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Influence of Colloidal Silica and Partial Replacement of Cement with Metakaolin in Concrete

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Abstract**:** ***High strength concrete is being required due to the construction industry's growth. Admixture and supplemental cementing materials (SCMs) are employed to attain this strength. According to earlier research, nanoparticles with a high surface area to volume ratio, such as colloidal nano-silica (CS), which contains an amorphous silicon dioxide (SiO2) core and a hydroxylated surface, have the potential for extremely high chemical reactivity. This study examined the results of adding metakaolin and colloidal silica to concrete in varying amounts. Tests in accordance with Indian standards have been conducted in order to evaluate and compare the mechanical properties of concrete, such as compressive strength, split tensile strength, and flexural strength, while employing different percentage replacements of metakaolin and colloidal silica. According to Indian norms, 150mm cubes were cast for compressive strength tests and 150mm diameter by 300mm height cylinders were produced for split tensile strength tests. In the investigation, metakaolin was used in instead of 10 to 30 percent cement mass, and 0 to 6 percent colloidal silica was added. The results of the experiments indicate that the most optimal mixture, for which the most desirable strength was obtained, is 10% metakaolin and 2% colloidal silica.***

Keywords: Metakaolin, Colloidal Silica, Compressive Strength, Split Tensile Strength, Flexural Strength.

I. INTRODUCTION

Concrete incorporates supplementary cementing materials (SCMs) to partially replace Portland cement is general practise from past few decades. Fly ash, slag cement, silica fume, rice husk ash, allcofine, and metakaolin are a few examples of SCMs. Although SCMs differ in origin, physical characteristics, and chemistry, they all exhibit pozzolanic and cementitious qualities. SCMs can successfully increase the concrete's long-term durability, mechanical strength, and transportability. Beyond the favorable benefits connected to the functionality of concrete including SCM, their incorporation is encouraged by their ability to lower the environmental responsibilities associated with concrete, such as energy use, greenhouse gas emissions, waste disposal, and resource scarcity. Due to the increasing demand for high performance concretes with high strength and durability, recent structural diversification has highlighted interest in the workability and durability of concrete.[1] Concrete is a heterogeneous substance in and of itself, composed of cement and particles of various sizes and forms. According to studies, each person produces more than 1 m3 of concrete annually on a global basis. According to researchers, between 5 and 7 percent of all global carbon dioxide (CO2) emissions are related to the cement producing business.[2] To tackle this, nanomaterials can be employed to patch gaps, build bridges, and serve as nano nuclei to encourage hydration. Some nanoparticles also have strong antimicrobial properties. Nano materials with filling effects, including nano SiO2, nano CaCO3 (metakaolin), etc., can improve the micropore structure of cement mortar and concrete, lower the porosity, and create a more dense structure.[3] Several researchers have recently looked into the characteristics of metakaolin as high-quality pozzolanic materials. Due to a lack of sufficient tests on this material in the Middle East, it is not commonly produced and used. Metakaolin was created by thermally treating local kaolin with a high kaolinite content for 60 minutes at 800 ^{o}C.[4] The area around the aggregate is the most crucial part of the microstructure of the concrete. When silica fume is added to concrete, the porosity of the area between the matrix and aggregate is reduced, and the microstructure required for a sturdy transition zone is created.[5] In the investigation, the author added fly ash, 17 percent alocofine, and silica fume at varying W/B ratios of 0.25, 0.30, and 0.35 to replace 10% by weight of the cementitious material. The author continues by saying that cementitious material substitution best suited while concrete is still fresh and also when hardened.[6] Due to the presence of nano-practical sizes of silica portion, which work faster in the bonding properties, the addition of colloidal silica has a similar impact at addition of a very little amount. This synopsis demonstrates the evolution of research on the physical characteristics of concrete containing metakaolin and colloidal silica. The current study examines some concrete properties, including compressive strength, split tensile strength, and flexural strength, with various additions of metakaolin and colloidal silica.

