Influence of Metakaolin in High Strength Concrete for Various Temperatures and Acidic Medium

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Abstract- *Concrete made of cement is the most adaptive material for construction purpose. Design and Preparation of such a concrete mix with good strength and durability has been always the need of the day. Use of mineral admixture in concrete mix has made a remarkable achievement in development and design of high strength concrete.*

Among many mineral admixtures available, Metakaolin (MK) is a mineral admixture, whose potential is not yet fully tested and only limited studies have been carried out in India on the use of MK for the development of high strength concrete. MK is a supplementary cementetious material derived from heat treatment of natural deposits of kaolin. MK shows high pozzolanic reactivity due to their amorphous structure and high surface area.

The present study is aimed to find out the improvement of durability properties of concrete for various critical aggressive environmental conditions like attack of Sulphuric acid (H2SO4) and Hydrochloric acid (HCl) under variable temperature conditions.

The experimental work has been carried out as partial replacement of cement with MK in M70 grade of concrete at 0%, 10%, 15%, 20%, 25%and 30% of replacements. The mix design was made making the use of Erntroy empirical Shacklock's method. Cubes are tested for durability studies with H2SO4 and HCl of 0.5% and 1% concentrations. Cubes, cylinders and prisms are tested for temperature study at 15% replacement. The specimens were heated to different temperatures of 100o C, 200o C, 300o C, 400o C and 500o C for three different durations of 1, 2 and 3 hours at each temperature. After the samples have been exposed to hot environment, they were tested for compressive strength, split tensile strength, stress-strain curve, and flexural strength. The cube specimens were also tested for weight loss i.e. the difference in weight of specimens before and after getting exposed to hot environment and cooling down the member to the normal room temperature.

Conclusions are made from the various results and the discussions there on to identify the effect of partial replacement of cement by MK in the design concrete mix. The results conclude that, the use of Metakaolin Concrete (MKC) has improved the performance of concrete under various conditions.

Keywords- Erntroy empirical Shacklock's method, compressive strength of cubes split tensile strength of cylinders, flexural strength of cylinders.

I. INTRODUCTION

Concrete is one of the most widely used man-made construction material in the world. Metakaolin is the cementetious material used as an admixture to produce high strength concrete. Optimal quality of metakaolin for M70 grade of concrete has been worked out, which can replace the cement in order to get better strength and durability. Also identification of the drying shrinkage and permeability characteristics of blended cement has been done. Jipingbai studied that when Metakaolin is used as a partial replacement for Portland cement, tends to improve both the mechanical properties and durability of concrete. Friars and Cabrera investigated the relation between the pore size distribution and degree of hydration of Metakaolin based cement pastes. It was reported that Metakaolin showed the best improvement on the mechanical properties of concrete. Palomo investigated the chemical stability as Metakaolin based cement composites. Not until the 1900's did engineers and materials technologists become involved in optimizing the strength of concrete, though concrete has been used throughout history as a building material. With each successive development and corresponding strength increase, the definition of "high strength" was revised. Of course, there is no exact point of separation between "normal-strength" concrete. According to the American Concrete Institute, high strength is defined as that over 6000psi (41 MPa) compressive strength. This value was adopted by ACI in 1984, but is not yet hard and fast, because ACI recognizes that the definition of high-strength varies on a geographical basis. J.Francis Young of the University of Illinois at Champaign-Urbana has developed a strength classification system that, though not yet adopted by a recognized authority, is a helpful tool for describing high strength concretes.

A versatile material, high strength concrete (HSC) possesses desirable properties other than high strength. The most dramatic and memorable applications stem from this aspect**,** however, as high-rise buildings like 311 South Wackier Drive create striking visual impressions. This structure, at 969 ft (295 m), was the world's tallest concrete building when completed in 1989, utilizing concrete with compressive strengths of up to 12,000 psi (83 MPa).

Metakaolin

Metakaolin is the white powder of A.2Si by dehydrating kaolin (A.2Si.2O) at an appropriate temperature (700-900^{o}C). Kaolin is in a layered silicate structure, with the layers binding with each other via the Van Der Weal's bond, among which O is bound firmly. Kaolin, when being heated in air, may experience several structural changes, and when being heated to around 600^{o}C, the layered structure of kaolin is damaged due to dehydration to form a transient phase with a poor crystallinity, i.e. Metakaolin. As the molecular arrangement of Metakaolin is irregular in a thermodynamic metastable condition, it is cementetious under an adequate excitation. With a high activity, metakaolin can be used to manufacture cementetious materials and mix high-strength high-performance concrete.

