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A Research on Investigation of Various Properties of Metakaolin Based Concrete

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ABSTRACT

Concrete is probably the most extensively used construction material in the word .However, environmental concerns both in terms of damaged caused by the extraction of raw material and co2 emission during cement manufacturing have brought pressure to reduce cement consumption by the use of supplementary material. The utilization of calcined clay, in the form of metakaolin (MK) in the concrete has received considerable attention in recent years . On this, subject, an experimental investigation on cement concrete using metakaolin has been conducted. The cement is replaced with 10%, 15%, 20%, and 25% metakaolin by weight of cement. Concrete cubes and beams are tested at the age of 7 days and 28 days. The study focuses on the compressive strength and flexural strength performance of the blended concrete containing different percentage of metakaolin .In addition, evaluation of durability properties like soundness, abrasion resistance, and impact resistance is also included in the study. The strength performance of metakaolin –concrete is compared with the performance of plain concrete. The results of the study show that the strength development of concrete blended with metakaolin is enhanced. The 20% replacement with metakaolin is found to be the most efficient replacement leading to maximum enhancement in the strength and durability properties of concrete.

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INTRODUCTION

Concrete is one of the most common materials used in the construction industry. In the past few years, many research and modification has been done to produce concrete which has the desired characteristics. There is always a search for concrete with higher strength and durability. In this matter, blended cement concrete has been introduced to suit the current requirements. Cementations materials known as pozzolans are used as concrete constituents, in additions to Portland cement. Originally the term puzzling was associated with naturally formed volcanic ashes and claimed earths will react with lime at ambient temperatures in the presence of water. Recently, the term has been extended to cover all siliceous / aluminous materials which, in finely divided form and in the presence of water, will react with calcium hydroxide to form compounds that possess cementations properties. The current area of research in the concrete is introducing clay (met kaolin) in the concrete.

Clays have been and continue to be one of the most important industrial minerals. Clays and clay minerals are widely utilized in our society. They are important in geology, agriculture, construction, engineering, process industries, and environmental applications, Traditional applications of clay including ceramics, paper, paint, plastics, drilling fluids, chemical carriers, liquid barriers, and catalysis. Research and development activities by researches in higher education industry are continually resulting new and innovative clay products.

Met kaolin is one of the innovative clay products developed in recent years. It is produced by controlled thermal treatment of kaolin. Met kaolin can be used as a concrete constituent. Replacing part of the cement content since it has pozzolanic properties. The use of metakaolin as a partial cement replacement material in mortar and concrete has been studied widely in recent years. Despite of the recent studies, there are still many unknowns with the use of metakaolin. Study is needed to determine the contribution of metakaolin to the performance of hardened concrete. There are great concerns on the strength and durability of metakaolin-concrete when used as construction materials in the construction industries. If it is proven that the concrete is durable and strong, this will lead to the use of metakaolin to replace part of the cement.

1.2.1 Advantages of metakaolin.

a) Increased compressive and flexural strengths
b) Reduced permeability
c) Increased resistance to chemical attack
d) Increased durability
e) Reduced shrinkage due to particle packing, making concrete denser
f) Enhanced workability and finishing of concrete
g) It controls consumption of cement.

Literature Review

Ambrosia et at. (2015) studied the improvements in the strength of metakaolinite cements activated with calcium hydroxide. It was found that more convenient curing process implied the immersion in water after the removal of samples form the moulds at 7 day, and roving ar 50oC for one day before mechanical testing. The process led to considerable improvement of strengths.

Zhang and Malhotra (2017) investigated various properties of metakaolin concrete having 10% replacement level of metakaolin. It was found to have higher compressive strengths for all the ages in comparison to that of control concrete.

Al amoudi et al. (2017) studied the behaviour of concrete using supplementary cementing material and found that the incorporation of blast furnace slag, fly ash, and silica fume as Partial replacement of ordinary cement had the beneficial effect of enhancing the resistance of concrete to sulfate attack.

