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Improving the Mechanical Properties of M35 Concrete Using Metakaolin and Silica Gel

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Abstract:** Concrete is the most commonly used material for construction. The worldwide production of cement has greatly increased since 1990. Production of cement results in a lot of environmental pollution as it involves the emission of CO2 gas. Supplementary cementitious materials (SCM) are finely ground solid materials that are used to replace a portion of the cement in a concrete mixture. These supplementary materials may be naturally occurring, manufactured or man-made waste. Various types of pozzolanic materials that improve cement properties have been used in cement industry for a long time. Metakaolin is a dehydroxylated aluminium silicate. It is an amorphous non crystallized material, constituted of lamellar particles. Conventional concrete is prone to issues like cracks that reduces its strength over time. From the recent research works using Metakaolin, it is evident that it is a very effective pozzolanic material and it effectively enhances the strength parameters of concrete. Incorporation of silica gel helps in developing self healing ability of the concrete. Self healing is essential to watertight structures and to increases the service life of infrastructures. Self-healing can be characterized as capacity of material to heal damages consequently. Acid attack or chemical attack is another thing that cause damage to concrete and reduced its durability. Metakaolin is an admixture that is acid resistant. This project involves the study of mechanical properties of incorporation of metakaolin to silica gel added concrete. Adding 0.3 % silica gel to concrete and replacing cement with metakaolin by 0, 10 & 15% by weight of cement can improve the mechanical properties of concrete.
***Keywords:** Metakaolin, silica gel, strength, self healing, durability, acid resistance, replacement, damage.*

I. INTRODUCTION

A. General

The most common cementitious materials that are used as concrete constituents, in addition to Portland cement, are fly ash, GGBS and silica fume. Metakaolin, produced by controlled thermal treatment of kaolin, can also be used as a concrete constituent, since it has pozzolanic properties. According to the literature, the research work on metakaolin is focused on two main areas. The demand for Portland cement is increasing dramatically in developing countries. Portland cement production is one of the major reasons for CO2 emissions into atmosphere. It is due to the use of fossil fuels, including the fuels required to generate electricity during cement manufacturing process. The use of pozzolanas for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. Metakaolin when used as a partial replacement substance for cement in concrete, it reacts with Ca(OH)2 one of the by-products of hydration reaction of cement and results in additional C-S-H gel which results in increased strength. Metakaolin is obtained by thermal activation of kaolin clay. This activation will cause a substantial loss of water in its constitution causing a rearrangement of its structure. Concrete is one of the extensively used civil engineering materials in the construction industry due to its strength characteristics, moderately minimal cost, etc. One hostile property of this is its affectability to formation of crackdue to low tensile strength. Silica gel has been used to help with the self healing properties of concrete that will prevent formation of cracks.

B. Aim

To study the mechanical properties metakaolin incorporated silica gel concrete.

C. Objectives

To compare the compressive strength of silica gel added concrete with silica gel added metakaolin based concrete and compare the tensile strength of silica gel added concrete with silica gel added metakaolin based concrete. To compare the workability of silica gel added concrete with silica gel added metakaolin based concrete and to test the durability of optimum mix obtained with silica gel and metakaolin.

D. Scope

The scope of this study is confined to creating a stronger M35 mix concrete that attains early age strength faster than conventional concrete. Addition of self healing agent and an admixture can increase the strength, chemical resistivity and durability of the concrete. The concrete can be used in petrochemical industries, chemical industries, marine structures etc.

II. LITERATURE SURVEY

V. Sumitha, T. Ravichandran, P Krishnan, K Divya (2018). [1] Studied that concrete is one of the extensively used civil engineering materials in the construction industry due to its strength characteristics, moderately minimal cost, etc.One hostile property of this is its affectability to formation of crackdue to low tensile strength. The crack occurring will affect the long term property of concrete structures as forceful fluids and gasses may enter into the matrix along these cracks and cause damage. Subsequently, cracks may become more extensive and the support might be presented to the earth. Once the reinforcement begins to erode, total failure of the structure may happen. Repairing of cracks will be troublesome when cracks are undetectable or out of reach. The above said issue can be solved by applying the principles of self healing concrete.

B.B. Sabir, S Wild, J Bai (2001). [2] The use of metakaolin as a partial cement replacement ma- terial in mortar and concrete has been studied widely in recent years. The work reviewed demonstrates clearly that MK is a very effective pozzolan and results in en-hanced early strength with no detriment to, and some improvement in, the long-term strength. Increase in the utilisation of pozzolanic materials in concrete will come from greater awareness of current and potential uses of alternative and recycled materials and wider realisation of the environmental benefits accrued.

M. Narmatha, T Felixkala (2016). [3] The strength of all Metakaolin concrete mixes over shoot the strength of OPC. 15% cement replacement by Metakaolin is superior to all other mixes. The increase in Metakaolin content improves the compressive strength and split tensile strength up to 15% cement replacement. The results encourage the use of Metakaolin, as a pozzolanic material for partial replacement in producing high performance concrete.

Nova John (2018). [4] The inclusion of metakaolin results in faster early age strength development of concrete. The strength of all Metakaolin admixed concrete mixes overshoot the strength of OPC Mix with 15% metakaolin is superior to all other mixes. The increase in metakaolin content improves the compressive strength, Split Tensile Strength and Flexural Strength upto 15% replacement. The results encourage the use of Metakaolin, as pozzolanic material for partial cement replacement in producing high-strength concrete.The utilization of supplementary cementitious material like Metakaolin in concrete can compensate for environmental, technical and economic issues caused by cement production. Inclusion of Metakaolin serves as an invaluable means to protect environmental resources, which may result in more viable constructions in the future.

Aiswarya S, Prince Arulraj G, and Dilip C (2013). [5] The demand for Portland cement is increasing dramatically in developing countries. Portland cement production is one of the major reasons for CO2 emissions into atmosphere. It is due to the use of fossil fuels, including the fuels required to generate electricity during cement manufacturing process. The use of pozzolanas for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. Metakaolin when used as a partial replacement substance for cement in concrete, it reacts with Ca(OH)2 one of the by-products of hydration reaction of cement and results in increased strength. Metakaolin is obtained by thermal activation of kaolin clay. This activation will cause a substantial loss of water in its constitution causing a rearrangement of its structure. Metakaolin is used in oil well cementing to improve the compressive and flexural strength of the hardened cement. Metakaolin also reduces the hardened cement permeability to liquids and gases. Hence by partially replacing Portland cement with Metakaolin not only reduces carbon dioxide emissions but also increases the service life of buildings.

A. Literature Outcome

With the help of above papers, we got information regarding various mix percentages for the replacements. Referring these journals helped us to do the durability test of hardened concrete.