Uses of Metakaolin

MK finds usage in many aspects of concrete:

- High performance, high strength and lightweight concrete
- Precast concrete for architectural, civil, industrial and structural purposes
- In tall and heavy structures where high strengths are required
- Fibre cement and Ferro cement products
- Glass fibre reinforced concrete
- Mortars, stuccos, repair material, pool plasters.

Advantages of Metakaolin

- Increased compressive and flexural strengths
- Reduced permeability (including chloride permeability)
- Reduced potential for efflorescence, which occurs when calcium is transported by water to the surface where it combines with carbon dioxide from the atmosphere to make calcium carbonate, which precipitates on the surface as a white residue.
- Increased resistance to chemical attack
- Increased durability
- Reduced effects of alkali-silica reactivity (ASR)
- Enhanced workability and finishing of concrete
- Reduced shrinkage, due to "particle packing" making concrete denser

Improved color by lightening the color of concrete making it possible to tint lighter integral color.

Frais.Met al.[8] (2000) The authors show the results of an investigation focusing on the effect of Metakaolin (MK) on the micro-structure of MK-blended pastes. Pastes containing 0%, 10%, 15%, 20% and 25% of MK were prepared at a constant water/binder ratio of 0.55 and cured at 200ºC for hydration periods from 1 to 360 days. They investigated total capillary and gel porosity evolution with the curing period and also estimated the degree of hydration in the ordinary Portland cement and Metakaolin blended pastes. The values of the degree of hydration are calculated from the amount of $Ca(OH)_2$ present in the paste and from the data of differential thermal analysis (DTA) thermogravimetry (TG). A good association between porosity and degree of hydration has been established. The total porosity decreases up to 28-56 days of curing time. They observed that, up to 28 to 56 days of curing the porosity is same for all the mixes. Beyond 56 days the porosity of all the Metakaolin mixes increasing when compared with OPC mix. Similar phenomenon is observed for capillary porosity. The best evidence of the influence of MK on the refineness of the pore structure was detected in pores with radius smaller than 100°A. Between 7-90 days, the gel porosity of MK mixes increase, while the OPC mix remains practically constant. The results show the necessity of obtaining important improvement in the porosity reducing the average pore diameter and gel porosity. Measured lime contents show the total consumption of MK (10% to 15%) at 90 days of hydration time. A good statistical relationship has been found between the degree of hydration and the porosity.
Xia Oquian and Zongjinli[20](**2001**)studied the stress–strain relationships of concrete containing 0% to 15% of Metakaolin at an incremental rate of 5%. They concluded that incorporation of Metakaolin up to 15% has increased the tensile and compressive strength and also peak strain is increased at increasing rate of Metakaolin up to 15%. Incorporation of Metakaolin has slightly increased the compressive elasticity modulus.

II. METHODOLOGY

Introduction

Based on the preliminary investigations carried out, the experimental investigation is planned as under.

1. To obtain the mix proportions of OPC concrete for M70 by Erntroy and Shacklock's Empirical graphs
2. To calculate the mix proportions with partial replacements such as 0%, 10%, 15%, 20%, 25%and 30% of Metakaolin with concrete.
3. Preparation of Testing Specimens

- To prepare concrete specimens such as cubes (150 x 150 x 150) for durability studies in laboratory with 0%, 10%, 15%, 20%, 25% and 30%replacement of OPC with Metakaolin for M70 grade concrete.
- To prepare the concrete specimens such as cubes (150 x 150 x 150mm) for compressive strength, cylinders (150 x 300mm) for split tensile test, prisms (100 x 100 x500mm) for flexural strength, cylinders (150 x 300mm) for modulus of elasticity with 0% and 15% replacement of OPC with Metakaolin for M70 grade concrete for temperature study i.e., for 100^{o}C, 200^{o}C, 300^{o}C, 400^{o}C and 500^{o}C.
- To cure the specimens for 28 days.

