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Effect of Temperature on Metakaolin Blended High Strength Concrete

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Abstract: The high strength concrete can be advantageously used for columns and shear walls of high rise buildings, elevated structures, precast and prestressed products and construction where durability is a function of compressive strength. The advent of prestressed concrete technology techniques has given impetus for making concrete of higher strength. Concrete is defined as "High-strength concrete" solely on the basis of its compressive strength measured at a given age. In the 1970's, any concrete mixture that showed 40 MPa or more compressive strength at 28-days were designed as high-strength concrete. Achievement of high strength concrete requires quality materials resulting in increase of cost which necessitates the use of chemical and mineral admixture in the concrete industry.

Metakaolin is a leader among a new generation of such materials. Metakaolin is relatively a new mineral admixture for concrete. An attempt is made in the present investigation to study the properties of high strength Metakaolin concrete. The present work aims to show the behavior of M50 grade of concrete at various temperatures and changes in its compressive strength, flexural strength and split tensile strength. The strength properties studied in general are found to be improved by replacing the cement with Metakaolin in all the mixes. The study reveals that concrete has very distinct bonding properties that change with change in exposure conditions.

Keywords: High Strength Concrete, Metakaolin (MK), Compressive Strength, Flexural Strength, Split Tensile Strength.

I. INTRODUCTION

Recent research aimed at energy conversation in the cement and concrete industry has in part, focused on the use of less energy intensive materials such as fly ash, slag and silica fume. Lately some attention has been given to the use of natural pozzolans like Metakaolin as a possible partial replacement for cement. Amongst the various methods used to improve the durability of concrete, and to achieve high performance concrete, the use of Metakaolin is a relatively new approach, the chief problem with its extreme fineness and high water requirement when mixed with Portland cement. However the availability of super plasticizers has opened up new possibilities for its use. Metakaolin manufactured from pure raw material to strict quality standards. Metakaolin is a high quality pozzolanic material, which is blended with Portland cement in order to improve the strength and durability of concrete and mortars. In this study an attempt has been made to know the high strength concrete with blended Metakaolin.

I. Materials

The materials used in the experimental work namely cement, Metakaolin, fine aggregate and coarse aggregate (passing through 20mm and retained 10mm sieve was used) have been tested in laboratory for use in mix designs. The details are presented below.

1) Cement: The cement used was ordinary Portland cement (43 grade) with specific gravity of 3.15, initial and final setting time of the cement was 90mins and 210mins.
2) Metakaolin: The Metakaolin used in this experimental work was obtained from Baroda of Gujarat. Metakaolin is manufactured by calcinations of pure kaolinite clay at a temperature between 650º C to 850º C followed by grinding to achieve fineness 700 to 900 m^2/kg. The average particle size is 1.5µm. Its specific gravity as found is 2.65 and bulk density is $0.5 kg/m^3$.
3) Fine aggregate: Locally available river sand having fineness modulus 2.015, specific gravity 2.51 and conforming to grading zone-III as per I.S: 383 – 1970[8].
4) Coarse aggregate: Coarse aggregate passing through 20mm and retained 10mm sieve was used. Its specific gravity was 2.7and fineness modulus is 7.17.
5) Admixture: A locally available admixture by the name CONPLAST SP 430 has been used to enhance the workability of the concrete.

II. EXPERIMENTAL WORK

This paper presents the feasibility of the usage of Metakaolin usage as partially replaced material for cement. Mix design has been developed for M50 grade using design approach of Erntroy and Shahlock's empirical method. Initially four trails were conducted by partially replacing cement with Metakaolin starting from 0% to 20% with the gradual increase of 5% for each trail and observed that the maximum strength was occurred at 15% replacement of Metakaolin and after that at 20 % the strength began to decrease. Now keeping 15% Metakaolin various cubes, cylinders and prisms were casted.Cubes of size 100 mm× 100 mm× 100 mm, cylinders of size 150 mm Ø × 300 mm and prisms of size 100 mm× 100 mm× 500 mm were casted and tested for compressive strength, split tensile strength and flexural strength after the completion of respective curing periods. The specimens were kept in furnace for various temperature periods of 100°C, 300°C and 500°C.The results of 0% Metakaolin and 15% Metakaolin were compared for mechanical properties.

A. Batching, casting, vibrating and curing specimens

All the test specimens were cast in removable standard (cast iron) moulds conforming to IS: 10086-1982 and vibrated on a standard vibrating table conforming to IS 7246-1974. Test specimen were demoulded after a lapse of 24 hours from the commencement of casting and submerged under water until the time of testing.

B. Testing of specimens for compressive strength

Concrete specimen cubes are used to determine compressive strength of concrete and were tested as per IS 516-1959[9].

C. Testing of specimens for split tensile strength

Concrete specimen cylinders are used to determine split tensile strength of concrete and were tested as per IS 516-1959[9].

D. Testing of specimens for flexural strength

Concrete specimen beams are used to determine flexural strength of concrete and were tested by applying two point loading as per IS 516-1959[9].

