

Study On the Strength Characteristics of Concrete with Partial Replacement of Cement by Zeolite and Metakaolin

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ABSTRACT: Zeolite is a popular type of natural pozzolanic material which has been widely utilized in constructions since ancient times and zeolite is the largest group of silicate minerals. The present study is, carried out in two phases in first phase mix of M35 grade concrete with partial replacement of cement by 0%, 10%, 15%, 20%, and 25% zeolite is carried out to determine the optimum percentage of replacement at which maximum compressive strength, tensile strength, flexural strength is achieved. It is observed that when cement is partially replaced with 15% of zeolite concrete maximum strength is achieved. In phase two mix of M35 grade concrete combination of zeolite and metakaolin is partially replaced with cement. The composition 15% of zeolite constant + 5%, 10%, 15%, 20% of metakaolin is carried out to determine the maximum strength. It is observed that when cement is partially replaced with 15 % of zeolite + 10 % of metakaolin concrete maximum strength is achieved. Test results indicate that use of combination of zeolite and metakaolin in partial replacement of cement in the concrete has improved the mechanical properties.

KEYWORDS: Zeolite, Metakaolin, Compressive strength, Tensile strength, Flexural strength, M35 grade concrete.

I. INTRODUCTION

Concrete is one of most extensively used construction materials in the world, with two billion tons placed worldwide each year It is attractive in many applications because it offers considerable strength at a relatively low cost. Concrete can generally be produced of locally available constituents, can be cast into a wide variety of structural configurations, and requires minimal maintenance during service. Portland cement industry is responsible for approximately 7% of global CO₂ emission. Partial replacement of portland cements by one or more additives to obtain blended cements not only provides reduction in CO₂ emission and energy saving in cement product. ion but also supplies more durable cementitious systems to construction industry.

Supplementary cementitious materials (SCMs) are finely ground solid materials that are used to replace part of the cement in a concrete mixture. These materials react chemically with hydrating cement to form a modified paste microstructure. In addition to their positive environmental impact, SCMs may improve concrete workability, mechanical properties, and durability. SCMs may possess pozzolanic or latent hydraulic reactivity or a combination of these. The term pozzolan refers to a silicious material, which, in finely divided form and in the presence of water, will react chemically with calcium hydroxide to form cementitious compounds. Supplementary cementitious materials (SCMs), such as natural Pozzolans or industrial by-products (artificial Pozzolans) like fly ash, slag and silica fume, have been recently utilized toward solving these issues. While partial replacements of PC with SCMs lead to decreases in CO₂ emission, their inclusions in concrete mixtures have been proven to be effective in enhancement of concrete properties in terms of late-age strength and durability. Using pozzolans has become one of the most common ways to increase the service life of concrete structures. Pozzolans primarily affect the pore structure refinement of concrete, which leads to higher strength and lower permeability Two of the most commonly used pozzolans in industrial projects are metakaoline and silica fume (SF). According to several studies, both of these pozzolans used at the same

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replacement level can sharply increase the compressive strength of concrete and decrease its permeability. However, in recent years, the industry has shifted to using natural pozzolans because of their lower cost and accessibility. One of the most common natural pozzolanic materials is natural zeolites.

Zeolite is a crystalline, hydrated aluminosilicate of alkali and alkaline earth cations having infinite, open, three-dimensional structures. Natural zeolite has a cryptocrystalline structure, and like other pozzolans, it undergoes pozzolanic activity due to its high quantity of reactive SiO_2 and Al_2O_3 , which combines with $\text{Ca}(\text{OH})_2$ to form additional C-S-H gel. The presence of zeolite can retard the hydration process, thereby reducing the permeability, sorptivity and diffusivity of concrete because it reduces porosity and improves the transition zone structure between the blended cement paste and the aggregate.

