Experimental Investigation on the Mechanical Properties of Concrete using Metakaolin

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***Abstract*: Concrete, in construction, a structural material consisting of binding material, fine aggregate, coarse aggregate and water. Today construction cost is very high with using conventional material, due to unavailability of materials. This problem can be solved by replacement of concrete with different material which is not convenient in terms of required properties. Due to this limitation of unavailability of material which plays the vital role of concrete, we have only choice of partial replacement of concrete ingredients by different waste material and pozzolanic material. Today's annual global cement production has reached 2.8 billion tonnes and is expected to increase to some 4 billion tonnes per year. The cement production also emits co2 into the atmosphere which is harmful to the nature. If we partially replace the cement with material having desirable properties then we can save natural material and reduce the emission of co2.In this experiment we will study the behaviour of concrete in which the cement will be partially replaced by Melakoalin. Metakaolin is a pozzolan, probably the most effective pozzolanic material for use in concrete. Metakaolin was successfully incorporated into the concrete with the original intension of suppressing any damage due to alkali-silica reaction. This study reports of an experimental study on mechanical properties of plain and M.K concrete, cement is partially replaced by M.K about (3%,6%,9%,12%) by weight of total binding material. Compressive strength, split tensile strength and flexural strength were calculated by replacing M.K with cement at the end of 7 days and 28days. It was found that partial replacement of M.K increases the compressive strength and split tensile strength of concrete up to 9% replacement of M.K and after that it decreases.The primary objective of this study is to get the quantity of Metakaolin for partial replacement of concrete for making concrete without compromising the properties of concrete.**

***Keywords*: Metakaolin, concrete mix, compressive strength, split tensile strength, flexural strength**

I. INTRODUCTION

An ever-evolving world needs constantly developing construction ways. Concrete is a main constituent of the civil engineering structures. We cannot imagine the structures without concrete. Concrete has capacity to enhance its properties with the help of other suitable constituents. Concrete has significantly influenced the nature of engineering projects.

Concrete, in construction, structural material consisting of a hard, chemically inert particle known as aggregate (usually sand and gravel), that is bonded together by cement and water with a definite mix proportion. The formulation for producing concrete from its ingredients can be presented in the following equation:-

Concrete= Binding material + Fine aggregate + Water + Admixture (optional)

Since aggregates occupy 70-80 percent of volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.

The current concrete construction practice is unsustainable because, not only it consumes enormous quantities of stones, sand and drinking water, but also one billion tons a year of cement, which is not an environment friendly material. For production of cement huge amount of energy is needed and 8 % of CO_2 is released to atmosphere during cement production.

So we can partially replace the cement and aggregate by different by- products and solid wastes for preparation of concrete depending on their physical and chemical characteristics.

II. LITERATURE REVIEW

The present work is drafted after referring the following previous researches:

Romualdi and Batson (2019) after conducting impact test on fibre reinforced concrete specimens, they concluded that first crack strength improved by addition of closely spaced continuous steel fibres in it. The steel fibres prevent the adverting of micro cracks by applying pinching forces at the crack tips and thus delaying the propagation of the cracks. Further, they established that the increase in strength of concrete is inversely proportional to the square root of the wire spacing.

Sridhara, S., et al. (2020) carried out experimental investigations to study the blast resistance of concrete, by adding different types of fibres like, nylon, coir and Jute at various percentages by volume of concrete. They concluded that fibres increased the impact and shatter resistance of concrete. Out of nylon fibres even at low fibre contents found to be the most effective reinforcement for increasing the impact strength of the concrete.

Jack Synder and David hankard (2018) investigated mortars and concrete by reinforcing small short steel fibres in flexure. They concluded that there is significant increase in the first crack strength and ultimate strength. Due to addition of coarse aggregate to a reinforced mortar there is decrease in the first crack and ultimate strength of the material.

Rajagopalan and others (2018) developed equations to predict the first crack and ultimate moment of resistance of the SFRC beams with steel fibres. Also they concluded that there is much improvement in ductility and large rotation capacity which can be used effectively in redistribution of movements in beams and frames.