Table 1: Literature survey

SL NO	TITLE	OBJECTIVE	OUTCOME
1	Study on behaviour of self - healing	Here they discuss about the crack occurring will affect the long term property of concrete structures as forceful	Studied the behaviour of self healing concrete using silica gel. The healing agent is mixed in

	concrete using silica gel.	fluids and gasses may enter into the matrix along these cracks and cause damage. Once the reinforcement begins to erode, the total structural failure may happen. They explains the solution for these problems.	varying proportions. 0.3% of silica gel gives 6.5% more strength compared to the control specimens at the age of 28 days testing.
2	Metakaolin and calcined clays as pozzolanas for concrete.	The work reviewed demonstrates clearly that MK is a very effective pozzolan and results in enhanced early strength and some improvement in, the long-term strength. They reviews the properties of metakaolin also.	Cement replacement by metakaolin will help in the development of early strength and some improvement in long term strength.
3	Metakaolin – the best material for replacement of cement in concrete	This paper discuss about the replacement of material in concrete. In this paper they do the replacement for different percentages, and the result may shows that 15% have more strength compare to the other replacement mixes.	Studied the characteristic properties of metakaolin. They conduct a experimental study of metakaolin as a partial replacement with cement was done at 5%, 10%, 15%, 20%.
4	Strength properties of Metakaolin admixed concrete.	This paper addresses the inclusion of metakaolin. The utilization of supplementary cementitious material like Metakaolin in concrete can compensate for environmental, technical and economic issues caused by cement production. It also explains inclusion of Metakaolin serves as an invaluable means to protect environmental resources, which may result in more viable constructions in the future.	In this study investigate the cement replacement levels were 5%, 10%, 15%, 20% by weight for metakaolin. Mix with 15% metakaolin is superior to all other mixes. This mix is having high compressive and tensile strength.
5	A review on use of metakaolin in concrete	From this paper it was found that cement can be replaced effectively with Supplementary Cementitious Materials(SCM's) like Metakaolin. In the case of strength and durability, the SCM's shows better results than normal mixes. With regard to workability and setting time, Metakaolin generally required more super plasticizer and it reduces the setting time of pastes as compared to control mixtures. When compared with cement, the use of Metakaolin can be economical in the aspects of durability and strength.	Metakaolin, it is evident that it is a very effective pozzolanic material and it effectively enhances the strength parameters of concrete. In this study discussed about the various types of pozzolanic materials that improve the properties of cement have been used in cement industry for a long time. Mainly discussed about the properties of metakaolin

III. METHODOLOGY

A. General

The study started with the collection of raw materials. Then established M35 equivalent grade concrete by calculating the mix proportions for various mixes. We then prepared cubes and cylinders for 0% ,10% and 15% replacemt of cement with metakaolin meanwhile adding 0.3% of silica gel to all the mixes.

During the casting of cubes and cylinders we also conducted workability test such as slump test. After 7 days and 28 days of curing we carried out the compressive and split tensile strength test. After obtaining the result we found the optimum mix and conducted the durability test on the optimum mix.

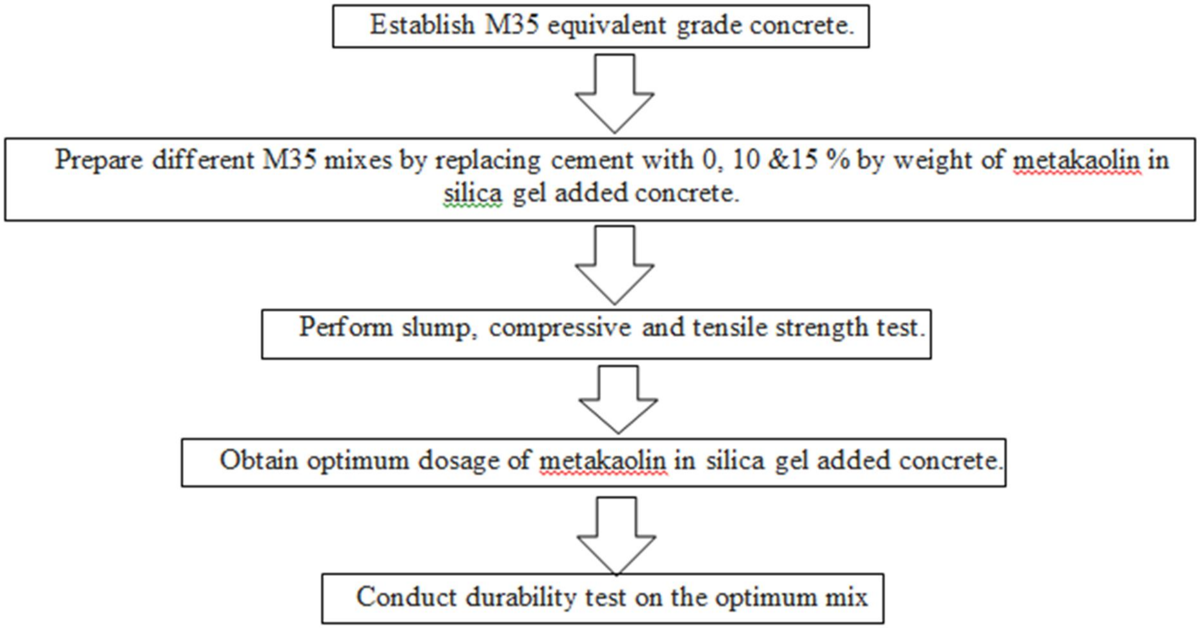

Fig 1: Project Methodology chart

IV. EXPERIMENTAL STUDY ON MATERIALS

A. General

In this chapter, the description of materials and their properties are discussed. Preliminary tests are done on the materials and their results are obtained. A consolidated table of test results is also included in this chapter.

B. Description Of Materials

The materials used in the experimental study are cement (OPC), metakaolin, silica gel, fine aggregate, coarse aggregate and water. The description of materials are given below.

1) Cement

In the present experimental work, OPC 53 grade was used. Ordinary Portland Cement (OPC) is the commonly used cement in the world. It is manufactured by mixing limestone and other raw materials which consist of argillaceous, calcareous and gypsum. This cement is available in three grades namely OPC 33, OPC 43 and OPC 53.These grades imply the maximum strength of the particular cement after 28 days. Specific gravity, initial setting time, fineness and standard consistency of cement were tested.

2) Fine Aggregate

Fine aggregate is basically sand obtained from the land or marine environment. It consists of natural and crushed stone which passes through 4.75 mm sieve. Its size range from 4.75 mm to 75 microns as per IS 383-1970(Reaffirmed 2016) and allowable maximum absorption is 2.3%. Here manufactured sand (M-sand) is used as fine aggregate. It is a better substitute to river sand because it has no silt organic impurities and is mostly well graded. Various factors of fine aggregate such as fineness modulus, moisture content, specific gravity, and silt content affect the mix proportions of concrete.

3) Coarse Aggregate

Coarse aggregates are commonly considered as inert fillers. The coarse aggregates of size ranging from 10 mm to 4.75 mm are used for casting. The maximum allowable water absorption is 2% as per IS 383:1970 (Reaffirmed 2016). It reduces volume changes resulting from settling and hardening process.

The various properties of aggregates include shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk density. Aggregates can form 80% of the concrete mix so their properties are crucial to the properties of concrete.

4) Metakolin

Metakaolin is a high-quality pozzolanic material. Metakaolin is one of the most widely used mineral admixtures these days. It helps concrete obtain both higher performance and is cost effective. Metakaolin in concrete tend to reduce the size of pores which consequently lead to obtain more strength, higher density, and more resistance to acid. Metakaolin has smaller particle size which initiates good filler effect and increases the pozzolanic effect and increases strength of concrete. Metakaolin is shown in the figure below.

