COMPARATIVE STUDY ON HIGH PERFORMANCE CONCRETE WITH VARIOUS CEMENT REPLACING MATERIALS (SILICA FUME, FLY ASH, GGBS, AND METAKAOLIN

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Abstract -*High Performance Concrete is widely used in construction because it is very strong and lasts a long time compared to regular concrete. The problem is that making cement is really bad for the environment. It also makes a lot of carbon dioxide. To solve these problems people use things like silica fume fly ash, Ground Granulated Blast Furnace Slag and metakaolin of cement. These things are used to replace cement in High Performance Concrete. This study looks at how these things work in High Performance Concrete. The cement was replaced with these things: silica fume was used for 10 percent of the cement fly ash for 20 percent Ground Granulated Blast Furnace Slag for 40 percent and metakaolin for 12 percent. Concrete cubes were tested to see how strong they were after 7 days and 28 days. Tests were also done to see how water the concrete would absorb, which shows how durable High Performance Concrete is. The results showed that the High Performance Concrete with metakaolin and silica fume was stronger than the High Performance Concrete without these things. The Ground Granulated Blast Furnace Slag also helped to make the High Performance Concrete more durable.It absorbed water. Using these things makes the High Performance Concrete better. It also reduces the amount of cement that is needed which's good for the environment and it saves money. Overall using these things in High Performance Concrete makes it stronger and more durable. It reduces the amount of cement needed which is good, for the environment and saves money.*

Key Words: High Performance Concrete, M60 Concrete, Silica Fume Fly Ash, GGBS, Metakaolin, Compressive Strength, Water Absorption, Supplementary Cementitious Materials

I. INTRODUCTION

Concrete is a popular material that people use to build things because it is strong lasts a long time and can be used in many different ways.. Making Ordinary Portland Cement, which is a key part of concrete releases a lot of carbon dioxide into the air, which is bad for the environment. To solve this problem people have started using materials called supplementary cementitious materials to help make concrete. High Performance Concrete is a kind of concrete that is designed to be even stronger, last longer and be able to withstand different environmental conditions. To make this kind of concrete people use materials like silica fume fly ash, Ground Granulated Blast Furnace Slag and metakaolin. These materials are used to replace some of the cement in the concrete. They help make the concrete stronger and more durable. When we replace some of the cement and fine aggregate with fly ash it makes the concrete easier to work with and stronger over time. It also makes the concrete last longer. Perform better than regular concrete. A study by M. A. Karim in 2025 found that using the amount of fly ash makes a big difference. Ground Granulated Blast Furnace Slag is another material that makes concrete longer and stronger but it can make it weaker at first and we have to use the right amount of it. J. Ahmad and his team found this out in 2022. Fly ash is a material to use because it makes concrete stronger lasts longer and is better for the environment. It reduces the amount of cement we need to use, which means less carbon dioxide is released into the air. D.K. Nayak and his team wrote about this in 2022. Silica fume is a material that makes concrete stronger and lasts longer because it has a lot of activity and helps fill in the gaps. When we use the amount of silica fume we can make high-performance concrete that uses less cement and is better for the environment. Y.S. Wang and his team found this out in 2022. Metakaolin, silica fume and Ground Granulated Blast Furnace Slag are all materials that make concrete stronger and lasts longer because they have properties. When we use the amount of these materials we can make concrete that is stronger lasts longer and is better for the environment. A. Ghosh and his team found this out in 2022. Fly ash is a way to replace some of the Portland cement we use which makes concrete stronger and reduces the cost of building things. It also helps the environment by using up waste materials and reducing the amount of carbon dioxide released into the air. Mr. Vinod B.R. And his team wrote about this in 2022. Many researchers have studied how to use cementitious materials to make High

Performance Concrete stronger and more durable. They found that silica fume makes concrete stronger because it is very fine and has a lot of activity which makes the concretes structure better. When we replace 10% of the cement with silica fume it makes the concrete stronger at first. Reduces the amount of water that can get in. Fly ash is a material to use because it makes concrete easier to work with and stronger over time. Researchers found that replacing 15-25% of the cement with fly ash makes the concrete last longer and reduces the heat it produces. Ground Granulated Blast Furnace Slag makes concrete more durable and resistant to chemicals. Studies show that replacing 30-50% of the cement with Ground Granulated Blast Furnace Slag makes the concrete stronger over time and reduces the amount of water it absorbs. Metakaolin is another material that makes concrete stronger both at first and over time. Researchers found that replacing 10-12% of the cement with metakaolin makes the concrete stronger and more durable than concrete. From all these studies we can see that using cementitious materials makes concrete stronger more durable and better, for the environment.. We need to compare these materials to each other to find out which one is the best to use in High Performance Concrete.