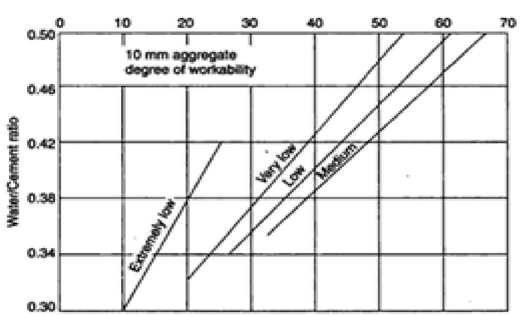
4. To evaluate the mechanical characteristics of concrete such as compressive strength, split tensile, flexural strength, modulus of elasticity.
5. To evaluate the durability studies of M70 grade Metakaolin replacement concrete with 0.5% and 1% concentrations of HCland H_2SO_4.
6. To evaluate the temperature studies of M70 grade MKC at an exposure of100^{o}C, 200^{o}C, 300^{o}C, 400^{o}C and 500^{o}C for 1hr, 2hr and 3hr duration.

To evaluate and compare the results.

III. MIX DESIGN PROCEDURE

The mean design strength is obtained by applying suitable control factors to the specified minimum strength.

1. For a given type of cement and aggregates used, the reference number corresponding to the design strength at a particular age is interpolated from graph 3.3.1 to 3.3.4.
2. The water-cement ratio to achieve the required workability and corresponding to the reference number is obtained from graph 3.3.5 for aggregates with maximum sizes of 20mm and 10mm.
3. The aggregate-cement ratio to give the desired workability with the known water cement is obtained by absolute volume method.
4. Batch quantities are worked out after adjustments for moisture content in the aggregates.



Graph-3.3.6: Relation between water-cement ratio and Reference Number

Design of M70 Grade Concrete by Erntroy and Shacklock's Method

Specified 28 day cube strength = 70MPa.
Very good degree of control:
Control factor =0.85.
Degree of workability = very low.
Type of cement = Ordinary Portland cement (43 grade)
Type of coarse aggregate = crushed granite (angular) maximum size-20mm
Type of fine aggregate – natural sand
Specific gravity of cement = 3.15
Specific gravity of sand = 2.60
Specific gravity of Coarse aggregate = 2.64

The fine and coarse aggregate contains 5 and 1 percent moisture respectively and by assuming aggregate is 100% passing through 20mm IS sieve and 96% through 10mm IS sieve.
Average strength = 70/0.85 = 82.35MPa.
Reference number = 0.
With reference number, the water/ cement ratio is = 0.30.
For 20mm maximum size aggregate and very low workability, aggregate / cement ratio for the desired workability = 3.3
The aggregate are combined so that 30percent of the material passes through the 4.75mm I.S. sieve.
Ratio of fine to total aggregate = 35%.
Required proportions by weight of dry material are

Cement	F.A	C.A.	Water.
1	( ) X 3.3	( ) X 3.3	0.30
1	1.155	2.145	0.30.

If C= weight of cement required per m^3 of concrete.
Then + + + = 1000
C [0.317 + 0.444+0.812 + 0.30] =1000
C=533.9 kg/m^3 of concrete
=534 kg/m^3

Design MIX Proportion:

Ratio of mix proportion by weight:

Mix Grade	Cement	Fine Aggregate	Coarse Aggregate	Water/Cement
M 70	1	1.155	2.145	0.30

Material requirement (M70)

Mix design ratio **1: 1.155: 2.145: 0.30**

S.No	Material required	Quantity in kg/m3
1	Cement	534
2	Fine Aggregate	616.77
3	Coarse Aggregate	1145.43
4	Water	160.2 liters

The compressive Strength of OPC concrete after the trials mixes is 79.55 Mpa at 28 days. And also admixtures (water reduces 30%) super plasticizers (conplast sp430) is approximately 8 litres.

Replacement of cement with Metakaolin

Calculated the mix proportion by partial replacement of OPC with 0%, 10%, 15%, 20%, 25% and 30% of MK.

Preparation of Testing Specimens

The specimens of standard cubes (l50mm x 150mm x 150mm), Standard prisms (100mm x 100mm x 500mm) and Standard cylinders (150mm x 300mm) are casted.

In all 18 specimens (cubes) the cement was replaced by MK (0%, 10%, 15%, 20%, 25% and30%) with M70 grade of concrete mix were cast, cured for 28 days and compressive strength of the cubes were noted.