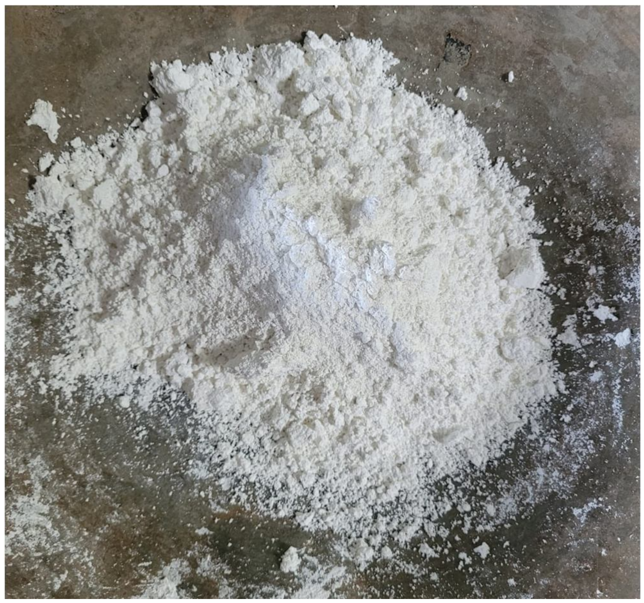

Fig 2: Metakaolin

5) Silica Gel

Silica gel is a granular, porous form of silicon dioxide made from quartz sand. It is a desiccant, meaning it absorbs water vapor, and is used to control humidity. It helps the concrete to develop self healing ability. The performance of the 0.3% of Silica gel replacement in mechanical strength properties gives considerable effective enhancer compare to the control specimens. Silica gel can be used as one of the healing material in the construction of tunnel, underwater structures etc. Silica gel is shown in the figure below.

Fig 3: Silica gel

6) Water

Water fit for drinking is used for making concrete. It should be free from acids, oils, alkalis and vegetables or other impurities. Soft waters also produce weak concrete. Function of water in concrete are:

a) It reacts chemically with cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened.

b) It serves as a vehicle or lubricant in the mixture of fine aggregates.

C. Testing Of Materials

The materials using for the preparation of concrete are tested to determine their quality and physical properties and the tests were done according to relevant Indian Standard Codes.

1) Tests On Cement

a) Specific Gravity Test

The specific gravity is the ratio between the weight of a given volume of material to weight of an equal volume of water. Kerosene is used determine the specific gravity of cement. Kerosene does not react with cement. The specific gravity of Portland cement is generally ranged from 3 to 3.15. The test was conducted as per IS 4031:1988 Part II (Reaffirmed 2005). 2016

Weight of the bottle, W1 = 0.114 kg

Weight of bottle + cement, W2 = 0.164 kg

Weight of bottle+ cement + kerosene, W3 = 0.364 kg

Weight of bottle + kerosene ,W4 = 0.328 kg

W3 - weight of bottle+cement+kerosene

Specific gravity of cement = $(W_2\text{-}W_1) / (W_4\text{-}W_1) - (W_3\text{-}W_2)$

= (0.164-0.114)/(0.328-0.114)-(0.364-0.164)

= 3.57

=3.57 x 0.79

= 3

As per IS 4031 Part 2 :1988, allowable limit is 3.1 to3.6

Hence ok

b) Standard Consistency

The basic aim is to find out the water content required to produce a cement paste of standard consistency as specified by the IS: 4031 (Part 4) – 1988. The principle is that standard consistency of cement is that consistency at which the Vicat plunger penetrates to a point 5-7mm from the bottom of Vicat mould. Standard consistency = (Quantity of water for 5−7 mm penetration Weight of cement) 300 g of cement was taken for consistency test. Water was added from 25 % of cement till the cement paste gave 5-7mm plunger penetration reading in vicat’s apparatus. The results from the standard consistency test is made into a tabular form below.

Table 2: Standard consistency of cement

Weight	Percentage of water	Amount of water	Penetration
300	26	78	39
300	28	84	22
300	30	90	5

The consistency of cement taken is 34%.

As per IS 4031 part 4:1988 , allowable limit is 25 to 35%

Hence ok

Standard consistency test is shown in the figure below.

Fig 4: Standard consistency test using Vicat's apparatus

c) Initial Setting Time

Initial setting time is the period elapsing between the time when the water is added to the cement and the time at which the needle of 1mm square section fails to pierce the test blocks to a depth of about 5 mm from the bottom of the Vicat's mould. Vicat's apparatus is used to find out the initial setting time according to IS 4031-1968.

To find initial setting time, 0.85 times consistency value of water is added.

ie, 0.85P = 0.85x 34= 28.9ml

Note the time from the point water is added to mix. The time taken for vicat needle to penetrate 5 to 7 mm is taken as initial setting time. Values from the test is shown in the table below.

Table 3: Initial setting time value of cement

Time(min)	Penetration of needle (mm)
30	0
35	2
40	5

As per IS 4031 Part 6:1988, allowable limit is > 30 min.

Hence ok

d) Fineness Test

The fineness of cement has a great effect on the rate of hydration and hence the rate of gain of strength. The fineness of cement increases the rate of evolution of heat. Finer cement offers a great surface area for hydration and hence faster the development of strength. The fineness of cement is measured by sieving it using standard sieve.

The proportion of cement of which the grain sizes are larger than the specified mesh size is thus determined. Fineness of cement is determined by dry sieving as per IS 4031:2019 Part II. The principle of this is what determines the proportion of cement, whose grain size is larger than specified mesh size. The apparatus used are 90µm IS Sieve, Balance capable of weighing 10g to the nearest 10mg, a nylon or pure bristle brush, preferably with 25 to 40mm, bristle, for cleaning the sieve. 100g of cement is taken as sieved for 10 to 15 minutes in 90 micron sieve. The weight retained is taken and fineness is determined through following equation.

Percentage weight of residue = Weight of sample/100

= 9/100

= 0.9 ie,9%

As per IS 4031:2019, allowable limit is < 10%.

Hence ok

2) Tests On Fine Aggregate

a) Sieve Analysis

Particle size distribution of a sample (fine aggregate) is determined by sieve analysis. The sample is sieved through a set of sieves. The material retained on different sieve is determined. According to IS: 1498-1970, the sieves are designated by the size of square opening, in mm or microns. A gradation curve is plotted between percentage finer and sieve size on a semi-log graph to get the grade of sample as well as the effective size of sample particles. Results from sieve analysis is shown in the figure below. Sieve distribution curve is also given below.

Table 4: Sieve analysis of fine aggregate

IS Sieve size	Weight retained	% weight retained	Cumulative % weight retained	% weight passing
4.75	0	0	0	100
2.36	82	8.2	8.2	91.8
1.18	154	15.4	23.6	76.4
0.6	126	12.6	36.2	63.8
0.3	282	28.2	64.4	35.6
0.15	338	33.8	98.2	1.8
Pan	18	1.8	100	0

Fineness modulus = cumulative weight retained/100 = 3.184

As per IS 383 : 2016, allowable limit is 2 to 3.5mm

Hence ok.