2. OBJECTIVES

- To examine the effect of fly ash, silica fume, GGBS and metakaolin on the fresh and hardened properties of high-performance concrete.
- To evaluate the mechanical strength of HPC mixes using different SCMs.
- To assess durability characteristics such as water absorption, permeability and chemical resistance.
- To determine the optimum replacement level for each SCM.
- To compare the cost of SCM-based HPC with conventional concrete.
- To identify the most suitable SCM for producing economical and durable HPC.

3. METHODOLOGY

The methodology includes the mixes with different materials to see how they worked. First we got the amounts of cement, aggregates and other materials. We mixed everything together to get a mix. Then we added water and a special helper to make the mix easy to work with. We put the concrete into special boxes that were 150×150×150 mm big. We did this in three parts. used a special tool to get rid of any air pockets. After we filled the boxes we made the top surface flat and smooth. We left the boxes alone for 24 hours. Then we took out the blocks and put them in a special tank filled with clean water. We kept the blocks, in the water for 7 days and then for 28 days before we tested the concrete blocks. We did this to see how the concrete blocks would do over time. The concrete blocks were made with materials so we wanted to see how the different materials would affect the concrete blocks.

3.1 MATERIALS AND METHODS:

The materials used in this study were chosen based on Indian Standard rules. We picked these materials because we wanted to make sure the results were good and consistent. We used Ordinary Portland Cement as the binder. This was OPC 53 grade. We also used natural river sand. Crushed coarse aggregates. We added some things to the cement to make it stronger and last longer. These things were silica fume fly ash, GGBS and metakaolin. We used these things to replace some of the cement. We used water to mix and cure the concrete. We also added a helper to make the concrete easy to work with. This helper was a superplasticizer. It helped us get the concrete Right even when we used less water. All these materials together helped us make high-performance concrete, for our experiment.

3.1.1 Cement

Ordinary Portland Cement, which is 53 grade was used in this study. It follows the IS 12269:2013 standard. This cement gives early strength. It also provides durability. That makes it good, for making high-performance concrete.

3.1.2 Fine Aggregate

Natural river sand was used as an aggregate. It followed the IS 383:2016 standard. The sand was, from Zone II grading. It did not have any impurities.

3.1.3 Coarse Aggregate

We used crushed angular coarse aggregate that was 20 mm, in size. This aggregate met the standards of IS 383:2016. The crushed angular coarse aggregate we used was really good. We made sure the crushed coarse aggregate was proper.

3.1.4 Supplementary Cementitious Materials

- The following materials were used to replace some of the cement:
- **Silica Fume** – 10% replacement of cement
- **Fly Ash** – 20% replacement of cement
- **GGBS** – 40% replacement of cement
- **Metakaolin** – 12% replacement of cement

These materials, like Silica Fume and Fly Ash and GGBS and Metakaolin were used to replace some of the cement. Silica Fume and Fly Ash and GGBS and Metakaolin make the concrete stronger and more durable. These materials, Silica Fume and Fly Ash and GGBS and Metakaolin make the concrete stronger and more durable because they have properties that help them work well with the cement.

3.1.5 Water

Potable water that meets IS 456:2000 standards was used for mixing and curing concrete. The water used for concrete was drinking water. It followed IS 456:2000 guidelines.

3.1.6 Chemical Admixture

A special kind of additive called High Range Water Reducing Admixture also known as Superplasticizer that meets the standards of IS 9103:1999 was added to the mix to make it easy to work with when the amount of water and cement were low. This High Range Water Reducing Admixture or Superplasticizer helped a lot, in getting the consistency.

3.2 Mix Design (As per IS 10262:2019)

The M60 mix design was made following the rules of the Bureau of Indian Standards IS 10262:2019. This was done by replacing some of the cement with materials like Silica Fume, Fly Ash, GGBS and Metakaolin. Concrete cubes that were 150 × 150 × 150 mm, in size were made using the rules of IS 516. The M60 mix design and these concrete cubes were used to see how these extra materials affected the properties and performance of the M60 mix design and concrete.

