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Study and Analysis of High-Performance Concrete Using Metakaolin and Silica Fume

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Abstract : In recent times, due to high risk of natural disasters and collapsing of structures, modern solution has to be found. HPC are mostly used in high rise structures, bridges etc. But in this paper, the study and analysis of metakaolin based High Performance Concrete (HPC) is shown.M80 mix design is preferred in this study. With partial replacement of cement as metakaolin and silica fume, the study is done. Firstly various materials used for making of HPC are identified and then later with the help of mix design, quantities of materials are to be found out. Metakaolin has good durability making HPC more durable and also silica fume is added to it to enhance HPC properties. As metakaolin has enhanced properties, it is used as partial replacement of cement. Various tests are to be performed on the sample cubes, cylinders and beams made from these materials. Various proportions of silica fume as 10% constant and metakaolin as 2.5%, 5%, 7.5% and 10% are taken respectively for four different samples. In summary it is concluded that best results are obtained in mix proportion where 10% metakaolin and 10% silica fume are added as partial replacement of cement.

Keywords: High-Performance Concrete, Metakaolin, Silica fume

INTRODUCTION

The purpose of improving the durability and strength of the structure, High performance concrete was invented in late 1960s by the invention of water reducing admixtures lead to high strength structures and structural elements. High performance concrete (HPC) is a type of concrete that is designed and formulated to have superior physical and chemical properties compared to traditional concrete. It is often used in applications that require exceptional durability, strength, and resistance to environmental factors, such as corrosion, abrasion, and extreme temperatures.

One of the key characteristics of HPC is its high compressive strength, which can exceed 100 MPa. This is achieved through the use of advanced materials, such as high-strength cement, silica fume, and superplasticizers.

In addition to its high compressive strength, HPC also has excellent tensile strength and flexural strength. It can also have a high modulus of elasticity, which means it is more resistant to deformation under stress. HPC also has a low permeability, which means it is less susceptible to water and chemical penetration.

HPC can be used in a wide range of applications, including bridges, tunnels, high-rise buildings, offshore structures, and precast concrete products. It can also be used for decorative purposes, such as in architectural facades and exposed aggregate finishes. Overall, HPC is a versatile and durable material that can provide exceptional performance and longevity in a variety of construction applications.

Metakaolin is a highly reactive pozzolanic material that is produced by calcining kaolin clay at a temperature between 600-800°C. It is a type of supplementary cementitious material that is commonly used in the production of high-performance concrete and cement-based products. Metakaolin is a white, amorphous powder that is composed of highly reactive and finely divided particles.

Figure 1: Metakaolin

Silica fume, also known as micro silica, is a by-product of the production of silicon and ferrosilicon alloys. It is a very fine, amorphous powder. Silica fume is also commonly used in the production of refractory materials, ceramics, and as a filler in polymer composites.

Figure 2: Silica Fume

Fly ash is fine powder that is produced while coal is burned in thermal power plants. Fly ash is also used in the production of cement blocks, bricks, and other construction materials. It can also be used as a soil amendment to improve soil structure, increase fertility, and reduce erosion.

Figure 3: Fly Ash

In summary, High performance concrete enhances properties of concrete making it highly durable and more strength as compared to normal concrete. And with addition of metakaolin and silica fume to it, its overall performance could be improved drastically.

LITERATURE REVIEW

Osama Zaid, Faisal M. Mukhtar, Rebeca M-García, Mohammad G. El Sherbiny, Abdeliazim M. Mohamed, "Characteristics of high-performance steel fiber reinforced recycled aggregate concrete utilizing mineral filler"

