A STUDY ON THE EFFECT OF METAKAOLIN ON STRENGTH PROPERTY OF CONCRETE

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ABSTRACT

Concrete is used extensively as building materials yet Portland cement production emits large quantities of CO2 (carbon dioxide), a greenhouse gas. One ton of Portland cement clinker output produces around one ton of CO2 and other harmful gasses. Environmental concerns play an important part in concrete industry's sustainable growth. The use of mineral additives as a partial replacement of Portland cement clinker has been one of the key ways of producing more eco-efficient cements. Metakaolin is used as a binder with partial cement replacement which takes part of the reaction at the time of hydration. At the age of 7, 28 days it was tested for compressive strength, Split tensile strength and flexural strength and compared with standard concrete performance. Metakaolin is Aluminium silicate dehydroxylated which is non-crystallized, amorphous material. It is clear from recent work using metakaolin that it is a very effective pozzolanic material and effectively improves the strength and durability parameters of concrete. The overall test results indicate that metakaolin could be used as a partial replacement of cement in concrete. The efficiency of metakaolin-containing concrete (MK) is studied. Portland cement was replaced by 0-30 percent MK partly. The water-to-binder ratio was maintained at 0.48 on all mixes. Compressive strength of mixes after 7 and 28 days of water curing, splitting tensile strength after 7 and 28 days of water curing, flexural strength after 14 and 28 days of water curing were studied. The concrete strength is significantly reduced during the first day of hydration particularly at high MK content. The application of up to 15 per cent MK, however, triggers an rise in concrete strength beyond 7days and 28 days of healing. Depending on the age of curing and the MK material, this increase may be up to 30 per cent. The relative intensity is continuing to increase after 28days of curing.

K**eywords- Metakaolin, Conventional Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength, Durability**

INTRODUCTION

Concrete, which is used extensively as building materials emits large quantities of CO2 (carbon dioxide), as well as oxides of Sulphur and nitrogen which causes greenhouse gas effects [1,2]. In addition, the production of cement needs huge quantity of energy and natural minerals like lime [1,2]. To reduce the impacts caused by of cement industries, MK and other cementitious materials are used to replace part of cement [3,4] or as a source of geopolymer materials [2,4,5]. High-reactivity metakaolin (MK) is one of the newly developed supplementary cementing materials for high-performance concrete [17,18,19]. MK is carefully optimized for lightening its color, eliminating neutral impurities and regulating particle size. This well-controlled process leads to a highly reactive white powder which is consistent in appearance and performance. Metakaolin was widely studied for its highly pozzolanic properties, suggesting the use of metakaolin as an SCM

[12,13,14,15]. Like other SCMs that are secondary products or by-products, metakaolin is a primary product obtained through the calcination of kaolin clay between 650^0C and 800^0C. To test the strength and durability of concrete, the cement was substituted with metakaolin (MKF). Without the presence of free calcium chloride, other technological advantages can be found for the substituted concrete such as lower permeability, higher strength and lower chloride ion penetration occurs. The use of metakaolin as pozzolana would help to build early strength and increase some long-term strength. Metakaolin alters the pore structure of cement paste mortar and concrete, and greatly enhances its resistance to water transportation and the diffusion of harmful ions that leads to matrix degradation. The use of finer metakaolin was more successful than the coarser metakaolin in improving the concrete properties. Addition of metakaolin showed improvements in aspects of shrinkage, longevity and other energy. Durability of self-compacting concrete enhances significantly with partial replacement of metakaolin [20]. Microcrack width in hard mix was reduced with inclusion of metakaolin in the control mix [21]. Replacement of Portland cement with 15% metakaolin and an additional 5% polymer (by weight) gives the optimum improved proporties on both mechanical properties and durability [22]. The sulfate resistance of metakaolin based concrete increased with increase in the MK replacement level. Autoclaved MK concrete specimens showed superior sulfate resistance compared to moist cured ones[23]. Partial replacement of Portland cement by 30 percent fly ash results in a significant decrease in compressive strength in early age compared to the comparison mix made with Portland cement of 100 percent. The use of hybrid mixtures at 15 percent Fly ash and 15 percent Metakaolin-based mixtures resulted in a slight loss of strength in early stages but showed significant improvement in durability. Bai and wild [21] looked especially at the effects of FA and MK on heat evolved using embedded thermocouples [24]. Super plasticizer is required as inclusion of MK causes lowering of workability of fresh concrete [25,26].

