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# Performance Evaluation Of M60 Grade Concrete Using Metakaolin And Colloidal Silica As Partial Cement Replacements.

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***Abstract:*** This study investigates the influence of metakaolin (MK) and colloidal silica (CS) as partial replacements for cement on the mechanical properties of M60 grade concrete. Four mix proportions with varying MK (10% to 30%) and CS (0% to 6%) were evaluated for compressive strength, split tensile strength, and flexural strength at curing periods of 7, 14, and 28 days. Results indicate that the mix containing 10% metakaolin and 2% colloidal silica (MD2) exhibited the highest compressive strength, achieving up to 37% greater strength than the conventional concrete at 28 days. Split tensile and flexural strength tests showed improved performance with lower percentages of colloidal silica, with the optimal tensile strength also observed in the MD2 mix. Higher replacement levels (20%-30% MK and 4%-6% CS) led to a decrease in tensile and flexural strengths and did not consistently improve compressive strength beyond early curing ages. The findings suggest that 10% metakaolin combined with 2% colloidal silica is the most effective replacement for enhancing the overall mechanical properties of M60 grade concrete.

***Index Terms*** - Metakaolin, Colloidal Silica, M60 Grade Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength.

## I. INTRODUCTION

### 1.1 General

Introduction to supplementary cementing materials Supplementary cementing materials (SCMs) are used to partially replace the Portland cement component in concrete. Some examples of SCMs are the following fly ash, slag cement, silica fume, and metakaolin. Although SCMs vary in origin, physical properties and chemistry, they all exhibit pozzolanic and/or cementitious properties. The use of SCMs can effectively improve the concrete's fresh, mechanical, and transport properties and long-term durability. Beyond the desirable advantages associated with the performance of concrete containing SCM, their incorporation is also motivated by their ability to reduce concrete's environmental burdens related to energy use, greenhouse gas emissions, waste disposal, and depletion of natural resources. Concrete containing SCMs as partial cement replacement has been used successfully for decades and is widely regarded as adorable, long lasting, and sustainable structural material. SCMs are used in ready-mix, precast, and pre-stressed concretes as well as in mortars and grouts. Some structural applications of concrete containing SCMs include bridges, roads, buildings, massive concrete structures, highway barriers, sidewalks, tunnels, and underground infrastructure.MK is one of the construction materials classified as a new generation of miner admixtures which can be used as SCMs, which offers technical and environmental advantages. It can be used in its finely ground form as a partial substitute of the cementin the concrete mixture

## 1.2 Metakaolin

Metakaolin is an amorphous aluminosilicate that is a highly reactive natural pozzolan produced by the calcination and dehydroxylation of kaolinitic clay at temperatures between 500oC and 900oC. Metakaolin is a porous, angular shaped, platy particle with a mean size that can range from 1 to 20 μm. The specific gravity of metakaolin can fall between 2.20 and 2.60. Although the major constituents of metakaolin are silicon dioxide and alumina oxide, its composition varies with different sources of kaolin. Other components are ferric oxide, calcium oxide, magnesium oxide, and potassium oxide. In order for metakaolin to be classified as Class N (raw or calcined natural pozzolan).

### 1.2.1 Uses of metakaolin Metakaolin finds usage in many aspects of concrete:

- High performance, high strength and lightweight concrete
- Precast concrete for architectural, civil, industrial, and structural purposes
- Fiber cement and ferrocement products ➢ Glass fiber reinforced concrete
- Mortars, stuccos, repair material, pool plasters

Fig. 1 − Metakaolin

## 1.3 Colloidal Silica

Among all the oxide minerals in the Earth's crust, silicon dioxide, or silica, is the most abundant. It is present in not only in combination with other oxide minerals but also in its isolated forms such as sand. The semi-precious mineral opal is a form of amorphous silica that has been prized for centuries. In the most general terms colloidal silica is a dispersion of amorphous silicon dioxide (silica) particles in water. These amorphous silica particles are produced by polymerizing silica nuclei from silicate solutions under alkaline conditions to form nanometer sized silica sols with high surface area. A charge is then induced on the silica nano-particle surface that allows the silica particles to repel one another and form a stable dispersion, or colloid. Besides being the most abundant mineral on the Earth, it is also very important to life on our planet. Diatoms, a type of phytoplankton forming the base of the ocean's food chain, have skeletons composed of silica. Many plants use silica to stiffen stems for holding fruit and to form external needles for protection. The role of silica is less obvious in animals, but each one of us contains about half a gram of silica – without which our bones, hair, and teeth could not be formed. Not only does silica play an important role in biology, it had played an important role in civilization. Flint is a form of silica that was used in ancient tools. The sand used in pottery is also a form of silica. Two-thousand-year-old Roman cement contains amorphous silica from volcanic ash which helps give it high strength 4 and durability. Present technology would be very different without the silica used to create the catalysts of our oil refineries, bind the molds for casting super-alloys, form modern glass and ceramics, and polish electronic materials.