The other pozzolanic material that used in this work was metakaolin. Metakaolin (MK) is a supplementary cementing material that conforms to ASTM C 618, Class N pozzolan specifications and it is considered as a pozzolanic material which is without direct cementitious value, but will, in the presence of moisture, react chemically with calcium hydroxide (CH) to form compounds possessing cementitious properties. It is obtained by the calcinations of kaolin at a temperature ranging between 500°C and 800°C . The material is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. The Meta prefix in the term is used to denote change. In the case of MK, the change that is taking place is dehydroxylation, brought on by the application of heat over a defined period of time. MK is a silica and alumina based product that, on reaction with $\text{Ca}(\text{OH})_2$, produces calcium silicate hydrates (CSH) gel and others hydrate products at ambient temperature. MK has been known to enhance strength and pore-refinement at relatively early ages.

II. LITERATURE REVIEW

In this literature review the through study of research papers on partial replacement of cement with zeolite and metakaolin in the concrete.

B. Uzal et.al.(2009) studied the Pozzolanic activity of clinoptilolite, the most common natural zeolite mineral, was studied in comparison to silica fume, fly ash and a non-zeolitic natural pozzolan. The results showed that the clinoptilolite possessed a high lime-pozzolan reactivity that was comparable to silica fume and was higher than fly ash and a non-zeolitic natural pozzolan. The high reactivity of the clinoptilolite is attributable to its specific surface area and reactive SiO_2 content. Relatively poor strength contribution of clinoptilolite in spite of high pozzolanic activity can be attributable to larger pore size distribution of the hardened zeolite-lime product compared to the lime-fly ash system.

Babak Ahmadi and Mohammad Shekarchi (2009) studied the effectiveness of a locally quarried zeolite in enhancing mechanical and durability properties of concrete is evaluated and is also compared with other pozzolanic admixtures. The experimental tests included three parts: In the first part, the pozzolanic reactivity of natural zeolite and silica fume were examined by a thermogravimetric method. In this case, the results indicated that natural zeolite was not as reactive as silica fume but it showed a good pozzolanic reactivity. In the second part, zeolite and silica fume were substituted for cement in different proportions in concrete mixtures, and several physical and durability tests of concrete were performed. Based on these results, the performance of concretes containing different contents of zeolite improved and even were comparable to or better than that of concretes prepared with silica fume replacements in some cases.

B.Uzal and L.Turanl(2011) studied the properties and hydration characteristics as well as paste microstructure of blended cements containing 55% by weight zeolitic tuff composed mainly of clinoptilolite mineral were investigated. Superplasticizer requirement and compressive strength development of blended cement mortars were also determined. The blended cements containing high volume of natural zeolites were characterized with the following properties; (i) no free $\text{Ca}(\text{OH})_2$ in hardened pastes at the end of 28 days of hydration, (ii) less proportion of the pores larger than 50 nm when compared to portland cement paste, (iii) complete decomposition of crystal structure of zeolite at the end of 28 days of hydration, (iv) presence of tetra calcium aluminate hydrate as a crystalline product of pozzolanic reaction, (v) more compatibility with the melamine-based superplasticizer when compared to the naphthalene based product, and (vi) similar 28 days compressive strength of mortars to that of reference portland cement.

F. Canpolat et.al.(2003) studied the effects of zeolite, coal bottom ash and fly ash as Portland cement replacement materials on the properties of cement are investigated through three different combinations of tests. These materials are substituted for Portland cement in different proportions, and physical properties such as setting time, volume expansion, compressive strength and water consistency of the mortar are determined. Then, these physical properties are compared

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with those of PC 42.5. The results showed that replacement materials have some effects on the mechanical properties of the cement. The inclusion of zeolite up to the level of 15% resulted in an increase in compressive strength at early ages, but resulted in a decrease in compressive strength when used in combination with fly ash. Also, setting time was decreased when zeolite was substituted. The results obtained were compared with Turkish Standards (TS), and it was found that they are above the minimum requirements.

Meysam Najimi et.al. (2012) studied the application of natural zeolite as a supplementary cementitious material has been investigated. To this aim, some mechanical and durability properties of concrete made with 15% and 30% of natural zeolite are studied in comparison with concrete without natural zeolite replacement. The results revealed considerable effectiveness of natural zeolite application on water penetration, chloride ion penetration, corrosion rate and drying shrinkage of concrete; however, satisfactory performance was not observed in acid environment. Altogether, from the practical point of view, the incorporation of 15% natural zeolite was found as an appropriate option for improving strength and durability properties of concrete.