MATERIALS USED IN EXPERIMENTAL INVESTIGATION

a. CEMENT

It is necessary to know the properties of cement in the mix design procedure. Specific gravity is 3.03, fineness modulus is 4.6%, were determined in concrete technology laboratory.

b. METAKAOLIN

Metakaolin is a pozzolan, which is potentially the most effective pozzolanic material for concrete use. It is a product created for use rather than a by-product, and it is formed when china clay, the mineral kaolin, is heated to a temperature between 600^0C and 800^0C. The consistency is regulated during production, resulting in a material much less variable than industrial pozzolans which are by-products. Metakaolin was first used in the 1960s to construct a number of major dams in Brazil, and was successfully introduced into the concrete with the original intention of preventing any damage caused by alkali-silica reaction. Slightly higher rates of replacement (up to 20 per cent) create a low porosity and permeability cement matrix. It results in increased resilience of the hardened concrete to sulfate, chloride ions and other harmful substances such as mineral and organic acids being targeted.

Table-1 Chemical Composition of Metakaolin

Chemical Composition	Metakaolin %
Silica (SiO_2)	54.3
Alumina (Al_2O3)	38.3

Calcium Oxide (CaO)	0.39
Ferric oxide Calcium Oxide (Fe_2O_3)	4.28
Magnesium Oxide (MgO)	0.08
Potassium Oxide (K_2O)	0.50
Sulphuric Anhydride (SO4)	0.22
LOI	0.68
Specific Gravity	2.5
Physical Form	Powder
Colour	Off white

Table-2 Initial and Final Setting Times of Metakaolin

% of MK in Mortar	Standard Consistency (%)	Initial Setting Time	Final Setting Time
N(MK0)	35	33min	8hr55min
MK10	37	5min	8hr30min
MK15	39	4min	8hr15min
MK20	41	4min	8hr2min
MK30	43	4min	7hr50min

Table-3 Physical Properties of Metakaolin & Cement

Property	Metakaolin	Cement
Specific Gravity	2.8	3.03
Fineness Modulus	5%	4.6%

c. FINE AGGREGATES

The fine aggregates used in this investigation were Kuakhai River sand, with a specific gravity of 2.64, passing through 4.75 mm sieve. As an Indian Standard Specification the percentage of passage is within the limits.

d. COARSE AGGREGATES

Machine crushed angular broken stone was used as coarse aggregates. One fraction of coarse aggregates is used i.e 20mm, with a specific gravity of 2.84.

Table-4 Specific Gravity of Coarse Aggregate & Fine Aggregate

Property	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.84	2.64

e. SUPER-PLASTICIZER

Armix Emme Crete PC10 is a high-performance super-plasticizer was used in this investigation.

Table-5 Properties od Super Plasticizer

Appearance	Clear to Brown
pH @25°C	Min 6.0
Specific Gravity	1.07 kg/lit±0.05
Chloride Content	NIL