III. RESULTS AND DISCUSSIONS

Tests are conducted for concrete made of different replacements of cement with Metakaolin and the compressive strength, split tensile strength and flexure strength are studied for 28 days and 91 days of curing. The results are tabulated and discussions have been made.

A. *Effect of Variation of Metakaolin on Compressive Strength*

Concrete cubes are casted for 0%, 10%, 15% and 20% Metakaolin as replacement. The compressive strength for M50 grade is tested for 28 days and 91 days of curing and the results are tabulated in table.1 and the graph is shown in Fig.1.

Table I: Compressive Strength of M50 Grade Concrete

S. No:	% of Metakaolin	Compressive Strength(N/mm^2)	
		28 days	90 days
1	0	59	61.34
2	10	60.20	62.12
3	15	61.86	63
4	20	57.1	58.3

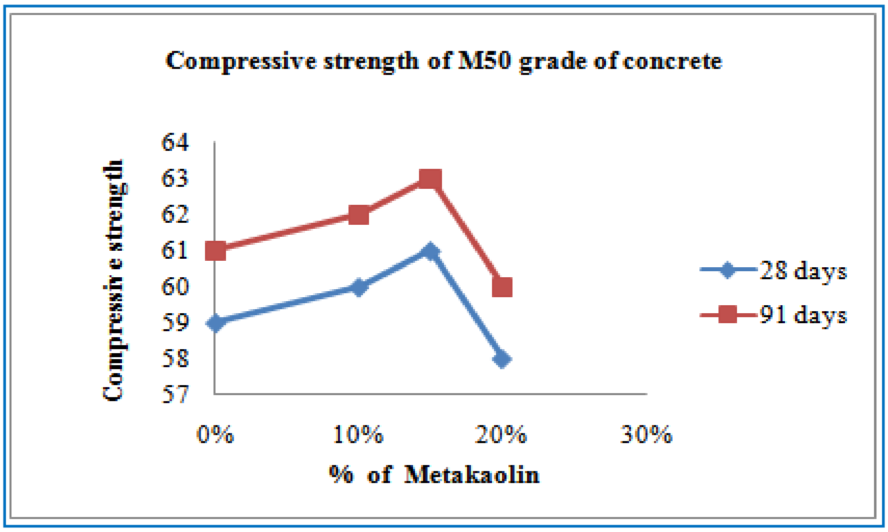

Fig. 1. Compressive Strength of M50 Grade of Concrete

Table 1 shows the compressive strength of M50 grade of concrete with no replacement of cement and 15 % replacement of cement by Metakaolin. At the age of 28 days the strength increases from 0 % Metakaolin to 15 % Metakaolin. The maximum compressive strength is obtained at 15 % of cement replacement by Metakaolin and thereafter the strength decreases with increases in percentage of Metakaolin replaced with cement. It can be seen from table.1 and fig.1 the strength obtained at 91 days is more than the strength obtained at 28 days of curing.

B. Effect of Temperature on Compressive Strength of Metakaolin Blended Concrete:

Concrete cubes are casted for 0% Metakaolin and 15% Metakaolin replacement of cement. The compressive strength for M50 grade is tested for 28 days and 91 days of curing. These cubes which are cured for 28 days and 91 days curing specimens are kept in furnace at various temperatures for duration of 1hour, 2 hours and 3 hours and the results are tabulated in table.2 and graph are shown in graph 2 to graph 5.