Swamy, R.N. (2017) studied the mechanical properties and applications of fibre reinforced concrete using polypropylene, glass, asbestos and steel fibres. The factors influencing the effectiveness of fibre reinforcement and the efficiency of stress transfer were discussed. The author concluded that Asbestos, glass and steel fibres can be used at higher temperature than the low modulus fibres like nylon and polypropylene which lose their load carrying capacity around 1000C. The great improvements in impact resistance and ductility at failure provided by glass, steel and plastic fibres are not reflected by asbestos, whose characteristic property is its high tensile strength.

Swamy, R.N (2018) After experimental investigations on the flexural strength of concrete by using small short steel fibres, he concluded that the first crack strength is significantly improved. Also he has derived equations to determine the first crack flexural and ultimate flexural strength of the composite based on experimental and previous investigations.

Charles H.Henage (2019) developed an analytical method based on ultimate strength approach, which has taken into account of bond stress, fibres stress and volume fraction of fibres. After his investigations, he concluded that the incorporation of steel fibres significantly increases the ultimate flexural strength, reduces crack widths and first crack occurred at higher loads.

Krishna Raju et al. (2015) after conducting experimental investigation on the compressive strength and bearing strength of steel fibre reinforced concrete with fibre content varying from to 0% to 3%, they concluded that, both compressing and bearing strength increases with increase in fibre content. Also the experimental results were predicted by theoretical method.

Kormeling, Reinhardt and Shah (2014) after carrying out investigations on the influence of using steel fibres on the static and dynamic strength of RCC beams using hooked straight and raddled fibres, they concluded that incorporation of above type of fibres increased the ultimate moment and reduces the crack width and average crack spacing.

Ramakrishnanetal.(2011) carried out experimental investigations on properties of concrete like, flexural fatigue, static flexural strength, deflection, modulus of rupture, load deflection curves, impact strength to first crack, ultimate tensile, compressive strength, plastic workability including vee-bee, slump and inverted cone time by reinforcing two types of steel fibres (straight and fibre with deformed ends) in the concrete. From the investigations, they concluded that no balling of fibres occurred in the cone of hooked fibres, the compressive strength is slight higher than the normal concrete, excellent anchorage by hooked fibres resulting in ultimate flexural strength. Also the hooked end fibres have greater ability to absorb impact than straight fibre reinforced concrete

III. MATERIALS USED

Cement

Cement is a binding material. It is available in 3 grades that is;33, 43 & 53 . The property of cement varies according to the grade. In this study we used 53 grade of cement having brand name Ultratech.

Fine Aggregate

The material which passes through 4.75mm sieve is termed as fine aggregates. Generally, river sand is used as fine aggregate in concrete. Normal river sand is used as fine aggregate of zone III as per the specifications of IS 383: 1970 in this study.

Coarse Aggregate

Locally available coarse aggregate of maximum size of 20mm was used in the present work. The sieve analysis of combined aggregates confirms to the specifications of IS 383:1970 for graded aggregate.

Metakaoline

Metakaolin is the anhydrous calcined form of the clay mineral kaolinite. Minerals that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume. It is formed, when china clay is heated to a temperature between 6000c and 8000c.

Fig. 1 Metakaoline

Water

Another main ingredient for making concrete is water. The water which is portable for drinking is suitable for making concrete. In this experiment the tap water available nearby is used.

IV. RESULTS & DISCUSSIONS

Table 1: Concrete mixture proportioning for 1m3 (cement replaced by Mk)

Mix	Cement (kg)	Metakaolin (kg)	Water (lts)	Fine aggregate (kg)	Coarse aggregate (kg)	Water-cement ratio
Controlled mix	500	0	200	546	1166	0.40
3% Mk	485	15	220	546	1166	0.45
6% Mk	470	30	240	546	1166	0.50
9% Mk	455	45	255	546	1166	0.56
12% Mk	440	60	275	546	1166	0.60

Slump Test Results:

Table 2: Slump value for 0.4 W/C ratio (cement replaced by Mk)

Sl no.	% of Mk replaced	Slump value (mm)
1	0	68
2	3	63
3	6	59
4	9	57
5	12	54

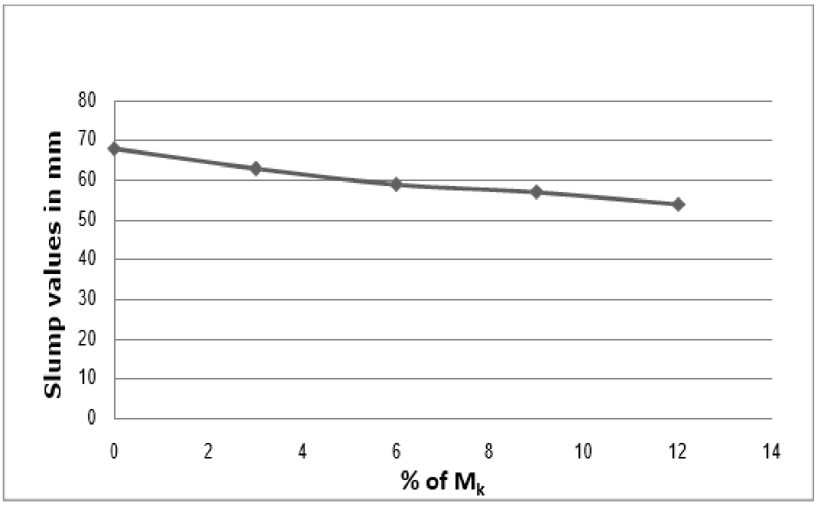

Fig 2: Slump value for various concrete mixes incorporated with metakaoline (M_k) at 0.4 W/C ratio

Discussions:

The slump cone test is one of the methods which are carried out to measure the workability of concrete mix. In this experiment the cement was partially replaced by various % of Mk . To measure the workability of concrete mix at various % of Mk the slump cone test was carried. The slump value of conventional concrete having 0% of Mk is 68mm. From the test it was observed that the concrete mix slump value decreases with increase in % of Mk. The slump value for mix with 3% of Mk for partially replacing cement is 66mm. The slump value for mix with 12% of Mk for partially replacing cement is 54mm. It means concrete mix prepared with Mk requires move water to give the desirable workability. As per the codal provision, the water cement ratio was taken as 0.4.

Compressive Strength Results:

Table 3: Compressive strength of concrete after 28 days curing (cement replaced by Mk)

Sl no.	Sample name	Compressive strength (N/mm^2)	% increased
1	CM_0	46.44	----
2	CM_3	46.64	0.4
3	CM_6	46.89	0.9
4	CM_9	47.71	2.7
5	CM_{12}	48.01	3.1

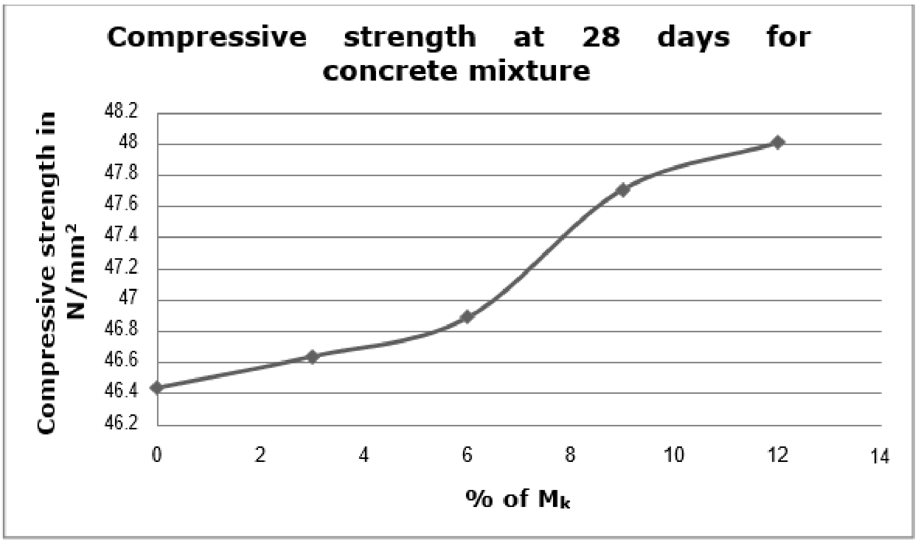

Fig 3: Compressive strength for various concrete mixes incorporated with metakaoline (M_k)