Now a days, lot of construction is destroyed to construct new building over it. As this waste is of no use, in this paper, recycled aggregates are used for construction purpose with utilizing mineral filler. As this destroyed buildings produce waste and as pollution is increasing in world, using recycled aggregates can help lowering the pollution. This research aims to utilize and evaluate the performance of high performance concrete by using steel fibers with recycled aggregates. In this research, four high strength mixes were produced with Portland cement with 15 different geopolymer concrete mixes. Compressive strength, tensile strength, flexural strength and modulus of elasticity at 3, 7, 28 and 91 days were also measured and analyzed as mechanical properties. Water permeability coefficient, durability properties of 3, 7, 14, 21, 28, 56 and 91 days and temperature studies from 100° to 700° were investigated. mixtures of cement and geopolymer concrete were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). Regarding fresh performance, the results showed that the geopolymer concrete based on 500 kg/m3 of slag had a slump of 225 mm, while in terms of hardened performance, the mixture containing 200 kg of metakaolin and 300 kg The cases all have the maximum compressive strength of, and the early and late ages are 63.3 and 82.6 MPa respectively also has the maximum tensile strength of of 6.2 MPa, and the bending strength reaches 9.2 MPa, while the modulus of elasticity of is 37.68 GPa. Also, the coefficient of permeability decreases as the granulated blast furnace slag increases.

G.M. Sadiqul Islam, Suraiya Akter, Tabassum Binte Reza "Sustainable high-performance, self-compacting concrete using ladle slag"

G.M. Sadiqul Islam, Suraiya Akter, Tabassum Binte Reza researched the experimental study on high performance concrete using ladle slag. High Performance Concrete (HPC) satisfies unique specifications like low shrinkage and low permeability, high strength and improved durability, and uniformity specifications above and beyond those of standard concrete. Because Self-Consolidating Concrete (SCC) is fluid enough to travel through crowded reinforcement areas and prevent total segregation, it is applied by weight. Ladle slag is substituted for cement in the production of HPSCC to reduce the amount of cement required and related CO2 emissions. The material's chemical makeup suggests that it has pozzolanic and self-adhesive capabilities. In place of cement, slags (5%, 10%, 15%, and 25%) were utilized, and the concrete samples' freshness, mechanical, and durability characteristics were compared to control samples (no waste). Using Slump Flow, T 500, V-Funnel, and L-Box, test and confirm freshness characteristics. The results obtained generally show that the properties of freshness, mechanics and durability of the artificial concrete containing up to 15% slag are improved compared to the control concrete. A cost analysis shows that industrial waste can be a promising green material for HPSCCs by economically reducing carbon footprints.

Roja A. Nambiar, M.K. Haridharan "Mechanical and durability study of high performance concrete with addition of natural fiber (jute)"

The study is aimed to determine the properties of high performance concrete (HPC) by partially replacing silica fume (10%) and fly ash (20%) with concrete. In this analysis, the compressive strength values of concrete were determined for different test mixes on days 7, 14 and 28. According to the compressive strength of the test mix, determine the proportion of materials. With this outcome, cast the specimen with a reserve for curing at a constant water-to-cement ratio (w/c = 0.28). This study's primary goals are to investigate and establish the ideal dosage of superplasticizer to use in place of cement in mixtures containing various ratios of silica fume and fly ash, as well as to assess the mechanical characteristics of HPC, such as resistance to compression and tensile strength. Study durability factors such adsorption, acid attack, etc. after adding natural fiber (jute). The following results confirm that concrete with 1% jute also outperforms any other concrete in terms of mechanical properties and durability.

Venkatesh Kodur and Wasim Khaliq "Effect of Temperature on Thermal Properties of Different Types of High-Strength Concrete"

This study determines effect of temperature on thermal properties of different types of high-strength concrete. The specific heat, thermal conductivity and thermal expansion of three types of concrete, namely HSC, self-consolidating concrete (SCC) and fly ash fly ash concrete (FAC), were measured in the temperature range of 20 to 800 °C. It was also investigated how steel, polypropylene, and mixed fibres affected the thermal characteristics of HSC and SCC. According to experimental findings, in the temperature range of 20 to 800°C, SCC has higher thermal conductivity, specific heat, and coefficient of thermal expansion than HSC and FAC. In order to describe different thermal properties as a function of temperature, simplified relationships have been developed using the data produced from the experiments. A concrete structure's reactivity to fire conditions can be assessed using the proposed thermal property relationship as input data.

