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EFFECT OF NANO-SILICA AND METAKAOLIN ON PROPERTIES OF RECYCLED COARSE AGGREGATE CONCRETE

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Abstract - The present work is directed towards the evaluation of concrete using partial replacement of natural coarse aggregate (NCA) with 25%, 50%,75% and 100% Recycle Coarse Aggregate and Cement is partially replaced with Metakaolin at 10%, 15% and 20% and Nano-silica at 1%,2% and 3% respectively. The experimental results of Strength properties are evaluated and compared with NCA concrete. RCA was obtained from the tested laboratory concrete specimens. Tests were carried out to obtain the compressive strength of RCA concrete. Based on the test results it can be observed that Recycled Coarse Aggregate Concrete has 29.35% more compressive strength when 15% of Metakaolin and 2% of Nano-silica is used as admixtures at 28 days curing. The strength characteristics had considerable improvement at optimum percentage of 50% Recycled Coarse Aggregate, 15% Metakaolin and 2% of Nano-silica.

***Key Words*: Compressive strength, Concrete, Recycled coarse aggregate ,Nano-silica, Metakaolin.**

1.INTRODUCTION

In India, a huge quantity of construction and demolition wastes is produced every year. These waste materials need a large place to dump and hence the disposal of wastes has become a severe social and environment problem. On the other hand scarcity of natural resources like river sand is another major problem which results in increasing the depth of river bed and also changes in climatic conditions. Hence, it becomes necessary to protect and preserve the natural recourses. The possibility of recycling demolition wastes in the construction industry is thus of increasing importance. In addition to the environmental benefits in reducing the demand of land for disposing the waste, the recycling of demolition wastes can also help to conserve natural resources.

1.1 RECYCLED COARSE AGGREGATE (RCA)

In many countries, recycled concrete aggregate have been proven to be practical for low strength concrete, and to a limited extent, for some structural-grade concrete.

Positive benefits include:

1. The amount of material going to land fill is reduced and
2. Aggregate can be used economically as structural concrete and as road construction materials

1.2 METAKAOLIN

The demand for Portland cement is increasing dramatically in developing countries. Portland cement production is one of the major reasons for CO2 emissions into atmosphere. It is due to the use of fossil fuels, including the fuels required to generate electricity during cement manufacturing process. The use of pozzolanas for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. 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-Hgel which results in increased strength. Metakaolin is obtained by thermal activation of kaolin clay. This activation will cause a substantial loss of water in its constitution causing a rearrangement of its structure. To obtain an adequate thermal activation, the temperature range should be established between 600ºC to 750ºC. Metakaolin is used in oil well cementing to improve the compressive and flexural strength of the hardened cement. Metakaolin also reduces the hardened cement permeability to liquids and gases. Hence by partially replacing Portland cement with Metakaolin not only reduces carbon dioxide emissions but also increases the service life of buildings. Metakaolin is a dehydroxylated form of the clay mineral Kaolinite. Rocks that are rich in Kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of Metakaolin is smaller than cement particles, but not as fine as silica fume .The quality and reactivity of Metakaolin is strongly dependent of the characteristics of the raw material used. Metakaolin can be produced from a variety of primary and secondary sources containing Kaolinite. Metakaolin is refined calcined kaolin clay under carefully controlled conditions to create an amorphous alumina silicate which is reactive in concrete. Natural pozzolanas like fly ash and silica, Metakaolin also reacts with the calcium hydroxide (lime) byproducts produced during cement hydration. Between 100-200°C, clay minerals lose most of their adsorbed water. Between 500-800°C Kaolinite becomes calcined by losing water through dehydroxilization. The dehydroxilization of kaolin to Metakaolin is an endothermic process due to the large amount of energy required to remove the chemically bonded hydroxyl ions. Above this temperature range, Kaolinite becomes Metakaolin, with a two dimensional order in crystal structure. This material is ground to a required fineness of 700-900m2/kg. In order to produce a pozzolana (supplementary cementing material) nearly complete dehydroxilization must be reached without overheating, i.e., thoroughly roasted but not burnt. This produces an amorphous, highly pozzolanic state, whereas overheating can cause sintering, to form the dead burnt, nonreactive refractory, called Mullite. The mineral composition of cement and Metakaolin highly resembles with each other along with their functions.