In all 72 specimens (cubes) the cement was replaced by MK (0%, 10%, 15%, 20%, 25% and 30%) with M70 grade concrete mix were cast, cured for 28days for durability studies.

In specimens 96(cubes), 192(cylinders), 96(prisms) the cement was replaced by MK (0% and 15%) with M70 grade concrete mix were cast, cured for 28days for temperature studies.

Mixing

In the present work, the machine mixing process is employed. In the individual mix, ingredients are weighed with their proportions exactly and then the materials are thoroughly mixed in their dry condition before water is added. The prepared mix was then immediately used for testing workability of fresh concrete mix. In case of replacement cement with MK, the MK is first thoroughly mixed with cement in dry state and then this was mixed with aggregate.

Casting of the Specimens

The cast iron moulds are cleaned to avoid dust particles and applied with oil on all sides before concrete is poured in to the moulds. The moulds are placed on a level platform. The well mixed green concrete is filled in to the moulds by vibration with table vibrator. Excess concrete was removed with trowel and top surface is finished level and smooth as per IS 516-1959.

Compaction of Concrete

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In the process of placing and mixing of concrete, air is likely to get entrapped in the concrete. If air is not removed fully, the concrete loses strength considerably.

In order to achieve full compaction and maximum density, Table vibrator is used in this experiment.

Curing of test specimens

After casting, the moulded specimens are stored in laboratory in room temperature for 24 hours. After these periods the specimens were removed from the moulds and immediately submerged in clean, fresh water curing tank for required period as per IS 516-1969. The specimens are cured for 28 days.

Tests for Workability

Slump Cone Test

Slump cone test is a very common test for determination of workability of concrete. This test was carried out for M70 grade concrete mix, before casting the specimens.

Compaction Factor Test

This test is more accurate than slump cone test and this test is used to determine the workability of low water cement ratio concrete more accurately. This test is conducted as per IS 1199-1959.

Table3.6.1 Slump and Compaction Factor Values for M70

S.No	Description for M70	Compaction Factor	Slump(mm)
1	Plain concrete	0.84	25
2	Metakaolin 10%	0.83	23
3	Metakaolin 15%	0.82	21
4	Metakaolin 20%	0.80	19
5	Metakaolin 25%	0.78	16
6	Metakaolin 30%	0.76	11

Testing of specimens

A time schedule for testing of specimens is maintained to ensure their proper testing on the due date and time. The cast specimens are tested as per standard procedures, immediately after they are removed from curing pond and wiped off the surface water, as per IS 516-1959. The test results are tabulated.

Test for compressive strength

The specimens of 150 X 150 X 150 mm cubes exposed to a specific temperature and duration were released from the furnace and tested for compressive strength after cooling down the specimens to normal room temperature condition. The specimen cubes were placed in the compression testing machine such that the load was applied on the opposite sides of the cube as shown in fig 3.3. The axis of the cube was meticulously aligned with the centre of steel plate of the test machine. The load was gradually applied without any shock and increased continuously at a rate of 140 $kg/cm^2/min$(approximately) until the resistance of the specimen to the increasing load broke down and no greater load was sustained. The compressive strength of the specimen was computed by dividing the maximum load received by the specimen with the cross sectional area. Average of three test results of the specimen was considered as the compressive strength by ensuring the individual variation is not more than 15% of the average value.

Test for split tensile strength

The specimen cylinders of 150 mm in diameter and 300 mm long after subjected to temperature exposure for specified duration were released from the furnace and tested for split tensile strength after the specimens were cooled down to the normal room temperature condition. Before placing the cylinder specimens in the compressive testing machine, diametrical lines were marked at the two ends of the specimen. Plywood strip was arranged in the machine to place the specimen by aligning in such a way that the lines marked on the end of specimen are truly vertical and centred over the plywood strip. Another plywood strip was then placed on the cylinder length wise in such a way that it is centred on the lines marked at the ends of the cylinder as shown in fig3.4. The failure load applied on the specimen was recorded. Finally the split tensile strength of the specimen was computed as mentioned below.

Where d = dia of the cylinder measured.
l = length of cylinder measured.
P = maximum load recorded.