Wild et al. (2016) investigated the effect of varying percentages of metakaolin on the compressive strength of concrete mixtures. Replacement levels of ordinary Portland cement (OPC) by metakaolin (MK) were 0, 5, 10, 15, 20, 25, and 30% having w/c ratio 0.45. OPC concrete mixture Proportion was 1:2.3:3.4. Compressive strength tests were conducted up to the age of 90 days. They concluded that inclusion of MK as partial replacement of cement enhanced the compressive strength of concrete at all ages, but the optimum replacement level of OPC by MK to give maximum long term strength enhancement was about 20% Curios et al. (1998) examined the role of metakaolin as pozzolanic micro filler for high performance super-plasticized mortars containing (MK) as 15% replacement of cement with a w/c ratio of 0.33. Four commercially available MK samples and one silica fume sample ware studied for comparison. They concluded that: Specimens containing three of the four metakaolin samples had a higher rate of compressive strength development as compared to that of the control mix at ages below 28 days, a consequence of the higher hydration rate. Silica fume and the fourth and coarser metakaolin had a less pronounced effect at 90 and 180 days, metakaolin and silica fume specimens gave similar strengths. The difference in the compressive strength between the specimens with micro fillers and the control mix decreased after 28 days, because of a reduced slow down of the hydration rate in the control mix.

Khatib and wild (2018) evaluated the effect of metakaolin on the sulphate resistance of mortar. The types of cements were used; high C3A and intermediate C3A content. Cement was replaced with 0, 5, 10, 15, 20, and 25% of metakaolin (MK). Specimens of size 150 x 150 x 150 mm were moist-cured in air for 14 days, and their length was measured before immersing in 5% Na2So4 solution. Test results demonstrated that:

Qian and Li (2015) observed the effects integrating metakaolin on stress – strain relationships (tension and compression) and flexural strength for concrete at 0%, 5%, 10%, and 15% metakaolin. From test results it was observed that the addition of metakaolin is directly proportional to increase in modulus of rupture, compressive strength, tensile strength and peak strain while tensile elastic modulus showed minor changes.

Poon et al. (2019) showed that the cement pastes containing 5% -20% MK had higher compressive strengths than the control at all ages from 3 to 90 days, with the paste containing 10 % MK performing the best. The cement pastes containing silica fume (SF) or Fly ash (FA) had lower compressive strengths tham the control at early ages. The SF replacements resulted in higher compressive strengths than the control at 28 and 90 days, while the FA replacement resulted in a higher compressive strength than the control only at 90 days. The above results indicated that at early ages, the MK contributed better to the compressive strength development of high performance cement pastes than the SF.

Roy (2017) studied the effect of silica fume (SF), metakaolin (MK), and low-calcium fly ash on compressive strength of concrete. It was reported that compressive strength increased on addition of MK. SF also increased compressive strength but lesser than MK. Similarly, FA also increased compressive strength but to a lesser magnitude. No significant change in compressive strength was found as a function of replacement level for SF and MK series. However, the compressive strength decreased as the FA replacement level increased. This clearly showed that low-calcium fly ash is less reactive than SF and MK and Needs an external activation.

Brooks and Johri (2016) determined the compressive strength of concretes containing 0, 5, 10, and 15% metakaolin (MK). Mixture proportion of OPC concrete was 1:1. 5:2.5 with a water-to-cement Ration of 0.28. It was observed that compressive strength increased with the increase in the metakaolin content.

Bai et al. (2012) reported the influence of the composition of Portland cement-pulverized ivel ash-metakaolin binders on strength development of PC-PFA-MK concrete cured both in air and water. Concrete mixtures were made with cement replacement levels (10, 20, 30 and 40%) for PC-PFA-MK concrete with various MK/PFA proportions and cured in water and air up to 10 months. In water-cured concrete made with PC-PFA-MK binder, the MK enhanced early (28 days) strength, and PFA retarded early strength. Air-cured concrete showed a loss in strength relative to equivalent concrete that was water cured and the strength difference increased with curing period. The difference was enhanced in concrete made with PC-PFA binder at high replacement levels, which showed a much reduced strength gain with time when air cured, whereas for PC-PFA-MK concrete, this difference as the MK content increased.

