STUDY OF SELF-HEALING ABILITY OF FIBER REINFORCED CONCRETE WITH METAKAOLIN AND CRYSTALLINE ADMIXTURE

Jamjala Siva JNTUA College Of Engineering, Anantapur, Andhra Pradesh, India
Prof.C.Sashidhar Professor In Civil Engineering Department, JNTUA College Of Engineering, Anantapur, Andhra Pradesh, India
M. Sravanthi Research Scholar In Civil Engineering Department, JNTUA College Of Engineering, Anantapur, Andhra Pradesh, India

Abstract :
The purpose of this study is to examine the self-healing capacity of M40 concrete with partial replacement of cement with metakaolin and with addition of crystalline admixture. Percentage of replacement of metakaolin is 0% 6%,12%, 18% and crystalline admixture is 1%.Specimens are set for artificial structural cracks after 28 days of casting whose magnitude is of range 0.1mm–0.4mm and exposed to various environmental conditions for 7,14, 28,42 days. The results shows that all the mixes have a considerable amount of closing ability and strength regaining capacity for various exposure conditions.

Keywords: Metakaolin, crystalline admixture, self-healing concrete**.**

1.Introduction :

With the increase in age, concrete structures will subject to fatigue loads, sudden loads, unexpected environmental exposure conditions which consists of temperature variations and due to many other reasons, fissures and cracks take place in concrete structures. which also leads to spalling in a structure. These cracks will reduce the strength of the concrete, cause corrosion of the reinforcement in the concrete, which will eventually lead to the failure of the concrete, and so on. To reduce those cracks, in present investigation we discuss one of the remedial concepts, which is "self-healing concrete." A novel method was discussed for fitting those cracks using a crystalline admixture. Self-healing concrete is one that senses crack formation and reacts to cure itself without human inference. A partially replacement of cement with metakaolin was also done to check the better efficiency with replacement. Metakaolin is used as a partial replacement for cement in this investigation as cement production causes more emissions of carbon-dioxide, which is a greenhouse gas (which effects the temperature around the earth).

S. Guzlena[1] studied self-healing concrete with crystalline admixture made for different types of concretes and discovered that concrete immersed in water healed faster and better than any other exposure condition.**Roig-Flores [2]** studied the self-healing capacity and effectiveness of crystalline admixture on fiber-reinforced concrete subjected to four environmental conditions and concluded that their self-healing rate was as follows: water immersion (around 0.9), water contact (around 0.80), humidity chamber (around 0.15), and air exposure (around 0.15).**Liberato Ferrara [3]**added a crystalline admixture comprising a mixture of cement, sand, and active silica to the raw concrete constituents before mixing. The results indicated that the underwater immersion crack healed properly,The crystalline additive speeds up the crack healing process and Air exposure was not enough to induce any significant recovery.**VenuMalagavelli[4]**in their study on the influence of metakaolin in concrete as partial replacement of cement with supplementary materials, the authors concluded that metakaolin can be used in concrete in place of cement and that maximum strength is obtained at 10%, which can be replaced by cement with metakaolin. **Sirajuddin [5]** studied the effect of nano-silica on the self-healing ability of high-strength concrete with crystalline admixture, where specimens were subjected to pre-cracking after 28 days of curing and exposed to 3 environmental conditions afterwards. He concluded that the specimen with 2% nano-silica and 1.1% crystalline admixture showed complete closing ability after 42 days after pre-cracking for all exposure conditions.**M.Narmatha[6]**in this paper properties of metakaolin in cement replacement is studied and concluded that 8% - 20% (by weight) of Portland cement replaced by metakaolin. Such a concrete exhibits favourable engineering properties. This study is taken as a reference for the present case for variation in replacement of metakaolin.

2. Experimental Investigation

The primary goal of the exploratory study is to identify as well as to evaluate improved performance in hardened concrete by replacing cement partially with metakaolin and adding crystalline admixture along with an optimal proportion of metakaolin replacement. This research focuses on the methodology that will be applied, such as material characterization, concrete mix, and estimating the quantity of materials required for the specimens that are going to be examined.