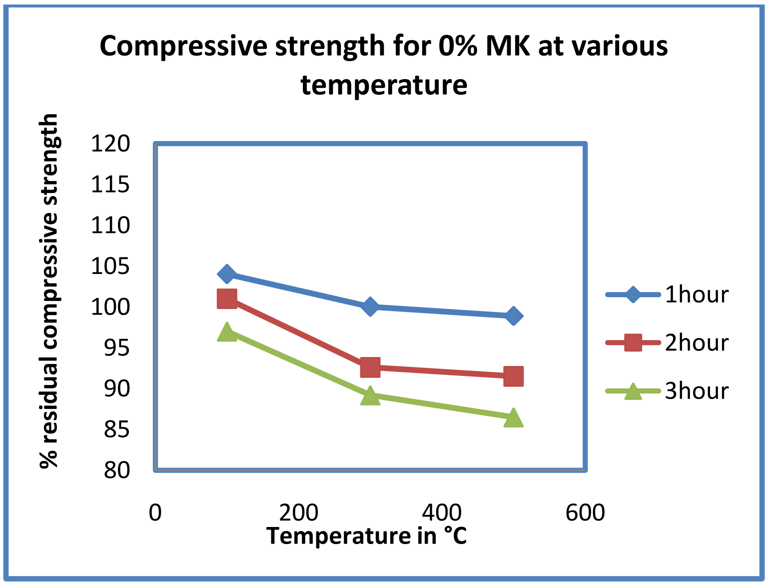

Fig. 2. Compressive Strength of 0% MK at Various Temperatures

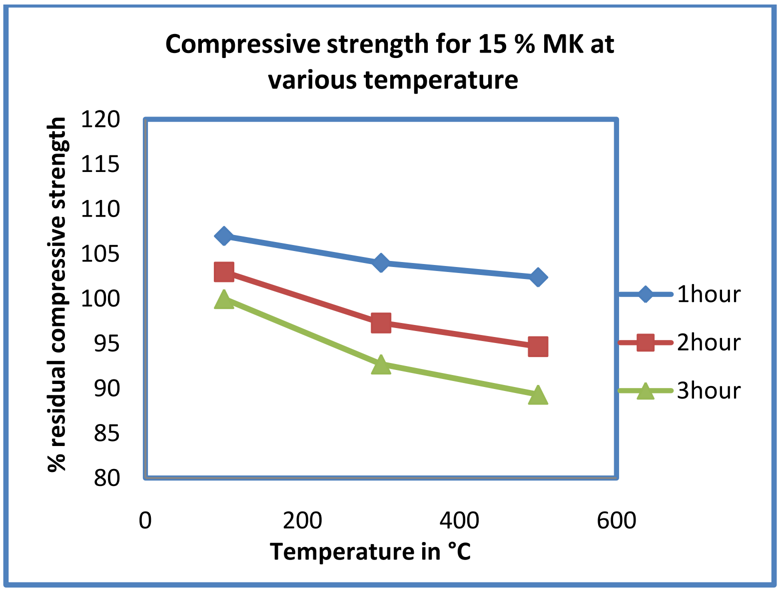

Fig. 3. Compressive Strength of 15% MK at Various Temperatures

Table II: Compressive Strength of M50 Grade Concrete at Various Temperatures

S.No	Temperature °C	0% of Metakaolin			15% of Metakaolin		
		1hour	2hours	3hours	1hour	2hours	3hours
For 28 days							
1	27	59	59	59	61.86	61.86	61.86
2	100	62.24	61.01	60.25	64.45	62.2	61.01
3	300	60.3	59.5	57.01	62.33	60.1	58.26
4	500	57.1	56.10	55.23	59.12	57.23	56
For 91 days							
5	27	61.34	61.34	61.34	63	63	63
6	100	63.03	62.11	61.41	65.25	62.67	60.2
7	300	61.1	59.27	57	64.05	61.2	58
8	300	61.1	59.27	57	64.05	61.2	58