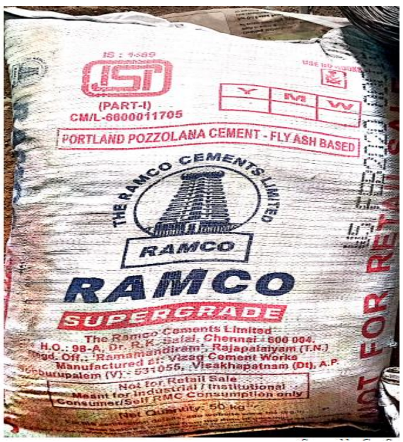


Fig 1. Cement

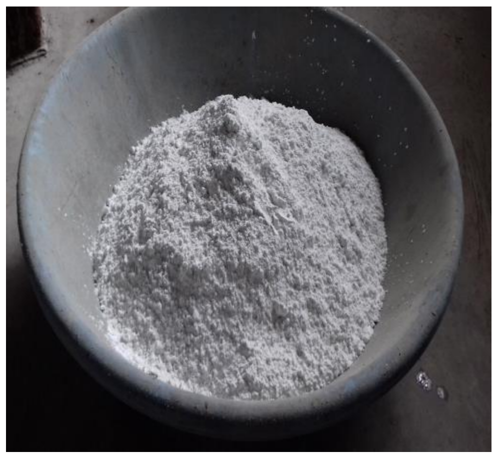


Fig.2 Metakaolin

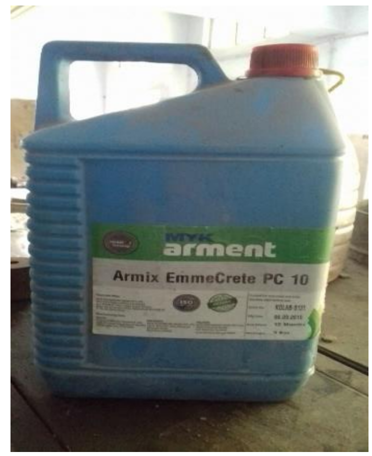


Fig.3 Super Plastisizer

DESIGN MIX CALCULATIONS

In the CUTM laboratory, Jatni, the physical properties of the materials were identified according to the laboratory procedures. The specification of the mix was designed for grade M25 concrete according to standard concrete mix specification as per IS10262-2019 & IS456-2000. For the M25 design mix concrete the targeted compressive strength (Comp. Strength) was determined as per IS 456-2000.The formulae used is f 'ck= fck+1.65 *S = 25 + 1.65* 4 = 31.6N/mm^2, where S= 4N/mm^2 (the standard deviation), f'ck= Target Mean strength of concrete cube (average) after curing for 7, 14 and 28 days, fck = Comp strength of the cube after curing for 28 days, and water cement ratio=0.46. Applying the normal measurement method as per IS 456-2000, the measured quantity of ingredients is cement= 400 Kg /m^3, water=191.5 ltr / m^3, fine aggregate= 646.27 Kg / m^3, coarse aggregate1240.32 Kg/m^3, in W / C ratio= 0.48. Proportion by weight of the final design combination was found to be 0.47:1:1.615:3.10. Cubes, cylinders and beams were casted and cured for different mix proportions and replacements with portable normal supply water for 7, 14, and 28days.

Design Stipulations:

Characteristic compressive strength of required in the field at 28 days = 25 N/mm^2
Maximum size of aggregates = 20mm
Degree of workability = Medium (0.90)
Degree of quality control = Good
Type of exposure =Moderate
Method of concrete placing= Manual

Table-6 Design Mix

	Water	Cement	Fine aggregate	Coarse Aggregate
By Weight	191.58 Ltrs	400 Kg	646.27 Kg	1240.32 Kg
By Proportions	0.47	1	1.615	3.10