Mohamed Amin, Yara Elsakhawy, Khaled Abu el-hassan, Bassam Abdelsalam Abdelsalam "Behavior evaluation of sustainable high strength geopolymer concrete based on fly ash, metakaolin, and slag"

In this paper industrial wastes such as fly ash, metakaolin and granulated blast furnace slag were used as the base for High Strength Geopolymer Concrete (HSGC). Four high strength concrete (HSC) mixes containing Portland cement were produced for comparison with fifteen different geopolymer concrete mixes. All compounds are poured, cured and tested. Measurement of sag and air content as fresh properties of HSC and HSGC blends. Compressive strength, ultimate tensile strength, flexural strength and modulus of elasticity at 3, 7, 28 and 91 days were also measured and analyzed as mechanical properties. Water permeability coefficient, durability properties of 3, 7, 14, 21, 28, 56 and 91 days and temperature studies from 100° to 700° were studied mixtures of cement and geopolymer concrete were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). Regarding the fresh performance, the results showed that the geopolymer concrete based on 500 kg/m3 of slag had a slump of 225 mm, whereas in terms of hardened performance, the mixture containing 200 kg of metakaolin and 300 kg Both cases have the maximum compressive strength of in the early and late stages, which are 63.3 and 82.6 MPa respectively, and also have the maximum tensile strength of 6.2 MPa, bending strength in the range of 9.2 MPa, modulus of elasticity is 37.68 GPa.

MATERIALS USED

The materials used in HPC are fine aggregates, coarse aggregates, cement, water, mineral admixtures and chemical admixtures.

Cement

Conforming from IS: 12269, ordinary Portland cement (OPC) to be used. Physical and chemical property identified by the requirement of SCC properties.

Fine aggregate

River sand is used ass fine aggregate. For avoid the problem of bulking sand was dried before use.

Coarse aggregate

Locally available granite with maximum size of 20mm is used as coarse aggregate.

Water

The Purpose of mixing and curing, portable water was used.

Mineral admixtures

Mineral admixtures are useful to reduce cost of cement and also for improve fresh and hardened properties of cement. The mineral admixtures are **Fly ash, Metakaolin, Silica fume.**

Chemical admixtures

Superplasticizer as Polycarboxylate Ether was used.

MIX DESIGN

The mix design process for HSC involves several steps:

1. **Determine the design requirements and specifications, such as the desired strength, workability, and setting time.**
2. **Select the appropriate type and amount of cement, fine and coarse aggregates, metakaolin, water, and superplasticizer.**
3. **Conduct laboratory tests, such as flowability, passing ability, and segregation resistance tests, to evaluate the mix's performance and adjust the proportions of ingredients if necessary.**
4. **Prepare trial batches of concrete and evaluate the properties, such as flow, filling ability, stability, and strength, to fine-tune the mix design.**
5. **Repeat the trial and adjustment process until the desired properties are achieved.**

Design stipulations for proportioning :

Grade Designation: M80 as HPC Concrete
Type of cement: OPC 53 grade
Maximum nominal size of aggregates: 10 mm
Minimum Cement Content: 450 Kg/m3
Maximum Water Content ratio: 0.283
Exposure conditions: Moderate
Degree of supervision: Good
Type of aggregate: Crushed angular aggregate

1. M-80 Grade of concrete design for a mean target strength of:
   80 + 1.65 x 5 = 88.3 N/mm2 at 28-day age
2. With the given set of materials from various trials it was found that with OPC 450 Kg/m3 Silica Fume 45 Kg/m3 and W/C+SF ratio of 0.283 gives 28-day average cube compressive strength of 90.4 N/mm2.
3. Calculated density of the mix
   10 X 2.65 (100-1.5) + {450[1-(2.65/3.15)] + 45[1-(2.65/2.20)]}-140(2.65-1)
   = 2610 + 62.55-231
   = 2441.6 kg/m3
4. Aggregates = 2440 – 140 – 450 – 45 = 1805 kg/m3
5. Sand = 1805 x 0.45 = 810 kg/m3
6. 12.5 mm Aggregate = 1805 x 0.55 = 995 kg/m3