Table 3.1 shows the percentage of cement that we replace with Supplementary Cementing Materials

Mix ID	Cement (%)	SCM (%)	Type
M1	100	0	Control Mix
M2	90	10	Silica Fume
M3	80	20	Fly Ash
M4	60	40	GGBS
M5	88	12	Metakaolin

The table 3.1 shows the mix proportions of cement and supplementary materials or SCMs used in different concrete mixes. The Control Mix, M1 contains 100 percent cement. It does not have any SCM. In the modified mixes: M2 uses cement and 10 percent Silica Fume. M3 uses cement and 20 percent Fly Ash. M4 uses cement and 40 percent GGBS. M5 uses cement and 12 percent Metakaolin. These mixes are made to see how different types and amounts of SCMs affect performance.The cement in the modified mixes is partially replaced with SCMs. We use these varying replacement levels to evaluate the effect of SCM types and percentages on the performance of concrete, with cement and SCMs. The SCMs used are Silica Fume, Fly Ash, GGBS and Metakaolin. We check how well concrete works with these SCMs and cement.

Table 3.2 : Mix Design Details of M60 Grade Concrete Mixes

Mix ID	Cement (%)	SCM (%)	Water (kg)	Sand (kg)	CA (kg)
M1	533	-	160	787	981
M2	480	SF= 53 kg	160	787	981
M3	426	FA= 107 kg	160	787	981
M4	320	GGBS= 213 kg	160	787	981
M5	469	MK= 64 kg	160	787	981

The mix design for M60 grade High Performance Concrete was done using the guidelines from IS 10262:2019. You can see the details in table no 3.2. This table shows the mix proportions of M60 grade concrete made with materials that replace some of the cement. We followed the rules from Bureau of Indian Standards IS 10262:2019 and IS 456:2000. We had one control mix, which's M1 and it only used ordinary Portland cement. The other mixes used things like Silica Fume in M2 Fly Ash in M3 GGBS in M4 Metakaolin in M5 and a mix of GGBS and Fly Ash in M6. For all the mixes we kept the water, aggregate and coarse aggregate the same.. The cement content was different because it depended on how much of the supplementary cementitious materials we used. The table shows that when we added these mineral admixtures the cement content went down but we still had binder content for M60 grade concrete. The M60 grade concrete mix design is important. Using these supplementary cementitious materials, like Silica Fume, Fly Ash, GGBS, Metakaolin and a combination of GGBS and Fly Ash helps to make the M60 grade concrete stronger.

Cube Casting Details

- Cube Size: 150 × 150 × 150 mm
- Number of Cubes: 1 per mix
- Total Mixes: 5
- Total Cubes Cast: 5 cubes

The mix design for M60 grade High Performance Concrete was done. We made cube specimens that were 150 × 150 × 150 mm, in size. These were made according to the rules of the Bureau of Indian Standards which're IS 516 and IS 10262:2019. We did this to see how good the M60 grade concrete is. For each mix of M60 grade High Performance Concrete we made one cube specimen. So we had a total of 5 cubes to test and see how they perform.

4 Experimental Procedures: -

4.1 Slump cone Test:

The slump cone test was done according to the rules of the Bureau of Indian Standards IS 10262:2019 and IS 1199. This test was to find out how easy it is to work with concrete mixes. We made five mixes:

Fig 4.4.1 shows the conduction of slump cone test

In which is the control mix, M2 which has 10 percent Silica Fume, M3 which has 20 percent Fly Ash, M4 which has 40 percent GGBS and M5 which has 12 percent Metakaolin. We used these things to replace some of the cement in the mixes. We put the slump cone on a surface that does not soak up water and filled it with fresh concrete. We did this in four layers. Pressed down on each layer 25 times with a special rod. After we made the top surface flat we lifted the cone up. Measured how much the concrete had sunk down. We call this the slump value of the mixes. We used these slump values to see which concrete mix is the easiest to work with. The slump cone test is a way to compare the workability of different concrete mixes, like M1 and M2 and M3 and M4 and M5.

4.2 Cube Casting Procedure

Concrete cubes were made for testing how strong they are when squished. Each cube was 150 × 150 × 150 mm in size. The moulds were cleaned well. Coated with oil so the concrete wouldn't stick to them. The concrete mix was put into the moulds in three layers. Each layer was tapped 25 times with a rod to get rid of air bubbles. The top surface was then made smooth with a trowel. The moulds were left alone for 24 hours, at room temperature. This process is shown in figure 4.1.1.