EXPERIMENTAL INVESTIGATION & RESULT

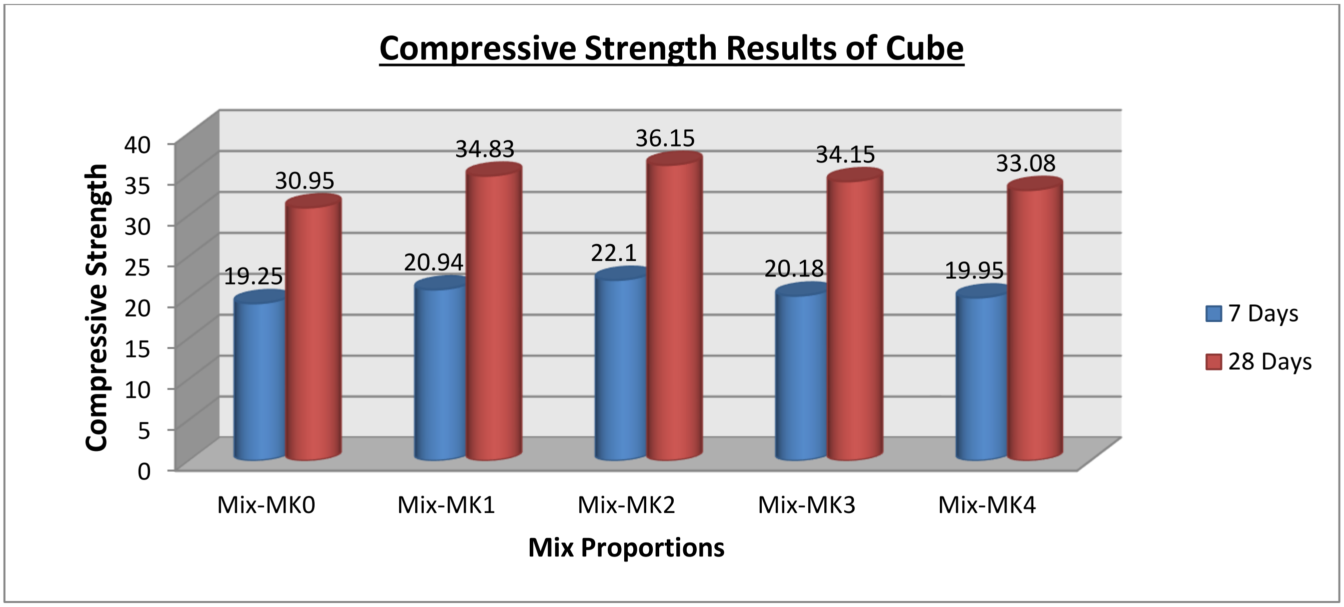
Trial mixtures were prepared to obtain target strength more than 31.6 N/mm^2 for the control mixture at 7, 14 and 28 days and the w/c ratio for all the mixtures were kept at 0.47. The details of the mixture (MK10, MK15, MK20, and MK30,) were employed to examine the influence of low w/c ratio on concretes containing MK on the mechanical and durability properties. Concrete has been put in three layers in regular moulds, and the tamping rod compacts each layer and vibrates on the table vibrator for 10 to 15 seconds for full compaction. For smooth surface finally the top surfaces of concrete specimens were completed. Cubes (150x 150x 150), cylinders (150x 300), beams (100x 100x 500) mm of standard sizes have been cast and tested for a healing period of 28 days and tests for compressive strength, split tensile strength & flexural strength are tabulated in tables.