Mahdi Valipour et.al.(2013) studied to improve the durability and serviceability of concrete structures in such environments, several investigations have been conducted that address the addition of silica fume and metakaolin, while less attention has been given to the newly introduced pozzolan called natural zeolite. In this paper, the performance of concretes containing natural zeolite, metakaolin and silica fume and that of concretes with different water-to-binder ratios under various exposure conditions in terms of chloride ion diffusivity were investigated. To achieve this objective, concrete specimens with water-to-binder ratios (w/b) of 0.35, 0.40, 0.45 and 0.50 were fabricated. In addition, to examine the performance of three different pozzolans, other specimens with constant water-to-binder ratios of 0.40 containing 10% natural zeolite, 5% metakaolin and 5% silica fume were prepared. The results were obtained from a field exposure site and indicate that natural zeolite exhibits good performance in terms of improving the durability of concrete in harsh environments.

III. EXPERIMENTAL PROGRAM

MATERIALS USED

CEMENT

The cement used was ordinary Portland cement 53 (OPC 53). All properties of cement were determined by referring IS 12269 - 1987. The specific gravity of cement is 3.15. The initial and final setting times were found as 55 minutes and 258 minutes respectively. Standard consistency of cement was 32%.

AGGREGATE

Coarse Aggregate 20mm size aggregates-The coarse aggregates with size of 20mm were tested and the specific gravity value of 2.88 and fineness modulus of 3.11. Fine Aggregate The sand which was locally available and passing through 4.75mm IS sieve is used. The specific gravity of fine aggregate was 2.66 and fineness modulus of 3.22. Aggregates were available from local sources

ZEOLITE

Zeolite is a popular type of natural pozzolanic material which has been widely utilized in constructions since ancient times and zeolite is the largest group of silicate minerals. Zeolite occur naturally but are also produced industrially on a large scale naturally it is obtained by open pit mining and industrially it is produced synthetically by typical procedure heating aqueous solutions of alumina and silica with sodium hydroxide. equivalent reagents include sodium aluminate and sodium silicate. Zeolite Procured from Sri maruthi industries Hyderabad, Specific gravity 2.1.

METAKAOLIN

Metakaolin is an amorphous material that is obtained by dehydrating kaolin at temperature of about 800⁰ C. the high reactivity of metakaolin with cement and its usability to accelerate the cement hydration differentiates it from other pozzolanic materials. metakaolin Procured from Astra chemicals Chennai, Specific gravity 2.5.

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CHEMICAL COMPOSITION OF ZEOLITE AND METAKAOLIN:

Table 1: chemical composition of Zeolite and Metakaolin

Materials Chemical composition: wt. %	Zeolite	Materials Chemical composition: wt. %	Metakaolin
SiO ₂ (S)	64.44	SiO ₂ (S)	51.58
Al ₂ O ₃ (A)	8.3	Al ₂ O ₃ (A)	43.87
Fe ₂ O ₃ (F)	1.66	Fe ₂ O ₃ (F)	0.99
CaO	1.77	CaO	0.2
MgO	0.07	MgO	0.18
SO ₃	0.04	SO ₃	---
Na ₂ O	2.3	Na ₂ O	0.01
K ₂ O	2.24	K ₂ O	0.12
Loss on ignition	18.95	Loss on ignition	0.57

WATER

The water used for experiments was potable water.

SUPER PLASTICIZER

The super plasticizer used in the work is FOSROC CONPLAST SP430 is a chloride free, Procured from Astra chemicals Chennai, Specific gravity 1.20-1.22.

SCOPE OF WORK

For **M35** grade concrete Experimental work can be done in two phases

Phase 1 : Partial replacement of cement by Zeolite at 10%,15%,20%,25% to determine the optimum percentage of replacement at which maximum strength is achieved.