Discussions:

The 28 days compressive strength of conventional M30 concrete was 46.42 N/m2 it was observed that the concrete mix prepared partially replacing cement goes on increasing upto 12% of Mk. When cement partially replace by 3% Mk after 28 days of curing the compressive strength is 46.64 N/m2 and when cement was replaced by Mk 6% the value is 46.89 N/m2. When the cement was partially replaced by 9% the compressive strength value increases to 47.71 N/m2 and when cement is partially reduced by 12% also after 28 days curing the compressive strength increases and the value is 48.01 N/mm2.

It has been observed that in 7 days test after 9% of replacement by Mk the compressive strength decreases but in 28 day test of concrete upto 12% of replacement the strength goes on increasing.

For 3% of replacement of cement by Mk increases the % of compressive strength is 0.4% then for 6% of replacement the % increases in strength is 1%, for 9% the strength increases to 2.7% and for 12% of replacement the percentage of increase is 3.1%.

<u>Flexural Strength Results:</u>

Table 4: Flexural strength of concrete after 28 days curing (cement replaced by Mk)

Sl no.	Sample name	Flexural strength (N/mm^2)	% increased
1	FM_0	4.28	----
2	FM_3	4.33	1.16
3	FM_6	4.45	3.70
4	FM_9	4.52	4.70
5	FM_{12}	4.55	5.10

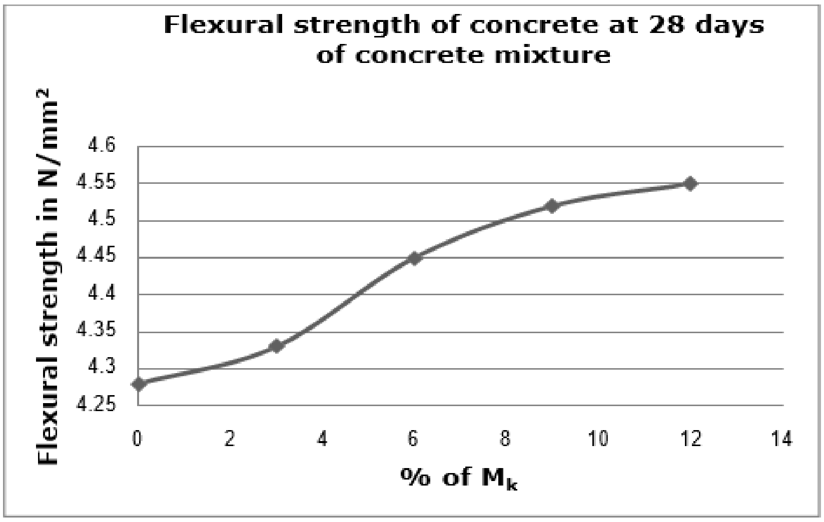

Fig 4: Flexural strength for various concrete mixes incorporated with metakaoline (M_k)

Discussions:

The 28 days flexural strength of conventional M30 concrete was 4.12 N/mm2. It was observed that the concrete mix prepared partially replacing cement goes on increasing up to 12% of Mk.

When the cement is replaced by 3% of Mk after 28 days of curing the flexural strength of the concrete is 4.33 N/mm2, when 6% replaced then the flexural strength is 4.45 N/mm2 and 9% replaced then the flexural strength is 4.52 N/mm2 and finally after 12% replaced the flexural strength becomes 4.55 N/mm2. For calculation of the flexural strength the load taken by the beam was noted and it has been observed that if the percentage of Mk increases than the load bearing capacity of the beam also increases.