Table-7 Mix Proportions

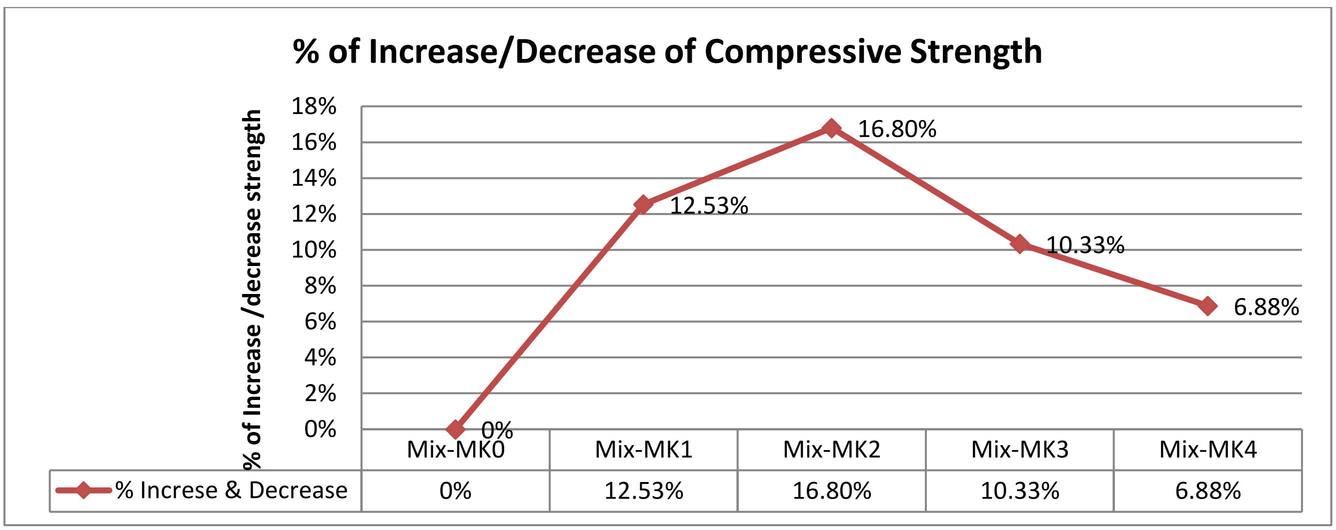
	Percentage of Metakaolin				
	0%MK	**10%MK**	**15%MK**	**20%K**	**30%MK**
	Mix Designation				
Ingredients	**Mix-MK0**	**Mix-MK1**	**Mix-MK2**	**Mix-MK3**	**Mix-MK4**
Cement (kg/m³)	400	360	340	320	280
Metakaolin(kg/m³)	0	40	60	80	120
Fine Aggregates (kg/m³)	646	646	646	646	646
Coarse Agg. 20mm (kg/m³)	1240	1240	1240	1240	1240
Super Plasticizer(% of binder)	0	1.5	1.75	2.0	2.25
Slump (mm)	78	85	87	91	96
Water (litre)	191	191	191	191	191

Table-8 Compressive Strength Results of Cube

Nomenclature Mix Designations	**Compressive Strength of Cube After Curing (N/mm^2)**		**% of Increase/Decrease in Strength**
	7days	**28days**	
Mix-MK0	19.25	30.95	0%
Mix-MK1	20.94	34.83	+12.53%
Mix-MK2	22.1	36.15	+16.8%
Mix-MK3	20.18	34.15	+10.33%
Mix-MK4	19.95	33.08	+6.88%