Phase 2 : cement is replaced with combination of Zeolite and Metakaolin by taking zeolite optimum as constant and replacing metakaolin as 5%,10%,15%,20% .

properties like compressive strength, split tensile strength, flexural strength are to be determined .

Experimental work consist casting cubes of size 150mm×150mm×150mm will cast to determine compressive strength, cylinders of size 150mm dia×300mm height will cast to determine split tensile strength, beams of 500mm length ×100mm width ×100mm depth to determine flexural strength.

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IV. RESULTS AND DISCUSSIONS

MIX DESIGN :M35 grade concrete

Mix design of control concrete AS per IS 10262-2009,IS 456-2000

Table No. 2: Mix proportions of zeolite concrete.

Mix No.	Replace-ment Details	Zeolite(Z) (Kg/m ³)	C.A (Kg/m ³)		F.A (Kg/m ³)	Cement (Kg/m ³)	Water (Kg/m ³)	Sp (Kg/m ³)
			20-12.5 mm	12.5 -4.75 mm				
M0	0% Z	0	789.06	526.04	690.42	383.16	153.24	3.06
M1	10% Z	38.316	789.06	526.04	690.42	344.84	153.24	3.06
M2	15% Z	57.47	789.06	526.04	690.42	325.69	153.24	3.06
M3	20% Z	76.63	789.06	526.04	690.42	306.53	153.24	3.06
M4	25% Z	95.71	789.06	526.04	690.42	287.37	153.24	3.06

PHASE 1 :

In phase 1 partial replacement of Cement by Zeolite in M35 grade concrete with 10%,15%,20%,25%.

Table 3: strength results for Zeolite concrete

STRENGTH (Mpa)	CONV.		Z 10 %		Z 15 %		Z 20%		Z 25 %	
	28days	7days	28days	7days	28days	7days	28days	7days	28days	7days
Compressive	44.14	32.8	45.92	32.8	47.40	30.8	42.37	25.33	38.51	22
Flexural	3.90	2.88	3.98	2.88	4.12	2.84	3.62	2.34	3.14	2.15
Split Tension	3.37	2.54	3.48	2.54	3.63	2.51	3.28	2.08	2.9	1.87
Compaction Factor	0.89		0.91		0.91		0.90		0.86	
Slump Cone Test	70mm		60mm		60mm		55mm		40mm	

COMPRESSIVE STRENGTH

Compressive strength is compared with the results obtained from the conventional mix, It was observed that the increase in compressive strength gradually up to 15% replacement of cement by zeolite and then decreased. The maximum compressive strength **47.40 N/mm²** was obtained at **15%** replacement of cement by zeolite, which was **7.38 %** more than the conventional mix.

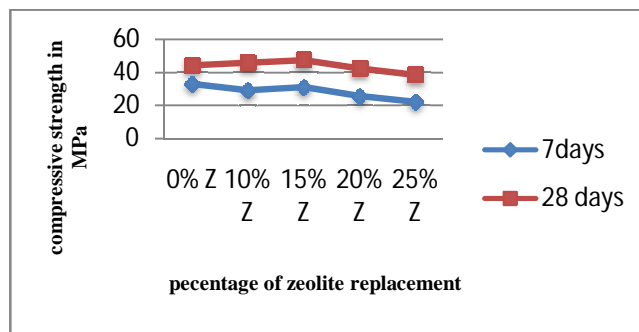


Fig 1: compressive strength curve of zeolite replacement concrete

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SPLIT TENSILE STRENGTH

The maximum Split tensile strength 3.63 N/mm^2 was obtained at **15%** replacement of cement by zeolite, which was **7.7 %** more than the conventional mix.

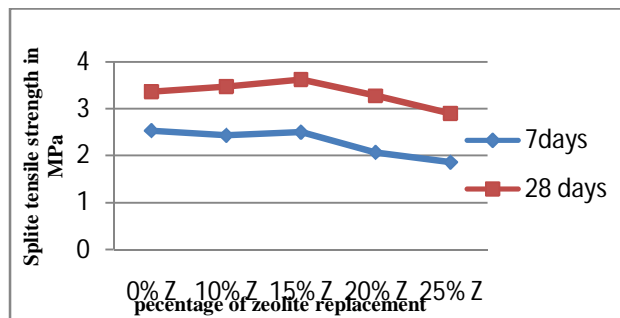


Fig 2: split tensile strength curve of zeolite replacement concrete

FLEXURAL STRENGTH

The maximum Flexural strength strength 4.12 N/mm^2 was obtained at **15%** replacement of cement by zeolite, which was **5.64 %** more than the conventional mix.