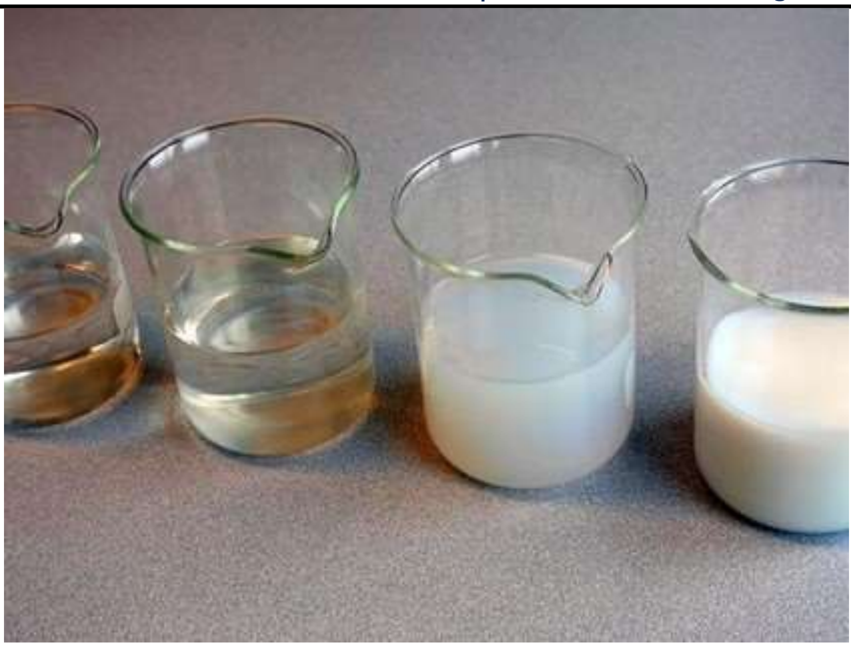


Fig.2 – Colloidal Silica

### 1.3.1 Uses of Colloidal Silica

- It can be used for surface coating without fear of surface cracks, which happens with sodium particles.
- Due to the above-mentioned property, it can be mixed with other silicates for various formulations particularly for coating.
- Both potassium and silica are beneficial for agriculture.
- As additive to cement mix, it results in higher strength of concrete mix. It is used as binder in refractory mortar and specialty cements.
- Used as surface treatment for smooth finish on tiles and concrete surface
- It is used to make the surface heat resistant.

## 1.4 Objectives of Studies

### 1.4.1 Need for the Study

- To find an alternative for the ordinary Portland cement.
- To reduce CO2 emission and produce eco-friendly concrete.
- To provide high strength concrete than ordinary Portland concrete.
- To find economic replacement for cement in construction industry.

### 1.4.2 The following are the objectives of study

- To understand the mechanical properties (compressive strength, flexural strength and split tensile strength) of concrete incorporating Metakaolin and colloidal silica.
- To determine the most optimized mix of Metakaolin-based concrete.
- To determine the most optimized dosage of Colloidal Silica

# II. LITERATURE REVIEW

## 2.1 Overview

A literature review is carried out as a part of the previous and present study. This chapter presents a brief summary of the literature review. Following are the previous studies and literature reviews about Metakaolin and Colloidal Silica in concrete which help us in this project work.