So Finally we get quantity of materials
Water = 140kg/m3
Opc 53 Grade cement =450kg/m3
Silica Fume = 45kg/m3 (10%)
River sand = 810kg/m3
12.5mm crushed Aggregate =995kg/m3
Super plasticizer = 11.250kg/m3
W/(C+SF) Ratio = .283
Slump = 102mm

Sr. No.	Materials	M80 Concrete (KG/m3)	M80 Concrete (2.5% MK) (Kg/m3)	M80 Concrete (5% MK) (Kg/m3)	M80 Concrete (7.5% MK) (Kg/m3)	M80 Concrete (10% MK) (Kg/m3)
1.	**Water**	140	140	140	140	140
2.	**Cement(OPC53)**	450	438.5	427.5	416.25	405
3.	**Silica Fume(10% mass of cement)**	45	45	45	45	45
4.	**River Sand**	810	810	810	810	810
5.	**Aggregates**	995	995	995	995	995
6.	**Super plasticizer**	11.25	11.25	11.25	11.25	11.25
7.	**Metakaolin**	0	12.5	25	37.5	50

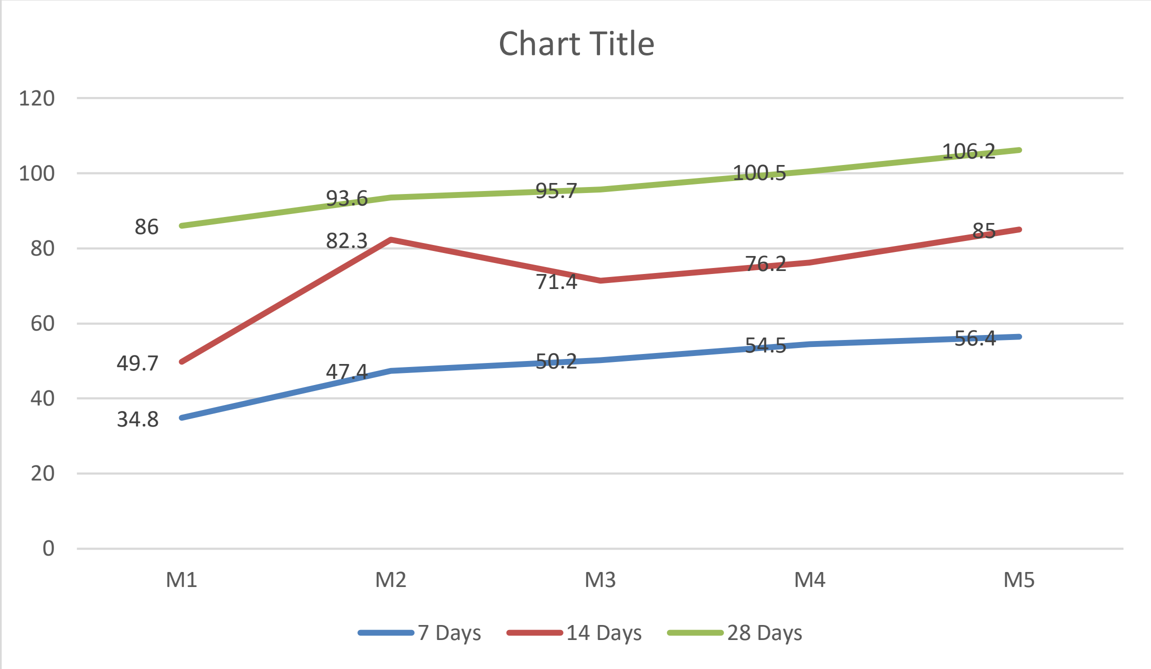
RESULTS

1. Compressive strength test

The cubes of size 15cm x 15cm x 15cm were preferred for test. The tests were performed at 7 days, 14 days, 28 days. Mix designs M1, M2, M3, M4 and M5 were taken and their compressive strength results can be seen in below table :