When there is no replacement of cement for my design mix the load taken by the beam was 23.17KN. When the replacement of cement by Mk was 3% than load carrying capacity of the beam increases to 24.05KN, when 6% replacement was done the load is 25.1, when 9% replacement was done the load is 25.42 KN and finally when 12% replacement was done the load taken by the beam after 28 days of curing was 25.5 KN.

Split Tensile Strength Results:

Table 5: Split tensile strength of concrete after 28 days curing (cement replaced by Mk)

Sl no.	Sample name	Split tensile strength (N/mm^2)	% increased
1	SM_0	2.95	----
2	SM_3	3.01	2.03
3	SM_6	3.35	13.20
4	SM_9	3.44	15.80
5	SM_{12}	3.01	-13.00

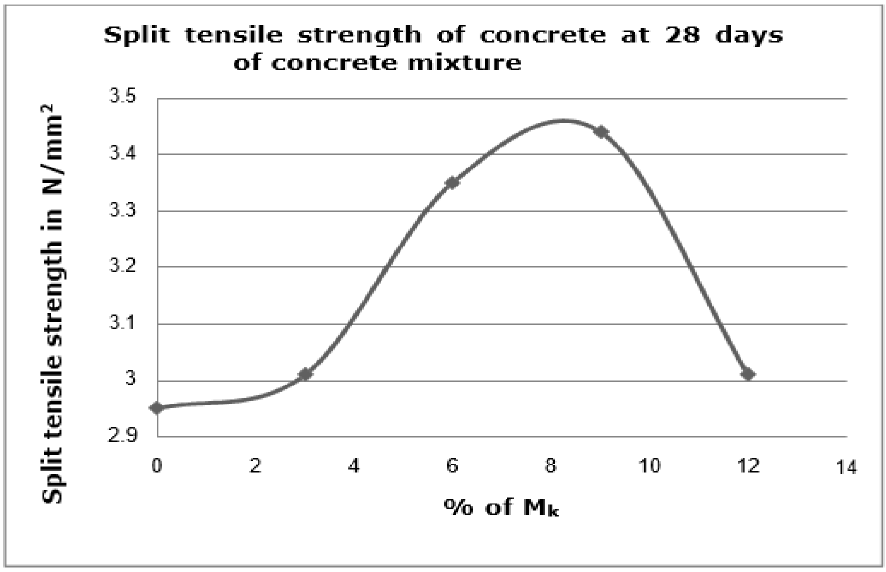

Fig 5: Split tensile strength for various concrete mixes incorporated with metakaoline (M_k)

Discussions:

The 28 days split tensile strength of conventional M30 concrete was 2.95 N/mm2. It was observed that the concrete mix prepared partially replacing cement goes on increasing up to 9% by Mk and after that the split tensile strength decreased. When cement was partially replaced by 3% Mk after 28 days of curing the split tensile strength was 3.01 N/mm2 and when cement was replaced by Mk 6% the value is 3.325 N/mm2. When the cement was partially replaced by 9% the value is 3.44 N/mm2. After that the cement was replaced by 12% Mk, here the split tensile strength value decreased. That means, the strength was increased by and reduced by as that of conventional concrete.

V. CONCLUSIONS

Based on experiment observation, following conclusion can be done:

1. Specific gravity of metakaolin is 2.26 which are than both cement and sand. So the concrete mix prepared by partially cement or sand with Mk will produce a light weight concrete.
2. Consistency of Mk is more than that of cement. So more water will be required to get the desirable paste or we can us superplasticizer to reduce the water quantity.
3. Workability of concrete mix prepared by partially replacing cement with Mk reduces with increase in % of Mk. It requires more quantity of water to get the required workability can also be achieved.
4. The concrete mix prepared by partially replacing cement with Mk gives lighter concrete as compare to conventional concrete. So light weight structures can be constructed by using Mk in concrete.
5. Compressive strength of concrete mix prepared by partially replacing cement with Mk increases up to 9% replacement in 7 days test and in 28 days test up to 12% replacement it increases.
6. Flexural strength of concrete mix prepared by partially replacement of cement with Mk is increases up to 12% of replacement in 7 days and 28 days test.