Zongjin and Ding (2015) investigated that a 10 % blend of metakaolin reduces the fluidity of the mixture. The water demand was increased by roughly 11%, which is attributed to the plate-like particle shape and its tendencies to absorb water. Setting times were also shown to decrease by 26% and 36% for initial and final setting times.

Kim et al, (2017) conducted research on metakaolin blends of 5, 10, 15, and 20% There is no significant effect on the flexural strength or split tensile strength for replacement levels of 5 to 15% However, there appears to be slight decreases in strength in the 20%blends at ages less than 28 days.

Objective of the work

This study is conducted to accomplish the following objectives:
- To collect Suitable materials and metakaolin for use in the study.
- To evolve mix designs for M-30 grade concrete with varying proportions of metakaolin for use in the study.
- To investigate compressive and flexural strengths of metakaolin concrete.
- To investigate durability properties of metakaolin concrete like its soundness and abrasion resistance.
- To determine suitability of use of metakaolin as a mineral admixture in cement concrete in the construction work.

Materials and Methodology

In this study, rubber is used as the partial replacement of coarse aggregate by different amount of percentage. Cement

- ✓ Fine aggregate
- ✓ Coarse aggregate
- ✓ metakaolin
- ✓ Water

Result

In this study, metakaolin is used as the partial replacement of coarse aggregate by different amount of percentage.

To evaluate properties of met kaolin, the following lab tests were performed. .
- Wet sieve analysis
- Proctor tests

To evaluate properties of aggregates, the following lab tests were performed.
- Specific gravity test
- Gradation test
- Water absorption

To evaluate properties of cement, the following lab tests were performed.
- Specific gravity test
- Compressive strength at 7 days

To evaluate properties of metakaolin based cement concrete, the following lab tests were performed.
- Compressive strength
- Flexural strength
- Abrasion resistance
- Soundness.

EFFECT OF METAKAOLIN ON COMPRESSIVE STRENGTH

In this section the main concern is to study the compressive strength of concrete containing various percentage of met kaolin. Plain concrete specimens are compared with the strength performance of cement concrete containing 10%, 15%, and 25% met kaolin. Concrete cubes of size 150x150x150m were tested at the age of 7 and 28 days. The results of the compressive strength (7days) are shown in table 7.1, where each vale is averaged from the results of the cube.

Table Compressive Strength at 7-Days

Serial NO.	Mix Designation	% of Met kaolin by wt of cementations material in the mix	Avg. Comp. St. at 7 Days (MPs)	% increase w. r. t control mix
1	M0 (control mix)	0	26.9	0
2	M10	10	28.1	4.5
3	M15	15	29.3	8.9
4	M20	20	30.6	13.8
5	M25	25	29.2	8.6

All the percentage of cement replacement with met kaolin showed higher compressive strength than the control mix. Thus concrete with met kaolin replacement achieves higher early compressive strengths. It is observed that the maximum increase of 13.8% in 7-days compressive strength occurs for 20% met kaolin based concrete.

Table Compressive Strength at 28 Days

Serial NO.	Mix Designation	% of Met kaolin by wt of cementations material in the mix	Avg. Comp. St. at 7 Days (MPs)	% increase w. r. t control mix
1	M0 (control mix)	0	38.5	0
2	M10	10	38.9	1.0
3	M15	15	39.6	2.9
4	M20	20	40.5	5.2
5	M25	25	38.6	0.3

All the percentage of cement replacement with metakaolin showed higher compressive strength than the control mix. Thus concrete with met kaolin replacement achieves a higher early. It is observed that the maximum increase of 5.2% in 28 days compressive strength concurs for 20% met kaolin based concrete.