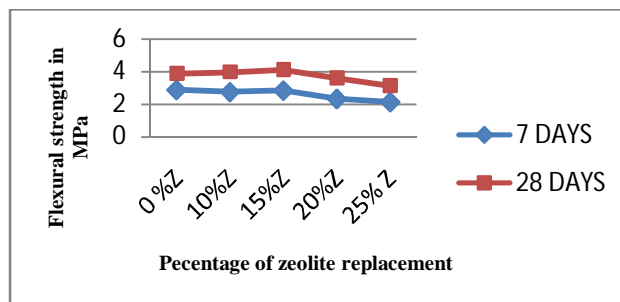


Fig 3: Flexural strength curve of zeolite replacement concrete

PHASE 2 :

In Phase 2 partial replacement of cement with combination of Zeolite and Metakaolin in the M_{35} grade concrete. Taking zeolite 15% optimum as constant and replacing metakaolin as 5%, 10%, 15%, 20% .

Table No. 4: Mix proportions of combination zeolite and metakaolin concrete.

Mix No.	Replacement Details	Zeolite (Z) Kg/m^3	Metakaolin (MK) Kg/m^3	Coarse aggregate Kg/m^3		Fine aggregate Kg/m^3	Cement Kg/m^3	Water Kg/m^3	Sp Kg/m^3
				20-12.5 mm	12.5 -4.75 mm				
M0	0%Z+ 0%MK	0	0	789.06	526.04	690.42	383.16	153.24	3.06
M5	15%Z+ 5%MK	57.47	16.28	789.06	526.04	690.42	309.41	153.24	3.06
M6	15%Z+ 10%MK	57.47	32.56	789.06	526.04	690.42	293.13	153.24	3.06
M7	15%Z+ 15%MK	57.47	48.85	789.06	526.04	690.42	276.84	153.24	3.06
M8	15%Z+ 20%MK	57.47	65.13	789.06	526.04	690.42	260.56	153.24	3.06

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Table 5: strength results for combination of Zeolite and Metakaolin concrete

STRENGTH (Mpa)	CONV.		Z 15 % +M5%		Z 15 % M10%		Z 15 % + M15%		Z 15 % + M 20 %	
	28days	7days	28days	7days	28days	7days	28days	7days	28days	7days
Compressive	44.14	32.8	47.70	30.44	49.33	32.44	43.70	26.44	33.18	20.88
Flexural	3.90	2.88	4.16	2.8	4.34	2.98	3.52	2.38	3.26	2.16
Split Tension	3.37	2.54	3.67	2.58	3.92	2.68	3.43	2.12	3.14	1.90
Compaction Factor	0.89		0.91		0.90		0.87		0.83	
Slump Cone Test	70mm		60mm		55cm		50mm		40mm	

COMPRESSIVE STRENGTH

Compressive strength is compared with the results obtained from the conventional mix, It was observed that the increase in compressive strength gradually up to **15%+10%** replacement of combination of Zeolite and Metakaolin and then strength decreased. The maximum compressive strength **49.33 N/mm²** was obtained at **15% +10%** replacement of combination of Zeolite and Metakaolin, which was **11.78 %** more than the conventional mix.