7. In split tensile strength of concrete mix prepared by partially replacement of cement with Mk is increases up to 9% of replacement of cement with metakaolin is done.

REFERENCES

[1] Abdul Razak (2005), ".strength estimation model of high-strength concrete incorporating metakaolin and silica fume." Cement and Concrete Reasearch.vol.35PP.688-695.

[2] Bamonte P (2001), "Thermal and mechanical properties at high temperature of a very high- strength Durable Concrete." Soural of materials in civil engineering ASCE,PP.545-555.

[3] Bo Wu, xiao-ping su. Hui li and ie yuan (2002) "effect of high temperature on Residual mechanical properties of confined and unconfined high strength concrete". Act materials journals, vol.99, No4 PP.231-239.

[4] Beulah M (2012), "Effect of Replacement of cement by metakaolin on the properties of high performance concrete subjected to Hydrochloric Acid Attack". IJERA, vol.2, issue 6, PP-033-038.

[5] Chi-sun poon (2003), "performance of metakaolin concrete at elevated temperatures, cement and concrete research, vol.25,PP.83-89.

[6] Chi-sun poon (2006), "compressive strength, chloride diffusity and pore structure of high performance metakaolin and silica fume concrete", cement and concrete Research, vol.20, PP.858-865.

[7] Dinaka P (2011), "High reactive metakaolin for high strength and high performance concrete". The Indian concrete journal,PP. 28-34.

[8] Frias M (2000), "Pore size distribution and degree of hydration of metakaolin –cement pastes", cement and concrete Reasearch, vol.30, PP.561-569

[9] IS:516-1959, " Method of test for strength of concrete", Bureau of Indian standards, New Delhi.

[10] IS:1062-2009, "Specification for M30 grade Design mix concrete" 11)IS:12264-1987, "Specification for 53 grade Ordinary Portland Cement, "Bureau Of Indian Standards,New Delhi.

[11] IS:456-2000 Indian Standard Plain And Reinforced Concrete code used for specification of water cement ratio and minimum water content.

[12] IS:383-1970 Indian Standard Code book for finding the zone of the fine aggregate.

[13] Khatib and wild S (1996), "pore size distribution of metakaolin paste in cement and concrete research". ICJ vol.28, No-1,PP.1543-1553.

[14] Khatib and wild (1998), "Sulphate Resistance Of Metakaolin Mortar", cement and concrete Research,ICJ vol.28, No-1,PP.8392.

[15] Long T-phan (2000), "fire performance of high strength concrete", journal of materials in civil engineering ASCE, may 8-10.

[16] Nabil M AI-Akhras (2006), "Durability of metakaolin concrete to sulphate attack". Cement and concrete Research, vol.36,PP.1727-1734.

[17] Rama Rao G V and Seshagiri Rao MV (1997), important in durability characteristics of concrete using pozzolanic material as admixture". Proceedings of international conference on maintenance and durability of concrete structures, Mar4-6.

[18] Rafat Siddique (2010), "Effect of metakaolin on the near surface characterstic of concrete", Materials and structures, vol.44, PP.77-88.

[19] M S, "Concrete Technology", S. Chand and company LTD,New Delhi. 21)Srinivasa Rao K,Potha Raju M and Raju P S N (2004), "Effect of age on

[20] HSC on Residual Compressive Strength under elevated temperatures", International Conference On Advances in Concrete And Construction, PP.733-741.

[21] Vikas Srivastava (2012), "Effect of Silica fume and metakaolin combination on concrete", IJCSE, vol.2 Issye 3, PP.893-898.

[22] Xia oquian and Zongjinli (2001), "The relationships between stress and strain for high performance concrete with metakaolin.

[23] Sabir B.B, Wild S, Baij, "Metakaolin and calcined clay as pozzolans for concrete a review" cement and concrete composite 23, (2001), PP.441- 454.