## 2.2 Previous Studies

**Namitha Raveendran & Vasugi Krishnan [1] (2024).** The carbon footprint associated with cement production, coupled with depletion of natural resources and climate change, underscores the need for sustainable alternatives. This study explores the effect of metakaolin (MK) and nano-silica (NS) on concrete's engineering performance and environmental impact. Initially, compressive, tensile, and flexural strength tests, along with durability assessments like water absorption, sorptivity, rapid chloride permeability, and resistance to acid and sulphate attacks, were conducted. Later, X-ray Diffraction spectroscopy and Field-emission scanning electron microscopy were employed for microstructural analysis. Subsequently, the environmental impact of micro and nano materials was assessed using embodied carbon emissions and eco-strength efficiency. The results revealed that the hybrid mixes of 12.50% MK and 2% NS (M7) showed superior performance, demonstrating significant strength enhancements and eco-efficiency, achieving 0.15 MPa/kg $CO_2/m^3$ at 28th day. Meanwhile, the MK-only mix (M6) yielded the lowest embodied $CO_2$ emissions at 330 kg $CO_2/m^3$. MK and NS effectively reduce porosity and enhance durability against environmental factors while lowering clinker content, contributing to sustainability. Furthermore, the microstructural behaviour showed early hydration, dense microstructure and additional Calcium Silicate Hydrate formation, leading to improved properties. The outcomes reveal that the concrete configuration has altered at micro and nano levels by the inclusion of MK and NS, demonstrating their substantial contribution to producing environmentally friendly, effective, and beneficial concrete.

**Pillay Et.Al. [2] (2021).** investigated the engineering properties of metakaolin (MK) based concrete exposed to chloride attack. The investigation was conducted for different w/b ratios of 0.54–0.61. The MK, used as cementitious material, was substituted 0, 5%,10%,15% and 20% and ages of concrete from 7 to 56 days were considered. The effects of the above-mentioned parameters on the various properties of concrete such as workability, compressive and flexural strength, durability, resistance to chloride attack and microstructure properties of the concrete samples were investigated. From the favorable strength and durability results that were observed during the experimental study (optimum compressive strength of 49.8 MPa for 10% MK and optimum flexural strength of 8.35 MPa for 5% MK), and they concluded that MK is a feasible supplementary cementitious material for combating chloride attack in coastal/marine concrete structures. The obtained results, in combination with the lack of carbon dioxide CO2 released during the MK manufacturing process, further highlights the positive influence of MK on improving the serviceability and sustainability states of coastal/marine structures.

**Zaid Ali Hasan [3] (2021).** have worked to produce environmentally friendly Reactive powder concrete in which 50% of the cement was replaced by metakaolin (MK) and fly ash (FA) combinations. He has used three RPC mixtures: 10MK + 40FA, 15MK + 35FA, and control mixture (without replacement) were cast. The fresh and mechanical properties tests were performed. The results showed that the combination of MK and FA improved the fresh properties of RPC, while the hardening properties were decreased.

**Jun Xie [4] (2020)** Have replaced in equal mass by nano metakaolin, and its contents were 0%, 3%,5% and 7% respectively
and Natural gravels were replaced by recycled coarse aggregate in equal mass, the replacement percentage were 0%, 30%, 50% and 100% respectively. As results when the replaced amount of recycled aggregate was 30% and 50%, and the nano metakaolin content was 5%, the compressive strength values of recycled aggregate concrete each were the largest, and the strength increase were 17.0% and 8.0%, respectively also when nano metakaolin was replaced 7%, the 28-day compressive strength was increased by 27.1%.

**Jamal M. Khatib [5] (2018)** in there investigated work shows that depending upon purity, MK can be an effective pozzolan if used in cement-based system, in that it leads to strength enhancement, lower drying shrinkage, and higher durability. They found that the MK with high purity is much more expensive than cement and this will affect the unit cost of concrete. So, they stated that, other types of MK need to be explored. If the MK is not pure, the strength of concrete may not be enhanced but comparable to the control. Also, the durability is higher if used as partial replacement of cement.

**P. Dinakar [6] (2014)** have studied that mix proportioning procedure for developing high strength SCC with metakaolin has been presented considering the efficiency factor of metakaolin. It was found that self-compacting metakaolin concretes designed with the proposed methodology could achieve the expected strengths (80, 100 and 120 MPa) in general, at all the metakaolin percentages (7.5%,15%,22.5%) for a fixed power content of 550 kg/m3. Also, the mechanical properties are concerned, the compressive strength of the concretes obtained with the proposed mix methodology surpass very high strengths of 100 MPa at 28 days and 120 MPa at 90 days.