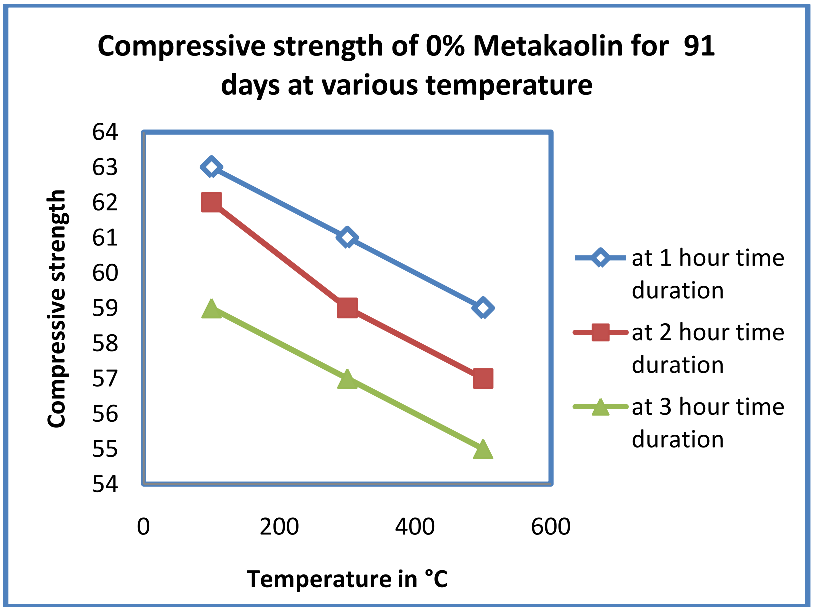

Fig. 4. Compressive Strength of 0% MK for 91 days at Various Temperature

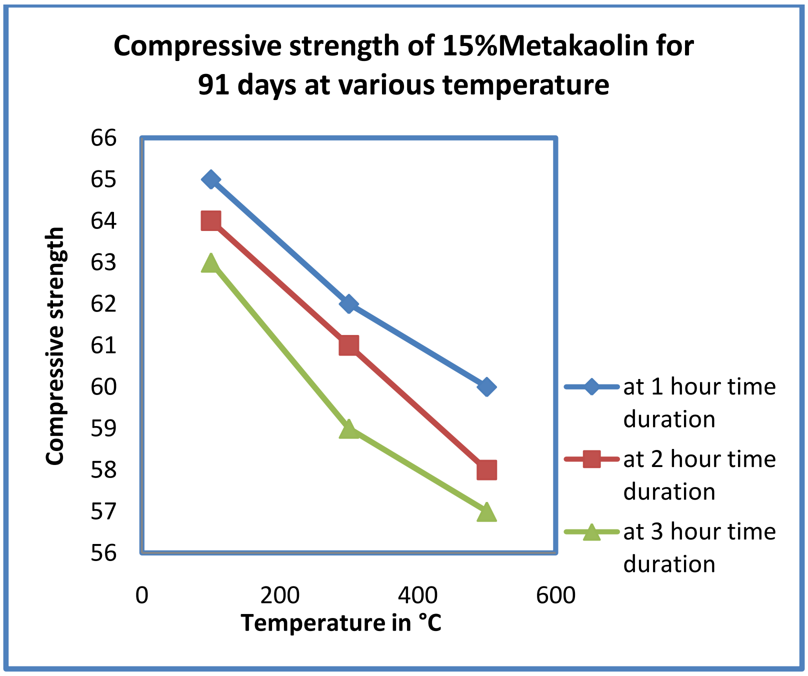

Fig. 5. Compressive Strength of 15% MK for 91 days at Various Temperature

It is seen from the table2 that the strength increases at 100ºC temperature when compared to the strength obtained at normal room temperature. It was found that after an increase in compressive strength at 100ºC, the Metakaolin suffered a more severe loss of compressive strength than 0% MK at higher temperatures. Explosive spalling was observed in high temperature and frequency increased with higher Metakaolin contents. After 300ºC the severe strength loss was due to very dense pore structure of Metakaolin which enhanced the buildup of vapour pressure upon heating and resulted in spalling and cracking. . The spalling frequency increased with the higher Metakaolin percentage content

C. EFFECT OF VARIATION OF METAKAOLIN ON SPLIT TENSILE STRENGTH

Concrete cylinders are casted for 0%, 10%, 15% and 20% Metakaolin. The compressive strength for M50 grade is tested for 28 days and 91 days of curing and the results are tabulated in table.3 and the graph is shown in fig .6

Table III: Split Tensile Strength of M50 Grade Concrete

S.No:	% of Metakaolin	Split Tensile Strength(N/mm^2)	
		28 days	90 days
1	0	3.9	4.39
2	10	4	4.6
3	15	4.01	4.9
4	20	3.95	4.5

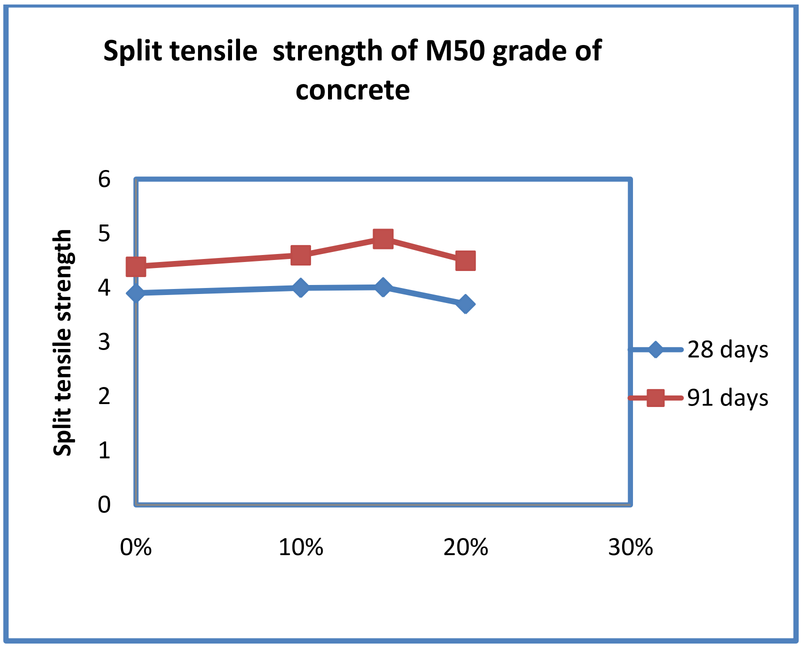

Fig. 6. Split Tensile Strength of M50 Grade of Concrete

At the age of 28 days the strength increases from 0% Metakaolin to 15 % Metakaolin. The optimum value is obtained at 15% of cement replacement by Metakaolin and thereafter the strength decreases with increases in percentage of Metakaolin replaced with cement. This is due to the fact that at higher percentages of replacement, the demand for water is more which is not actually available and hence the compaction of concrete becomes somewhat difficult in spite of the increase dosage of Superplasticizer. The strength obtained by 91 days cured cylinders is more than the strength obtained at 28 days of curing.