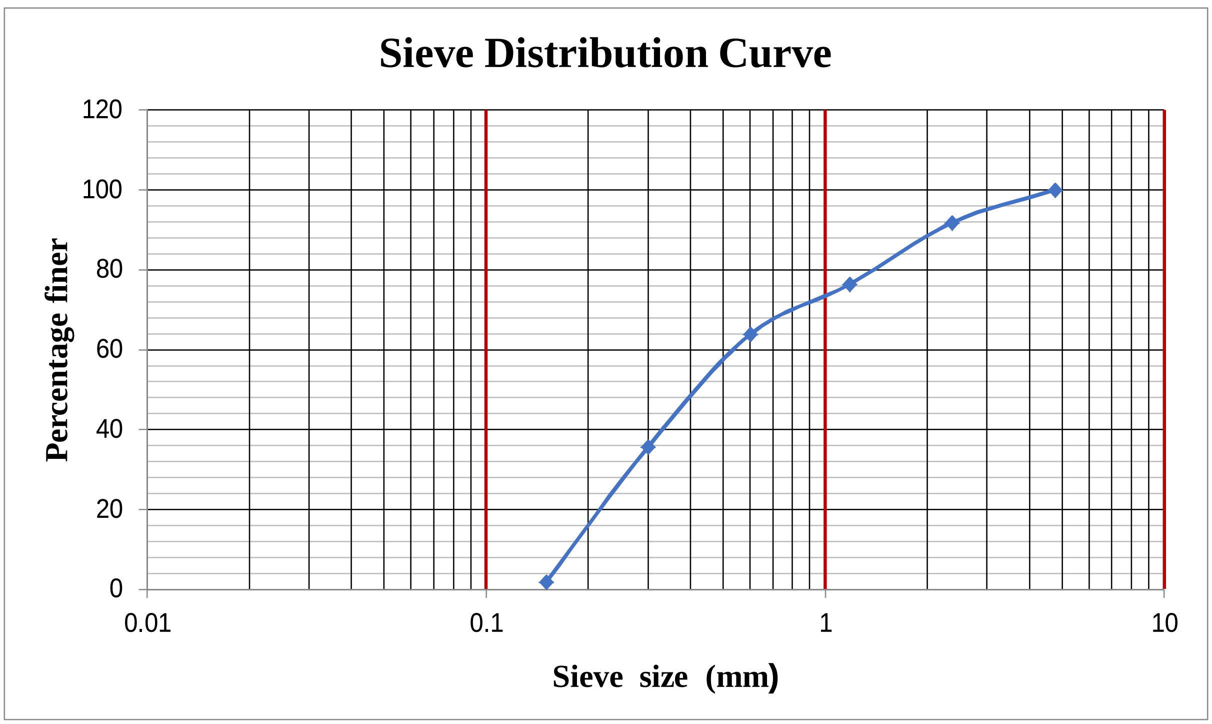

Fig 6: Sieve distribution curve

b) Specific gravity of fine aggregate

Using Pycnometer the specific gravity of M-sand was determined according to IS 2386 (Part 3) - 1963 (Reaffirmed 2011). The specific gravity ranges from 2.5 to 3.

c) For loose fine aggregate

Weight of pycnometer,W1=2.966

Weight of pycnometer + fine aggregate, W2= 6.772

Weight of pycnometer + fine aggregate +water, W3= 8.270

Weight of pycnometer+ water , W4 = 5.964
Specific gravity =$(W_2\text{-}W_1) / (W_4\text{-}W_1) - (W_3\text{-}W_2)$
= (6.772-2.966)/(5.964-2.966)-(8.270-6.772)
= 2.53
As per IS 383 ;2016, allowable limit is 2.5 to 3
Hence ok
Specific gravity test for Fine aggregate is shown in the figure below.

Fig 7: Specific gravity test for Fine aggregate

d) For compact fine aggregate
Weight of pycnometer,W1=2.966
Weight of pycnometer + fine aggregate, W2= 7.540
Weight of pycnometer +fine aggregate +water, W3= 5.716
Weight of pycnometer+ water , W4 = 5.964
Specific gravity =$(W_2\text{-}W_1) / (W_4\text{-}W_1) - (W_3\text{-}W_2)$
=(7.540-2.966)/(5.964-2.966)-(5.716-7.540)
=2.51
As per IS 383:2016, allowable limit is 2.5 to 3
Hence ok

3) Tests On Coarse Aggregate
Specific Gravity Test
a) For loose coarse aggregate
Weight of empty cylinder,W1=2.966
Weight of cylinder + coarse aggregate, W2=7.460
Weight of cylinder + coarse aggregate + water, W3=8.770
Weight of cylinder + water, W4=5.930
Specific gravity = $(W_2\text{-}W_1) / (W_4\text{-}W_1) - (W_3\text{-}W_2)$
= (7.460-2.966)/(5.930-2.966)(8.770-7.460)
=2.71
As per IS 383: 2016, allowable limit 2.6 to 2.8
Hence ok..

b) For compact fine aggregate

Weight of pycnometer, W1=2.966
Weight of pycnometer + fine aggregate, W2= 7.540
Weight of pycnometer + fine aggregate +water, W3= 5.716
Weight of pycnometer + water, W4 = 5.964
Specific gravity = (W2-W1) / (W4-W1) - (W3-W2)
=(7.540-2.966)/(5.964-2.966)-(5.716-7.540)
=2.51
2.5<2.51<3
As per IS 383: 2016, allowable limit 2.6 to 2.8. Hence ok.
Specific gravity test for Coarse aggregate is shown in the figure below.

Fig 8: Specific gravity test for Coarse aggregate

c) Sieve Analysis

Particle size distribution of a sample (coarse aggregate) is determined by sieve analysis. The sample is sieved through a set of sieves. The material retained on different sieve is determined. According to IS: 1498-1970, the sieves are designated by the size of square opening, in mm or microns. A gradation curve is plotted between percentage finer and sieve size on a semi-log graph to get the grade of sample as well as the effective size of sample particles. Weight of coarse aggregate used = 2 kg
Test results are shown in the following table.

Table 5: Fineness modulus of coarse aggregate

IS Sieve size	Weight retained (g)	% weight retained	Cumulative % weight retained	% weight passing
25	42	2.1	2.1	97.9
20	700	35	37.1	62.9
16	612	30.6	67.7	32.3
12.5	400	20	87.7	12.3
8	228	11.4	99.1	3.9
6.3	18	0.9	100	0
4.75	0	0	100	0
Pan	0	0	100	0

Fineness modulus = cumulative weight retained/100
= 593.7/100
=5.937

As per IS 383:2016, allowable limit is 5 to 8. Hence ok.
Sieve analysis using 25mm, 20mm, 16mm, 12.5mm, 8mm, 6.3mm, 4.75 mm sieves and pan is shown in the figure below.

D. Consolidated Preliminary Test Results

The final result from all the preliminary tests are consolidated into a table below. The specific gravity, fineness, consistency and initial setting time of cement, fineness modulus and specific gravity of fine and coarse aggregate, specific gravity of metakaolin are given in the table below.

Table 6: Properties of materials

Material	Experiment	Result	Allowable limit
Cement	Fineness	9	>10%
	Specific Gravity	3	3.1 - 3.6
	Consistency	30 %	25 – 35 %
	Initial Setting Time	44 min	<30 min
Coarse aggregate	Fineness modulus	5.937	5-8
	Specific Gravity	2.638	2.6 - 2.8
Fine aggregate	Fineness modulus	3.184	2 – 3.5
	Specific gravity	2.51	2.5 – 3
Metakaolin	Specific gravity	2.6	2-3

V. TESTS ON CONCRETE

A. General

Casting of various specimens was done as per IS 516:1956 (reaffirmed 2011). The procedure for casting of cubes and cylinders are mentioned below. The compressive strength test, split tensile strength test and durability test of the mixes are done.

B. Casting Procedures

Cubes and cylinders are to be casted and the procedures for casting these are discussed below.

