS. Being a by-product and waste, using it effectively up to some extent serves as a step for a greener environment and at the same time keeping in mind that the strength of the concrete doesn't degrade by the use of GGBS. Ground Granulated Blast Furnace Slag also has a lower heat of hydration and hence, generates less heat during concrete production and curing. As a result, GGBFS is a desirable material to utilize in mass concrete placements where control of temperatures is an issue.

USES OF GGBS

- Better workability, making placing and compaction easier.
- Lower early age temperature rise, reducing the risk of thermal cracking in large pours.
- Elimination of the risk of damaging internal reactions such as ASR

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- High resistance to chloride ingress, reducing the risk of reinforcement corrosion
- High resistance to attack by sulphate and other chemicals
- Considerable sustainability benefits.

QUARRY DUST (QD):

Quarry Dust is a waste material obtain from crusher plants during the process of making of coarse aggregate of different sizes, about 175 million ton stone dust is produced every year, which is discarded as a waste. This enormous quantity of Stone dust requires a suitable disposal site for its easy and safe disposal, as a large land area is required to accomplish the requirement which would again be a great problem in a thickly populated country like India. Stone dust, being final part of a coarse aggregate is an inert material and may be used in Concrete making as a partial replacement of fine aggregate.

ADVANTAGES OF QUARRY DUST REPLACED WITH FINE AGGREGATE:

Quarry Dust also offers many advantages with the replacement of fine aggregate. The Quarry Dust has advantages over sand due to following points.

- The cost of sand is very high as compare to the Quarry Dust.
- Quarry Dustgives the better result with the help of suitable admixtures.
- Due to non-availability of well specified sand near by the construction site.
- It reduces the cost of construction at the same time it solve the problem of disposal of Quarry Dust.
- The Quarry Dust is cheaply available and application is very easy.

The main disadvantage with the Quarry Dust is it is full of fine particles hence due to this fine particles, the water cement ratio will increase due to this, the demand of cement content also increases. Hence to overcome this disadvantage the Quarry Dust is sieved on 150 micron sieve and the sample retained on 150micron sieve is taken.

MATERIALS

The materials used in experimental investigation include
1. 53 Grade Ordinary Portland Cement (OPC)
2. Fine aggregate
3. Coarse aggregate
4. Ground Granulated Blast Furnace Slag
5. Quarry Dust
6. Nano Silica
7. Water

CEMENT:

In the present investigation UltraTech Ordinary Portland Cement (OPC) of 53 grade confirming to IS: 12269-1987 specifications was used. All the tests are carried out in accordance with procedures described in IS: 4031-1985. Tests were conducted for the determination of physical properties of the cement. The chemical composition of the cement as obtained from the suppliers are presented in the Table 3.1.

Table 3.1 Chemical Composition of Cement

S.NO	PARTICULARS	TEST RESULTS (%)
1	Silica (SiO_2)	21.04
2	Allumina (Al_2O_3)	6.02
3	Iron Oxide (Fe_2O_3)	3.77
4	Calcium Oxide (CaO)	62.93
5	Magnesium Oxide (MgO)	2.49
6	Total Sulphur	1.72
7	Loss on Ignition	1.63
8	Insoluble Residue	2.80
9	Chlorides	0.016

Table 3.2 Physical properties of 53 Grade Ordinary Portland Cement

S.NO	PROPERTY	RESULTS
1	Fineness	7.6%
2	Specific Gravity	3.15
3	Normal Consistency	30%
4	Setting Time	
	i)Initial Setting Time	90 min
	ii)Final Setting Time	330 min

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FINE AGGREGATE:

The locally available Natural Sand is procured and is found to be conformed to Grading Zone-II of IS 383-1970. Various tests have been carried out as per the procedure given in IS 383-1970 from them it is found that,

- Specific Gravity of Fine Aggregate is 2.52
- Fineness Modulus of Fine Aggregate is 3.76

The particle size distribution of sand was determined and the results are tabulated in Table 3.3.