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II. EXPERIMENTAL PROGRAM

A. Flow Chart of Experimental Program

The following figure shows the experimental program of the study.

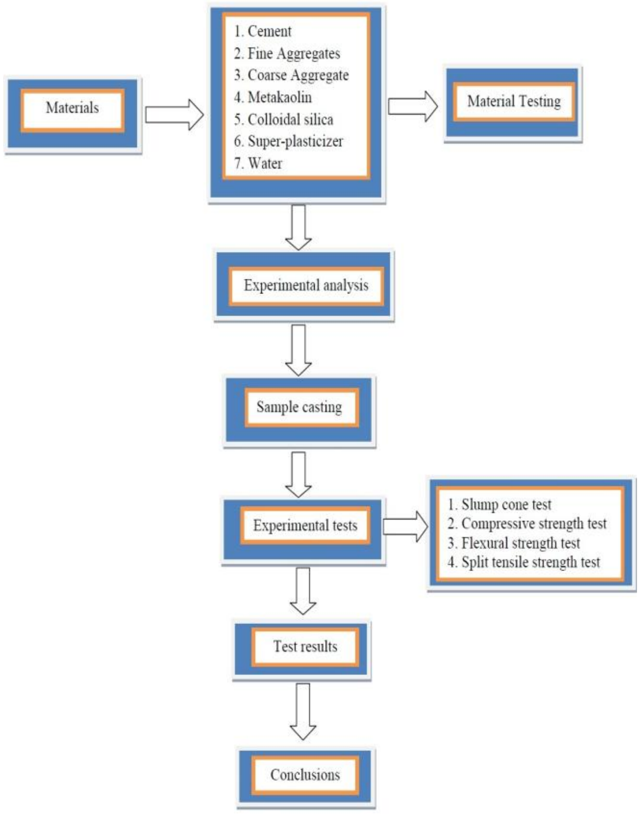

Fig -1: Flow chart

B. Material

For the study, ordinary Portland cement (OPC) of grade 53 was used.[10] As fine aggregate and coarse aggregate, respectively, natural sand with a fineness modulus of 2.60 and natural gravel with a fineness modulus of 3.40 are employed. The specific gravities of fine and coarse aggregates were 2.70 and 2.80, respectively. The Indian standards were followed for testing of the materials.[11]

Table- I: Chemical composition of Metakaolin

Chemical Elements	% By mass
SiO_2	51.52
Al_2O_3	40.28
Fe_2O_3	1.43
CaO	2.0
MgO	0.13
K_2O	0.53
SO_3	0.0
TiO_2	2.37
Na_2O	0.08
L.O.I	2.11

Table-I I: Physical Properties of Metakaolin

Property	Value
Specific gravity	2.11 to 2.5
Bulk density (g/cm3)	0.33 to 0.4
Water absorption	0.3 to .8%
pH	7.7 to 8
Physical form	Powder
Color	white
GE Brightness	78 to 82

Table- III: Chemical and Physical properties of Colloidal silica

Colour	Milky White liquid
K2O	0.10 % +/- 0.05 % w/w
SiO2	30.0 % +/- 0.50 % w/w
Total Solids	30. % w/w (approx)
Weight Ratio	300.0
Molar Ratio	470.0
pH	9.0 +/- 0.2
Specific Gravity	1.25 +/- 0.2 at 25^{o}C

C. Experimental Work

1) In This experiment a total of 72 number of concrete specimen were casted.
2) The specimens in this study consists of 48 numbers of 150mmx150mmx150mm cube, 12 numbers of 150 mm ø and 300mm long cylinder and 12 numbers of 100mm x 100mm x 500mm beam.
3) The mix design of concrete was done according to Indian Standard guidelines for M60 grade i.e. IS 10262:2009 for water cement ratio of 0.29.
4) Four mix designs were made after going through the literatures,
Following proportions are used for all the tests
1. 10% MK, 90%OPC, Fine Aggregate, Coarse Aggregate
2. 10% MK, 2% CS, 90% OPC, Fine Agg., Coarse Agg.
3. 20% MK, 4% CS, 80% OPC, Fine Agg., Coarse Agg.
4. 30% MK, 6% CS, 70% OPC, Fine Agg., Coarse Agg.
5) Compressive strength test, Flexural strength test and split tensile strength test were performed on the test specimens as per IS standards.