D. Effect of Temperature on Split Tensile Strength of Metakaolin Blended Concrete

Concrete cylinders are casted for 0% Metakaolin and 15% Metakaolin replacement of cement. The split tensile strength for M50 grade is tested for 28 days and 91 days. These cylinders which are cured for 28 days and 91 days curing specimens are kept in furnace at various temperatures for duration of 1hour, 2 hours and 3 hours and the results are tabulated in table.4 and graph in fig.7 to fig.10

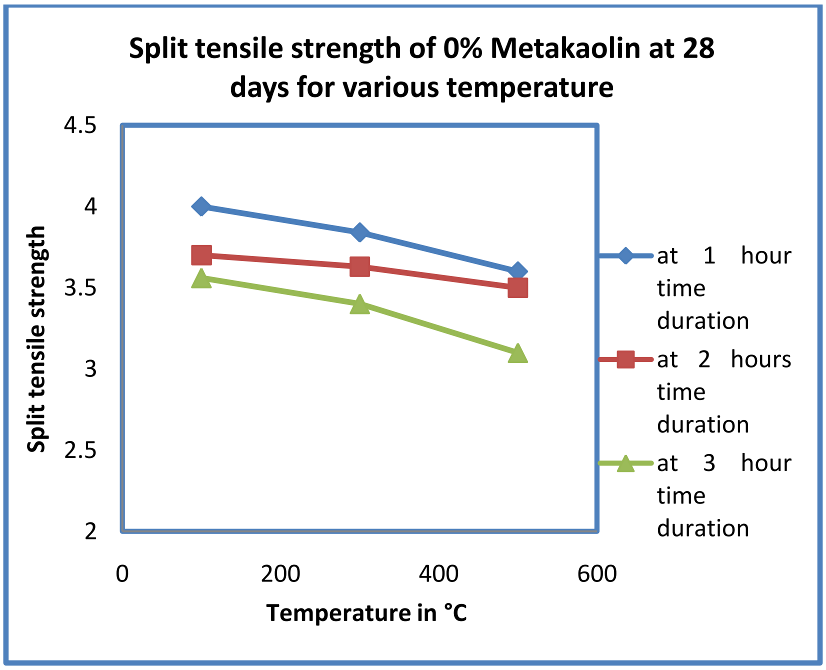

Fig. 7. Split Tensile Strength of 0% MK at 28 Days for Various Temperature

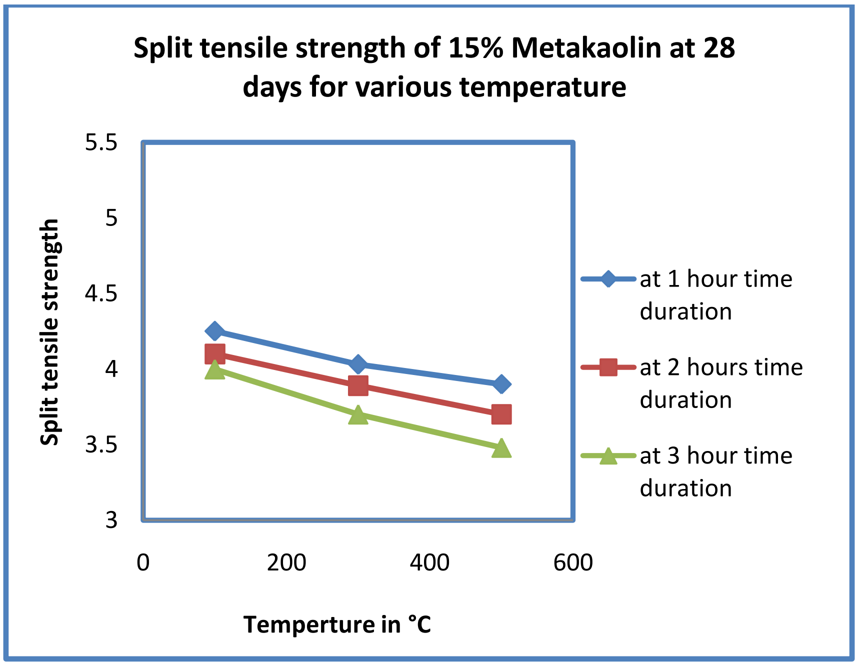

Fig .8. Split Tensile Strength of 0% MK at 28 Days for Various Temperature

Table IV: Split Tensile Strength of M50 Grade Concrete at Various Temperatures

S.No	Temperature °C	0% of Metakaolin			15% of Metakaolin		
		1hour	2hours	3hours	1hour	2hours	3hours
				For 28 days			
1	27	3.9	3.9	3.9	4.01	4.01	4.01
2	100	4	3.7	3.56	4.25	4.1	3.9
3	300	3.84	3.63	3.4	4.03	3.89	3.7
4	500	3.6	3.5	3.1	3.99	3.7	3.48
				For 91 days			
5	27	4.39	4.39	4.39	4.9	4.9	4.9
6	100	4.54	4.33	4.1	5.1	4.9	4.76
7	300	4.36	4.1	3.87	4.89	4.6	4.2
8	300	4.11	3.89	3.65	4.65	4.37	4