Table 3.3 Sieve Analysis of Fine Aggregate

IS Sieve Designation	Weight retained (gm)	Percentage weight retained (%)	Cumulative percentage weight retained (gm)	Percentage of weight passing	Percentage of cumulative weight passing
4.75 mm	15	1.5	1.5	98.5	98.5
2.36 mm	72	7.2	8.7	91.3	189.8
1.18 mm	148	14.8	23.5	76.5	266.3
600 micron	362	36.2	59.7	40.3	306.6
300 micron	270	27	86.7	13.3	319.9
150 micron	97	9.7	96.4	3.6	323.5
75 micron	31	3.1	99.5	0.5	324

GROUND GRANULATED BLAST FURNACE SLAG

GGBS used in this present experimental study is obtained from ASTRRA chemicals, Chennai Theproperties of GGBS as given by the supplier are shown in the Table5.

Table 3.6 Properties of GGBS

CHARACTERISTICS	TEST RESULTS
Fineness	3.9
Specific Gravity	2.85
Insolble Residue	0.49

Fig.3.4 GGBS SAMPLE

QUARRY DUST

Quarry Dust is collected from local stone crushing units of Chandragiri near, Tirupati, Andhra Pradesh. The particle size distribution of Quarry Dust was determined and the results obtained are tabulated in Table 3.7

Specific gravity observed for Quarry Dust is 2.3

Water absorption of Quarry Dust is 3.5%

Fineness Modulus of Quarry Dust is 2.18

Table 3.7 Sieve Analysis of Quarry Dust

IS Sieve Designation	Weight retained (gm)	Percentage weight retained (%)	Cumulative weight retained (gm)	percentage of weight passing (gm)
4.75 mm	0	0	0	100
2.36 mm	3	0.3	0.3	99.7
1.18 mm	36	3.6	3.9	96.1
600 micron	406	40.6	44.5	55.5
300 micron	355	35.5	80	20
150 micron	95	9.5	89.5	10.5
Pan	78	7.8	97.3	2.7

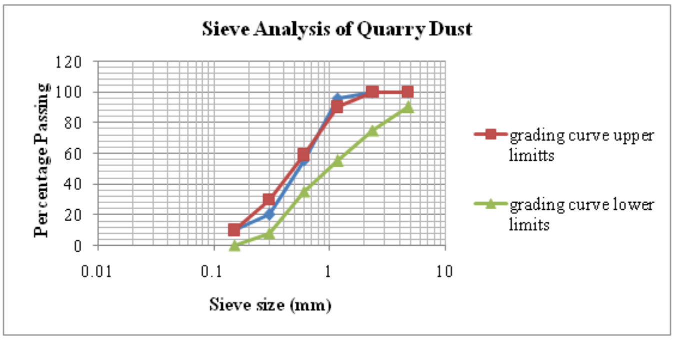

Fig 3.5 Grading Curve of Quarry Dust

Fig.3.6Quarry Dust used for replacement of Fine Aggregate

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NANO SILICA

Nanotechnology is the use of very small particles of material either by themselves or by their manipulation to create new large scale materials. The size of the particles, though, is very important because at the length scale of the nano - meter, 10-9m, the properties of the material actually become affected. The precise size at which these changes are manifested varies between materials, but is usually in the order of 100 nm or less.

NANO TECHNOLOGY IN CONCRETE

Nano Technology applied to concrete includes the use of nanomaterials like nano silica, nano fibers etc. By adding the nanomaterials, concrete composites with superior properties can beproduced.Addition of nano silica (nS) in concretes and mortars results inmore efficient hydration of cement. Due to the pozzolanic activity, additional calcium silicate hydrates are formed togenerate more strength and to reduce free calcium hydroxide.

This also helps in reducing the cement requirement, nS improvesthe microstructure and reduces the water permeability of concretethus making it more durable. Use of nano silica in HPC and SCCimproves the cohesiveness between the particles of concrete andreduces segregation and bleeding. Concretes with strengths ashigh as 100 MPa with high workability, anti-bleeding propertiesand short de-moulding time can be produced. Nano silica can beused as an additive to eco concrete mixtures.