D. Specimens preparation

A small electric concrete mixer was used to make the concrete. Four series of concrete mixtures were created, each with constant total binder content (cement + metakaolin) of 528 kg/m3 of M60 grade and a water/binder (w/b) ratio of 0.29. The mix ratios were calculated using the IS 10262-2009 technique [7]. The amounts of metakaolin that replace OPC in this study's cement mass are 10%, 20%, and 30%, respectively. 0 %, 2 %, 4 %, and % of colloidal silica were added. Table 4 gives information about the blends. According to the results for the slumps, relatively low percentages of superplasticizer were applied. Concrete test specimens were cast in two layers.

Table- IV: Mix proportions of concrete.

Series	W/b	MK (%)	CS (%)	Cement (kg/m^3)	MK (kg/m3)	CS (kg/m^3)	Water (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)
MD1	0.29	10	0%	484	44	0	154	718.2	1117.2
MD2	0.29	10	2%	484	44	10.4	154	718.2	1117.2
MD3	0.29	20	4%	440	88	20.8	154	718.2	1117.2
MD4	0.29	30	6%	396	132	31.2	154	718.2	1117.2

E. Test Performed

1. Compressive strength

For compressive strength test, concrete cubes with dimensions of 150 mm x 150 mm x 150 mm were cast. After 7, 14, and 28 days of water curing, the compressive strength of the materials was evaluated.

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Three specimens were tested for each age, and the mean value of these measurements is stated.

2. Split tensile strength

For testing split tensile strength, concrete cylinders 300mm long and 150mm in diameter were cast. After 28 days of water curing, their split tensile strength was measured. Three samples were examined for each mix proportion, and the mean value of these measurements is reported.

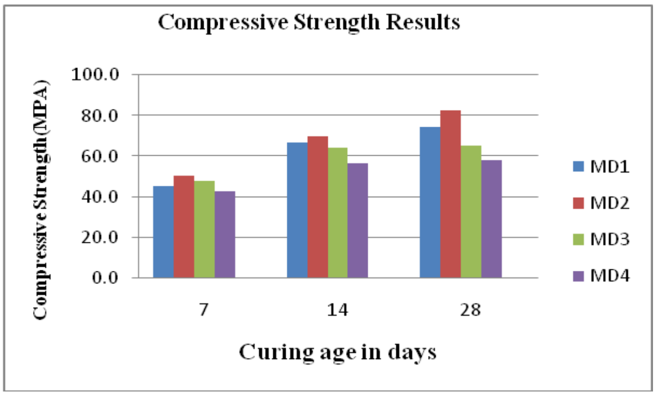
3. Flexural strength test

Concrete cylinders measuring 100 mm by 100 mm by 500 mm long were produced for a flexural strength test. After 28 days of water curing, they underwent a flexural strength test using a Universal testing machine. Three samples for each mix proportion were evaluated, and the average value of these measurements is reported.