The average value of the three specimens was considered as the split tensile strength after satisfactory compliance of the condition that individual variation shall not be more than 15 % of the average strength observed.
Fb=2P/PILD

3.7.3 Test for flexural tensile strength (two point load test)

Test specimens (100x100x500 mm beams) exposed to specific temperature with specific duration were released from the furnace and tested for flexural tensile strength or modulus of rupture after the specimens were cooled down and brought to normal room temperature conditions. The beams were placed in the Universal Testing Machine such that the load was applied to the upper most surface as laid in the mould along two parallel lines spaced at 133 mm apart as shown in fig 3.5. The load was applied gradually without any shock and increased until the specimen failed. The maximum load applied to the specimen during the test was recorded. The distance between the line of fracture and the nearest end support along the tensile side of the specimen was measured and recorded. Then the flexural strength or modulus of rupture was computed by using the relevant equation out of the two as mentioned below basing on the value of 'a' which is the distance between the line of fracture and the nearest support.

(i) If a> 13.33 cm

$$fb = \frac{(p \, x \, l)}{(b \, x \, d^2)}$$

(ii) If a< 13.33 cm
But a < 11.0 cm

$$fb = \frac{(3p \, x \, a)}{(b \, x \, d^2)}$$

Where b = measured width in cm of specimen.
d = length in cm of the span on which the specimen
L = length in cm of the span on which the specimen, and
P = maximum load in kg applied to the specimen

Durability Studies with $H_2SO_4$and HCl

Concrete cubes of 150x150x150 mm size were cast for durability studies, M70 grade of concrete cubes are cast for0.5% and 1%concentration of HCl and H_2SO_4 for 28 days. The specimens of M70 grade consists of 6 series 0%, 10%, 15%,20%, 25%, and 30%. So, 6 no of cubes placed in individual tubs for each concentration and check the normality of solution for every 3 days.

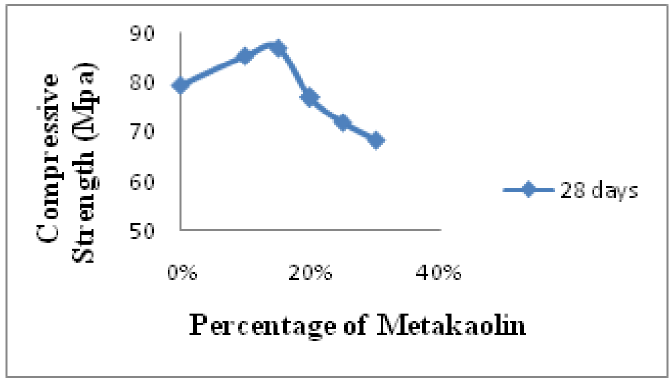
IV. RESULTS AND DISCUSSION

The tests were carried out to obtain compressive strength, split tensile strength, flexural strength and stress-strain curve of M70 grade concrete. The specimens are tested for 28 days for 0%, 10%, 15%, 20%, 25% and 30% replacement of MK for compressive strength and the specimens are tested for 28 days for 0% and 15% replacement of MK for flexural strength,stress-strain curve, split tensile strength.These are presented in tables and graphs were plotted correspondingly.

4.1 Effect of variation of Metakaolin on Compressive Strength

Table 4.1.1 Compressive Strength of concrete for M70

S.No	Percentage of Metakaolin	Compressive strength of cube(Mpa)
		28 Days
1	0	78.93
2	10	84.95
3	15	86.88
4	20	75.54
5	25	72.09
6	30	67.74



Graph 4.1.1 Compression strength of concrete vs. % of Metakaolin

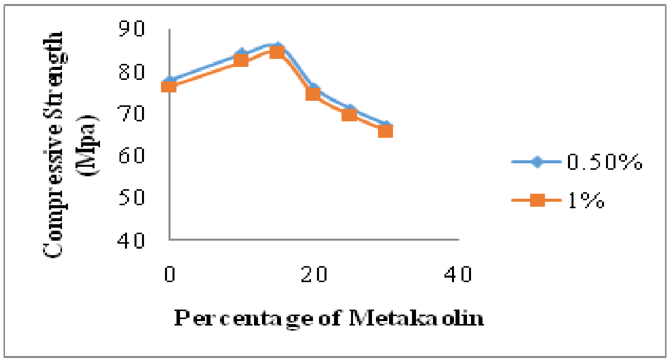
From the above graph4.1.1 it is observed that at 15% replacement of cement with MK, concrete attains its maximum compressive strength. When the replacement exceeds 15%, the compressive strength is found to be decreasing slightly.