1.3 NANO-SILICA

Nano-technology can be defined as a creation of materials and devices by controlling of matter at the levels of atoms, molecules and Nano-scale structures. Nanotechnology has great effects on different areas of science and industry. Nano-technology provides improvement for system reliability, extend functionality beyond traditional applications and decrease cost, size and energy consumption. Incorporating nanotechnology in the field of materials facilitates increasing materials strength and durability. It also enables better usage of natural resources and getting the required materials properties with minimal usage.

Concrete is commonly used in large quantities and huge scale but it is very crucial to study its structural elements which are effective at the micro and Nano-silica in order to control the basic properties of concrete such as compressive strength, tensile strength, durability and ductility. Concrete performance is strongly dependent on Nano-size dimensions of solid material such as C-S-H particles or voids such as the gel porosity in the cement matrix and the transition zone at the interface of cement paste with aggregate or steel reinforcement, typical properties affected by Nano-sized particles are strength, durability, shrinkage and steel-bond.

1.4 MERITS OF NANO-SILICA

Adding Nano-silica to concrete enhances its mechanical properties and durability. Concrete is the most commonly used material for construction. The use of large quantities of cement produces CO2 emissions and as a consequence the green house effect. A method to reduce the cement content in concrete mixes is the use of silica fines. One of the silica fines with high potential as cement replacement and as concrete additive is Nano-silica. It may replace cement in the mix, which is the most costly and environmental unfriendly component in concrete. The use of Nano-silica makes concrete financially more attractive and reduces the CO2 emissions results a concrete with better performance, lower overall costs and an improved ecological footprint can be obtained.

2 . OBJECTIVE

The aim for this present investigation is to determine the strength characteristic of recycled aggregate concrete with partial replacement of cement with Metakaolin and Nano-silica for application in structural concrete, which will give better understanding on the properties of concrete with recycled coarse aggregate, Metakaolin and Nano-silica.

3 . OBJECTIVE

The scope of this project:

1. Review and research of concrete properties using RCA,Metakaolin and Nano-silica.
2. Casting of concrete specimens by using different percentage of RCA, Metakaolin and Nano-silica.
3. Testing on concrete specimen prepared using RCA,Metakaolin and Nano-silica.
4. Analysis of test results and recommendation for further research area.

4. MATERIALS

4.1 CEMENT:

Portland cement grade 53 is used in this test. It is the basic ingredient of concrete, mortar and plaster. Cement is an amorphous (glassy) powdered siliceous material that responds to the alkali content in cements to react with lime in the high pH environment in concrete to form additional CSH (calcium silicate hydrate) binder within the pore structure of the concrete. Pozzolana is effective as minus 325 mesh powders. Much of the chemistry associated with certain Pozzolana, such as sulfides, carbon, sulfates, and alkalis can be quite deleterious to the long-term durability of concrete. The properties of cement were within limits as per IS 8112:1989. The properties are shown in Table-1.

Table-1. Physical Properties of 53 Grade Ordinary Portland Cement

S.No.	Property	Result
1.	Fineness	7%
2.	Specific gravity	3.12
3.	Normal Consistency	30%
4.	Setting time(min) a) Initial b) Final	90 min 330 n

4.2 Fine Aggregate:

Grading of fine aggregate shall confirm to IS and shall within limits of one of the four zones given in IS 383-1970.The properties of sand were analyzed in accordance with the procedure laid down in IS 2386 (part 1): 1963 and were presented in Table-2. And Fig1.