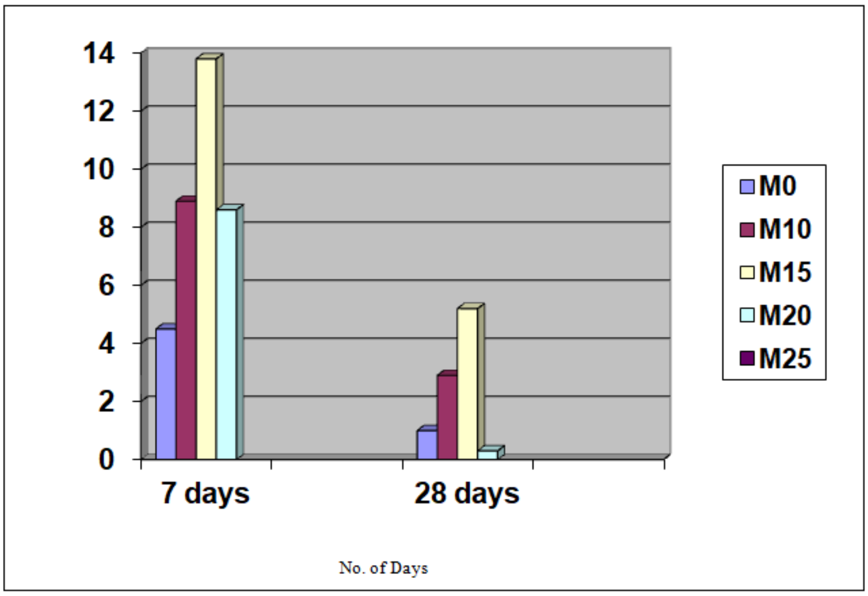

Fig COMPRESSIVE STRENGTH TEST RESULTS

EFFECT OF METAKAOLIN ON FLEXURAL STRANGTH

Flexural strength of concrete is also affected with the addition of varying percentage of met kaolin in the concrete mix. Flexural strength test results of various concrete mixes.

Table Flexural Strength of Concrete Mixes

Serial NO.	Mix Designation	7 Days Flexural	% increase w.r.t. control mix	28Days Flexural St.	% increase w.r.t. control mix
1	M0 (control mix)	3.58	0	4.47	0
2	M10	3.76	0.5	4.56	2.0
3	M15	3.90	8.9	4.79	7.2
4	M20	4.14	15.6	4.96	11.0
5	M25	4.0	11.7	4.66	4.3

It is observe that the flexural strength increased both at 7-days and 28 days with addition of met kaolin to concrete. The maximum increase in found for 20% addition of met kaolin. The increase in flexural strengths follows the same pattern as that of compressive strength.

Table Gain in Strength

Serial NO.	Mix Designation	Percentage(%) gain in 7 days Strength		Percentage(%) in 28 days Strength	
		Comp. Strength	Flexural Strength	Comp Strength	Flexural Strength
1	M0	0	0	0	0
2	M10	4.5	5	1	2.0
3	M15	8.9	8.9	2.9	7.2
4	M20	13.8	15.6	5.2	11.0
5	M25	8.6	11.7	0.3	4.3