4.2 Effect of H_2SO_4 and HCL acids on Metakaolin Concrete (Durability Studies)

Table 4.2.1 Compressive strength for M70 grade concrete after 0.5% and 1% HCl acid curing

S.No	% of Metakolin	Compressive strength of cube0.5%HCL(Mpa)	Compressive strength of cube 1 % HCL (Mpa)
		28 days	28 days
1	0	76.92	75.84
2	10	83.21	81.68
3	15	84.92	83.88
4	20	74.78	73.41
5	25	70.02	69.15
6	30	66.25	64.98

Concrete cubes of 0%, 10%, 15%, 20%, 25%and 30% of MKC of M70 grade concrete exposed to HCL and H_2SO_4 of 0.5% and 1% concentrations are tested for compressive strength for 28 days respectively. The results are presented in the following tables and the graphs are plotted.



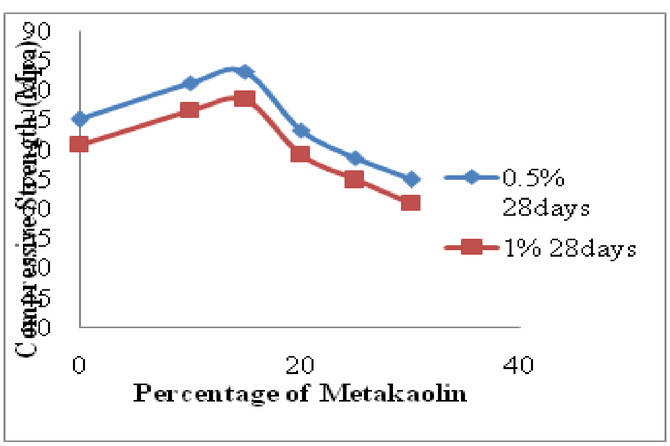
Graph 4.2.1 Compressive Strength of concrete vs. % of MK at 0.5% and 1% HCl

From the above graph4.2.1, it is observed that at 15% replacement of cement with MK, concrete attains maximum compressive strength when exposed to 0.5%, 1% HClat the age of28 days.When the replacement exceeds 20%, the compressive strength is found to be decreasing slightly.

4.2 Effect of H_2SO_4 and HCL acids on Metakaolin Concrete (Durability Studies)

Table 4.2.2 Compressive strength for M70 grade of concrete after 0.5% and 1% H_2SO_4acidcuring

S.No	% of Metakolin	Compressive strength of cube0.5% H_2SO_4 (Mpa)	Compressive strength of cube 1 % H_2SO_4 (Mpa)
		28 days	28 days
1	0	74.87	69.98
2	10	80.70	75.82
3	15	82.12	77.32
4	20	72.40	68.32
5	25	67.53	63.71
6	30	63.74	59.97



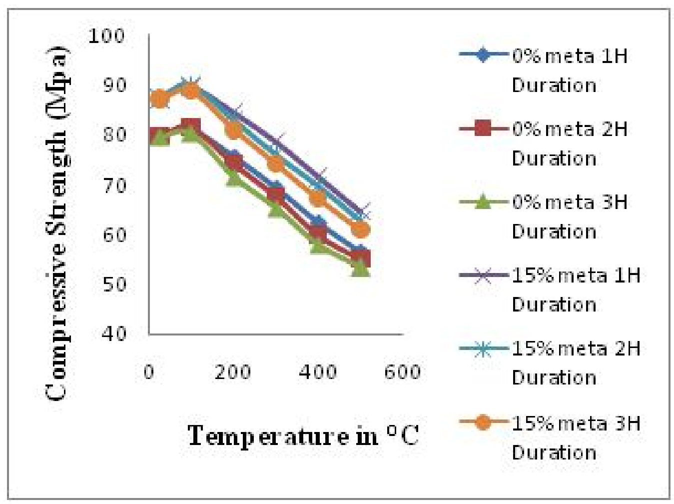
Graph 4.2.2 Compressive Strength of concrete vs. % of Metakaolin at 0.5%, 1% H_2SO_4

From the above graph4.2.2, it is observed that at 15% replacement of cement with MK, concrete attains maximum compressive strength when exposed to 0.5%, 1%H_2SO_4 at the age of 28 days. When the replacement exceeds 20%, the compressive strength is found to be decreasing slightly.