III. RESULTS AND DISCUSSIONS

A. Compressive strength

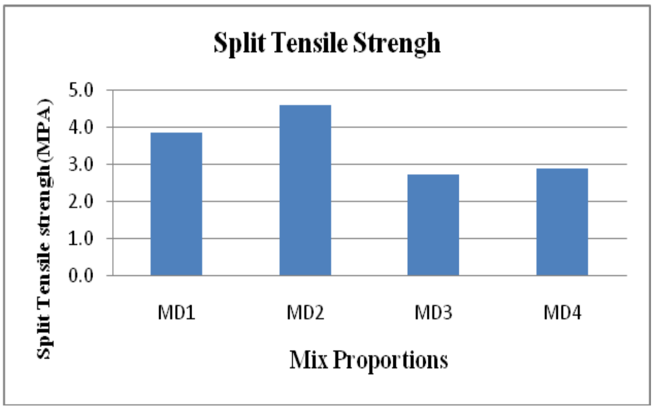
According to the specifications of Indian standards, the strength test of various mix proportions is conducted. Graph illustrates the compressive strengths of concrete specimens with various amounts of metakaolin and colloidal silica. 1. The graph-1 compares the test results for various mix proportions, including MD1, which contains 10% metakaolin and 0% colloidal silica, MD2, which contains 10% metakaolin and 2% colloidal silica, MD3, which contains 20% metakaolin and 4% colloidal silica, and MD4, which contains 30% metakaolin and 6% colloidal silica. According to the graphical data, the highest compressive strength is attained with a 10% metakaolin replacement and a 2% colloidal silica content. For MD2, it is seen that compressive strength increases dramatically with curing age. Greater strength of up to 30% is attained.



Graph-I Graphical representation of compressive strength test results

B. Split tensile strength

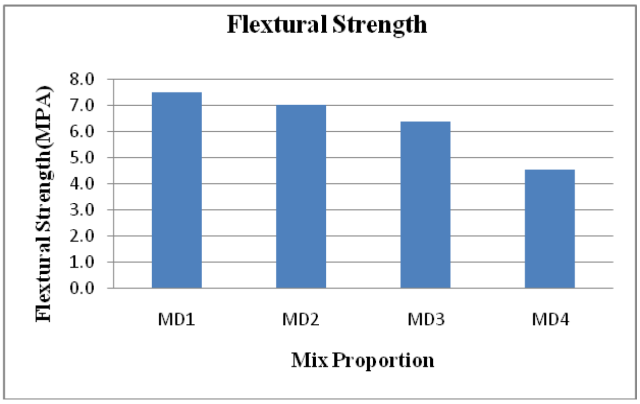
Graph displays the Split tensile strength of concrete specimens with various metakaolin and colloidal silica concentrations. 2. The 10 percent metakaolin replacement and 2 percent colloidal silica, as shown in the graph, achieve the highest split tensile strength, although MD3 and MD4, which contain 4 and 6 percent colloidal silica, respectively, have not.



Graph–II Graphical representation of split tensile strength test results

C. Flexural strength test

The Flexural strength of concrete specimens with varying metakaolin and colloidal silica proportions are shown in Graph. 3. As the graphical data shows the 10% metakaolin replacement and 0% colloidal silica achieves the maximum Flexural strength.



Graph–III Graphical representation of flexural strength test results

IV. CONCLUSIONS

Following are the conclusions obtain from test results:

a) According to the results of the compressive strength test, the mix design with 10% metakaolin and 2% colloidal silica has the highest compressive strength compared to other mix designs.

b) The 28-day compressive strength is 37 percent greater for this Mix percentage MD2.

c) Similar findings were seen in the results of the split tensile strength test, where the MD2 material, which contains 10% metakaolin and 2% colloidal silica, reached its peak flexural strength after 28 days of curing.

d) The MD1 mix design, which contains 10% metakaolin and 0% colloidal silica, outperformed the other mix designs in the flexural strength test.

e) The outcome also demonstrates that the replacement of 30% metakaolin and 6% colloidal silica tends to not achieve the desired strength, possibly even reducing it.

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f) Based on the data, we can further conclude that replacing metakaolin with colloidal silica helps to increase early-stage strength but that doing so more frequently tends to reduce 28-day strength.
g) Based on the findings of the investigation, it is clear that a mixture of 10% metakaolin and 2% colloidal silica is the best way to produce concrete with a high strength.

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