Mix Design	7 Days Strength (N/mm2)	14 Days Strength (N/mm2)	28 Days Strength (N/mm2)
M1 (Nominal)	34.8	49.7	86
M2 (2.5% MK)	47.4	82.3	93.6
M3 (5% MK)	50.2	71.4	95.7
M4 (7.5% MK)	54.53	76.2	100.5
M5 (10% MK)	56.4	85	106.2

Graphical representation of above result :



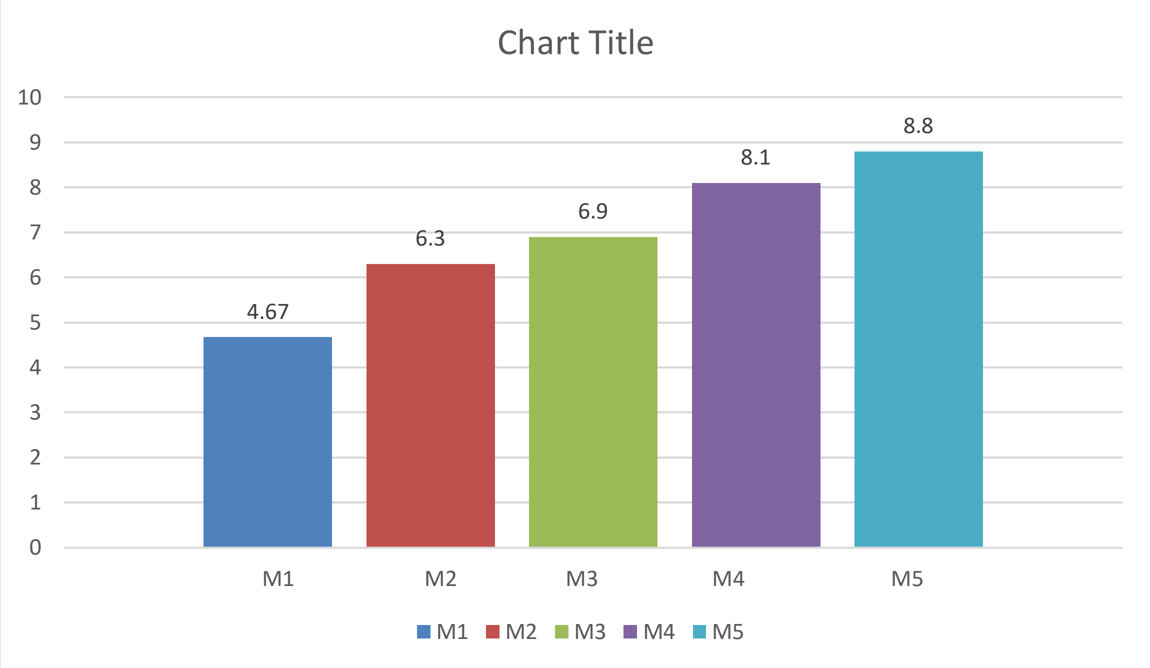
Comparing the results of M1 and M2, we can clearly see that there is increase in compressive strength of concrete as metakaolin and silica fume are added in various proportions as cement replacement and as we go higher in percentage, we can clearly see the increase in strength of all mix designs M2, M3, M4, and M5 as compared to nominal mix design M1.