Table No. 3.8 Physical Properties of Nano Silica

Property	Characteristics
Surface Area (m^2/g)	200 ± 30
Tamped Bulk Density (g/l)	Approx. 40
Moisture (%)	< 1.5
Loss on Ignition (%)	< 1.5
PH Value (4 % dispersion in Water)	3.8 – 4.3

Table No. 3.9. Chemical Properties of Nano Silica

Property	Characteristics
SiO_2 content (%)	> 99.8
Al_2O_3 Content (%)	< 0.05
Fe_2O_3 Content (%)	< 0.005
TiO_2 Content (%)	< 0.003

TYPES OF CONCRETE MIX DESIGN

Nominal mix Concrete

Traditional way of mix proportion specified in terms of fixed ratios of Cement : Sand : coarse aggregate (In general by volume)

- Useful for small works.
- Useful for routine Concrete construction.
- Limited upto M20 grade Concrete.
- Requires high Cement content.

STANDARD MIXES

The nominal mixes of fixed Cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum Compressive Strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the Concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

REQUIREMENTS FOR CONCRETE MIX DESIGN:

- The grade designation giving the characteristic strength requirement of Concrete.
- The type of Cement influences the rate of development of Compressive Strength of Concrete.

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- Maximum nominal size of aggregates to be used in Concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The Cement content is to be limited from shrinkage, cracking and creep.
- The workability of Concrete for satisfactory placing and compaction is related to the size and shape of section , quantity and spacing of reinforcsement and technique used for transportation, placing and compaction.

RESULTS AND DISCUSSION
TEST RESULTS
COMPRESSIVE STRENGTH

Compressive Strength of concrete is commonly considered as the most reliable property because the strength is usually reliable measure of the quality of concrete.

The Compressive Strength values of both Control Concrete along with different combinations of GGBS, NS and Quarry Dust are shown in Figure 6.1. when compared to Controlled Concrete, It is observed that the Compressive Strength of Concrete increases up to 18% when cement is replaced with 40% of GGBS and 50% of Quarry Dust at 28 days.

Table 6.2 Compressive Strength Test Results of M40 Grade Concrete

Concrete Mix	Compressive Strength of Concrete (MPa)				
	3 Days	7 Days	28 Days	56 Days	90 Days
Control Concrete	18.14	28.5	38.8	39.1	42.2
3%NS +GGBS 20%+QD25%	26.2	33.6	43.4	46.2	48.8
3%NS +GGBS 20%+QD50%	27.8	34.2	44.8	48.4	49.5
3%NS +GGBS20%+QD75%	24.7	31.4	43.2	45.5	44.2
3%NS +GGBS20%+QD100%	22.1	30.3	41.5	43.1	42.3
3%NS +GGBS 40%+QD25%	34.6	38.2	47.8	51.2	53.8
3%NS +GGBS 40%+QD50%	36.5	44	52.6	54.8	56.4
3%NS +GGBS 40%+QD75%	35.4	41.8	47.5	50.2	53.2
3%NS +GGBS40%+QD100%	33.3	36.2	44.8	49.4	51.5
3%NS +GGBS 60%+QD25%	28.7	36.4	43.6	46.6	48.5
3%NS +GGBS 60%+QD50%	29.5	38.8	46.5	49.4	51.2
3%NS +GGBS 60%+QD75%	28.4	39.4	44.7	45.6	50.6
3%NS +GGBS 60%+QD100%	26.3	35.3	42.2	43.2	48.6

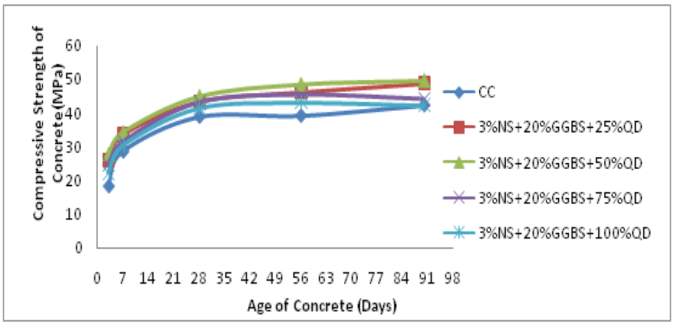

Fig.6.5. Variation of Cube Compressive Strength of M40 Grade Concrete with Different Percentages of 20%GGBS+ 3%NS and at 25% to 100% Quarry Dust

