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Strength Properties of Concrete Containing Nano- Silica, Metakaolin and Quarry Dust – A Study

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ABSTRACT:

This paper presents an experimental investigation on the influence of Nano-Silica (NS) on various strength characteristics of concrete containing Quarry Dust and Metakaolin. Nano-Silica is used as partial replacement of cement for the preparation of concrete. In the present investigation cement is partially replaced by 1%, 2% and 3% of Nano-Silica by weight. The combined application of Metakaolin and Nano-Silica on various properties of M25 grade of concrete is investigated. The various properties of concrete under investigation include the Cube Compressive strength, Split Tensile strength, Flexural strength & Modulus of Elasticity. The test results of M25 grade of concrete prepared using different proportions of Metakaolin and Nano-Silica are compared with that of controlled concrete. Based on the test results, concrete prepared with a combination of 10% Metakaolin and 2% Nano-Silica possesses improved strength properties compared to the controlled concrete. Regression Analysis is performed and equations were developed.

Keywords:

Metakaolin, Quarry Dust, Nano-Silica, Particle Packing, Combination and Strength of Concrete.

1.0 INTRODUCTION:

The concrete technology has made tremendous strides in past decades. Concrete is a very strong and versatile mouldable construction material or Concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate. Cement is one of the important components of concrete. The cement industry produces about 5% of global man-made CO_2 emissions, of which 50% is from the chemical process, and 40% from burning fuel. Hence, to reduce the consumption of cement, the application of Pozzolana materials is increasing day-by-day in the form of partial cement replacement for concrete preparation.

Recent developments in Nano-technology and availability of Nano-silica have made the use of such materials in concrete possible. Nano-silica (NS) is a Nano-sized, highly reactive amorphous material. Due to their small particle sizes and high surface areas compared to those of silica fume, NS may enhance the early compressive strengths of concrete more effectively than silica fume. As NS particles are very fine and they tend to agglomerate due to high surface interaction, uniform dispersion of NS is an important issue to get its beneficial effects. This research project is carried out with the objectives given in the following section using a systematic approach. Dr. D.V. Prasada Rao, U. Anil Kumar (2014), presented a paper on “An Experimental Investigation on Strength Properties of Concrete containing Silica-Fume and Nano-Silica” [1], Belkowitz J. and Armentrout, D.L. (2009), proposed a paper on ”The Investigation of Nano-Silica in the cement hydration process”[2], Buil M., Paillere A. M. and Roussel B., (1984), submitted a paper titled ”High strength mortars containing condensed Silica fume, Cement and Concrete Research” [3], Chandra S. and Berntsson L. (1996), proposed a paper titled “Use of Silica Fume in concrete” [4], Mullick A.K (2007), published a paper titled “Performance of concrete with Binary cement blends” [5], Surendra P. Shah, et al. submitted a paper titled “Controlling Properties of Concrete through Nano Technology” [6], N. Neelamegam, J. K. Dattatreya & S. Gopi Krishna presented a paper titled “ Pore structure effects in properties of concrete with Binary and Ternary Blends” [7].

2.0 OBJECTIVE:

The main objective of the present experimental investigation is to obtain the influence of the combined application of Metakaolin, Quarry Dust and Nano-Silica on various strength properties of M25 grade of concrete. 10% of Metakaolin and 1%, 2% and 3% of Nano-Silica by weight of cement replacement is adopted. Compressive strength, Split Tensile strength and Flexural strength & Modulus

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of Elasticity of the concrete prepared using different proportions Nano-Silica, Metakaolin and Quarry Dust are to be obtained and the results are to be compared with that of controlled concrete.

3.0EXPERIMENTAL INVESTIGATION
3.1 Properties of Materials
3.1.1 Cement
In the present investigation Ordinary Portland Cement (OPC) of 43 Grade conforming to IS specifications was used. The properties of cement are shown in Table.1.

Table 1. Properties of Cement

S.No	Property	Value
1	Specific Gravity	3.13
2	Normal Consistency	32 %
3	Setting Time i) Initial Setting time ii) Final setting time	 120 Min 6 hours

3.1.2 Fine Aggregate

Locally available river sand confirming to IS specifications was used as the fine aggregate in the concrete preparation. The properties of fine aggregate are shown in Table.2.