2.1 Materials Used

A. Cement:

Ordinary Portland cement of grade 53, conforming to IS:12269-1987, was used in this investigation. It was fresh and free of lumps. The physical characteristics as determined by different test in accordance with Indian standard IS 12269:1987. The various tests performed on cement is shown in table 2.1

Table 2.1: Physical properties of cement

S.No	Property	Test result
1	Normal consistency	28%
2	Specific gravity	3.14
3	Initial setting time	27min
4	Final setting time	550min
5	Soundness	3.5mm
6	Fineness	95%

B. Fine aggregate:

Naturally available river sand passing through a 4.75mm IS sieve and conforming to grading zone 2 of IS 383-1970 was used for experiment. Fineness modulus and particle size distribution of river sand were determined by using sieve analysis. Fine aggregate consists of physical properties mentioned in the table 3.2 and it is transported from local suppliers**.**

Table 2.2: Physical properties of Fine aggregate

S.No	Property	Test result
1	Specific gravity	2.62
2	Fineness modulus	2.51
3	Zone	2
4	Water absorption	0.15%

C. Coarse Aggregate:

The coarse aggregates used in this study are locally available granite-type coarse aggregates with a nominal size of 20mm and 12mm. Laboratory tests on coarse aggregate performed in accordance with IS: 2386 part(3)-1963 to determine the various physical properties and they can be shown in the table as follows

Table 2.3: Shows physical properties of 20mm coarse aggregate

S.No	Property	Test result
1	Specific gravity	2.74
2	Water absorption	0.15%

Table 2.4: Shows physical properties of 12mm coarse aggregate

S.No	**Property**	**Test result**
1	Specific gravity	2.68
2	Water absorption	0.2%

D. Metakaolin

Metakaolin is a valuable mineral admixture for concrete/cement applications. Replacing portland cement with 8–20 wt.% (% by weight) metakaolin produces a concrete mix that exhibits favorable engineering properties, including: the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction. The filler effect is immediate, while the effect of pozzolanic reaction occurs between 3 and 14 days.

From the above reasons metakaolin is considered as a good alternative in place of cement. To conduct the experimental investigation. The metakaolin powder capable of passing through 90 µm sieve of 50kgs was transported from Astra chemicals in Chennai. This powder was chemically analyzed to determine its chemical composition.

Fig 2.1 Metakaolin

The chemical analysis was carried out at Astra chemicals Limited in Chennai in accordance with standard procedures, and the lab reports were sent together with metakaolin powder bag. The following is the chemical composition of metakaolin powder.The specific gravity of metakaolin is **2.6.**

Table 2.5: Metakaolin powder and cement chemical composition

S.No	Component	Description	Content in cement	Content in metakaolin
1	SiO_2	Silica	17-25%	53%
2	Al_20_3	Alumina	3%-8%	43.8%
3	CaO	Calcium oxide	60%-67%	0.02%
4	MgO	Magnesium Oxide	0.1%-4%	0.035
5	Na_2O	Sodium oxide	0.2%-1.3%	0.23%
6	K_2O	Pottasium Oxide	0.25-1.3%	0.19%
7	SO_3	Sulphur trioxide	1%-3%	0.03%
8	LOI	Loss of ignition	<3%	0.46%

E. Crystaline Admixture:

Xypex C-2000NF[7] is an Additive product, which is added to the concrete at time of batching. Xypex C-2000NF has Crystalline Technology is excellent for reducing the water permeability of concrete and for the healing of leaking, non-moving cracks and joints in concrete structures. Xypex C-2000NF crystals will bridge most non-moving cracks up to 0.5 mm (0.02"). In situations where the cracks are larger (more than 0.5 mm but less than 3 mm (1/8"), the Xypex C-2000NF chip-and-pack method is used to form a 'plug' at the top portion of the concrete cross section, and the Xypex C-2000NF crystallization process heals any crack that may telegraph up through the repair.

The following was the dosage recommended by the supplier after many experimental tests done in their laboratory in accordance with Indian standards Xypex C-2000NF Admix C-500 NF (No Fines Grade): 1 - 1.5% by weight of cement

F. Steel fibers:

Steel fibers are that kind of material which has high tensile strength which helps the concrete specimen to not to break suddenly and due to its homogenous mix during batching will enable to introduce hair-line cracks in hardened concrete without failure of specimen. Here, we used steel fibers of size 0.012mm. Steel fibers were added about 2% weight of cementitious material

Fig 2.2 Steel fibers

G. Super plasticizer

As to attain the higher strength of concrete w/c ratio is as small as possible here in this work we use w/c ratio of 0.35. due to this the workability of concrete will be very low. in order to achieve higher workability a super plasticizer of Fosrac SP 430 DIS has been used as an admixture. It has a capability of reducing water content by 30%

The following were the properties specified by the manufacturer:

Table 2.6 Typical Properties of Fosroc sp430 DIS

Appearance	Brown liquid
Specific gravity	1.18 @ 25°C
Chloride content	Nil to BS 5075 / BS:EN934

Air entrainment : Less than 2% additional air is entrained at normal dosages

H. Water

The specimens were cured in water with a pH within the limits of IS 456-2000, and the temperature was kept between 10^0 and20^0c.

2.2 Mix design:

To attain M40 grade strength, the concrete was designed in accordance with IS:10262-2019 and a w/c ratio of 0.35 was employed. A total of 8 mixes with different percentages of metakaolin (0%, 6%, 12%, and 18%), with and without crystalline admixture (1%), were tested to analyse the strength characteristics in terms of compressive strength to determine the optimal proportion of metakaolin in concrete. The table 2.6 shows the designed proportions of basic ingredients in concrete.