4.3 Effect of Temperature on Compressive Strength of Metakaolin Concrete (Temperature Studies)

Table 4.3.1 28 Days Compressive Strength exposed to different Temperatures

S. No	Temperature	28 days compressive strength for duration of exposure of 0% MKC			28 days compressive strength for duration of exposure of 15% MKC		
		1 hr	2 hr	3 hr	1 hr	2hr	3hr
1	27	78.62	78.62	78.62	86.21	86.21	86.21
2	100	80.54	80.07	79.88	88.69	89.33	87.94
3	200	74.87	73.78	70.92	83.88	81.72	80.00
4	300	68.54	66.71	64.48	77.55	74.88	73.08
5	400	61.34	58.92	57.10	70.88	68.88	66.32
6	500	55.67	53.98	52.90	63.71	61.84	59.42



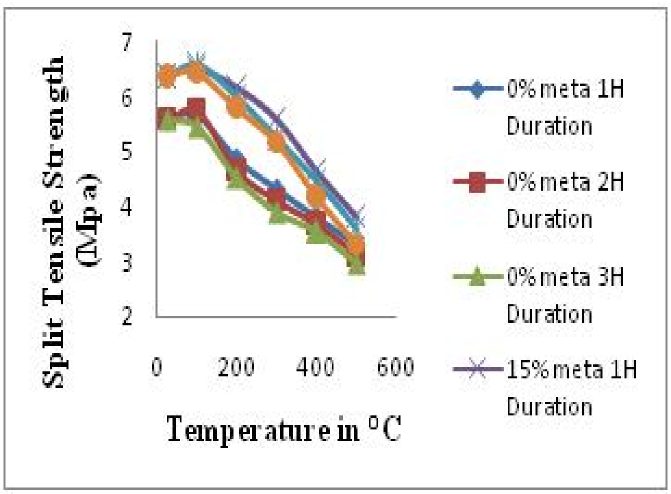
Graph 4.3.328 Days Compressive Strength of concrete (%) vs. Exposed temperature (°C) of 0% and 15% MKC

From the above graphs4.3.1, 4.3.2, it is observed that the compressive strength increases at 100°C temperature when compared to the strength obtained at normal room temperature for 0% and 15% replacement of MK. The increase in compressive strength associated with the increase in temperature is attributed to the increase in the surface forces between gel particles (Vander wall forces) due to the removal of moisture content. The compressive strength decreases from 100°C to 200°C and further decreases at 500°C.

4.4 Effect of Temperature on Split Tensile Strength of MetakaolinConcrete (Temperature Studies)

Table 4.4.1 28 Days Split tensile Strength exposed to different Temperatures

S. No	Temperature	28 days Split tensile strength for duration of exposure of 0% MKC			28 days Split tensile strength for duration of exposure of 15% MKC		
		1 hr	2 hr	3hr	1 hr	2 hr	3 hr
1	27	4.91	4.91	4.91	5.80	5.80	5.80
2	100	5.12	5.21	5.01	6.04	6.12	6.00
3	200	4.31	4.24	4.01	5.82	5.70	5.28
4	300	3.94	3.71	3.55	5.17	4.82	4.71
5	400	3.50	3.42	3.34	4.11	4.00	3.91
6	500	3.01	2.90	2.88	3.42	3.21	3.01



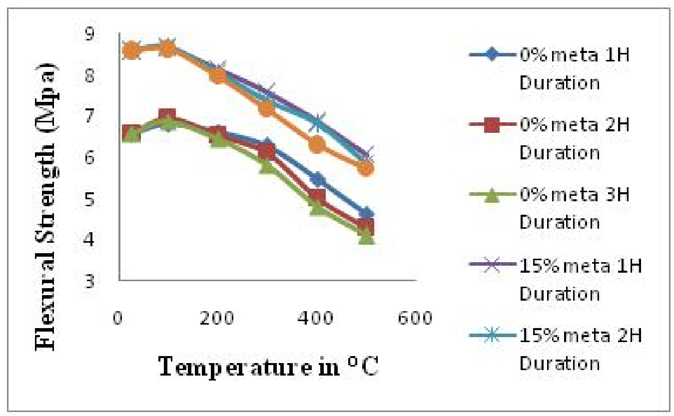
Graph 4.4.3 28 Days Split Tensile Strength of concrete (%) vs. Exposed Temperature (°C) of 0% and 15% MKC

From the above graphs4.4.1, 4.4.2, it is observed that the split tensile strength increases at 100°C temperature when compared to the strength obtained at normal room temperature for 0% and 15% replacement of MK. The increase in split tensile strength associated with the increase in temperature is attributed to the increase in the surface forces between gel particles (Vander wall forces) due to the removal of moisture content.