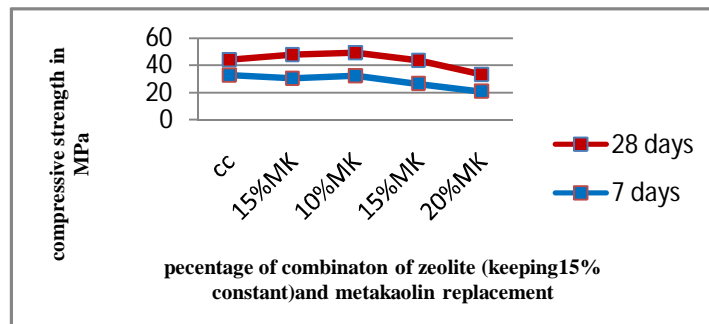


Fig 4: Compressive strength curve for Combination of Zeolite and Metakaolin concrete

SPLIT TENSILE STRENGTH

The maximum Split tensile strength **3.92 N/mm²** was obtained at **15%+10%** replacement of cement by combination of Zeolite and Metakaolin, which was **16.32 %** more than the conventional mix.

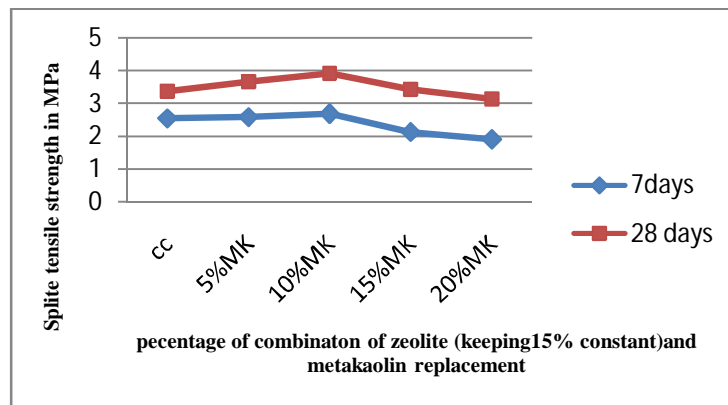


Fig 5: Split tensile strength curve for Combination of Zeolite and Metakaolin

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FLEXURAL STRENGTH

The maximum Flexural strength strength 11.28 N/mm^2 was obtained at **15%+10%** replacement of cement by combination of Zeolite and Metakaolin, which was **11.28 %** more than the conventional mix.

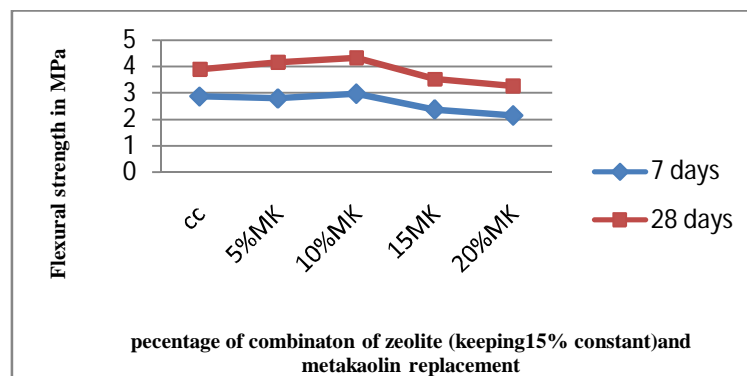


Fig 6: Flexural strength curve for Combination of Zeolite and Metakaolin concrete

V. CONCLUSIONS

Based on above study, the following observations are made regarding the strength properties of concrete on partial replacement of cement by zeolite and metakaolin.