2. Split tensile strength test

Cylinders of size 150 x 300mm were taken for split tensile strength. All mix proportions were cured for 28 days after removing the mould. And for test, cylinders were placed horizontally in compressive strength testing machine. Results of split tensile strength are as below:

MIX PROPORTION	28 Days Strength (N/mm2)
M1	4.67
M2	6.3
M3	6.9
M4	8.1
M5	8.8

Graphical representation for split tensile strength is shown below:



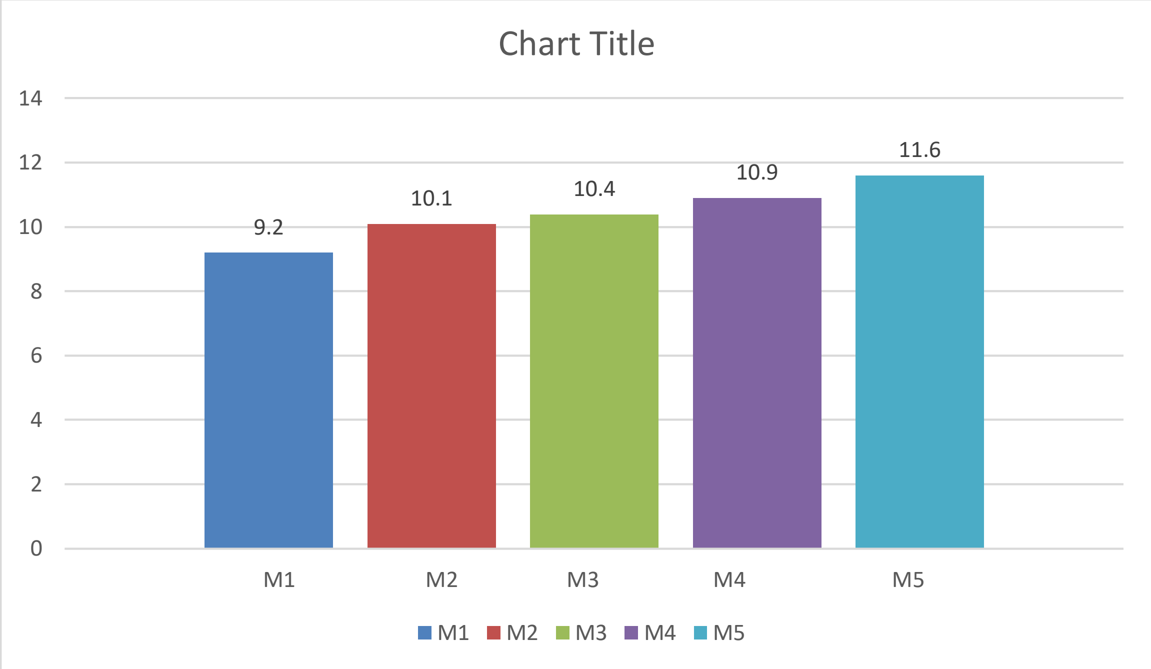
Comparing the results of M1 and M2, we can clearly see that there is increase in split tensile strength of concrete as metakaolin and silica fume are added in various proportions as cement replacement and as we go higher in percentage, we can clearly see the increase in strength of all mix designs M2, M3, M4, and M5 as compared to nominal mix design M1.

3. Flexural strength test

Flexural strength is measured with specimen size of beam 700mm x 150mm X 150mm. After removing mould, and curing for 28 days, samples were tested. Results for flexural strength of this HPC are as below:

MIX PROPORTION	28 Days Strength (N/mm2)
M1	9.2
M2	10.1
M3	10.4
M4	10.9
M5	11.6

Graphical representation for flexural strength is shown below:



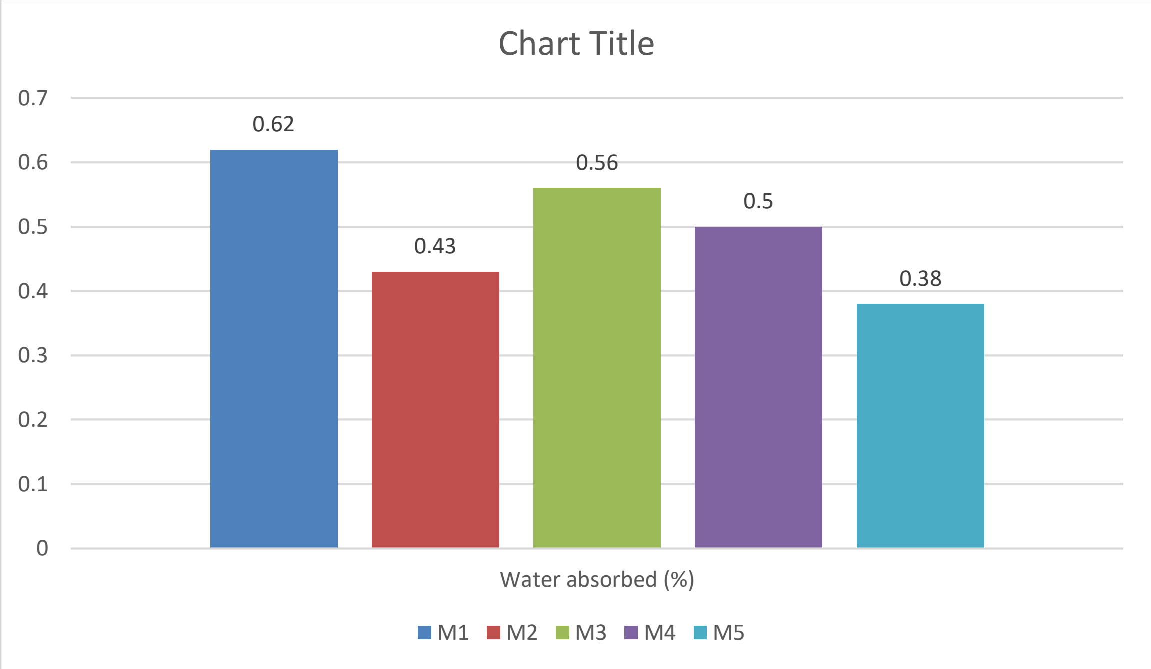
Comparing the results of M1 and M2, we can clearly see that there is increase in flexural strength of concrete as metakaolin and silica fume are added in various proportions as cement replacement and as we go higher in percentage, we can clearly see the increase in strength of all mix designs M2, M3, M4, and M5 as compared to nominal mix design M1.

4. Water absorption test

Cube carried out the water absorption test. The desired cube size was 150mm x 150mm x 150mm. Concrete cubes are immersed in water for 24 hours following their 28-day curing period. The initial weight of the concrete cubes is used to estimate how much water they will absorb. Results of water absorption test can be seen in below table :

MIX PROPORTION	28 Days (%)
M1	0.62
M2	0.43
M3	0.56
M4	0.50
M5	0.38

Graphical representation for flexural strength is shown below:



Clearly seen from above results the least water absorption is in M5 mix proportion having 10% metakaolin and 10% silica fume as partial replacement of cement and the most water absorption is in nominal mix where metakaolin and silica fume were not introduced.

CONCLUSION

Because of a lack of awareness, high performance concrete is used very little in India. HPC improves the workability, structural performance, and durability of concrete, but in India, a lack of information in the IS code results in complicated material. For mix design of HPC in India, IS code: 10262: 2019 is most frequently utilized. Yet, the lack of information in IS code 10262: 2019 makes work challenging for high strength. Research papers are therefore highly helpful.
Based on the experimental study conducted by using silica fume and metakaolin the conclusions are as below:

- The compressive strength of all mixes increases as they are cured and higher values are obtained at 28 days maturity. Mix proportion M5 with having 10% metakaolin and 10% silica fume has highest compressive strength among all mixes at 28 days.
- Among all mix proportions, the mix M5 having 10% metakaolin and 10% silica fume has highest split tensile strength.
- Mix proportion M5 with 10% metakaolin and 10% silica fume also has highest flexural strength among all other mix proportions.
- Water absorption is minimum in the mix M5 having 10% metakaolin and 10% silica fume and has highest in nominal mix design M1.
- Hence from above all experimental results, we can conclude that among all five mix proportions M1, M2, M3, M4 and M5, best results are obtained in M5 mix having 10% metakaolin and 10% silica fume in the mix.

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