**Amarnath Yerramala [7] (2013)** Investigated flexural strength of metakaolin ferrocements. Reference mortar with OPC of 43 grade and metakaolin mortars with 5–25% metakaolin replacement in the increments of 5% with cement were made. Constant water to cementitious ratio of 0.5 was maintained for all the mortars. Galvanized oven mesh (chicken mesh) was incorporated in the tension zone in one, three and five-layers to investigate the influence of reinforcement. The samples were water-cured for 7, 28,90 and 180 days. The results show that, up to 15% metakaolin replacement, flexural strengths were higher than control ferrocement at all curing ages and for all mesh layers. However, replacements equal and higher than 20% had lower strengths than control ferrocement for all mesh layers. It was further found that 10% metakaolin is the optimum content for maximum flexural strength.

**Behnam Behnia Et.Al. [8] (2021)** in this article effect of surfactant and calcination on the morphological properties of silica nanoparticles was investigated. They have prepared silica nanoparticles which were introduced to cement mortars at different dosage and their effects on compressive and flexural strengths were studied. They concluded that 4% (%wt.) have the highest improvement in cement mortars quality. 10 They further added, the presence of 4% contents of silica nano-particles in cement mortars increases the compressive strength by 10.54% in three days, 12.35% in one week, and 15.04% in 28 days also flexural strengths are increased to 23.25% in three days, 9.45% in one week, and 18.40% in 28 days.

**Deyu Kong Et.Al. [9] (2019)** have investigated the comparison of Influence of colloidal silica sol (SS) consisting of mono-dispersed nano-silica and the nano-silica (NS) powder on properties and microstructure of the hardened cement-based materials. They tested the mechanical as well as microstructure properties of the concrete. They found that the strength enhancement of the mortar with SS addition revealed an overall more improvement but a higher discreteness than that with NS addition. Also, after the calcium leaching test, it was found that the strength of the mortar with SS addition showed a clearly higher loss than that with NS addition, though the neutralization depth revealed a more reduction while incorporating SS and the residue strength still tends to increase with increasing the nano-silica addition. Also increasing the nano-silica addition from 1.0% to 2.0%, the flow value revealed a small decrease from 18.3cm to 16.5cm. They stated that the compressive strength showed an obvious improvement with increasing the SS content in the mortar; the enhancement reached 14.2% when the SS was 2.0%, as compared to that without nano-silica addition.

## III. METHODOLOGY

### 3.1 Material

For the study, ordinary Portland cement (OPC) of grade 53 was used. 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.

### 3.1.1 Metakaolin

We have used metakaolin having following properties
3.1.1.1 Chemical composition of metakaolin

Table 3.1 – Chemical composition of metakaolin

| Chemical elements | % by mass |
|---|---|
| $SiO_2$ | 51.52 |
| $Al_2O_3$ | 40.28 |
| $Fe_2O_3$ | 1.43 |
| CaO | 2 |
| MgO | 0.13 |
| $K_2O$ | 0.53 |
| $SO_3$ | 0 |
| $TiO_2$ | 2.37 |
| $Na_2O$ | 0.08 |
| L.O.I | 2.11 |

**3.1.1.2 Physical properties of Metakaolin**

Table 3.2 – Physical properties of Metakaolin

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

**3.1.2 Colloidal silica**

**3.1.2.1 We have used colloidal silica of following properties**

Table 3.3 – Physical and Chemical properties of Metakaolin

| | |
|---|---|
| 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 |
| Molar Ratio | 470 |
| pH | 9.0 +/- 0.2 |
| Specific Gravity | 1.25 +/- 0.2 at 25$^{o}$C |

### 3.2 Experimental Work

1) In This experiment a total of 72 number of concrete specimens 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.

### 3.3 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. 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 was added. According to the results for the slumps, relatively low percentages of superplasticizer were applied. Concrete test specimens were cast in two layers.

Table 1. Mix proportions of concrete.

| Serie s | 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 |

### 3.4 Test Performed

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

#### 3.4.2 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.

#### 3.4.3 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.

## IV. RESULTS AND DISCUSSION

### 4.1 Compressive strength Test results

a) The mix proportion MD1 which contains 10% Metakaolin and 0% Colloidal Silica had achieved 15% and 24 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. Also, the strength gained at 28 days curing age was 25% more that of desired strength.
b) This indicates that addition of 10% Metakaolin and 0% Colloidal Silica can improve the strength of concrete in early as well as 28 days curing ages.

c) The mix proportion MD2 which contains 10% Metakaolin and 2% Colloidal Silica had achieved 29% and 30 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. Also, the strength gained at 28 days curing age was 37% more that of desired strength.

d) From the above results we can say that 10% Metakaolin and 2% Colloidal Silica improvises the strength of concrete in a very good percentage at every curing age.