Table 2. Properties of Fine Aggregate

S.No	Property	Value
1	Specific Gravity	2.69
2	Fineness Modulus	2.9
3	Bulk Density (Loose)	15.75 kN/m^3
4	Grading of Sand	Zone – II

3.1.3 Coarse Aggregate:
Crushed granite metal of nominal size 20 mm and 10 mm obtained from the local quarry and confirming to IS specifications were used. The properties of coarse aggregate are shown in Table.3. The coarse aggregate used for the preparation of concrete is a combination of 20 mm and 10 mm size aggregates in ratio 1.5: 1.0.

Table3. Properties of Coarse Aggregate

S.No	Property	Result
1	Specific Gravity	2.60
2	Bulk Density (Loose)	14.13 kN/m^3
3	Water Absorption	0.4%
4	Fineness Modulus	7.2

3.1.4 Metakaolin:
Metakaolin (MK) is a Pozzolanic material. It is obtained by calcination or thermal activation of kaolinite clay at temperature between 500ºC and 800ºC. Its chemical formula is Al2O3.2SiO2.2H2O.Metakaolin when used as a partial replacement substance for cement in concrete, it reacts with Ca(OH)2 one of the by-products of hydration reaction of cement and results in additional C-S-H gel which results in increased strength. Table 3.3 shows the properties of white colored Metakaolin procured from ASTRA CHEMICALS, Chennai. The properties of Metakaolin are shown in Table 4.

S.NO.	Characteristics	Analysis Results
1	SiO_2 (Min)	52.86%
2	CaO	0.28%
3	MgO	0.20%
4	Fe_2O_3	0.45%
5	Al_2O3	44.10%
6	Loss on ignition	0.85%
7	Na_2O	0.25%
8	K_2O	0.20%
9	TiO_2	0.36%
10	Whiteness	95.80%
11	Brightness	93.50%
12	Retained on 500 mesh	0.05%
13	Bulk density(g/cm^3)	0.50
14	Oil absorption(ml/100gm)	64.00
15	Water absorption(ml/100gm)	66.80

Table 4. Properties of Metakaolin

3.1.5 Nano-Silica:
Nano-Silica is a new pozzolanic material in the form of water emulsion of colloidal silica. It appears to be potentially better than micro-silica because of higher content of amorphous silica (>99%)

and the reduced size of its spherical particles (1-50nm). In this experimental investigation cement is replaced by 1.5% and 3% of nano-silica by weight. The properties of nano-silica are shown in Table 5.

Table. 5. Properties of Nano-silica

S.No.	Property	Actual Analysis
1	Nano solids	39.5-41%
2	PH	9 -10
3	Specific Gravity	1.29-1.31
4	Texture	Milky White Liquid
5	Dispersion	Water

3.1.6 Water

Water used for casting and curing of concrete test specimens is free from impurities which when present can adversely influence the various properties of concrete.

3.1.7 Quarry Dust

Quarry Dust is procured from Chandragiri quarry,
a)Specific Gravity of fine Quarry Dust is 2.84
b)Fineness Modulus of Quarry Dust is 2.84
c)Water absorption of Quarry Dust is 5.6 %

3.2 Concrete Mix Proportion

In the present experimental investigation the influence of combined application of Nano Silica, Quarry Dust and Metakaolin as partial replacement of cement on M25 grade of concrete is studied. M25 grade of concrete were designed as per the Indian Standard code of practice.

The various ingredients for one cubic meter of M25 grade concrete are shown in Table 6 (a). As the nano-silica is available in the colloidal form, the quantity of water required for making concrete is adjusted to account for the water available in colloidal nano-silica.

3.3 Test Specimens

Concrete test specimens consist of 150 mm × 150 mm × 150 mm cubes, cylinders of 150 mm diameter and 300 mm height and 100 mm × 100 mm × 500 mm prisms. Concrete cube specimens were tested at 3, 7, 28, 56 and 90 days of curing to obtain the compressive strength of concrete. Cylindrical specimens were tested at the age of 28 days to obtain the split tensile strength of concrete. The prisms were tested at the age of 28 days to obtain the flexural strength of concrete. The rate of loading is as per the IS:516-1959.