Mix.ID	OPC (kg/m^3)	Metakaolin (kg/m^3)	F.A (kg/m^3)	C.A (12mm) (kg/m^3)	C.A(20mm) (kg/m^3)	Xypex C-2000NF (kg/m^3)	Super plasticizer (kg/m^3)	Steel fibers (kg/m^3)
M1	411	0	660	380	887	0	4.11	8.22
M2	386.34	24.66	660	380	887	0	4.11	8.22
M3	361.68	49.32	660	380	887	0	4.11	8.22
M4	337.02	73.98	660	380	887	0	4.11	8.22
MX1	411	0	660	380	887	4.11	4.11	8.22
MX2	386.34	24.66	660	380	887	4.11	4.11	8.22
MX3	361.68	49.32	660	380	887	4.11	4.11	8.22
MX4	337.02	73.98	660	380	887	4.11	4.11	8.22

Table 2.7 shows the mix design of M40 grade concrete with parial replacement of metakaolinand with and without crystalline admixture

Where,
M1 = (0% Metakaolin + 0% Crystalline Admixture) , M2 = (6% Metakaolin + 0% Crystalline Admixture)
M3 = (12% Metakaolin + 0% Crystalline Admixture) ,M4 = (18% Metakaolin + 0% Crystalline Admixture)
MX1 = (0% Metakaolin + 1% Crystalline Admixture) MX2 = (6% Metakaolin + 1% Crystalline Admixture)
MX3 = (12% Metakaolin + 1% Crystalline Admixture) ,MX4 = (18% Metakaolin + 1% Crystalline Admixture)

2.3 Experimental Methodology:

The following were the method used in this investigation

A) In the present investigation, 8 concrete mixes with varying amounts of metakaolin and crystalline admixture are cast, and each mix contains 51 cubes (150 mm x 150 mm x 150 mm); three of them were used for strength purposes, and the served as a reference for cubes that were subjected for structural cracks and exposed to different environmental conditions to test the effectiveness of their healing

B) After curing for 28 days, the remaining 48 cubes of each mix are set for hair-line cracks of width 0.1 mm–0.4 mm with the help of a compression testing machine. These hair-line cracks were induced by placing 8-mm-diameter rods on either sides of the cube and on the middle of the cube, which were placed in a compression testing machine. A slow load is applied until a hair-line crack appears on any side of the cube

Fig 2.3 Shows the specimen subjecting to pre-cracking

Fig 2.4 Shows the specimen after pre-cracking

C) Those cubes were exposed to different environmental conditions and tested again to failure in compression testing equipment after 7 days, 14 days, 28 days, and 42 days.

Exposure Conditions

Table 2.8 Shows the Exposure conditions

S.No	Exposure Condition	Explanation
1	**WI-** Water immersion	The specimens were in water completely
2	**W/D-**Wet and Dry cycles	The specimens were exposed to air and water alternatively for every 3 days
3	**WC-** Water contact	The specimens in which 75% of volume is immersed in water and remaining 25% in air completely
4	**AE-** Air exposure	The specimens were exposed to air completely

3.Results And Discussion

Compressive strength:

The compressive strength of M40 grade concrete with partial replacement of metakaolin increases up to 12% and later on its strength gets decreases. After 28 days structural cracks were introduced in the specimen and following were the compressive strength, regained compressive strength after 7,14,28,42 days with and without crystalline admixture.

Percentage of replacement of metakaolin(%)	Mixes	Compressive strength (MPa)
O	M_1	48.64
6	M_2	53.52
12	M_3	57.91
18	M_4	46.68

Tab 3.1 Shows the Compressive strength of concrete @28days with partial replacement of metakaolin without crystalline admixture

Percentage of replacement of metakaolin(%)	Mixes	Compressive strength (MPa)
O	MX_1	50.23
6	MX_2	55.21
12	MX_3	59.48
18	MX_4	48.86

Tab 3.2 Shows the Compressive strength of concrete @28days with partial replacement of metakaolin withcrystalline admixture(1%)

The specimens were undergone for pre-cracking after 28days of curing and exposed to 4 various environmental conditions. Their regained compressive strength after respective exposure condition and days are shown below in table 3.3

Table 3.3 shows the Regained compressive strength of mix without crystalline admixture