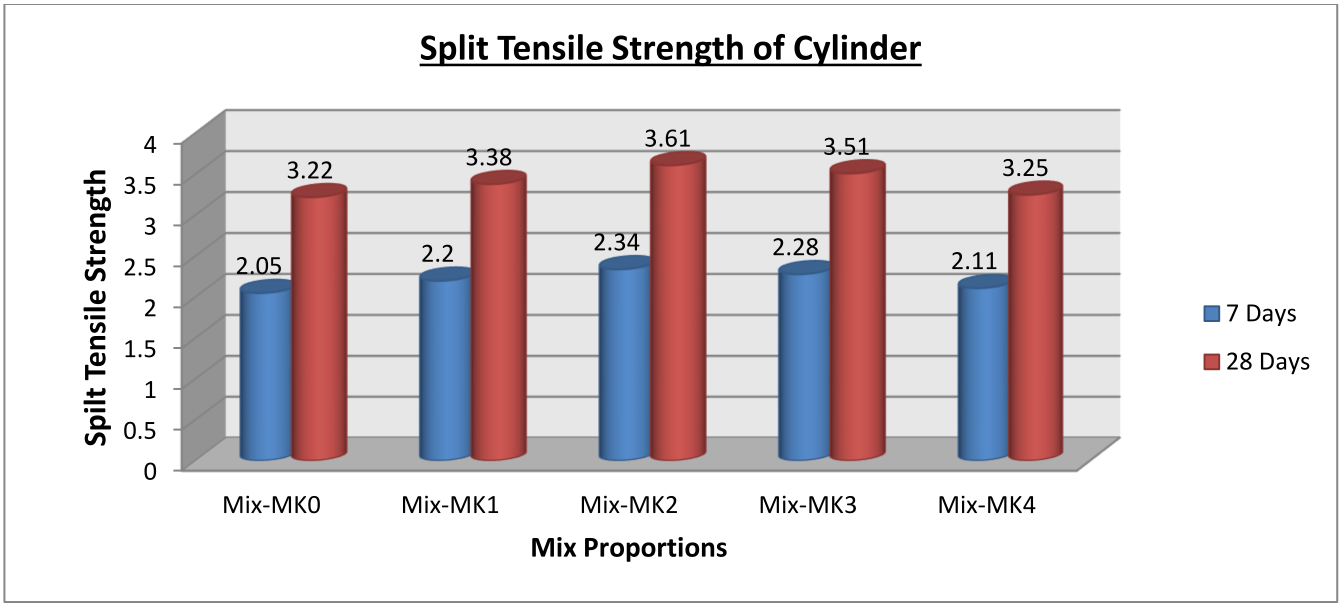
Graph-1 Compressive Strength of Cube



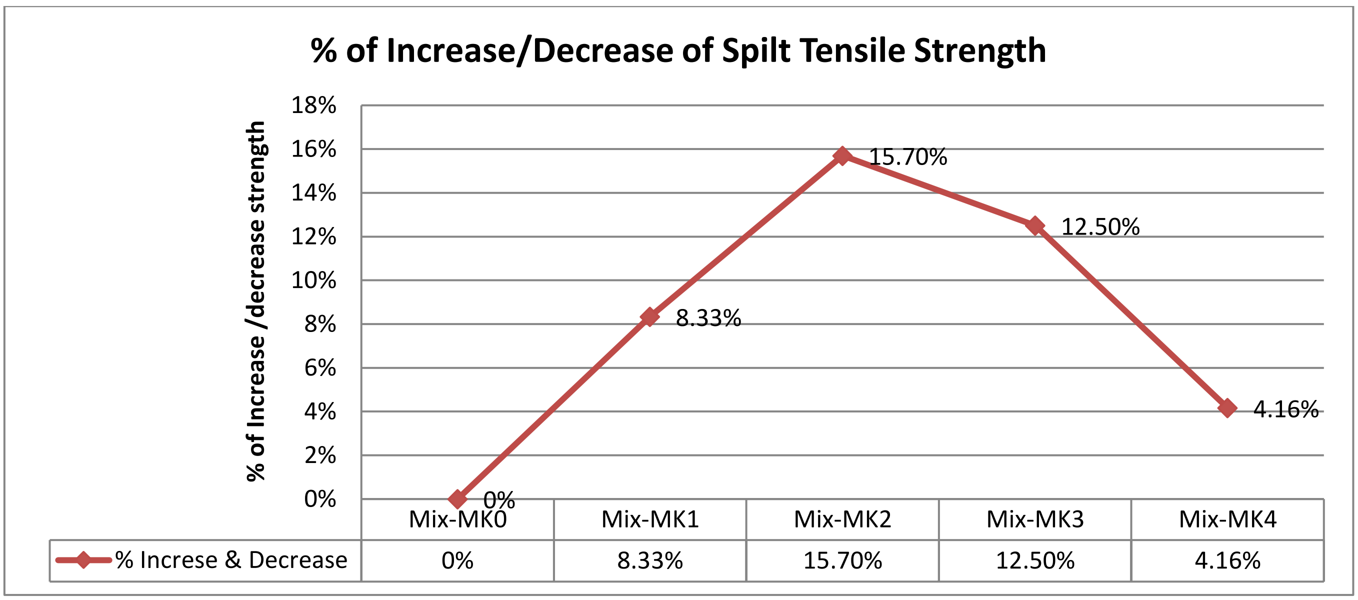
Graph-2 % of Increase/Decrease of Compressive Strength