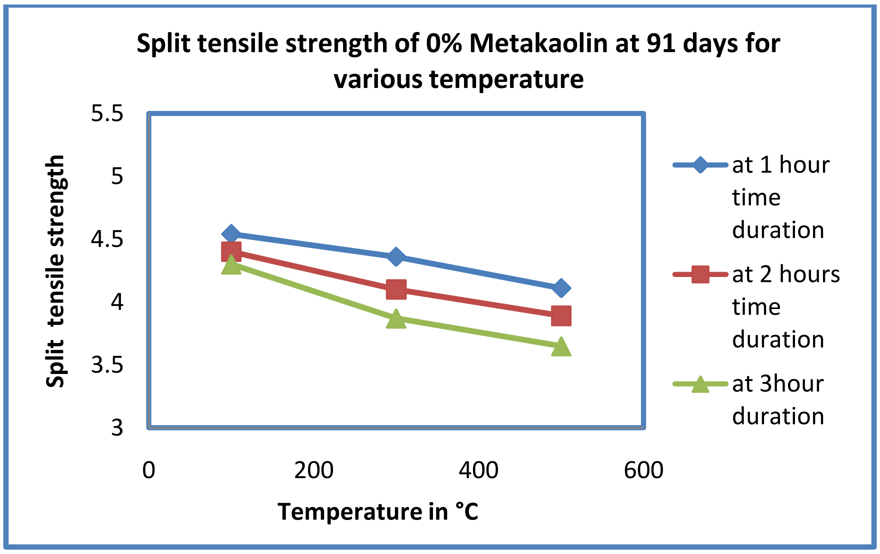

Fig. 9. Split tensile strength of 0% Metakaolin at 91 days for various temperature

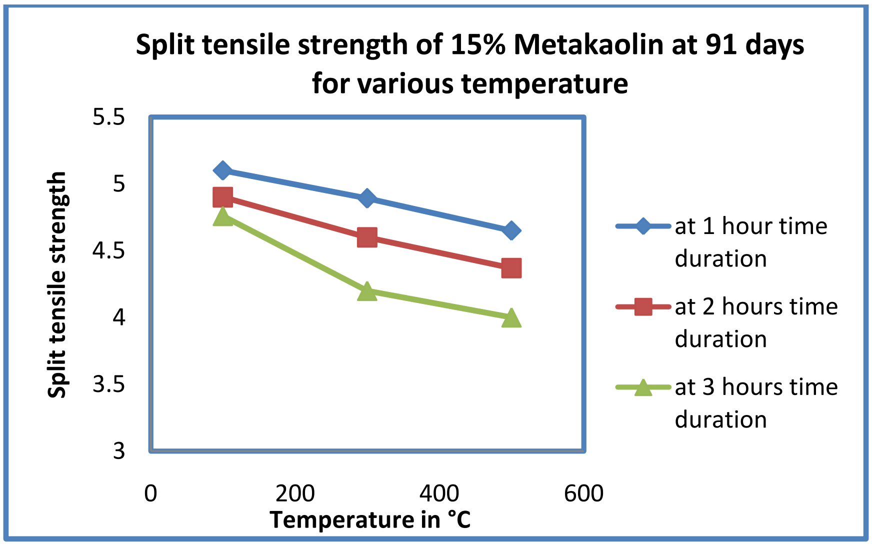

Fig. 10. Split tensile strength of 15% Metakaolin at 91 days for various temperature

It was seen that major loss of tensile strength was observed for both 28 days and 91 days curing during the first hour of exposure to heat at all temperatures. Longer curing accelerates the development of strength in the first 24 hours of hardening. The strength increases for 100 º C temperature when compared to the strength obtained at normal temperature.

The strength at 1hour duration is more when compared to the strength at 2 hours. The strength decreases with increase in time duration of cubes kept in furnace. As seen in the table 4 strength decreases from 100°C temperature to 300°C and further decreases at 500°C temperature.

E. EFFECT OF VARIATION OF METAKAOLIN ON FLEXURAL STRENGTH

Concrete prisms are casted for 0%, 10%, 15% and 20% Metakaolin. The flexural strength for M50 grade is tested for 28 days and 91 days of curing and the results are tabulated in table.5 and the graph in Fig .11

Table V: Flexural Strength of M50 Grade Concrete

S.No:	% of Metakaolin	Flexural Strength(N/mm^2)	
		28 days	90 days
1	0	5.21	6.51
2	10	5.64	7.12
3	15	5.91	7.95
4	20	5.32	6.62