DAYS	Percentage of metakaolin	mixes	Regained compressive strength			
			WI (MPa)	W/D (MPa)	WC (MPa)	AE (MPa)
7	0	M1	19.81	18.62	16.51	13.19
	6	M2	21.75	20.59	18.37	15.51
	12	M3	23.33	23.42	21.62	18.21
	18	M4	18.75	17.84	15.36	12.68
14	0	M1	21.17	20.26	18	15.4
	6	M2	25.02	23.86	20.22	18.44
	12	M3	29.46	27.34	25.08	19.3
	18	M4	26.28	25.06	23.93	18.91
28	0	M1	27.64	24	21.22	20.05
	6	M2	29.73	26.35	23.46	22.02
	12	M3	31.42	28.15	26.02	23.48
	18	M4	28.55	27.91	24.37	22.33
42	0	M1	33.37	31.16	26.86	24.05
	6	M2	34.64	32.62	29.95	24.97
	12	M3	37.08	35.22	31.86	26.06
	18	M4	32.86	28.73	28.73	23.51

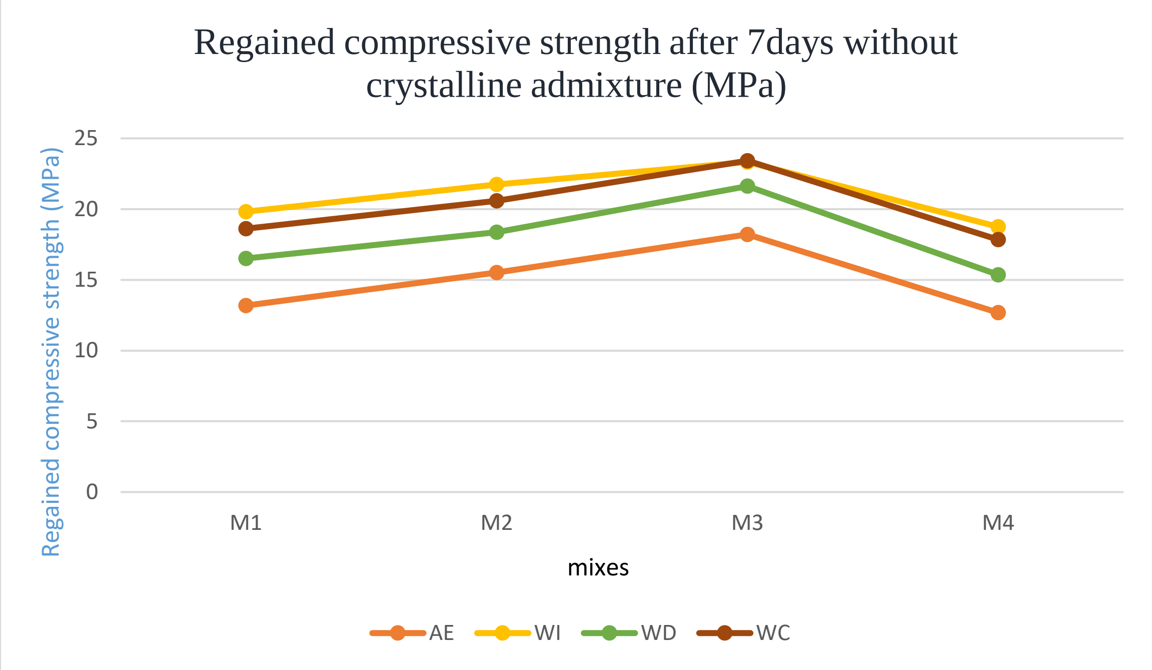

Fig 3.1 Shows the variation of regained compressive strength after 7 days without crystalline admixture