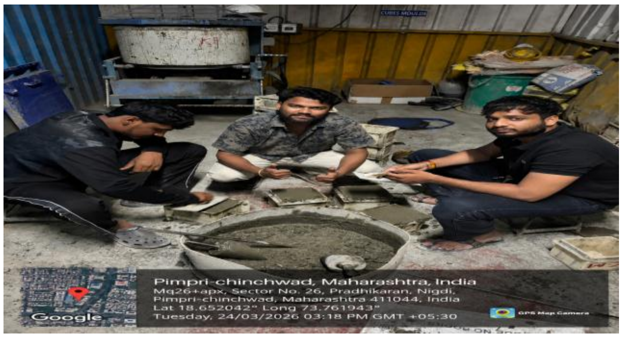

Fig 4.1.1 showing cube casting of Concrete specimens at site

Fig 4.1.2 Curing of Concrete Cube Specimens

Fig 4.1.1 shows freshly cast concrete cube specimens Concrete cubes that are 150 millimeters by 150 millimeters by 150 millimeters were made for testing. Figure 4.1.1 shows the cubes right after they were made and put in moulds at the site in Pimpri-Chinchwad, Maharashtra. The concrete cubes were made to check how strong and durable they are. We made sure the concrete cubes were filled and compacted properly and the surface was finished nicely before they were cured. Figure 4.1.2 shows the cubes in a special place where they can cure after they were made. The concrete cubes were kept in a place, with the right amount of moisture so they can get stronger. After one day the concrete cubes were taken out of the moulds. Put in a big tank filled with clean water. The concrete cubes were cured for 7 days. Then for 28 days before we tested them to see how strong the concrete cubes are. We did this to see how strong the concrete cubes would be after they were cured for a while.

4.3 Water Absorption Test: -

The compressive strength test was done using a Compression Testing Machine in line with the rules of IS 516:2018. After the concrete was cured we did the water absorption test to see how durable the concrete is. We followed the procedure for this test. First we put the cubes in a hot air oven at a temperature of 105 to 110 degrees Celsius for 24 hours to get rid of the moisture. Then we let the cubes cool down. Weighed them to find out their dry weight, which we call W_1. Next we put the dried cubes in water for 24 hours. After that we took the cubes out of the water wiped them with a cloth to remove the water from the surface and weighed them again to find out their weight, which we call W_2. We calculated the water absorption of the concrete using a formula for the water absorption of the concrete. The water absorption of the concrete is a thing to know about the concrete. The water absorption test is done to determine the durability of the concrete as, per procedure for the water absorption test.

Water Absorption (%) =W1 / W2–W1×100………. (2)

4.4 Compressive Strength Test: -

The compressive strength test was done using a machine called Compression Testing Machine. This test followed the rules in IS 516:2018. After curing the cubes were taken out of the water drier.

Fig 4..2.1 shows th conduction of compression Strength Test

The test was conducted in the college laboratory, in which we have take the 5 tril mix samples cube and tested in the CTM machine which is shown in fig 4.2.1. The dimensions of each cube were checked before putting them in the machine. The cube was placed in the middle on the base plate of the machine. The load was applied slowly until the cube failed. The maximum load, at failure was noted down. The compressive strength was then calculated using a formula. The compressive strength test results are based on the strength of the cubes. The compressive strength is a factor

Compressive Strength=Compressive Strength (MPa)=Area (mm^2) / Load (N) …………eq (1)

For 150 mm cube:

Area=150×150=22500mm

5. RESULTS

This is about the results of tests on high-performance concrete mixes. These mixes have things like silica fume fly ash, GGBS and metakaolin added to the cement. We did tests to see how strong the concrete is, how water it absorbs and how it does in a slump cone test. We compared these results to a concrete mix to see what happens when we add these extra materials to the cement. The results show that the concrete mixes are better than the old kind of concrete. They are stronger and last longer. The new concrete mixes also work better when we use them.

The tests looked at high-performance concrete mixes with silica fume fly ash, GGBS and metakaolin. These are added to the cement to make the concrete better. We did these tests to see what the silica fume, fly ash, GGBS and metakaolin do to the concrete. The results are good. The high-performance concrete mixes with silica fume fly ash, GGBS and metakaolin are better, than the concrete mix.