4.0 RESULTS AND DISCUSSIONS

4.1 Compressive Strength

The variation of the cube compressive strength with the age of M25 grade concrete prepared using the various proportions of Nano Silica, Quarry Dust and Metakaolin is shown in Fig.1. Each value of the cube compressive strength indicates the average of three test results. It can be observed that the compressive strength of nano-silica concrete exhibits more than the control concrete up to 2% of nano-silica and 10% Metakaolin and with further increase in nano-silica and Addition of Quarry Dust the strength decreases for the given Metakaolin content.

Concrete	Cement (kg)	Micro-Silica (kg)	Colloidal Nano-Silica (Lit)	Water (lit)	w/c	Fine Aggregate (kg)	Coarse Aggregate (kg)
Control	330	0	0	165	0.50	741	0
MK 10 %	297	33	0	165	0.50	741	0
MK 10% + NS 1.0 %	293.7	33	3.3	163	0.50	741	0
MK 10% + NS 2.0 %	290.4	33	6.6	161	0.50	741	0
MK 10% + NS 3.0 %	287.1	33	9.9	159.05	0.50	741	0
MK 10% + NS 1.0 %+ QD 30%	293.7	33	3.3	163	0.50	519	222
MK 10% + NS 1.0 %+ QD 40%	293.7	33	3.3	163	0.50	445	296
MK 10% + NS 2.0 %+ QD 30%	290.4	33	6.6	161	0.50	519	222
MK 10% + NS 2.0 %+ QD 40%	290.4	33	6.6	161	0.50	445	296
MK 10% + NS 3.0 %+ QD 30%	287.1	33	9.9	159.05	0.50	519	222
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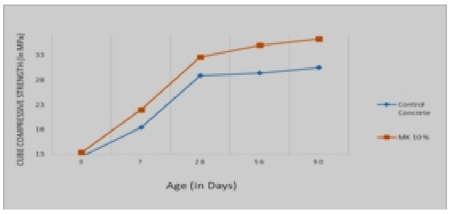

fig1(a) 10%Metakaolin

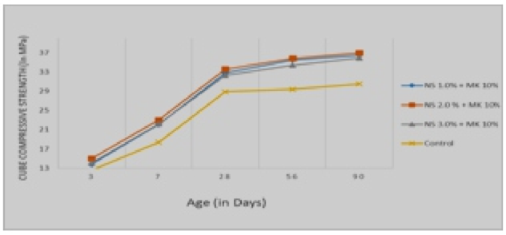

fig1(b) (1%, 2% & 3%) Nano Silica + 10% of Metakaolin

Fig. 1(a) and Fig. 1(b) Variation of Cube Compressive Strength of M25 Grade Concrete with age for different percentages of Nano Silica, Quarry Dust and Metakaolin.

The variation of 7 days and 28 days cube compressive strength of M25 grade of concrete prepared with different percentages of Nano Silica, Quarry Dust and Metakaolin is also shown in Fig.2 (a) & 2(b). The compressive strength of concrete initially increases up to 2% nano-silica and then the strength decreased with increase in Nano-Silica and addition of Quarry Dust.

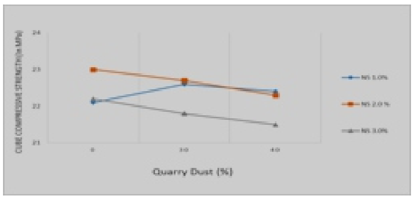

Fig. 2(a) 7 days Cube Compressive Strength

Fig.2(b) 28 days Cube Compressive Strength

Fig. 2(a) Variation of 7 days and from fig. 2(b) 28 days Cube Compressive Strength of M25 Grade of Concrete with different percentages of Nano Silica, Quarry Dust and Metakaolin.