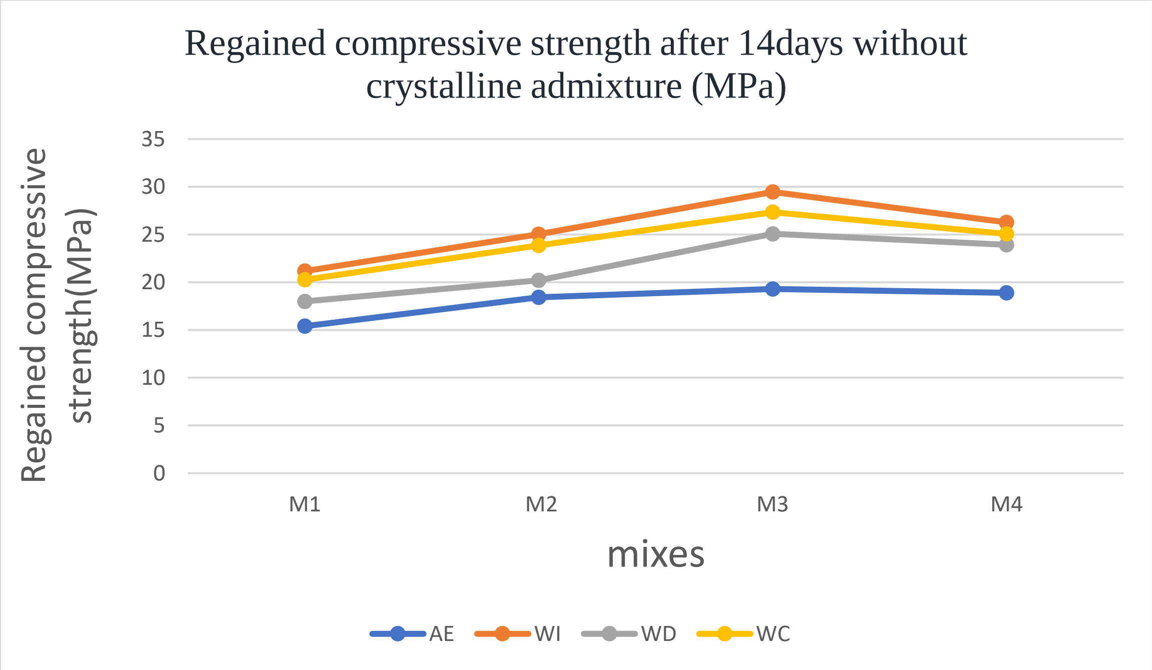

Fig 3.2 Shows the variation of regained compressive strength after 14 days without crystalline admixture

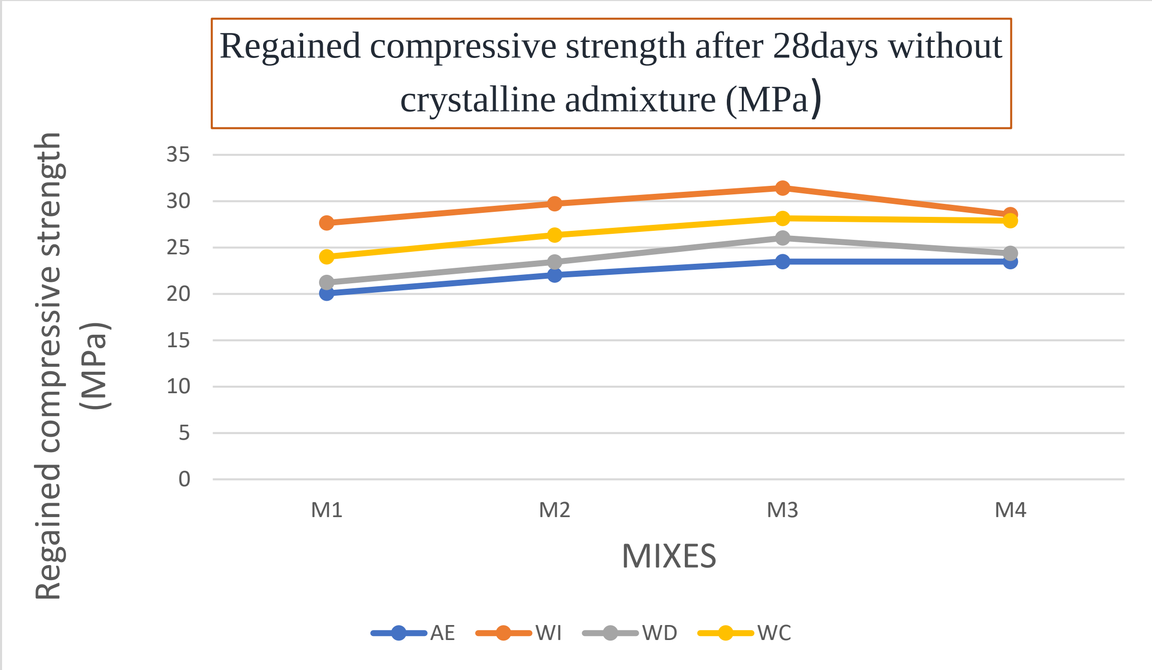

Fig 3.3 Shows the variation of regained compressive strength after 28 days without crystalline admixture