Table-9 Split Tensile Strength of Cylinder

Nomenclature Mix Designations	Spilt Tensile Strength of Cylinder After Curing (N/mm^2)		% of Increase/Decrease in Strength
	7 Days	28 Days	
Mix-MK0	2.05	3.22	0%
Mix-MK1	2.2	3.38	+8.33%
Mix-MK2	2.34	3.61	+15.7%
Mix-MK3	2.28	3.51	+12.5%
Mix-MK4	2.11	3.25	+4.16%



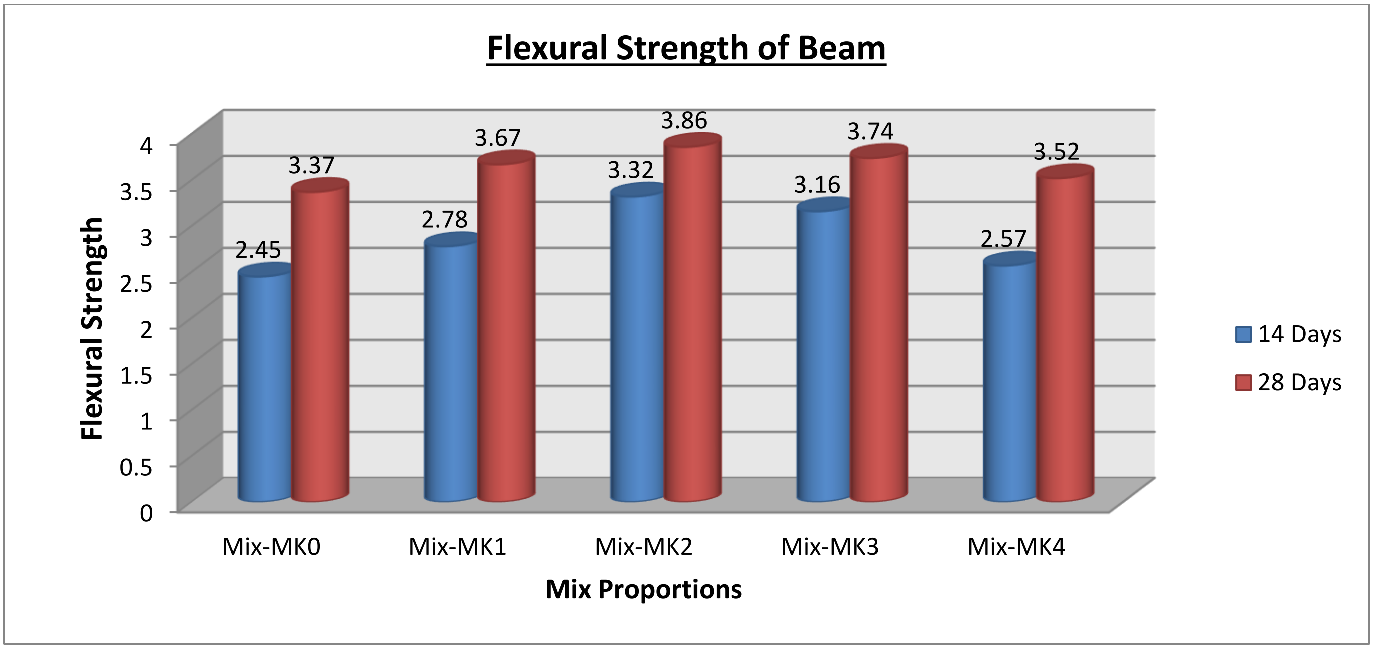
Graph-3 Spilt Tensile Strength of Cylinder