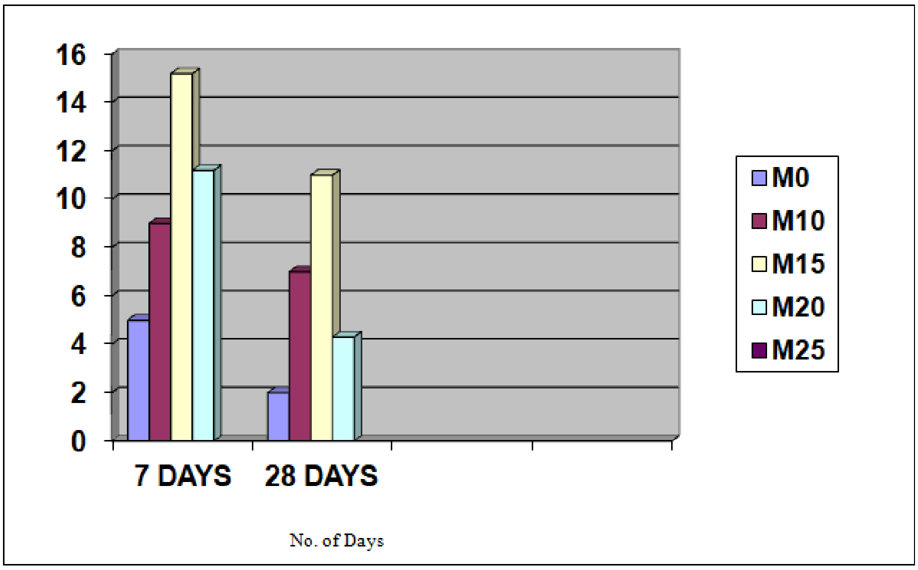

Fig FLEXURAL STRENGTH TEST RESULTS

Table Multiplying Co-efficient (k) of term (fck)0.5

Sr. No.	Mix Designation	28 days Strength		Multiplying Co-efficient, k
		Compressive Strength	Flexural Strength	
1	M0	38.5	4.47	0.720
2	M10	38.9	4.56	0.731
3	M15	39.6	4.79	0.761
4	M20	40.5	4.96	0.779
5	M25	38.6	4.66	0.750

It is seen that the coefficient k is found to be more than that suggested by IS:456. A higher value of this coefficient indicates higher value of obtained flexural strength.

Abrasion Resistance Test

Loss-Angeles Test

An improvised Los Angeles Test was conducted on 74mm size concrete cubes of various mixes. Three cubes of a mix after 28 days curing were tested in the machine for 500 revolution along with 4 No. abrasive charge balls.

Table Abrasion Test Results

Sr. No.	Mix Designation	% Wear	Reduction in Wear
1	M0	21	0
2	M10	19.47	7.3
3	M15	17.37	17.3
4	M20	14.46	31.1
5	M25	18.64	11.2

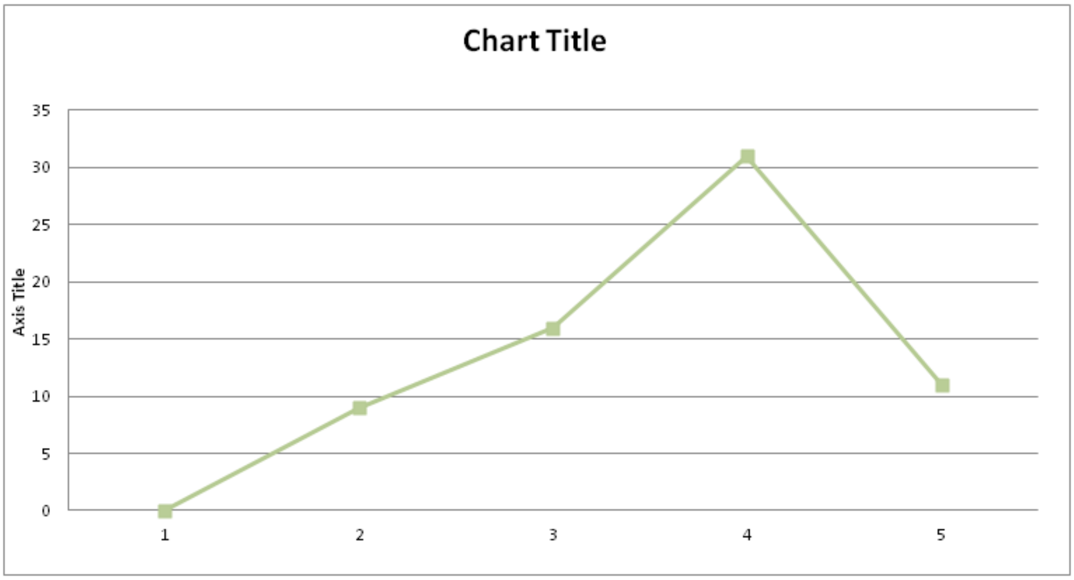

Fig. Effect of Met kaolin on Abrasion Resistance

It is observed that the abrasion resistance increases with increase in the proportion of met kaolin in concrete and is found to be maximum for 20% addition of metakaolin.

Impact Test

An improvised Impact Test was conducted on 74mm size concrete cubes of various mixes. Three cubes of a mix after 28 days curing were tested in the machine for 15 No. blows.

It is observed that the impact resistance increases with increase in the proportion of met kaolin in concrete and is found to be maximum for 20% addition of metakaolin. The values of impact test agree in general with that of abrasion test.