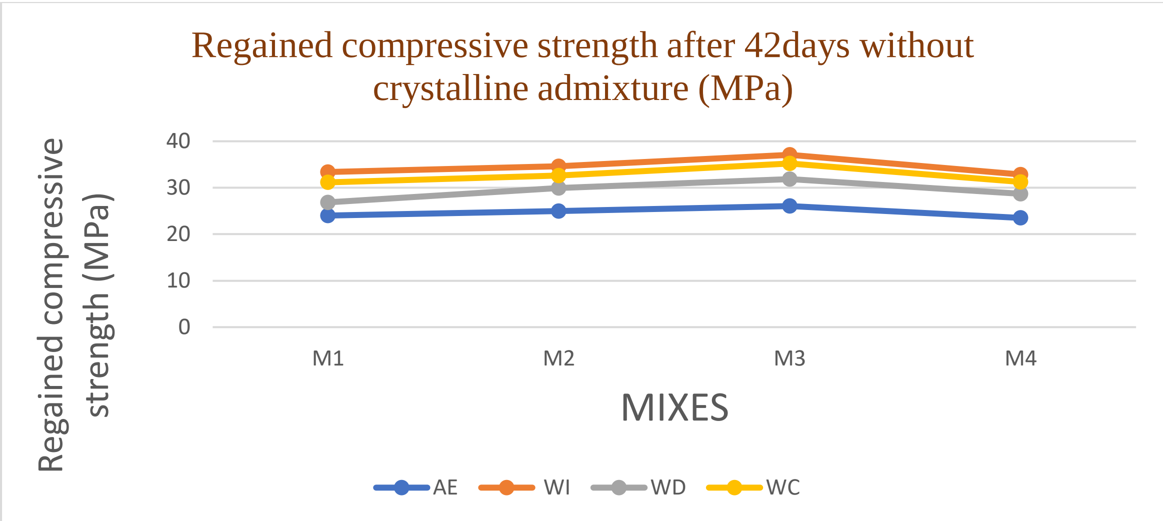

Fig 3.4 Shows the variation of regained compressive strength after 42 days without crystalline admixture

The variation of regained compressive strength after pre-cracking exposed to various environmental conditions with crystalline admixture are as shown in the following table 3.4.

DAYS	Percentage of metakaolin	mixes	Regained compressive strength			
			WI (MPa)	W/D (MPa)	WC (MPa)	AE (MPa)
7	0	MX1	31.64	30.51	28.62	26.38
	6	MX2	33.75	30.25	31.35	27.7
	12	MX3	36.12	33.2	34.1	30.1
	18	MX4	29.4	26.95	27.93	24.5

14	0	MX1	33.5	32	29.5	27.5
	6	MX2	36.85	35.2	32.45	30.25
	12	MX3	40.2	38.4	35.4	33
	18	MX4	32.83	31.36	28.91	26.95
28	0	MX1	47.5	44	40.51	35
	6	MX2	51.7	48.95	44.65	38.45
	12	MX3	57.21	53.1	48.36	42.95
	18	MX4	45.57	42.63	38.69	34.3
42	0	MX1	52.25	49.5	44.12	37.25
	6	MX2	57.75	54.54	48.39	40.7
	12	MX3	63.42	59.4	52.8	44.32
	18	MX4	51.25	48.51	43.12	36.26

Table 3.4 shows the Regained compressive strength of mix with crystalline admixture (1%)

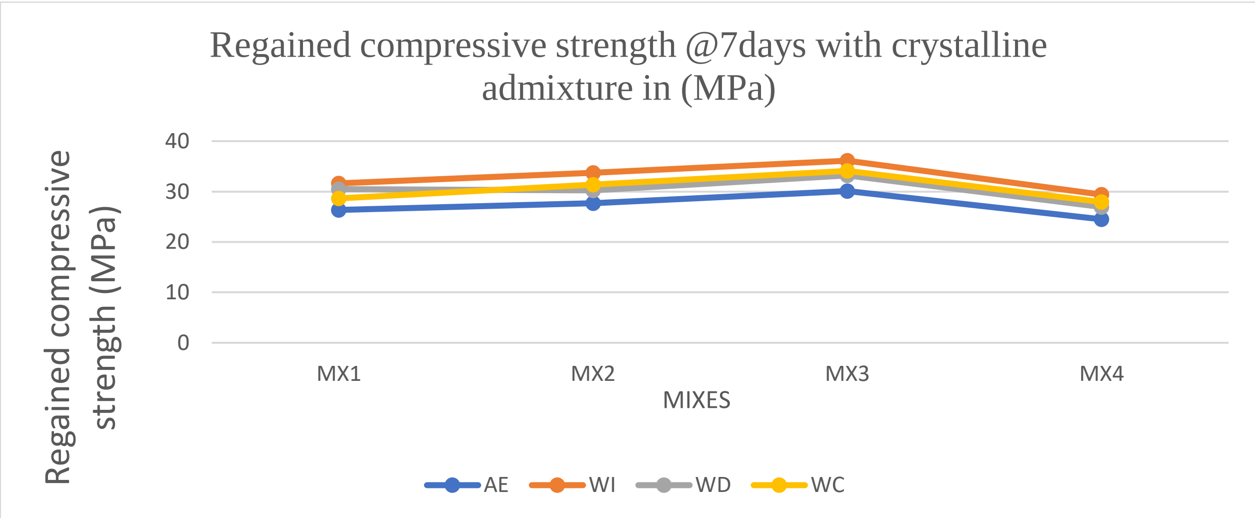

Fig 3.5 Shows the variation of regained compressive strength after 7 days without crystalline admixture