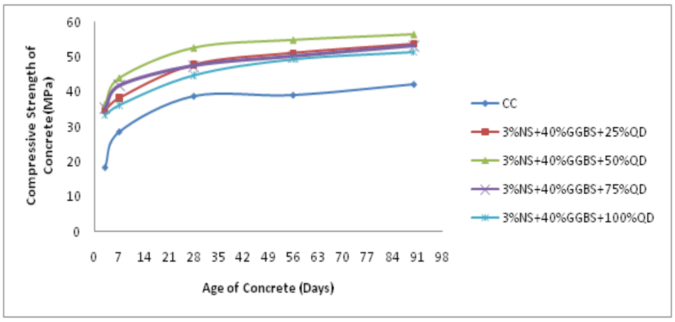

Fig.6.6. Variation of Cube Compressive Strength of M40 Grade Concrete with Different Percentages of 40%GGBS+3%NS and at 25% to 100% Quarry Dust

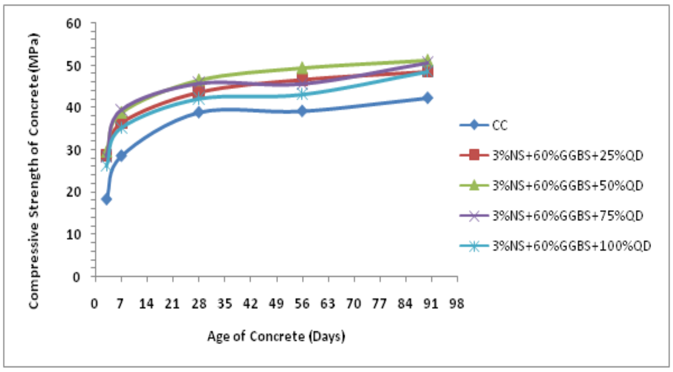

Fig.6.7. Variation of Cube Compressive Strength of M40 Grade Concrete with Different Percentages of 60%GGBS+3%NS and at 25% to 100% Quarry Dust

Split Tensile Strength

The Split Tensile Strength test was carried according to IS 5816-1999. The results of Split Tensile strength of Concrete with different percentages of GGBS and Quarry Dust are shown in Table 6.3

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Table 6.3 Split Tensile Strength Test Results of M40 Grade Concrete (28days)

Concrete Mix	GGBS (%)	QD (%)	Split Tensile Strength(MPa)
Control Concrete	0	0	3.73
0%NS+ GGBS0%+QD25%	0	25	3.82
0%NS+ GGBS0%+QD50%	0	50	3.91
0%NS+ GGBS0%+QD75%	0	75	3.63
3%NS+ GGBS0%+QD100%	0	100	2.83
3%NS+ GGBS20%+QDS25%	20	25	3.79
3%NS+ GGBS20%+QD50%	20	50	4.1
3%NS+ GGBS20%+QD75%	20	75	3.83
3%NS+ GGBS20%+QD100%	20	100	2.96
3%NS+ GGBS40%+QD25%	40	25	3.85
3%NS+ GGBS40%+QD50%	40	50	4.30
3%NS+ GGBS40%+QD75%	40	75	3.58
3%NS+ GGBS40%+QD100%	40	100	3.20
3%NS+ GGBS60%+QD25%	60	25	3.48
3%NS+ GGBS60%+QD50%	60	50	3.80
3%NS+ GGBS60%+QD75%	60	75	3.40
3%NS+ GGBS60%+QD100%	60	100	2.50

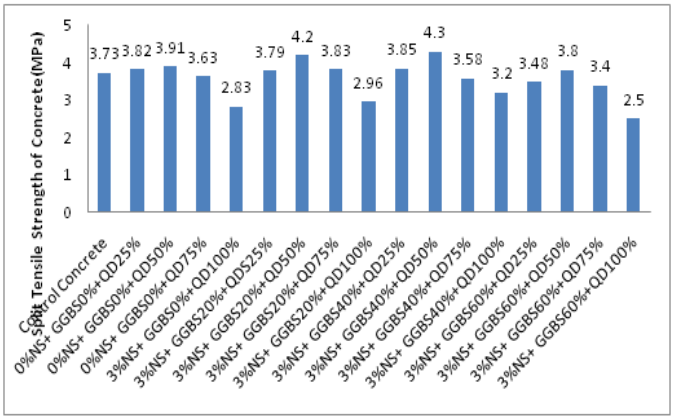

Fig.6.8. Variation of Split Tensile Strength of M40 Grade Concrete at Different Percentages of GGBS ,NS and Quarry Dust