Table-2. Grade Analysis of Fine Aggregate

IS Sieve Designation	Weight retained (gm)	%weight retained (%)	% passing by weight	Cumulative % wt. retained
10mm	0	0	100	0
4.75mm	5	0.5	99.5	0.5
2.36mm	45	4.5	95	5
1.18mm	130	13	82	18
600 micron	360	36	46	54
300 micron	350	35	11	89
150 micron	50	5	6	94
Pan	60	6	0	100

4.3 COARSE AGGREGATE

Aggregate shall be stored in such a way that it does not get mixed with mud, grass, vegetables and other foreign matter. The best way is to have a hard surface platform made out of concrete, bricks or planks. Once a specific source of supply of coarse aggregate is approved, the source shall not be changed. In this study, graded 20mm crushed granite coarse aggregate was used as the natural coarse aggregate.

The properties of coarse aggregate were analyzed in accordance with the procedure laid down in IS 2386 : 1963 and were presented in Table-4.

Table-4. Properties of Coarse Aggregate

S.No.	Property	Value
1	Specific Gravity	2.61
2	Water Absorption	0.4%
3	Fineness Modulus	6.53

4.4 RECYCLED COARSE AGGREGATE

The recycled aggregate is obtained by breaking the tested laboratory concrete specimens of grades M20, M25 and M30. The concrete specimens were made into smaller fragments manually and the recycled aggregate obtained.

The following process of crushing was used to obtain Recycled Coarse Aggregate.

1. Primary crushing
2. Secondary crushing.

Table-4. Properties of Fine Aggregate and Coarse Aggregate

S. No	Type		Specific gravity	Water absorption (%)
1	Coarse aggregate	Natural	2.67	0.4
		Recycled	2.56	1.75
2	Fine aggregate		2.56	0.2
3	Cement		3.12	-

4.5 Metakaolin (MK):

The sample of Metakaolin used in this present experimental study is shown in Fig-1, obtained from ASTRRA Chemicals, Chennai. Specification, physical and chemical properties of the Metakaolin are presented in the Table-5. and Table-6.

Fig-1 Metakaolin Sample

Table-5 Physical Properties of Metakaolin

Properties	Value
Density (gm/cm^3)	2.17
Bulk density (gm/cm^3)	1.26
Particle shape	Spherical
Color	Half-white
Specific gravity	2.1

Table-6 Chemical Properties of Metakaolin

Constituents	Value
Silica	53%
Alumina	43%
Iron Oxide	0.5%
Calcium Oxide	0.1%
Sulphate	0.1%
Sodium Oxide	0.05%
Potassium Oxide	0.4%

4.6 Nano-Silica

Nano-silica is a new pozzolanic material. Nano-silica has extremely large specific area. Nano-silica used in this research is in the form of colloidal silica type approximately with 40% suspension as shown in Fig-2.

Nano-silica used in the study was manufactured by Bee Chems HO: E-5, Panki Industrial Area, Site-1, Kanpur-208022, U.P, India. Specification of Nano-silica as given by the supplier is shown in the Table-7.

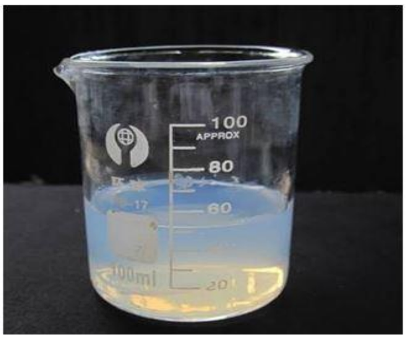

Fig-2 Nano-Silica Sample

Table-7 Specification of Nano-Silica

Parameter	Cemsyn XFX
Active Nano content (%wt/wt)	40.00-41.50
PH (20°C)	9.4-10
Specific gravity	1.3-1.32
Description	Colloidal

5 .MIX DESIGN

5.1 MIX DESIGN FOR M25 GRADE NATURAL COARSE AGGREGATE CONCRETE

a) Design Stipulations

(i) Characteristic compressive strength required in the field at 28 days: 25Mpa
(ii) Maximum size of aggregate : 20mm
(iii) Degree of quality control :good
(iv)Type of exposure :mild

b) Test data for material

(i) Specific gravity of Cement :3.12
(ii) Specific gravity of C.A. :2.67
(iii) Specific gravity of F.A. :2.56
(iv) Zone of soil :zone – II
(v) Water absorption of Coarse Aggregate : 0.4%

c) Target Mean strength of concrete

$$f_{ck} = f_{ck} + k \times s$$
$$= f_{ck} + 1.65 \times s$$
= 25 + 1.65×4
= 31.6 MPa