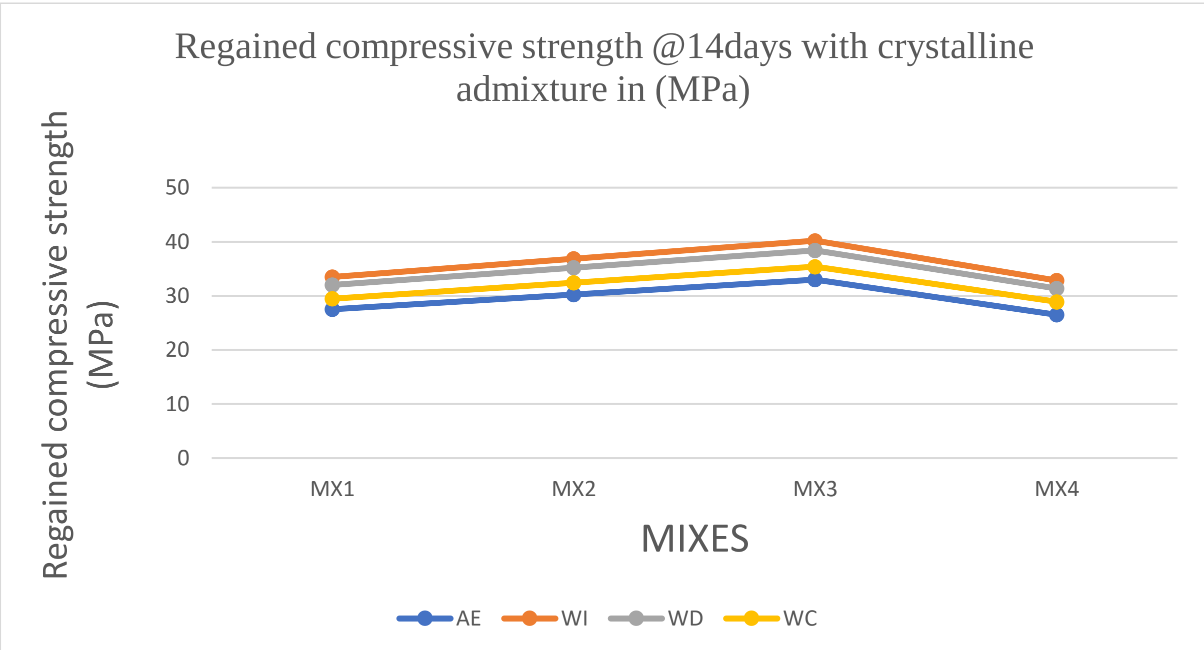

Fig 3.6 Shows the variation of regained compressive strength after 14 days with crystalline

admixture

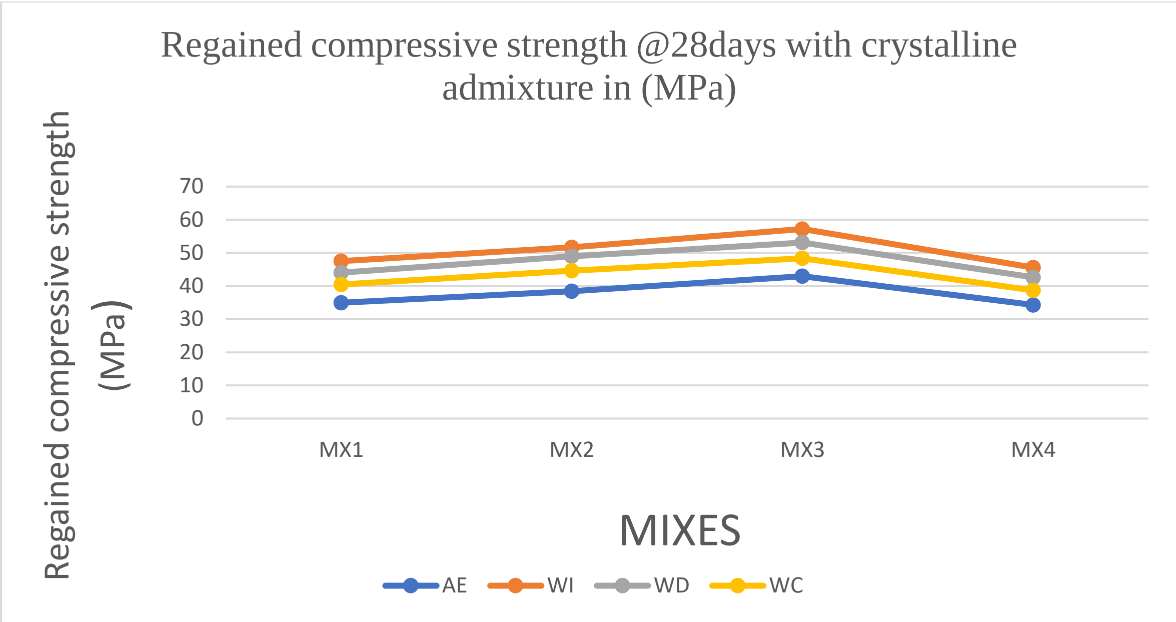

Fig 3.7 Shows the variation of regained compressive strength after 28 days with crystalline admixture