1. As percentage replacement of cement as zeolite is increased in concrete, its workability decreases.
2. The maximum compressive strength was obtained 47.40 N/mm^2 at 15% use of zeolite in the concrete. Maximum compressive strength was obtained with mix (M2) 15% use of zeolite in concrete 47.40 N/mm^2 which was 7.34% more compared reference mix (44.14 N/mm^2)
3. Maximum compressive strength was obtained with mix (M6) (15% Z(zeolite)+10% MK(metakaolin)) use of combination of zeolite and metakaolin in the concrete 49.33 N/mm^2 which was 11.78% more compared reference mix (44.14 N/mm^2).
4. The maximum split tensile strength was obtained 3.63 N/mm^2 at 15% use of zeolite in the concrete. Maximum split tensile strength was obtained with mix (M2) 15% use of zeolite in concrete 3.63 N/mm^2 which was 7.7% more compared reference mix (3.37 N/mm^2).
5. The maximum split tensile strength was obtained 3.92 N/mm^2 at (15% Z(zeolite)+10% MK(metakaolin)) . Maximum split tensile strength was obtained with mix (M6) (15% Z(zeolite)+10% MK(metakaolin)) of combination of zeolite and metakaolin in the concrete 3.92 N/mm^2 which was 16.32% more compared reference mix (3.37 N/mm^2).
6. The maximum flexural strength was obtained 4.12 N/mm^2 at 15% use of zeolite in the concrete. Maximum flexural strength was obtained with mix (M2) 15% use of zeolite in concrete 4.12 N/mm^2 which was 5.64% more compared reference mix (3.90 N/mm^2).
7. The maximum flexural strength was obtained 4.34 N/mm^2 at (15% Z(zeolite)+10% MK(metakaolin)) . Maximum flexural strength was obtained with mix (M6) (15% Z(zeolite)+10% MK(metakaolin)) of combination of zeolite and metakaolin in the concrete 4.34 N/mm^2 which was 11.28% more compared reference mix (3.900 N/mm^2).
8. Based on experimental results, it is observed that there is significance improvement in the strength properties of concrete with zeolite and metakaolin combination.

REFERENCES

- [1] Babak Ahmadi, Mohammad Shekarchi "Use of natural zeolite as a supplementary cementitious material" Cement & Concrete Composites 32 (2010) 134–14.
- [2] Rahimeh Mousavi "Micro and macro level properties of natural zeolite contained concretes" Construction and Building Materials 101 (2015) 347–358.
- [3] Mahdi Valipour "Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: A laboratory study" Construction and Building Materials 41 (2013) 879–888.
- [4] Meysam Najimi "An experimental study on durability properties of concrete containing zeolite as a highly reactive natural pozzolan" Construction and Building Materials 35 (2012) 1023–1033.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 12, December 2016

- [5] Alaa M. Rashad "A preliminary study on the effect of fine aggregate replacement with metakaolin on strength and abrasion resistance of concrete" *Construction and Building Materials* 44 (2013) 487–495.
- [6] Yilmaz Kocak "The effect of using natural zeolite on the properties and hydration characteristics of blended cements" *Construction and Building Materials* 47 (2013) 720–727.
- [7] C.S. Poon "A study on the hydration rate of natural zeolite blended cement pastes" *Construction and Building Materials* 13 _1999. 427|432.
- [8] Chang-Seon Shon , Young-Su Kim "Evaluation of West Texas natural zeolite as an alternative of ASTM Class F fly ash" *Construction and Building Materials* 47 (2013) 389–396.
- [9] F. Canpolat "Use of zeolite, coal bottom ash and fly ash as replacement materials in cement production" *Cement and Concrete Research* 34 (2004) 731–735.
- [10] B. Uzal "Pozzolanic activity of clinoptilolite: A comparative study with silica fume, fly ash and a non-zeolitic natural pozzolan" *Cement and Concrete Research* 40 (2010) 398–404.
- [11] Mahdi Valipour "In situ study of chloride ingress in concretes containing natural zeolite, metakaolin and silica fume exposed to various exposure conditions in a harsh marine environment" *Construction and Building Materials* 46 (2013) 63–70.
- [12] R. Torres "Geopolymer synthesis using alkaline activation of natural zeolite" *Construction and Building Materials* 24 (2010) 2084–2090.
- [13] A.V.S.Sai. Kumar1, Krishna Rao "A Study on Strength of Concrete With Partial Replacement Of Cement With Quarry Dust And Metakaolin" *ISSN: 2319-8753 Vol. 3, Issue 3, March 2014.*
- [14] P. Dinakar "Effect of Metakaolin Content on the Properties of High Strength Concrete" *International Journal of Concrete Structures and Materials* Vol.7, No.3, pp.215–223, September 2013.
- [15] B. Uzal "Blended cements containing high volume of natural zeolites: Properties, hydration and paste microstructure" *Cement & Concrete Composites* 34 (2012) 101–109.