1) Procedure for Casting Cube

The standard cube mould of size 150 mm x 150 mm x 150 mm is used to prepare the cubespecimen.

a) The quantity of material was calculated to prepare concrete cube of required dimension and the materials were taken by weigh batching.
b) The concrete was mixed in a mechanical mixer with a maximum capacity of 0.5 m^3.
c) The coarse aggregate was first added into the drum, followed by fine aggregate and cement and mixed it until the coarse aggregate was uniformly distributed throughout the batch.
d) Required amount of water was added to the mixture and mixed it until the concrete appears to be homogeneous.
e) Oil was applied to the internal surface of cube mould.
f) The concrete was filled in the mould in three layers and each layer was tamped 25 timesusing a tamping rod.
g) The top surface was leveled and made smooth with a trowel.
h) The specimen was removed from mould and immersed in water for curing after 24 hours of setting.

2) Procedure for Casting Cylinder

The standard cylinder mould of radius 150mm and height 300mm is used to prepare thecylinder specimen.

a) The quantity of material was calculated to prepare concrete cube of required dimension and materials were taken to prepare concrete cube of required dimension and materials were taken by batching. The concrete was mixed in a mechanical mixer with a maximum capacity of 0.5 m^3.
b) The coarse aggregate was first added into the drum, followed by fine aggregate and cement and mixed it until the coarse aggregate was uniformly distributed throughout the batch.
c) Water was added to the mixture in the required amount and mixed it until the concrete appears to be homogeneous.
d) Oil was applied to the internal surface of cylinder mould.
e) The concrete was filled in mould in three layers and each layer was tamped 25 times using a tamping rod.

f) The top surface was leveled and made smooth with a trowel.
g) The specimen was removed from mould and immersed in water for curing after 24 hours of setting.

C. Testing Of Fresh Concrete Specimen

The test on fresh concrete is discussed below:

Slump Test on Fresh Concrete

Slump test is a control test and it gives an indication about the uniformity of concrete. Concrete is workable if it can be easily mixed, placed, compacted and finished. Workable concrete do not show any segregation or bleeding. Slump test is a field test. It is conducted to determine the workability of fresh concrete.

1) Apparatus

Slump cone, Tamping rod, Trowel

2) Procedure
a) The test is done using a mould known as a slump cone or Abrams cone.
b) The cone is filled with concrete.
c) Each stratum is tamped 25 times with a rod. At the end concrete is struck off flush to the top of the mould.
d) The mould is carefully lifted up with twisting motion.
e) Concrete subsides in the mould subsides. This subsidence is termed as slump, and is measured to the nearest 5 mm if the slump is <100 mm and measured to the nearest 10 mm if the slump is >100 mm.

The sample cube and cylinder of 6 number as per the mix were cast and tested for 7 and 28 days. The compression test was carried out in compression testing machinein the college laboratory. Test results are shown in the table below.

Table 7: Slump test result

MIX (metakaolin replaced for % by weight of cement)	Slump value (mm)
0%	31
10%	40
15%	25

The concrete mixes have achieved low workability in the slump test. Which means the addition of admixture and silica gel has not helped in increasing the workability.

D. Testing Of Hardened Concrete Specimen

The cube specimens were tested for compression test, cylinder specimen for split tensile strength, beam specimen as per IS 516: 1959 (reaffirmed 2011). The test procedures for the specimen are listed below.

1) Compressive Strength Test

The test was conducted and the strength was obtained in N/mm^2

a) Apparatus

- Compression Testing Machine (CTM).

b) Procedure

- The specimen was removed from water after specified curing time and wiped outexcess water from the surface.
- Dimensions of the specimen were noted.
- The table surface of the compression testing machine was cleaned.
- The specimen was placed in machine such that the load shall be applied to the opposite sides of the cube.
- The specimen was placed centrally on the base plate of testing machine.
- The movable portion of machine was allowed to touch the top surface of thespecimen.
- The load was applied gradually without shock and continuously at the rate of $14N/mm^2$ till the specimen fails.
- The maximum load was recorded and noted if any unusual features in the type of failure.

Then compressive strength was calculated by,

$$\text{Compressive strength} = \frac{load}{area}$$

Compression test carried out on cube is shown in the figure below.

Fig 12: Compressive strength test on CTM

The test results are shown in the table below.

Table 8: Compressive strength test result

Mix (metakaolin replaced for % by weight of cement)	Compressive strength (N/mm^2)	
	After 7 days of curing	After 28 days of curing
0 %	24	38
10 %	32	41
15 %	18	35

The compressive strength of mix with 10% metakaolin is higher than the other mixes. It has also achieved an early age strength of 32 N/mm^2 in 7 days. Which indicate the admixture, metakaolin has impacted in helping the concrete achieve early age strength. Metakaolin has smaller particle area and higher surface area, which brings good filler effect. The material is also pozzolanic. All these helps in increasing the strength of concrete. The 28 day compressive strength of the same mix is found to be 41 N/mm^2 which is more than required for an M35 mix. It is also noted to be stronger than the rest of the mixes. So the mix which replaces 10 % of cement with metakaolin is taken to be the optimum mix. The same will be subjected to durability test.

The compressive strength graph of various mixes is shown below.

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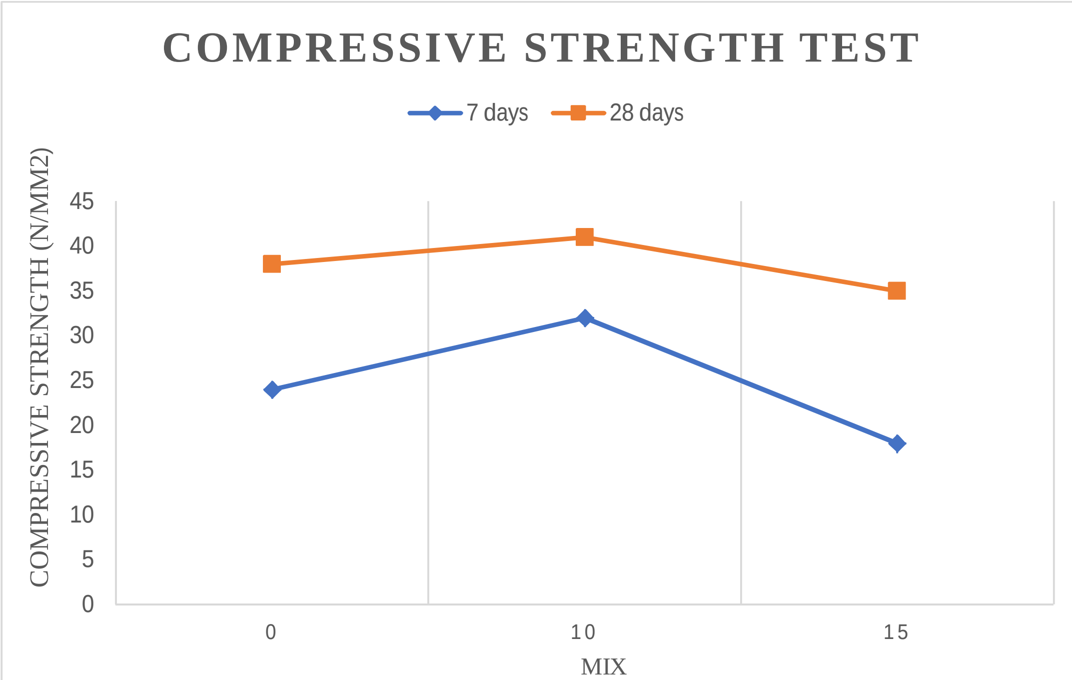