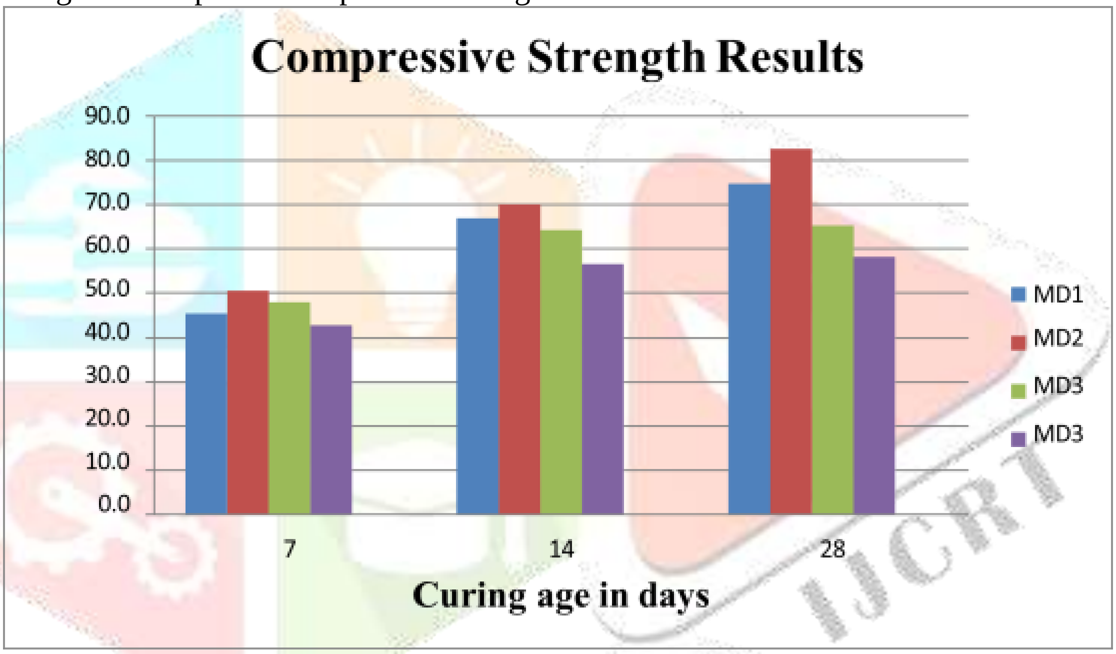
e) The mix proportion MD3 which contains 20% Metakaolin and 4% Colloidal Silica had achieved 23% and 18.5 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. Whereas this proportion of Metakaolin and Colloidal Silica addition only gained 9% more strength than the desired strength.

f) The results of mix proportion MD3 shows that the Metakaolin and Colloidal silica helps more in early age strength gain than that of 28 days strength.

g) The mix proportion MD4 which contains 30% Metakaolin and 6% Colloidal Silica had achieved only 9.5% and 5 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. And the results also show that this proportion of Metakaolin and Colloidal Silica addition in concrete not even achieved the desired strength.

h) The compressive strength of the mix proportion MD3 is 3% less than that of the desired strength for M60 grade of concrete.