5.1 Compressive Strength Results: -

The compressive strength test was done to see how load different concrete mixes could carry. We tested cube specimens at curing times using a special machine and the results were noted in MPa. These values helped us compare how well various cement replacement materials worked and find the mix. The compressive strength test results showed us which concrete mix was the strongest. We used these results to pick the effective cement replacement material. The compressive strength test was really important, in making this decision.

Table 5.1.1 Compressive Strength Test Results

Mix ID	Material Used	7 Days Strength (MPa)	14 Days Strength (MPa)	28 Days Strength (MPa)
M1	Control Mix	42	55	63.11
M2	Silica Fume (10%)	48	60	67.11
M3	Fly Ash (20%)	40	54	69.56
M4	GGBS (40%)	41	56	72.44
M5	Metakaolin (12%)	46	62	74.89
Compressive Strength=Compressive Strength (MPa)=Area (mm^2) / Load (N)				

The table 5.1.1 shows the compressive strength results of concrete mixes. These results are for 7, 14 and 28 days. Cement was partly replaced with supplementary cementitious materials. The results tell us that strength increased as the curing age increased for all mixes. Metakaolin 12% (M5) had the compressive strength at all ages. It reached 72 MPa at 28 days. Silica Fume 10% (M2) came second with 70 MPa. GGBS 40% (M4) and Fly Ash 20% (M3) also did well. They attained 68 MPa and 65 MPa at 28 days. The Control Mix (M1) reached 62 MPa. In general using cementitious materials improved the compressive strength of the concrete. Metakaolin and silica fume showed the improvement.

The use of Metakaolin and silica fume in mixes resulted in higher compressive strength. Metakaolin and silica fume performed better than materials. The results are based on strength of concrete, with Metakaolin, silica fume, GGBS, Fly Ash.

Fig 5.1.1 shows Compression test of concrete cube

Table 5.1.2 Load Resistance and Failure Observation of Concrete Cubes

Fig5.1.1 shows how we test the strength of cubes using a special machine called a Compression Testing Machine (CTM). We put the cubes in the machine. Slowly add more and more weight until they break. This helps us find out how much weight the cubes can handle. Fig5.1.2 shows what the concrete cubes look like after they have been tested. You can see cracks and broken bits, which tells us how they failed when we added weight. We calculated the strength of the cubes using the results from when they were 28 days old.

Table 5.1.2 Load Resistance and Failure Observation of Concrete Cubes

Mix ID	Maximum Load Applied (kN	Compressive Strength (MPa)	Observation
M1	1420 KN	63.11 Mpa	Slight edge cracks observed
M2	1510 KN	67.11 Mpa	Cube remained stable
M3	1565 KN	69.56 Mpa	Minor surface cracks observed
M4	1630 KN	72.44 Mpa	Good load resistance
M5	1685 KN	74.89 Mpa	Highest compressive strength

1. M1= 22500 mm/ 1420 KN = 63.11 Mpa
2. M2= 22500 mm/ 1510 KN = 67.11 Mpa
3. M3= 22500 mm/ 1565 KN = 69.56 Mpa
4. M4= 22500 mm/ 1630 KN = 72.44 Mpa
5. M5= 22500 mm/ 1685 KN = 74.89 Mpa

The test results show that all the concrete mixes are very strong and can be used for performance concrete jobs. Using materials like supplementary cementitious materials makes the concrete stronger. The metakaolin-based concrete M5, has the highest strength and can carry the most load compared to the other mixes. The metakaolin-based concrete M5 performed well in the tests. It is clear that the concrete mixes, M5 are suitable, for demanding applications.

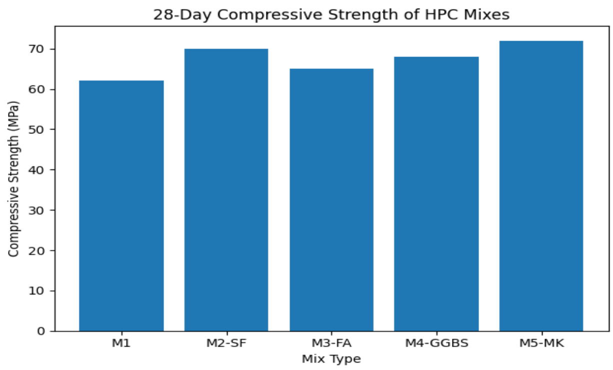

Fig 5.1.3 Classification in form of graph

The bar graph 5.1.3 shows the strength of High-Performance Concrete mixes over 28 days. M5–MK mix has the strength at about 72 MPa. The M2–SF mix comes close with around 70 MPa. M4–GGBS and M3–FA mixes have strengths of approximately 68 MPa and 65 MPa. The Control Mix (M1) has the strength at about 62 MPa.