Fig 13: Compressive test result graph

2) Split Tensile Strength Test

Tensile strength is an important property of concrete. Knowledge of its value is required for design of concrete structural elements subjected to transverse shear, torsion, shrinkage and temperature effects. Direct tensile strength of concrete is difficult to calculate and hence splitting tensile test is used for assessing tensile strength of concrete.

a) Apparatus:

- Compression Testing Machine (CTM)

b) Procedure:

- Cylinder specimens of size 150 mm diameter and 300 mm height were casted and provided proper curing.
- Water from the surface of specimen wiped out.
- Diametrical lines were drawn on the two ends of the specimen to ensure that they are on the same axial plane.
- The bearing surface of compression testing machine was cleaned.
- Plywood strip was kept on the lower plate and placed the specimen.
- Specimen was aligned so that the lines marked on the ends are vertical and centered over the bottom plate.
- The other plywood strip was placed above the specimen.
- The upper plate of the machine allowed to touch the plywood strip.
- Load was applied continuously without shock at a rate of approximately 14 N/mm^2till the specimen fails.
- The maximum load was recorded and noted if any unusual features in the type offailure.
- Splitting tensile strength of specimen was calculated by,

$$\text{Splitting tensile strength} = 2P / \pi DL$$

Where,

P: maximum load
D: Specimen diameter
L: Specimen length

The test results are shown in the table below.

Table 9: Split tensile strength test result

Mix (metakaolin replaced for % by weight of cement)	Split tensile strength (N/mm^2)	
	After 7 days of curing	After 28 days of curing
0 %	19	28
10 %	22	32
15 %	18	25

The split tensile strength graph of various mixes is shown below.

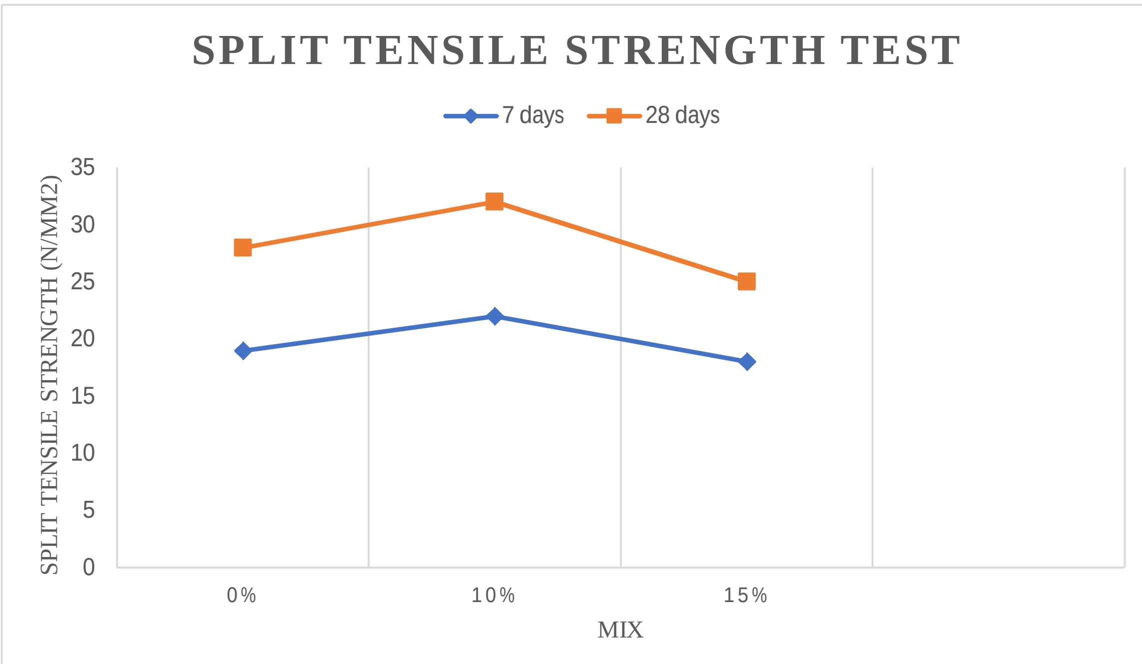

Fig 14: Split tensile strength result graph

Split tensile strength test being carried out on CTM is shown below.

Fig 15: Split tensile strength test on CTM

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The split tensile strength value is higher for the mix which replaces 10 % of cement with metakaolin. The optimum mix has achieved higher split tensile strength than the rest of the mixes.

➢ Durability test

For durability test concrete cube of size 150 x 150 x 150 mm are prepared for various percentages of silica gel and metakaolin. The specimen are cast and cured in mould for 24 hours, after 24 hours, all the specimen are demoulded and kept in curing tank for 7-days. After 7-days all specimens are kept in atmosphere for 2-days for constant weight, subsequently, the specimens are weighed and immersed in 5% sulphuric acid (H2SO4) solution for 60-days. After 60-days of immersing in acid solution, the specimens are taken out and were washed in running water and kept in atmosphere for 2-day for constant weight. Specimens kept for curing is shown in the figure below. The test results are shown in the table below.

Fig 16: Test specimens kept for curing in 5% H_2SO_4

Table 10: Durability test result

Mix (metakaolin replaced for % by weight of cement)	Compressive strength (N/mm^2)
After 60 days of curing	
Conventional concrete	29
0 % (0.3 % silica gel)	38
10 % (0.3 % silica gel & 10 % metakaolin)	62

Conventional concrete failed to pass the durability strength. It didn't even manage to acquire the characteristic strength of 35 N/mm^2. Concrete added with silica gel attained the strength of 38 N/mm^2 which is more than the required strength. Adding metakaolin to silica gel based concrete improved the durability to a great extent. Adding metakaolin and silica gel to concrete proved to make the concrete durable as reflected by the values from the test. Figure showing the testing of compressive strength of specimens subjected to durability test is shown below.

Fig 17: Testing the compressive strength of specimens subjected to durability test

VI. MIX DESIGN

A. General

The tesing of materials are explained in chapter 4. Based on the test results, mix design for M35 concrete was established by which the volume of the materials were calculated for different mixes.

B. Mix Design- M35 AS PER IS 10262: 2019 (M-P, M-P0)

1) Stipulations for proportioning

a) Grade designation = M_{35}

b) Type of cement = OPC 53 grade

c) Maximum nominal size of aggregate = 20mm

d) Minimum cement content and maximum water cement ratio to be adopted and very severe exposure condition as per table 3 and table 5 of IS 456 for reinforced concrete.

2) Test data for materials

a) Cement used = OPC

b) Specific gravity of coarse aggregate = 2.638 fine aggregate = 2.51

c) Moisture content of aggregate (as per IS 2386 part 3) coarse aggregate: nil fine aggregate: nil

d) Sieve analysis coarse aggregate : conforming to table 7 of IS 383
fine aggregate : confirming to grading zone 1of table 9 of IS 383

3) Target strength for mix proportioning

f'ck = fck + 1.65 S

f'ck = fck + X

from table 2, standard deviation, S= 5N/mm^2 from table 1 of IS 10262, 2019, X=6.5

Therefore target strength using both equation is

a) f'ck = fck + 1.65 S
=35+1.65x5 = 43.25N/mm^2

b) f'ck = fck + X
35+ 6.5 = 41.5 N/mm^2

43.25 N/mm^2 >41.5 N/mm^2

Therefore target strength = 43.25 N/mm^2

4) Approximate air content

From table 3 of IS 10262, 2019, the approximate amount of entrapped air to be expected in normal (non air-entrained) concrete is 1 percent for 20mm nominal maximum size of aggregate.