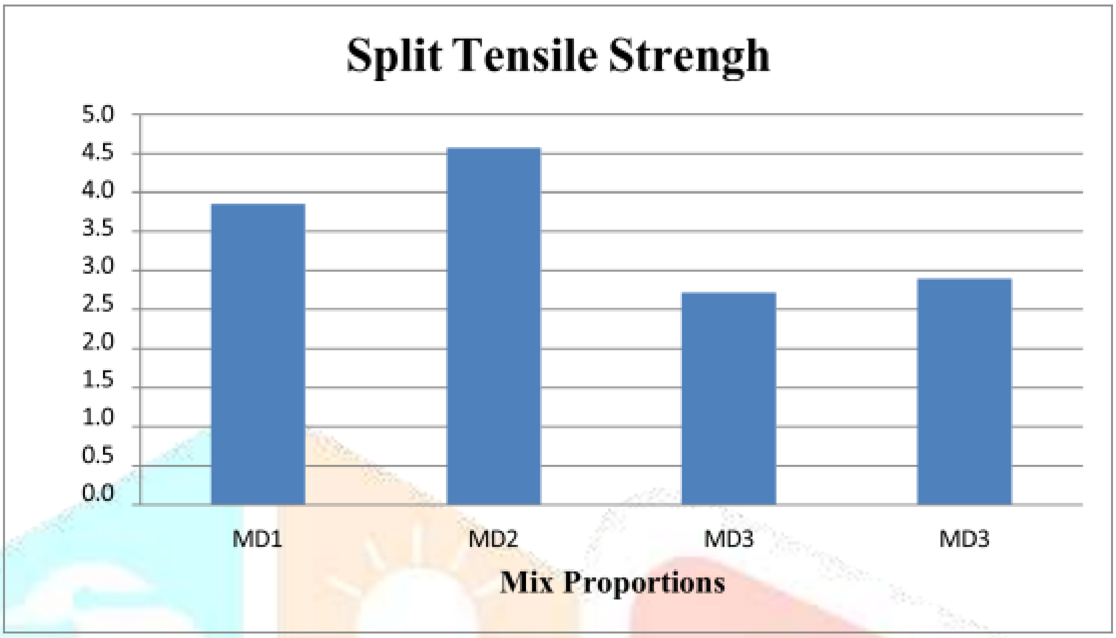
i) From all the compressive strength test results we can conclude that the 10% Metakaolin and 2% Colloidal Silica addition gives the optimal compressive strength results.




Graph 1 –Graphical representation of Compressive strength result

### 4.2 Split tensile strength Test results

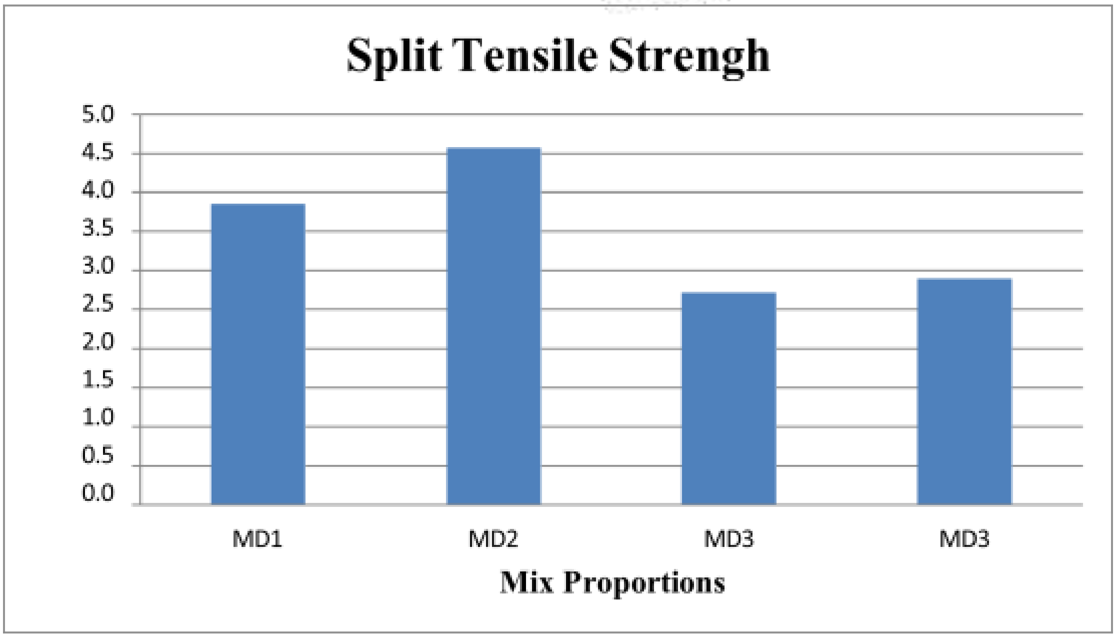
a) The split tensile strength test results show that the mix proportion MD1 and MD2 performs better in split tensile strength test as that of mix proportion MD 3 and MD4.
b) The split tensile strength of the mix proportion MD2 is maximum in all the 4 mix proportions which indicate that the more addition of Metakaolin and Colloidal silica gives negative impact on split tensile strength of the concrete.




Graph 2 – Graphical representation of Split Tensile strength result

### 4.3 Flexural strength Test results

a) Same as that of split tensile strength test results the mix proportions MD1 and MD2 gives better results as that of mix proportions MD3 and MD4.
b) In flexural strength test results, it can be seen that the mix proportion containing 0% Colloidal Silica achieved the optimal flexural strength.
c) From the above flexural strength test results, we can conclude that the addition of Colloidal silica significantly not helps in flexural strength gaining of the concrete.