Table Impact Test Result

Sr. No.	Mix Designation	% Wear	Reduction Wear
1	M0	10.74	0
2	M10	9.9	7.8
3	M15	8.33	22.4
4	M20	7.7	28.3
5	M25	8.6	19.9

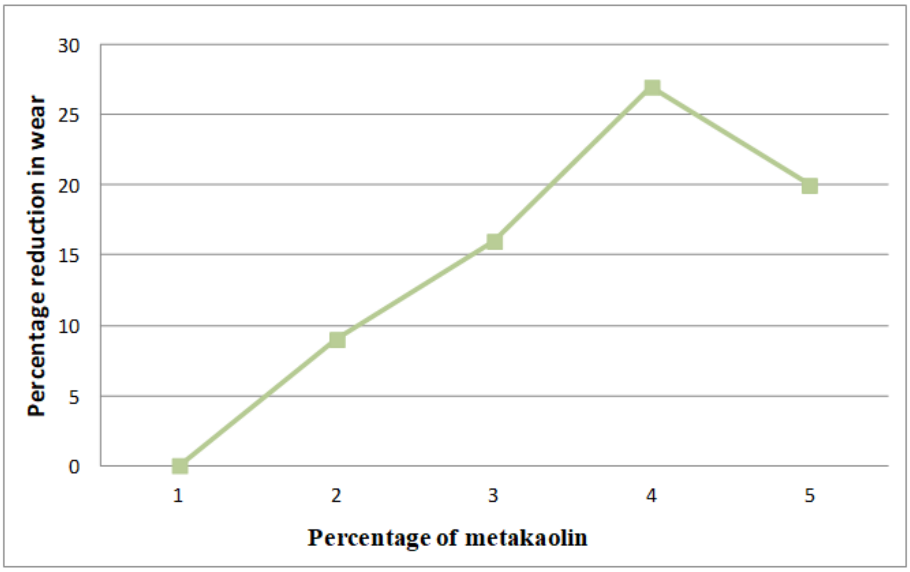

Fig. Effect of Met kaolin on Impact Resistance

Conclusion

The study 'Experimental investigations on cement concrete using metakaolin' has been taken up with a view to investigate the effect of addition of metakaolin as partial replacement of cement on strength and durability properties of cement concrete. Various investigations were made on M-30 grade concrete for pavements with varying proportion of metakaolin form 0 to 25% the main conclusions drawn from the study are:

i) Addition of metakaolin leads to slight reduction in slump which is due to its finer particle size as compared to cement. However, this reduction in slump is not found to affect the filling ability as required for pavement concrete.

ii) Metakaolin is an effective pozzolan and results in an enhanced 7-day and 28-day strength of concrete.

iii) Compressive strength, both at 7-days and 28-days, is found to increase with addition of metakaolin. The maximum increase in compressive strength occurs

iv) Flexural strength both at 7-days and 28-days is also found to increase with addition of metakaolin. The maximum increase in flexural strength occurs at 20% replacement level of cement by metakaolin.

v) The multiplying co-efficient k in the relationship Fc= k x (fck)0.5 given by IS:456 for deriving flexural strength from compressive strength is found to vary from 0.72 to 0.78 for various additions of metakaolin from 0 to 20%.

vi) The increase in flexural strength follows the same pattern as that of compressive strength. However, the gain in strength for a given percentage addition of metakaolin is more in flexural strexural strength than compressive strength.

vii) Durability resistance is found to increase with increase of metakaolin is concrete.

viii) The loss in weight after 5 cycles of alternate wetting and drying in soundness test is found to decrease with increase in proportion of metakaolin.

ix) Similarly, % wear in Los angeles abrasion test and impact test is found ot decrease with increase in proportion of metakaolin.

x) The 20% replacement with metakaolin is found to be the most efficient replacement leading to maximum enhancement in the strength and durability properties of concrete.

xi) The cost of metakaolin being higher than cement at present, its use in cement concrete is explored from the point of view of achieving more durable and environment friendly concrete.

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