Where f_{ck} = characteristic compressive strength
S = Standard deviation = 4
k = 1.65
Water / Cement ratio = 0.5

d) Selection of water and sand content

For 20mm maximum size aggregate sand confirming for grading Zone 2, Water content per cubic meter of concrete =186 kg
Required water content = 155 kg/m^3

e) Determination of cement concrete

Water cement ratio = 0.5
Water= 155 liters
Cement= 155/0.5 = 310 kg/m^3

f) Determination of C.A and F.A contents

From Table 3 (IS 10262:2009) volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate (zone-II) for water cement ratio of 0.5 = 0.62.
Volume of coarse aggregate = 0.62
Volume of fine aggregate = 1 - 0.62
= 0.38

g) Mix Calculations

Volume of Concrete = 1m^3

Volume of Cement $= \frac{Mass\ of\ cement \times 1}{sp.gravity\ of\ cement \times 1000}$

$= \frac{310 \times 1}{3.12 \times 1000}$

=0.009 m^3

Volume of Water $= \frac{Mass\ of\ water \times 1}{sp.gravity\ of\ water \times 1000}$

$= \frac{155 \times 1}{1 \times 1000}$

= 0.155 m^3

Volume of Aggregate =(0.009+0.155)
= 0.746 m^3
Mass of Coarse Aggregate=0.746×0.62×2.67 ×1000
= 1235 kg
Mass of Fine Aggregate=0.746×0.38×2.56× 1000
= 726 kg
Then mix proportion becomes
Cement = 310 kg
Sand = 726 kg
Coarse aggregate = 1235 kg
Water content = 155 (l)

6. Test Results

6.1 Compressive Strength

The results of compressive strength of natural coarse aggregate and recycled coarse aggregate of for different combinations of Metakaolin and Nano-silica are compared and presented in Table-7. It is observed that the Compressive strength of control concrete changes up to 29.4% when cement is replaced with 15% of Metakaolin and 2% of Nano-silica with a combination of 50% Recycled coarse aggregate.

Table-7. Test Results of Compressive Strength of Concrete

Type of Concrete Mix	Compressive Strength (MPa)					% increase
	3 days	7 days	28 days	56 days	90 days	
Control Mix	15.1	20.3	32.3	35.4	38.5	0
RCA 25%	17.8	23.1	32.6	36.2	38.8	0.93
RCA-50%	19.3	28.3	33.3	37.3	40.0	3.1
RCA-75%	15.6	22.5	26.1	29.4	32.6	-19.2
RCA-100%	14.4	17.6	25.5	27.6	30.5	-21.1
RCA-25% ;MK-10%	19.1	21.6	29.0	36.3	39.9	-10.2
RCA-25%;MK-15%	20.4	28.1	38.4	39.3	40.4	18.9
RCA-25%; MK-20%	18.0	20.0	28.6	35.0	38.1	-11.5
RCA-50%; MK-10%	20.4	32.3	35.7	39.3	43.0	10.5
RCA-50%; MK-15%	23.5	34.7	39.0	42.0	44.7	20.7
RCA-50%: MK-20%	19.8	28.6	34.4	38.8	40.6	6.5
RCA-50%;MK-15%;NS-1%	25.2	36.9	40.4	45.6	47.3	25.1
RCA-50%;MK-15%;NS-2%	28.4	38.4	41.8	48.2	49.5	29.4
RCA-50%;MK-15%;NS-	24.0	34.4	39.3	43.1	46.1	21.7

6.2 Split Tensile Strength

It is observed that the Split Tensile strength of control concrete increases from 3.4MPa of control concrete to

32.4MPa (32.4%) when cement is replaced with 15% of Metakaolin and 2% of Nano-silica with a combination of 50% Recycled coarse aggregate.