Graph 3 – Graphical representation of Flexural strength result

## V. CONCLUSION

### 5.1 Compressive strength Test

a) The mix proportion MD1 which contains 10% Metakaolin and 0% Colloidal Silica had achieved 15% and 24 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. Also the strength gained at 28 days curing age was 25% more that of desired strength.
b) This indicates that addition of 10% Metakaolin and 0% Colloidal Silica can improve the strength of concrete in early as well as 28 days curing ages.
c) The mix proportion MD2 which contains 10% Metakaolin and 2% Colloidal Silica had achieved 29% and 30 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. Also the strength gained at 28 days curing age was 37% more that of desired strength.
d) From the above results we can say that 10% Metakaolin and 2% Colloidal Silica improvises the strength of concrete in a very good percentage at every curing age.
e) The mix proportion MD3 which contains 20% Metakaolin and 4% Colloidal Silica had achieved 23% and 18.5 % more strength at 7 and 14 days of curing as that of design strength for M60 grade concrete. Whereas this proportion of Metakaolin and Colloidal Silica addition only gained 9% more strength than the desired strength.
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### 5.3 Flexural strength Test

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b) In flexural strength test results it can be seen that the mix proportion containing 0% Colloidal Silica achieved the optimal flexural strength.
c)From the above flexural strength test results we can conclude that the addition of Colloidal silica significantly not helps in flexural strength gaining of the concrete.

### 5.4 Future Scope

Following are the future scope of study

a) The Metakaolin and Colloidal silica helps in improvising the properties of concrete. Further studies can be done on the different proportion of Metakaolin and colloidal silica replacement so as to achieve more strength.
b) Metakaolin replacement in concrete reduces the CO2 imitation which is good from environmental point of view. So more study is required to know the optimal Metakaolin replacement in concrete.
c) The Colloidal Silica improvises the chemical resistivity of the concrete. Research can be done to achieve more chemical resistant concrete as it will be help full at constriction at chemical attack prone areas.
d) Effect of other forms of Silica such as Nano-silica, silica fume addition in concrete can be studied.
e) A very less amount of Colloidal Silica addition in concrete increases the properties of concrete which can help in economical way.

## VI. Acknowledgment

It is a great pleasure to acknowledge the contributions of those who played a vital role in the successful completion of this study and made the research journey a memorable experience. I am deeply grateful to Project Guide **Prof. Vaibhav B. Chavan** and **Dr. Lomesh Mahajan**, Head of the Department of Civil Engineering, for his unwavering support, insightful guidance, and valuable suggestions throughout the course of this work. His mentorship has been instrumental in shaping the direction and quality of this research. I extend my sincere thanks to **Dr. B. M. Patil**, Principal of the institute, for granting me the opportunity to undertake this dissertation and for providing a supportive academic environment. I also wish to express my appreciation to all the faculty members of the Civil Engineering Department for their encouragement, technical assistance, and continuous support during various stages of the project. Their collective efforts and inspiration have significantly contributed to the successful outcome of this work.

## References

[1] NAMITHA RAVEENDRAN & VASUGI KRISHNAN [1] (2024). Engineering performance and environmental assessment of sustainable concrete incorporating nano silica and metakaolin as cementitious materials
[2] Pillay Et.Al (2021), Engineering performance of metakaolin based concrete Deveshan.
[3] Zaid Ali Hasan Et.Al. (2021) Properties of reactive powder concrete containing different combinations of fly ash and metakaolin.
[4] Jun Xie Et.Al. (2020) Effect of nano metakaolin on compressive strength of recycled concrete.
[5] Jamal M. Khatib Et.Al. (2018) Selected engineering properties of concrete incorporating slag and MK.
[6] P. Dinakar Et.Al. (2014) Concrete Mix Design for High Strength Self-Compacting Concrete using Metakaolin.
[7] Amarnath Yerramala Et.Al. (2013) Flexural strength of metakaolin ferrocement.
[8] Behnam Behnia Et.Al. (2021) High-performance cement mortars-based composites with colloidal nano-silica: Synthesis, characterization and mechanical properties.
[9] Deyu Kong Et.Al. (2019) Effect and mechanism of colloidal silica sol on properties and microstructure of the hardened cement-based materials as compared to nano-silica powder with agglomerates in micron-scale.