The 7 days and 28 days cube compressive strength of M25 grade control concrete is 18.4 MPa and 28.9 MPa respectively. The increase in 7 days and 28 days cube compressive strength concrete with 2% Nano-silica and 10% Metakaolin combination is 25% and 16.26% respectively

4.2 Split Tensile Strength

The split tensile strength of M25 grade of control concrete is 2.96 MPa. The split tensile strength of concrete initially increases up to 2% of Nano-silica + 10% Metakaolin & 0% of Quarry Dust and with further increase in the Nano-Silica and Quarry Dust content the split tensile strength decreases. Similar trend can be observed with the concrete containing 10% Metakaolin. The increase in the split tensile strength of M25 grade of concrete with 2% Nano-Silica and 10% Metakaolin combination is 5.4 % as shown in figure No. 3.

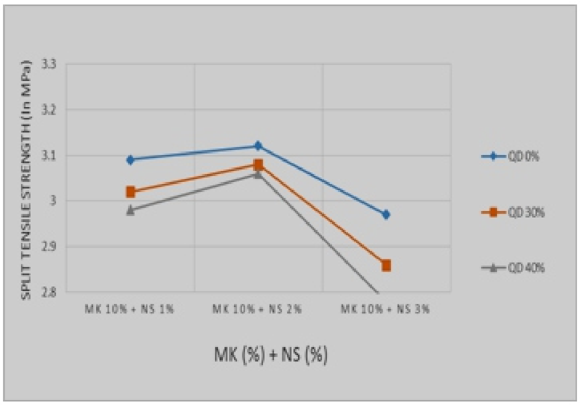

Fig.3 .Variation of Split Tensile Strength of M25 Grade of Concrete with different percentages of Nano Silica, Quarry Dust and Metakaolin.

4.3 Flexural Strength:

The Variation of Flexural Strength of M25 Grade of Concrete with different percentages of Metakaolin, Nano-Silica & Quarry Dust is shown in Figure No. 4. The flexural strength of M25 grade of Control concrete is 4.51 MPa. The flexural strength of concrete initially increases up to 2 % percentage of Nano-Silica & 0% Quarry Dust and then with further increase in the Nano-Silica the flexural strength decreases for different percentage of Quarry Dust content. The increase in the flexural strength of M25 grade of concrete with 2 % Nano-Silica and 10 % Metakaolin combination is 3.82%.

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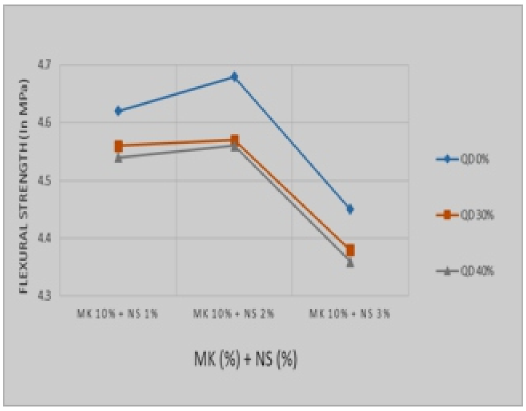

Fig.4 .Variation of Flexural Strength of M25 Grade of Concrete with different percentages of Nano Silica, Quarry Dust and Metakaolin.

4.4 Flexural Strength:

The Variation of Modulus of Elasticity of M25 Grade of Concrete with different percentages of Metakaolin, Nano-Silica & Quarry Dust is shown in Figure No. 5. The flexural strength of M25 grade of Control concrete is 27100 MPa. The Modulus of Elasticity of concrete initially increases up to 2 % percentage of Nano-Silica & 0% Quarry Dust and then with further increase in the Nano-Silica the Modulus of Elasticity decreases for different percentage of Quarry Dust content. The increase in the Modulus of Elasticity of M25 grade of concrete with 2 % Nano-Silica and 10 % Metakaolin combination is 7.17%.