4.5 Effect of Temperature on Flexural Strength of Metakaolin Concrete

Table 4.5.1 28 Days Flexural Strength exposed to different Temperatures

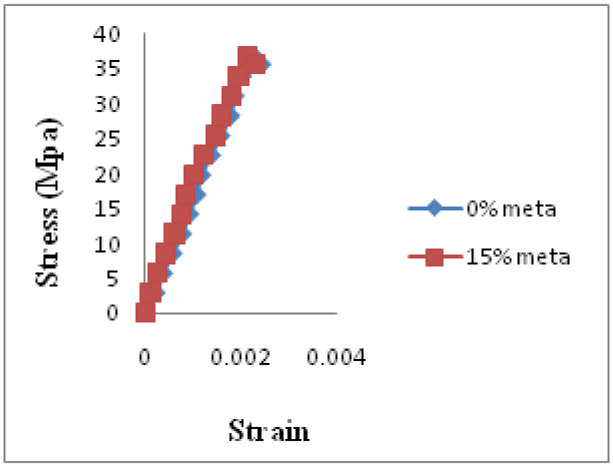
S. No	Temperature	28 days Flexural strength for duration of exposure of 0% MKC			28 days Flexural strength for duration of exposure of 15% MKC		
		1 hr	2 hr	3 hr	1 hr	2 hr	3 hr
1	27	6.01	6.01	6.01	8.02	8.02	8.02
2	100	6.27	6.39	6.30	8.08	8.12	8.04
3	200	6.05	6.02	5.93	7.68	7.64	7.40
4	300	5.78	5.60	5.32	7.10	6.91	6.80
5	400	5.04	4.58	4.40	6.41	6.38	6.00
6	500	4.10	3.91	3.71	5.84	5.48	5.33



Graph 4.5.3 28 Days Flexural Strength of concrete (%) vs. Exposed Temperature (°C) of 0% and 15% MKC

Effect of Temperature on Stress-Strain Curve of MetakaolinConcrete

The stress-strain behavior of cylinder specimens for 0% and 15% of metakaolin cured for 28 days age and subjected to elevated temperature from 100 to 500°C apart from room temperature were as shown below. The various graphs plotted are as shown in Fig.4.6.1 to 4.6.6.



Graph 4.6.1 Stress-strain curve of concrete at room temperature

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the experimental investigation carried out, the following conclusions are made.

1. Workability of concrete decreases with the increase in Metakaolin replacement level.
2. The compressive strength, flexure strength and split tensile strength of conventional concrete and concrete with MK as partial replacements are compared and observed and concluded that the strength of the conventional concrete is slightly lower than the MKC.
3. The compressive strength of concrete is increased when cement is replaced with Metakaolin. The compressive strength is maximum at 15% of replacement.
4. The split tensile strength of concrete is increased when cement is replaced with Metakaolin. The split tensile strength is maximum at 15% of replacement.
5. The flexure strength of concrete is increased when cement is replaced with Metakaolin. The flexure strength is maximum at 15% of replacement.
6. At room temperature and 100^{o}C exposure, the stress-strain relationship is similar to the conventional concrete&MKC behavior. However the trend is different for temperature exposure of 200^{o}C to 500^{o}C.
7. The compressive strength of concrete showed better result at 15% replacement of MK for 0.5% and 1% HCl at the age of 28days of strength.
8. The compressive strength of concrete showed better result at 15% replacement of MK for 0.5% and 1% H_2SO_4 at the age of 28 days of strength.
9. The effect of HCl on strength of the Metakaolin concrete is lower than the effect of H_2SO_4.

5.2 Scope for Further Study

1. The study may be extended to know the behavior of concrete at elevated temperatures up to 800^{o} C.
2. MKC exposed to duration of heating from 4 hours to 8 hours at different temperatures can be carried out.
3. Studies on replacement levels for higher grade concretes can be carried out.
4. Combination of Metakaolin with different other mineral admixtures like fly ash and Rise Husk Ash can be carried out.

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