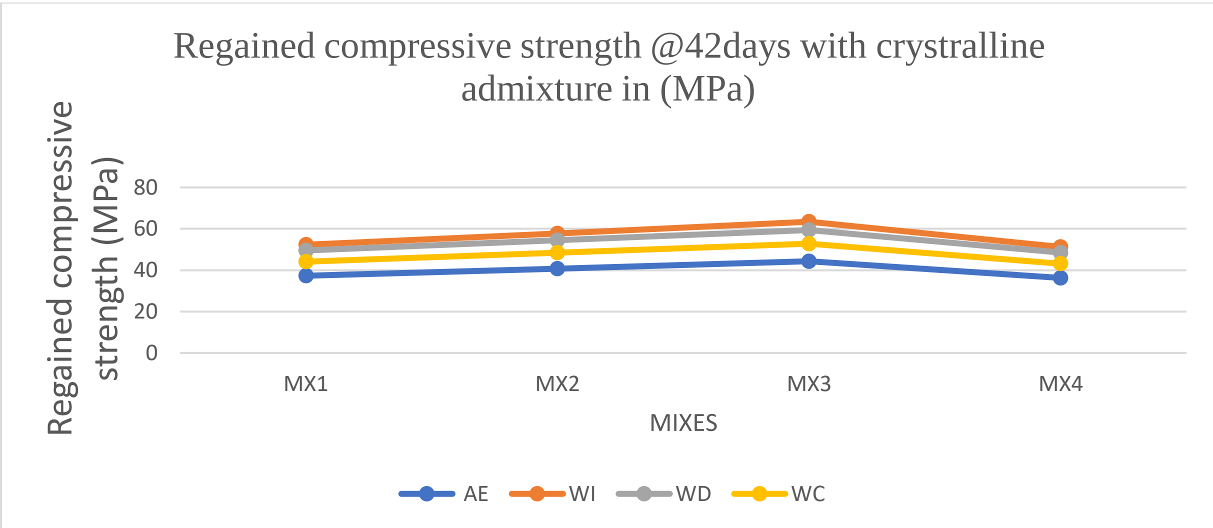

Fig 3.8 Shows the variation of regained compressive strength after 42 days with crystalline admixture

4. Conclusion

In the present work, the effect of partial replacement of cement with metakaolin and self-healing properties through addition of crystalline admixture has been investigated. Based on early research, mx3 has been determined as the optimum mix in terms of compressive strength. Mechanical properties like compressive strength were determined for all mixes which exposed to different environmental conditions. These results of regained compressive strength were compared with their respective mix compressive strength without introduction of cracks. The following were the conclusions drawn on this limited experimental investigation.

I. Compressive strength and regained compressive strength were increased up to 6% and 12% with metakaolin for with and without crystalline admixture later on it declines.
II. The regained compressive strength of all mixes with crystalline admixture were approximately about 105% after 42days which were exposed to water immersion environmental condition
III. It was shown that the crystalline Admixture enables its healing property comparatively high in water immersion condition
IV. The performance of crystalline admixture is lower in case of air exposure environmental condition

5.References

[1self-healing concrete with crystalline admixture – a review to cite this article: s guzlena and g sakale 2019 iop conf. ser.: mater. sci. eng. 660 01205
[2] roigflores, marta&serna, p. &moscato, simone&ferrara, liberato. (2015). self-healing capability of concrete containing crystalline admixtures in different exposure conditions.
[3] ferrara, liberato&krelani, visar&moretti, fabio. (2016). on the use of crystalline admixtures in

cement based construction materials
[4] malagavelli, venu&angadi, s. & prasad, jallipalli&joshi, s.. (2018). influence of metakaolin in concrete as partial replacement of cement. international journal of civil engineering and technology. 9. 105-111.
[5] international journal of civil engineering and technology (ijciet) volume 10, issue 05, may 2019,
[6] Narmatha, M. & Kala, Dr. (2016). Meta kaolin –The Best Material for Replacement of Cement in Concrete. IOSR Journal of Mechanical and Civil Engineering. 13. 66-71. 10.9790/1684-1304016671.
[7] Concrete Waterproofing by Crystallization™-catalogue
[8] IS 12269 (1987) specification for portland cement of grade 53.
[9] IS 10262 (2019) for concrete mix proportioning-Guidelines.
[10] IS 456-2000 practice code for plain and reinforced cement concrete
[11] IS 383-1970 specification for coarse and fine aggregate