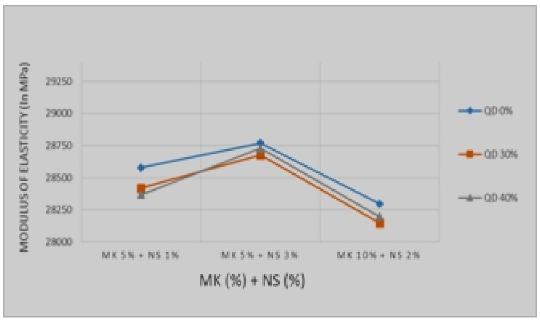

Fig.5 .Variation of Modulus of Elasticity of M25 Grade of Concrete with different percentages of Nano Silica, Quarry Dust and Metakaolin.

4.5 Regression Analysis for Percentages of Nano silica Vs Compressive strength

It can be observed from the Figure No. 6 which is drawn between Percentages of Nano silica and compressive strength. The points along the graph line were distributed evenly. Hence, the Regression value (R2) was in perfect order. Thus the Regression value (R2) is 1.

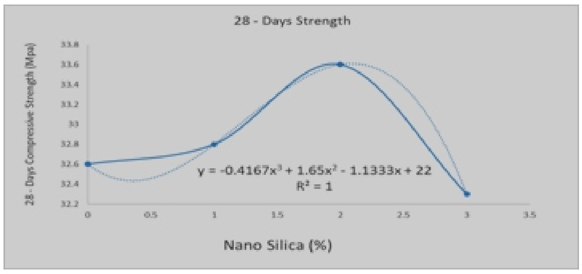

Fig. 6 Regression Line and Equation of Cube Compressive Strength of M25 Grade Concrete with 28 – Day Compressive Strength with Nano Silica

It can be observed from the Figure No. 7 which is drawn between Percentages of Quarry Dust and compressive strength. The points along the graph line were distributed evenly. Hence, the Regression value (R2) was in perfect order. Thus the Regression value (R2) is 1.

Fig. 7 Regression Line and Equation of Cube Compressive Strength of M25 Grade Concrete with 28 – Day Compressive Strength with Quarry Dust (Nano Silica 2%)

•The regression analysis is done for Nano silica and 28 days compressive strength for various percentages of Quarry dust by fixing Nano silica as 1% and Metakaolin as 10%, Nano silica as 2% and Metakaolin as 10%, Nano silica as 3% and Metakaolin as 10%. The values obtained from the graphs were analysed and equations were developed. Using these equations it is possible to predict the 28 days strength values at various percentages of quarry dust.

•The values obtained from the graphs were analysed and equations were developed. Using these equations it is possible to predict the 28 days strength at various percentage of Nano-Silica.

5.0 CONCLUSIONS:

Using the results of the experimental investigation, it can be concluded that the various strength characteristics of concrete are increased up to 2 %, with further increase in the nano-silica the various strength characteristics of concrete are decreased for various percentages of Metakaolin.

The Split Tensile strength, Flexural strength & Modulus of Elasticity of M25 grade of concrete indicated the similar trend. Quarry Dust has also been tested for 30% & 40%. The strength characteristics decreased gradually with addition of Quarry Dust (30%), Quarry Dust (40%) and it also decreases workability. The increase in the various strength properties of concrete containing Metakaolin and Nano-Silica can be the result of availability of additional binder in the presence of Nano-Silica. 10% cement replacement with Metakaolin gave optimum Strength and Workability for Metakaolin Concrete. Hence Metakaolin concrete consisted of 90% OPC & 10% Metakaolin is used as binary blending. The availability of additional binder improves the paste-aggregate bond and results in the increase in strength characteristics of concrete with Nano-Silica and Metakaolin. The decrease in the strength properties of concrete is due to the poor quality of binder in the presence of high percentage of Quarry Dust, Metakaolin and Nano-Silica. Based on the experimental investigation, the strength properties of concrete can be improved by the addition of 2% of Nano-Silica and 10% of Metakaolin by weight of cement. Hence, it can be concluded that the cement content can be reduced for the preparation of concrete by the use of Nano-Silica and Metakaolin combination as cement replacement. Maximum Compressive Strength is obtained at 30% Sand replacement by Quarry Dust when compared to 40% Quarry Dust. Hence, the production of Cement can be reduced to preserve the Natural resources for future generation and the CO2 content can be reduced

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