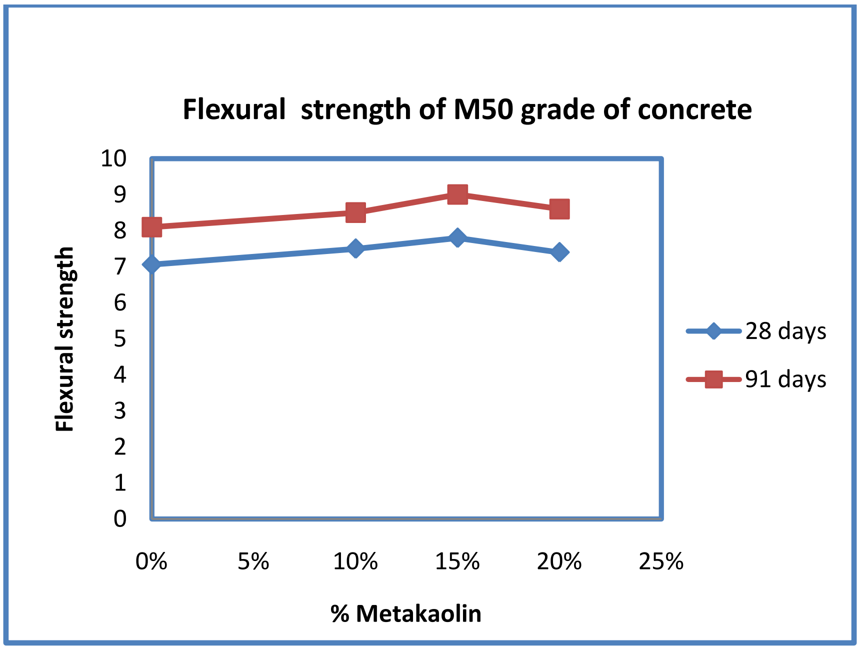

Fig. 11. Flexural strength of M50 grade of concrete

The flexural strength was determined using test accordance with IS 516.Table 5 shows value of 0% Metakaolin and 15 % Metakaolin. The table clearly shows that there is marginal improve mental of flexural strength from 0% to 15 % Metakaolin there after the strength decreases with higher Metakaolin contents. The strength obtained by 91 days cured prisms is more than the strength obtained at 28 days of curing. It shows that duration of curing has significant influence on the overall soundness, especially strength.

F. Effect Of Temperature On Flexural Strength Of Metakaolin Blended Concrete

Concrete prisms are casted for 0% Metakaolin and 15% Metakaolin replacement of cement. The flexural strength for M50 grade is tested for 28 days and 91 days of curing. These prisms which are cured for 28 days and 91 days curing specimens are kept in furnace at various temperatures for duration of 1hour, 2 hours and 3 hours and the results are tabulated in table.6 and graph is shown in fig.12 to fig.15

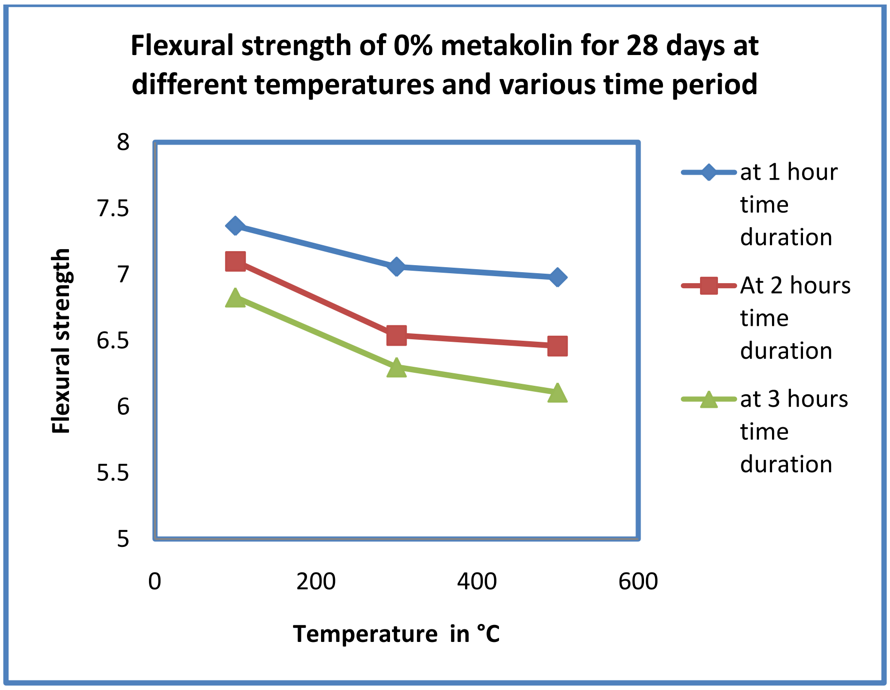

Fig. 12. Flexural strength of 0% Metakaolin for 28 days at different temperatures and various time period