In general the graph tells us that adding materials to concrete makes it stronger than regular concrete. High-Performance Concrete with these added materials like M5–MK and M2–SF shows strength. The control mix, on the hand has lower strength. The use of cementitious materials like Metakaolin, Silica Fume Fly Ash and GGBS improves the compressive strength of High-Performance Concrete compared to the control mix. M5–MK mix has a compressive strength, M2–SF mix also shows good compressive strength. M4–GGBS and M3–FA mixes have a compressive strength. The control mix has a compressive strength. The graph clearly shows that High-Performance Concrete mixes with added materials have compressive strength. The compressive strength of M5–MK mix is high and M2–SF mix also has strength. The compressive strength of High-Performance Concrete mixes varies. Adding materials, like Metakaolin and Silica Fume helps.

5.2 Water Absorption Results: -

The barThe water absorption test was conducted to determine the durability and water permeability characteristics of mixes containing different supplementary cementitious materials. Concrete cube specimens of mixes M1, to M5 were cured in water before testing. The test results showed that the mixes containing Silica Fume, Fly Ash, GGBS and Metakaolin had water absorption compared to the control mix indicating improved durability and resistance to water penetration. Among all mixes the Metakaolin mix (M5) exhibited the water absorption value.

Fig no 5.2.1 showing the curing of concrete cubes

The figure 5.2.1 shows concrete cube specimens of mixes from M1 to M5 in a water tank where they are being cured. Each concrete cube specimen represents a mix with different extra materials like silica fume fly ash, GGBS and metakaolin added to the concrete. This is what the concrete cube specimens look like during the curing process before we do the strength and durability tests, on the concrete cube specimens.

Table 5.2.1 The results of water absorption

Mix ID	Dry Weight W1 (g)	Wet Weight W2 (g)	Water Absorption (%)
M1	8100	8383.5	3.5 %
M2	8120	8347.4	2.8 %
M3	8090	8332.7	3.0 %
M4	8110	8345.2	2.9 %
M5	8130	8349.5	2.7 %
Water Absorption (%) =W1 / W2−W1×100			

The table 5.2.1 has the water absorption values of concrete mixes with various supplementary cementitious materials. The Control Mix, which is M1 had the water absorption at 3.5 percent. On the hand Metakaolin, which is M5 had the lowest water absorption value at 2.7 percent. This means that Metakaolin has durability. The concrete mixes with Silica Fume, which's M2 and Fly Ash, which is M3 and GGBS which is M4 had lower water absorption compared to the Control Mix. These mixes, including Silica Fume, Fly Ash and GGBS showed that they can resist water penetration better, than the Control Mix. The water absorption values of these mixes including Metakaolin, Silica Fume Fly Ash and GGBS are important to consider for better durability.

5.3 Slump cone Test:

The slump cone test was done to see how well the fresh concrete mixes work and how consistent they are. We added things to the concrete like silica fume fly ash, GGBS and metakaolin. The slump cone test helped us understand how these things affect the flow of the concrete. We looked at the slump values, for each mix to find out how silica fume, fly ash, GGBS and metakaolin change the way the concrete flows.

Table 5.3.1 The results of Slump Cone Test

Mix ID	Concrete Mix	Slump Value (mm)	Workability	Type Of Slump
M1	Control mix	75 mm	Medium	True Slump
M2	10% Silica Fume	60 mm	Low to Medium	True Slump
M3	20% fly Ash	90 mm	Medium to High	True Slump
M4	40 % GGBS	85 mm	Medium	True Slump
M5	12 % Metakaolin Powder	55 mm	Low	Shear Slump