Table-8. Test Results of Split Tensile Strength of Concrete

Type of Concrete Mix	Average Split Tensile Strength(N/mm²)	% increase
Control mix	3.4	0
RCA-25%	3.5	3.0
RCA-50%	3.7	8.8
RCA-75%	2.9	-14.7
RCA-100%	2.8	-17.7
RCA-25% ;MK-10%	3.7	8.8
RCA-25%;MK-15%	3.8	11.8
RCA-25%; MK-20%	3.6	6.0
RCA-50%; MK-10%	3.9	14.7
RCA-50%; MK-15%	4.0	17.6
RCA-50%: MK-20%	3.8	11.8
RCA-50%;MK-15%;NS-1%	4.2	23.5
RCA-50%;MK-15%;NS-2%	4.5	32.4
RCA-50%;MK-15%;NS-3%	4.1	20.6

6.3 Flexural Strength

It is observed that the Flexural strength of control concrete increases up to 4.3% when natural coarse aggregate is replaced with 50% recycled coarse aggregate. It further increases to 6.5% with replacement of cement by 15% Metakaolin in addition to replacement by 50% recycled coarse aggregate. The maximum increase in Flexural strength of Control concrete is observed when cement is replaced with 15% of Metakaolin and 2% of Nano-silica with a combination of natural coarse aggregate is replaced by 50% Recycled coarse aggregate to a value of 30.4%.

Type of Concrete Mix	Average Flexure Strength(N/mm²)	% increase
Control mix	4.6	0
RCA-25%	4.7	2.2
RCA-50%	4.8	4.3
RCA-75%	4.4	-4.4
RCA-100%	4.2	-8.7
RCA-25% ;MK-10%	4.8	4.3
RCA-25%;MK-15%	4.9	6.5
RCA-25%; MK-20%	4.8	4.3
RCA-50%; MK-10%	5.1	11.0
RCA-50%; MK-15%	5.3	15.2
RCA-50%: MK-20%	5.0	8.7
RCA-50%;MK-15%;NS-1%	5.6	21.7
RCA-50%;MK-15%;NS-2%	6.0	30.4
RCA-50%;MK-15%;NS-3%	5.2	13.0

7. Conclusions

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

- The Compressive Strength of Control Concrete (32.3 MPa) has increased by 3.1% with partial replacement of Natural Aggregate with 50% Recycled Aggregate (37.3MPa) and with Further addition the Strength decreases.
- The Compressive Strength of Recycled Coarse aggregate concrete increases by 29.4% when Cement is replaced with 15% of MK, 2% of NS and coarse aggregate with 50% of Recycled coarse aggregate.
- The split Tensile Strength, Flexure Strength, Elastic modulus of M25 concrete also increases by 32.4%, 30.4% and 6.7% respectively at replacement of 50% of RCA, 15% of MK and 2% of NS respectively.
- The Strength characteristics have considerable improvement when compared to control concrete at a optimum replacement percentage of 50% Recycled Coarse Aggregate, 15% of Metakaolin and 2% of Nano-silica.

- The strength improvement of recycle coarse Aggregate concrete prepared with Metakaolin and Nano-silica due to Replacement of Recycled Aggregate alone, this is due to the particle size of Metakaolin and Nano-silica. These supplementary materials react with Calcium Hydroxide to form additional binder material. The availability of additional binder enhances the paste-aggregate bond results the Recycled Coarse Aggregate Concrete to improve strength properties. Hence, low strength properties of partially used Recycled Coarse Aggregate Concrete can by improved by the addition of a specified percentage of (15%) Metakaolin and (2%) Nano silica.

8. Scope for the future work

The work can be extended for:

- The tests on Durability, creep, shrinkage properties of RCA concrete.
- Use of Recycled Coarse Aggregate, Metakaolin and Nano-Silica as admixture in high Strength Concrete.
- Study on properties of concrete at various percentages of Nano-Silica with combination of different percentages of other admixtures and Recycled Coarse Aggregate.

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