5) Selection of water cement ratio

From fig,1 of IS 10262, 2019, the free water cement ratio required for target strength of 43.25N/mm^2 is 0.44 for OPC 53 grade curve. This is lower than max value of 0.5 prescribed for 'very severe' exposure for RCC as per table 5 of IS 456.

0.44<0.45. Hence ok

6) Selection of water content

From table 4 of IS 10262, 2019, water content= 186 kg for 20mm aggregate (for 50mm slump).

Estimated water content for 75mm slump = 186 + (3x186)/100 = 191 kg

7) Calculation of cement content

Water cement ratio = 0.44

Cement content = 191/0.44 = 435 kg/m^3

From table 5 of IS 456, min cement content for " very severe" exposure condition = 340kg/m^3

$435.40 kg/m^3 > 340 kg/m^3$
Hence ok
Cementinious material content = 435 x 1.1 = 478.5 kg/m^3
So water cementinious ratio = 191/478.5 = 0.399

8) Proportion of volume of coarse aggregate and fine aggregate content
From table 5 of IS10262, 2019, the proportionate volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate (zone 1) for water cement ratio of 0.50 = 0.60 in present case water cement ratio is 0.44. Therefore volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water cement ratio is lowered by 0.06, the proportion of volume of coarse aggregate is increased by 0.012. therefore corrected proportion of volume of coarse aggregate for the water cement ratio of
0.44 = 0.60+0.012 = 0.612
Volume of fine aggregate content = 1-0.612 = 0.388

9) Mix calculation
The mix calculation per unit volume of concrete shall be as follows.
a) Total volume = $1m^3$
b) Volume of entrapped air in wet concrete = $0.01m^3$
c) Volume of cement = (mass of cement/specific gravity of cement)/1000
= (435.40/3)/1000 = 0.145 m^3
d) Volume of water = (mass of water/ specific gravity of water)/1000
= (191.5/ 1)/1000 = $0.1915m^3$
e) Volume of all in aggregate = [(a-b)-(c+d)]
= [(1-0.01)-(0.145+0.1915)]
=$0.6535m^3$
f) Mass of coarse aggregate = f x volume of coarse aggregate x specific gravity of coarse aggregate x 1000
= 0.635 x 0.612 x 2.638 x 1000 = 1055kg
g) Mass of fine aggregate = g x volume of fine aggregate x specific gravity of fine aggregate x 1000
= 0.635 x 0.388 x 2.51 x 1000 = 636kg

MIX PROPORTIONS FOR DIFFERENT MIXES THAT REPLACE CEMENT WITH METAKAOLIN
1) Metakaolin at 0% of total cementinious material content = 0 kg/m^3
Cement content = 478.5 kg/m^3
Silica gel at 0.3 % of weight of cement = (mass of cement x 0.3)/100
= (478.5 x 0.3)/100 =1.435 kg/m^3
The mix calculation per unit volume of concrete shall be as follows.
a) Total volume = $1m^3$
b) Volume of entrapped air in wet concrete = $0.01m^3$
c) Volume of cement = (mass of cement/specific gravity of cement)/1000
= (478.50/3)/1000 = 0.1595 m^3
d) Volume of water = (mass of water/ specific gravity of water)/1000
= (191/ 1)/1000 = $0.191m^3$
e) Volume of metakaolin = (mass of metakaolin / specific gravity of metakaolin)/1000
= 0
Silica gel at 0.3 % of weight of cement = (mass of cement x 0.3)/100
= (478.5 x 0.3)/100 =1.435 kg/m^3
f) Volume of silica gel = (mass of silica gel/specific gravity of silica gel x 1000)
= 1.435/0.88 x 1000 = 1.6 $x10^{-3}$ m^3
g) Volume of all in aggregate = [(a-b)-(c+d+e+f)]
= [(1-0.01)-(0.1595+0.198+$1.6x10^{-3}$)]

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$=0.6379 m^3$

h) Mass of coarse aggregate = f x volume of coarse aggregate x specific gravity of coarse aggregate x 1000
= 0.6379 x 0.612 x 2.638 x 1000 = 1029.86 kg

i) Mass of fine aggregate = g x volume of fine aggregate x specific gravity of fine aggregate x 1000
= 0.6379 x 0.388 x 2.51 x 1000 = 621.238 kg

2) Metakaolin at 10% of total cementinious material content = 478.5 x10/100 = 47.85 kg/m^3

Cement content = 478.5-47.85 = 430.65 kg/m^3

The mix calculation per unit volume of concrete shall be as follows.

a) Total volume = $1m^3$

b) Volume of entrapped air in wet concrete = $0.01m^3$

c) Volume of cement = (mass of cement/specific gravity of cement)/1000
= (430.65/3)/1000 = 0.1435 m^3

d) Volume of water = (mass of water/ specific gravity of water)/1000
= (191/ 1)/1000 = $0.191m^3$

e) Volume of metakaolin = (mass of metakaolin / specific gravity of metakaolin)/1000
= (478.5/2.6) x 1000 = 0.018 m^3
Silica gel at 0.3 % of weight of cement = (mass of cement x 0.3)/100
= (430.65 x 0.3)/100 =1.29 kg/m^3

f) Volume of silica gel = (mass of silica gel/specific gravity of silica gel x 1000)
= 1.29/0.88 x 1000 = 1.46 $x10^{-3} m^3$

g) Volume of all in aggregate = [(a-b)-(c+d+e+f)]
= [(1-0.01)-(0.1435+0.191+1.46$x10^{-3}$+0.018)]
$=0.6360m^3$

h) Mass of coarse aggregate = f x volume of coarse aggregate x specific gravity of coarse aggregate x 1000
= 0.6360 x 0.612 x 2.638 x 1000 = 1026.79 kg

i) Mass of fine aggregate = g x volume of fine aggregate x specific gravity of fine aggregate x 1000
= 0.6360 x 0.388 x 2.51 x 1000 = 619.38 kg

3) Metakaolin at 15% of total cementinious material content = 478.5 x 15/100 = 71.77 kg/m^3

Cement content = 478.5 – 71.77 = 406.73 kg/m^3

The mix calculation per unit volume of concrete shall be as follows.

a) Total volume = $1m^3$

b) Volume of entrapped air in wet concrete = $0.01m^3$

c) Volume of cement = (mass of cement/specific gravity of cement)/1000
= (406.73/3)/1000 = 0.135 m^3

d) Volume of water = (mass of water/ specific gravity of water)/1000
= (191/ 1)/1000 = $0.191m^3$

e) Volume of metakaolin = (mass of metakaolin / specific gravity of metakaolin)/1000
= (71.77/2.6)x1000 = 0.027 m^3
Silica gel at 0.3 % of weight of cement = (mass of cement x 0.3)/100
= (406.73 x 0.3)/100 =1.22 kg/m^3

f) Volume of silica gel = (mass of silica gel/specific gravity of silica gel x 1000)
= 1.22/0.88 x 1000 = 1.38 $x10^{-3} m^3$

g) Volume of all in aggregate = [(a-b)-(c+d+e+f)]
= [(1-0.01)-(0.135+0.191+1.38$x10^{-3}$+0.027)]
=0.6356 m^3

h) Mass of coarse aggregate = f x volume of coarse aggregate x specific gravity of coarse aggregate x 1000
= 0.6356 x 0.612 x 2.638 x 1000 = 1026.14 kg

i) Mass of fine aggregate = g x volume of fine aggregate x specific gravity of fine aggregate x 1000
= 0.6356 x 0.388 x 2.51 x 1000 = 618.99 kg