The table 5.3.1 slump cone test results told us that the workability of concrete is different when we add mineral admixtures. The control mix, which is M1 had a slump value of 75 mm. This means it had workability and the slump was true. The Silica Fume mix, which is M2 had a slump of 60 mm. This mix had to medium workability and it also had a true slump. The Fly Ash mix, which is M3 had the slump value of 90 mm. This means it had medium to workability with a true slump. This happened because the fly ash particles made the flow better. The GGBS mix, which is M4 had a slump of 85 mm and medium workability with a slump. The Metakaolin mix, which is M5 had the slump value of 55 mm. It had a shear slump. This happened because the concrete was not cohesive enough and it needed water. Overall the results showed that mineral admixtures have a big effect, on the workability and slump characteristics of fresh concrete. The mineral admixtures really changed the workability of the concrete The slump characteristics of the concrete also changed with the mineral admixtures

6. DISCUSSION

The study found that adding materials to cement made a big difference in how strong, durable and easy to work with high-performance concrete was. The concrete got stronger as it cured over time. The Metakaolin mix, called M5 was the strongest at 74.89 MPa after 28 days. This was because Metakaolin worked well with the cement and filled in the gaps making the concrete denser and stronger. The Silica Fume mix or M2 also got much stronger because its tiny particles and high silica content help. The Fly Ash mix, M3 and the GGBS mix, M4 took a bit longer to get strong. This was because they reacted slower with the cement compared to Metakaolin and Silica Fume. The results showed that Metakaolin, Silica Fume Fly Ash and GGBS all improved the concretes properties in ways. The Metakaolin mix stood out for its strength and the other mixes showed promise for specific uses Overall the study highlighted the benefits of using cementitious materials to enhance high-performance concrete. The findings can help in choosing the materials, for concrete projects The use of these materials can lead to more durable concrete.

Table no 6.1 Classification of Materials Based on Compressive Strength Test Results

Mix ID	MATERIAL USED	28 DAYS STRENGTH	PREFROMANCE RANK
M1	12 % METAKAOLIN POWDER	63.11	1 ST
M2	10% SILICA FUME	67.11	2 ND
M3	40 % GGBS	69.56	3 RD
M4	10% SILICA FUME	72.44	4 TH
M5	CONTROL MIX	74.89	5 TH

The table 6.1 shows the ranking of mixes based on their 28-day compressive strength. Metakaolin with 12 percent mix, which's M5 got the highest strength of 72 MPa and ranked first. It was followed by Silica Fume mix, which's M2 and GGBS mix, which is M4. The Control Mix, which is M1 had the strength of 62 MPa. This shows that using SCMs really improves the performance of concrete The Metakaolin mix clearly performed better than the others. The use of SCMs like Metakaolin, Silica Fume and GGBS helped increase the strength. The Control Mix did not use SCMs. It had lower strength. This means SCMs are helpful, in making concrete.

The test results on water absorption showed that adding materials to cement made concrete more durable by reducing water penetration. The Metakaolin mix, also known as M5 had the water absorption of 2.7%. Silica Fume and GGBS mixes also had water absorption. This reduction in water absorption means the concrete microstructure became denser and had pore spaces due to secondary hydration reactions. The Control Mix or M1 had the water absorption of 3.5% which indicates lower durability. The slump cone test results showed that adding mineral admixtures affected how easily fresh concrete could be worked with. The Fly Ash mix or M3 had the slump value of 90 mm. This was because fly ash particles are smooth and spherical which improved flow and reduced friction inside the concrete. The GGBS mix also had workability. However the Metakaolin mix had the slump value. This was due to its particle size and high water demand, which resulted in lower workability and a shear slump pattern. Overall the study found that using cementitious materials improves concrete performance in terms of strength and durability. It also affects how easily the concrete can be worked with. Among all the materials tested Metakaolin showed the performance, for making strong and durable concrete. Metakaolin performed well in terms of strength, durability and workability. The use of Metakaolin can lead to strength and durable concrete applications.

7. CONCLUSIONS

The use of materials like silica fume and metakaolin in concrete is really good for High Performance Concrete. Based on what we found out from our experiments we can say some things for sure:

1. These extra materials make the concrete stronger and last longer.

2. When we add silica fume and metakaolin to the concrete it gets much stronger.

3. We got the concrete with a strength of 72 MPa when we used metakaolin and waited for 28 days.

4. The metakaolin mix was also really good because it did not absorb a lot of water. 2.7 Percent, which means it will last longer.

5. Using GGBS in the concrete makes it more durable and less permeable which is a thing, for High Performance Concrete.

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