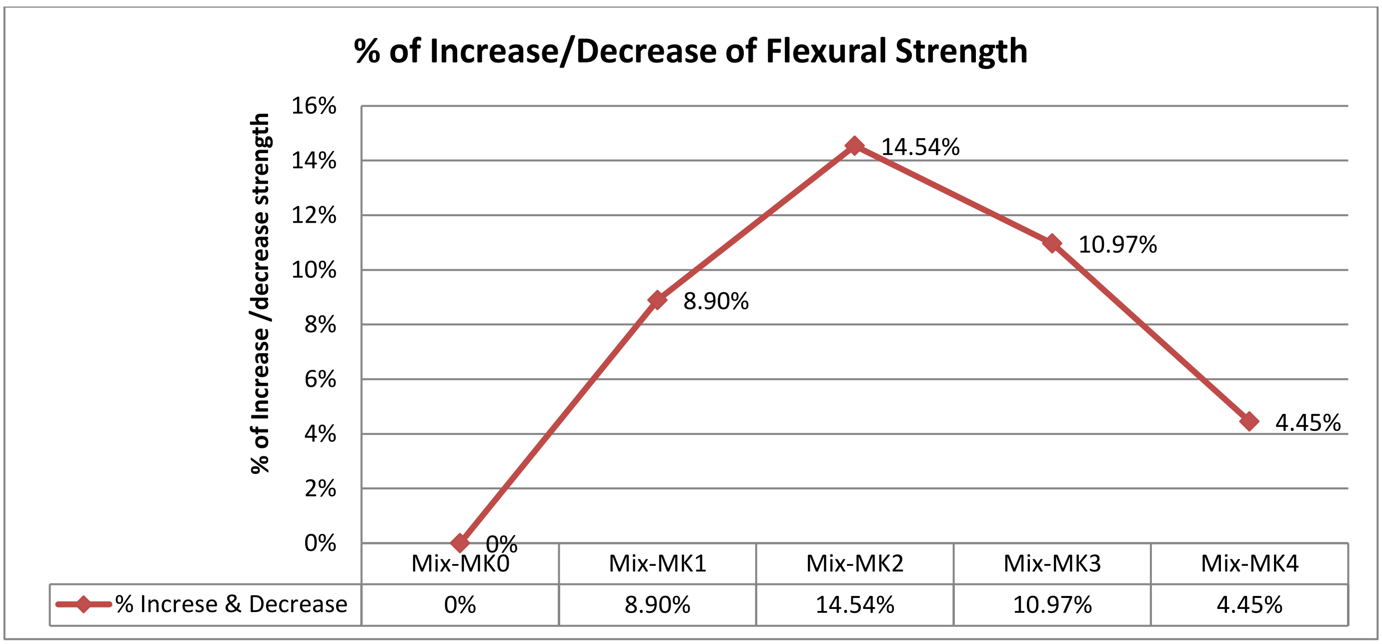
Graph-4 % of Increase/Decrease of Spilt Tensile Strength

Table-10 Flexural Strength of Beam

Nomenclature Mix Designations	Flexural Strength of Beam After Curing (N/mm^2)		% of Increase/Decrease in Strength
	14 Days	**28 Days**	
Mix-MK0	2.45	3.37	0%
Mix-MK1	2.78	3.67	8.9%
Mix-MK2	3.32	3.86	14.54%
Mix-MK3	3.16	3.74	10.97%
Mix-MK4	2.57	3.52	4.45%



Graph-5 Flexural Strength of Beam



Graph-6 % of Increase/Decrease of Flexural Strength

CONCLUSION

The strength of concrete in metakaolin content 15% replacement of cement gives best result among all percentage of replacement of metakaolin. At metakaolin content 15% the compressive strength increases by 16.80%, split tensile strength increases by 15.7% and flexural strength increases by 14.54% at the age of 28 days of curing period.

The following conclusions were drawn from the present investigation on the impact in concrete of partial replacement of cement with Metakaolin;

- The compressive strength, flexural strength and split strength of concrete increases with increase in metakaolin content up to 15% replacement of cement.
- Workability decreases as percentage of metakaolin in concrete increases. With percentage of metakaolin increases, the addition of admixture increases gradually.
- Use of Metakaolin in concrete speeds up the initial concrete setting process.

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