FLEXURAL STRENGTH

The Flexural Strength variation for all mixes is shown in Figure 6.3. Concrete Beams of size 500 mm Length and 100mm × 100 mm Cross-section area are cast to test the Flexure strength of Concrete at the age of 28 days. The variations of Flexural Strength at 28 days for different replacements are shown in table 6.9. The Flexural Strength of Conventional Concrete is 5.88 MPa. It is observed that for the combination of 40% of GGBS and 50% Quarry Dust content,maximumFlexural Strength occurs which is 7.5 MPa.

Table 6.5: Flexural Strength Test Results of M40 Grade Concrete (28days)

Concrete Mix	GGBS (%)	QD (%)	Flexural Strength(MPa)
Control Concrete	0	0	5.88
0%NS+GGBS0%+QD25%	0	25	6.6
0%NS+GGBS0%+QD50%	0	50	6.8
0%NS+GGBS0%+QD75%	0	75	6.4
3%NS+GGBS0%+QD100%	0	100	5.98
3%NS+GGBS20%+QDS25%	20	25	6.9
3%NS+ GGBS20%+QD50%	20	50	7.3
3%NS+ GGBS20%+QD75%	20	75	6.6
3%NS+GGBS20%+QD100%	20	100	6.2
3%NS+ GGBS40%+QD25%	40	25	6.9
3%NS+ GGBS40%+QD50%	40	50	7.4
3%NS+ GGBS40%+QD75%	40	75	6.7
3%NS+GGBS40%+QD100%	40	100	6.3
3%NS+ GGBS60%+QD25%	60	25	6.6

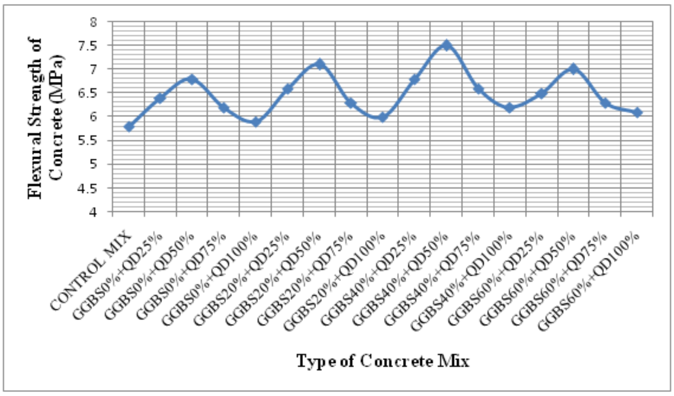

Fig.6.6 Variation of Flexural Strength of M30 Grade of Concrete at Different Percentages of GGBS and Quarry Dust

CONCLUSIONS:

Based on the test results of the present investigation, the following conclusions are drawn

- While using the nano silica solution in concrete the original water cement ratio of concrete mix is to be corrected by the amount of water available in nano silica solution
- An increase of 18% in Cube Compressive Strength at 28 days is observed with 40% GGBS, Nano Silica and 55% Quarry Dust.
- The maximum percentage increase of 18.4% in Split Tensile Strength compared to Control Concrete and it is obtained at 40% GGBS,3%Nano Silica and 50% Quarry Dust replacement.

- The maximum percentage increase of 29% in Flexural Strength compared to Control Concrete is obtained at 40%, 3% and 50% replacements of Cement and Fine aggregate with GGBS, Nano Silica and Quarry Dust respectively.
- At 40% and 50% replacement with GGBS and Quarry Dust respectively, Modulus of Elasticity of Concrete is 31.5MPa where as Control Concrete has Modulus of Elasticity of 27.4GPa, which is 13% more than the Control Concrete.
- At a replacement percentage of 40% cement with GGBS and 3% cement with Nano Silica and Fine aggregate with 50% Quarry Dust , the Water Absorption test results has the minimum value of 3.5%

Finally it is very interesting to note that the variation of various test results followed the similar trend.

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