4) Conventional concrete
a) Total volume = $1m^3$
b) Volume of entrapped air in wet concrete = $0.01m^3$
c) Volume of cement = (mass of cement/specific gravity of cement)/1000
   = (478.5/3)/1000 = 0.1595 m^3
d) Volume of water = (mass of water/ specific gravity of water)/1000
   = (191/ 1)/1000 = $0.191m^3$
e) Volume of all in aggregate = [(a-b)-(c+d)]
   = [(1-0.01)-(0.1595+0.191)]
   =$0.6395m^3$
f) Mass of coarse aggregate = f x volume of coarse aggregate x specific gravity of coarse aggregate x 1000
   = 0.6395 x 0.612 x 2.638 x 1000 = 1032.44kg
g) Mass of fine aggregate = g x volume of fine aggregate x specific gravity of fine aggregate x 1000
   = 0.6395 x 0.388 x 2.51 x 1000 = 622.796kg

The concrete was made by creating the mix design equivalent to M35 concrete. As concrete is subjected to acid/ chemical attack, guidelines for severe condition were adopted. IS 456: 2000 and IS 10262: 2009 IS codes where referred to create the mix design.

VII. RESULTS AND DISCUSSIONS

The following are the results from the study:

Table 11: Table of results

Test description	Silica gel based concrete (0.3 % silica gel)		Optimum mix (0.3 % silica gel and 10 % metakaolin)	
Workability	31(low workability)		40 (low workability)	
Compressive strength (N/mm^2)	7 days	28 days	7 days	28 days
	24	38	32	41
Split tensile strength (N/mm^2)	19	28	22	32
Durability test (Compressive strength after 60 days of curing in 5 % H_2SO_4 in N/mm^2)	38		62	

1) The test result shows that both silica gel concrete (0.3 % silica gel) and optimum mix (0.3 % silica gel and 10 % metakaolin) have low workability.
2) Compressive strength results shows that optimum mix have more compressive strength and achieves early age strength better than silica gel concrete.
3) Split tensile strength of optimum mix is higher than silica gel concrete.
4) Durability test result indicates that the optimum mix is more durable than silica gel concrete.
5) Silica gel concrete is stronger and durable than conventional concrete. Addition of metakaolin to silica gel based concrete can further more improve the mechanical properties and durability of the concrete.

VIII. CONCLUSIONS

The preliminary tests have proven that the materials are suitable for the experiment. The mix design has been calculated from the results of the preliminary tests that have been completed. Cubes and cylinders were casted after creating the mix design for M35 concrete. Slump test was done on fresh concrete and all the mixes proved to be low workable. Tests on hardened concrete was done and the mix which replaces 10 % of cement with metakaolin was found to be stronger in both compressive and split tensile strength. The same mix has strength values that is more than required for an M35 mix. Hence this mix was taken as optimum mix. The durability of the mixes are tested, by keeping them for curing in 5% sulphuric acid. The optimum mix have proven to be more durable than rest of the mixes and conventional concrete. Adding silica gel to concrete can improve its strength and durability. Thus adding metakaolin to silica gel based concrete can improve the strength, acid resistance, self healing ability and durability of the concrete.

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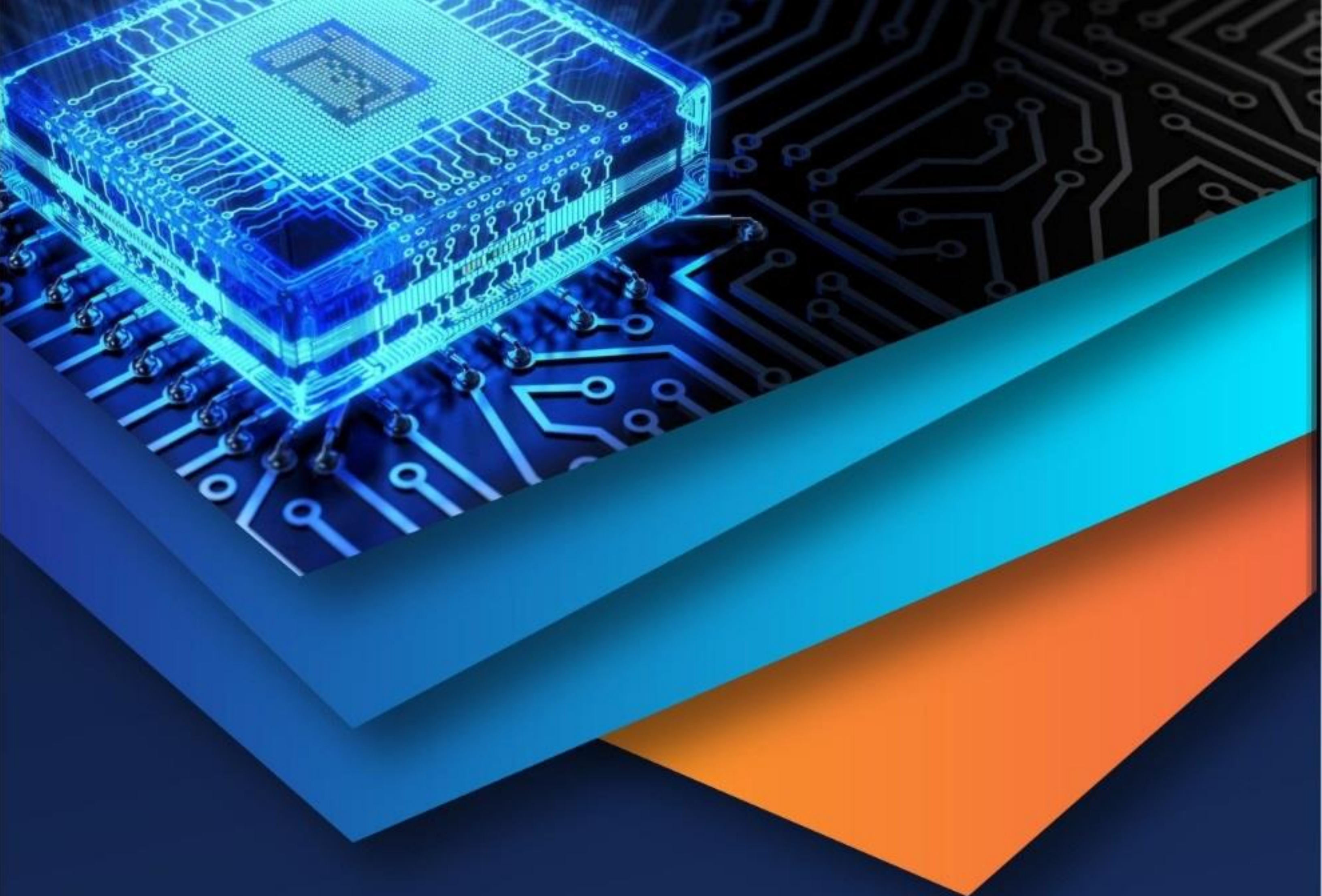

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