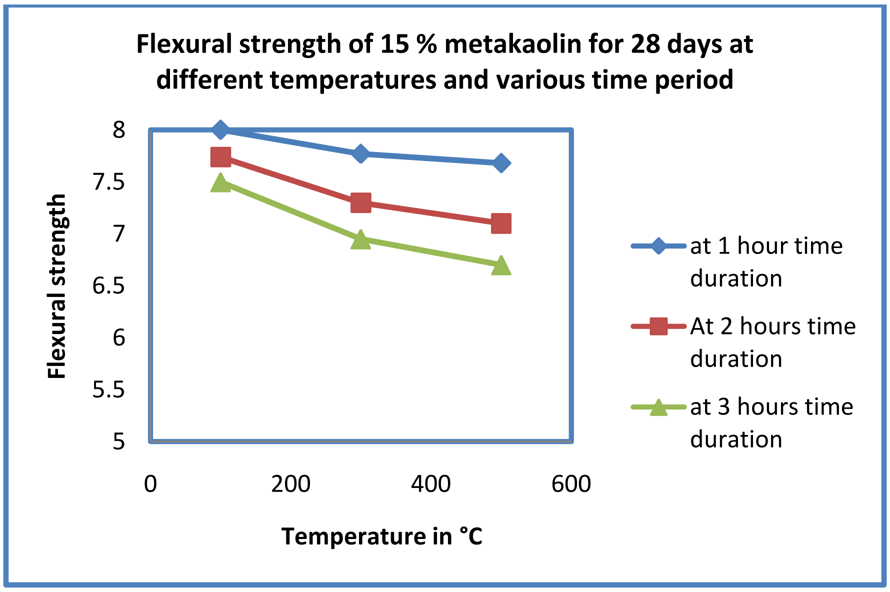

Fig. 13. Flexural strength of 15 % Metakaolin for 28 days at different temperatures and various time period

Table VI: Flexural Strength of M50 Grade Concrete at Various Temperatures

S.No	Temperature °C	0% of Metakaolin			15% of Metakaolin		
		1hour	2hours	3hours	1hour	2hours	3hours
For 28 days							
1	27	7.06	7.06	7.06	7.8	7.8	7.8
2	100	7.37	7.1	6.83	8	7.6	7.43
3	300	7.06	6.54	6.3	7.91	7.3	6.95
4	500	6.98	6.46	6.11	7.5	7.1	6.7
For 91 days							
5	27	8.1	8.1	8.1	9	9	9
6	100	8.2	7.3	7	8.5	8.23	7.8
7	300	7.86	7.2	6.91	8	7.6	7.48
8	300	7.2	6.94	6.4	7.89	7.45	7.03

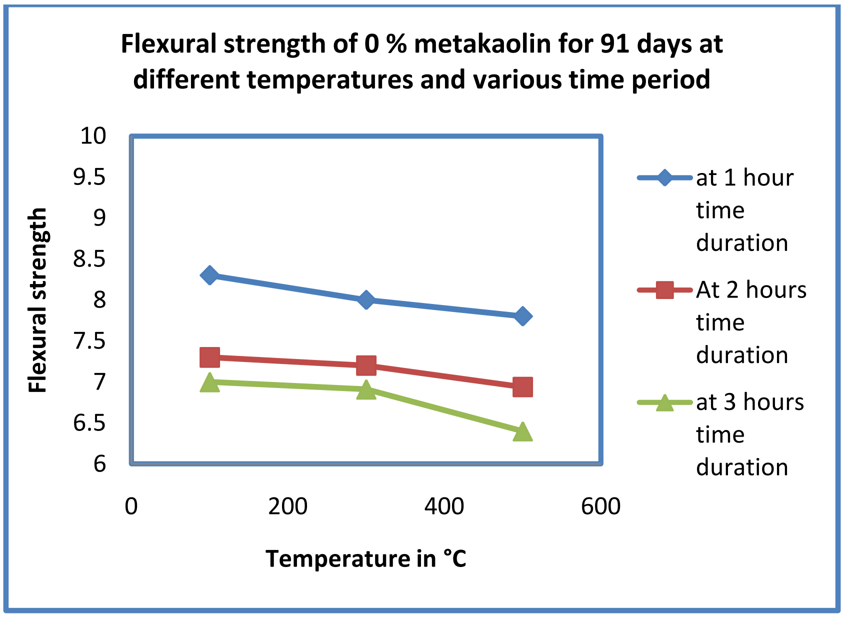

Fig.14 Flexural strength of 0 % metakaolin for 91 days at different temperatures and various time period

From the table.6 and the fig it is observed that the strength increases at 100ºC temperature when compared to the strength obtained at normal room temperature. The strength decreases from 100ºC temperature to 300ºC and further decreases at 500ºC temperature. The strength at 1hour duration is more when compared to the strength at 2 hours. The strength decreases with increase in time duration of prisms kept in furnace.

IV. CONCLUSIONS

Based on the analysis of experimental results and discussions there upon the following conclusions are drawn

(a) The compressive strength, flexural strength and split tensile strength of normal concrete and concrete with Metakaolin as partial replacements are compared and observed that the strength of the normal concrete is slightly lower than the Metakaolin replaced concrete.

(b) Among the various replacements, the concrete with 15% Metakaolin replaced cement showed good compressive strength than the other percentages of 10% and 20%.

(c) The strength of concrete increases at 100°C temperature and thereafter it starts loses its strength as the temperature increases.

(d) The strength of concrete decreases with increase in time duration of samples kept in furnace. The strength obtained by samples kept for 3 hours showed lesser strength than the samples kept for 1 hour at same temperature.

(e) The split tensile strength of concrete is increased when cement is replaced with Metakaolin. The split tensile strength is maximum at 15% of replacement.

(f) The flexural strength of concrete is increased when cement is replaced with Metakaolin. The flexural strength is maximum at 15%of replacement.

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