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MECHANICAL PROPERTIES OF HIGH PERFORMANCE CONCRETE WITH ADMIXTURES AND STEEL FIBRE

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ABSTRACT

This paper presents comparison of three mineral admixtures, Alccofine 1203 (A), Metakaoline (MK) and Ground Granulated Blast furnace Slag (GGBS) on the Mechanical properties of High Performance Concrete (HPC). Assessment of the mechanical properties of concrete mixes was based on compressive strength, split tensile strength, flexural strength of concrete and durability tests. Tests were carried out after first24 hour warped curing and then water curing. The results, in general, showed that mineral admixtures improved the properties of high performance concretes, but at different rates depending on the binder type.

Keywords:high performance concrete compressive strength, modulus of elasticity, flexural strength, durability tests.

INTRODUCTION

High Performance Concrete (HPC) is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. Long-term performance of structures has become vital to the economies of all nations. Concrete has been the major instrument for providing stable and reliable infrastructure. Deterioration, long term poor performance, and inadequate resistance to hostile environment, coupled with greater demands for more sophisticated architectural form, led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards(P.C. Aıtcin, 2003). As a result, innovations of supplementary materials have been developed.The use of blended cements or supplementary cementing materials decreases the permeability, thereby increasing the resistance of concrete to deterioration (Malhotra*et al.*, 1996, FIP Report, 1988). Therefore, the incorporation of pozzolanic materials has become an increasingly accepted practice in concrete structures exposed to despotic environments.Any concrete which satisfies certain criteria proposed to overcome limitations of conventional concretes may be called High Performance Concrete. It may include concrete, which provides either substantially improved resistance to environmental influences or substantially increased structural capacity while maintaining adequate durability. It may also include concrete, which significantly reduces construction time to permit rapid opening or reopening of roads to traffic, without compromising long-term serviceability. Therefore, it is not possible to provide a unique definition of High Performance Concrete without considering the performance requirements of the intended use of the concrete. The requirements may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, and early age strength or service life in severe environments. Normal concrete lacks required strength, workability and durability which are more often required for large concrete structures such as high rise buildings, bridges, and structures under severe exposure conditions. Therefore, it is felt necessary to improve the strength and performance of concrete with suitable admixtures to cater present need. (AElahi*et al*., 2010)

In this study, it is planned to replace some percentage of Cement with Alcoofine 1203 Metakaolin and GGBS to develop the high performance concrete.

EXPERIMENTAL PROGRAMME

Materials

The Ordinary portland cement of 53 grade confirming to IS 12269.1987 was used in the experimental programme.Coarse Aggregateof20 mm and 12.5mm size aggregate were used.The crushed sand was used as fine aggregate confirming to zone II, in which 50 percentage is replaced with aggregate size less than 600microns,asper IS: 383. Three types of mineral admixture used for the present study are Alccofine 1203, Ground Granulated Blast-furnace Slag (GGBS) and Metakaoline. The Chemical composition of three admixtures are given in Table-1.

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Table-1. Chemical composition of Mineral Admixturesfor a sample of admixture.

S. No.	Chemical content	Alccofine 1203-ultrafine GGBS (%)	GGBS (%)	Metakaoline(%)
1	CaO	32 - 34	32 - 34	0.4 - 0.8
2	SiO_2	28 - 32	28 - 32	50 - 54
3	Al_2O_3	18 - 20	18 - 20	41 - 45
4	Fe_2O_3	1.8 - 2	1.8 - 2	0.5 - 1
5	MgO	8 - 10	-	-
6	SO_3	0.3 - 0.7	-	-

Flat crimped Steelfibres used in this study were shown in Figure-1. The Properties of fibres obtained are shown in Table-2.Chemical Admixture, super plasticizer-MasterGlenium SKY 8233 was used, which is based on new generation modified polycarboxylic ether polymers.

Figure-1. Crimped steel fibre.

Table-2. Properties of fibres.

Properties	Steel
Length	10mm
Construction	Crimped
Acid Resistance	-
Alkali Resistance	-
Aspect ratio	45
Tensile strength	600Mpa

Mix proportionssteel fibre

M80 grade mix was designed (Khadiranaikar*et al*., 2012)and the same was used to prepare the test samples. The design Mix Proportion is shown in Table-3.Table-4gives the different percentage replacement of Alcoofine 1203, Metakaoline and GGBS by weight of cement Table-5gives the different percentage of steel fibreconsidered for the study.

Table-3. Concrete design mix proportion.

Mix proportioning for M80 target compressive strengths	
Materials	**Target compressive strengths (MPa)**
	80
Water cement ratio	0.3
Total Cementitious content (kg/m^3)	517
Fine aggregate, (kg/m^3)	659
Coarse aggregate, (kg/m^3)	1100
Water (kg/m^3)	155
Mineral admixture (kg/m^3)(Percentage replacement of cementitious content)	5 % to 25%
High-range waterreducers, (Percentage of cementitious content)	0.35 to 1
Fibres(Percentage of volume of concrete)	0.1 to 1

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Table-4. Percentage of Alcoofine 1203, Metakaoline, GGBS.

Notation for varying Alccofine 1203 percentage	Notation for varying Metakaoline percentage	Notation for varying GGBS percentage	Percentage of all admixtures (replacement of cement by weight)
A1	M1	G1	5
A2	M2	G2	10
A3	M3	G3	15
A4	M4	G4	20
A5	M5	G5	25

Table-5. Percentage of polymer fibre for design mix.

Fibre type	Notation	Percentage of fibre (Percentage volume of concrete)
Steel fibre (Flat crimped steel fibre)	ST1	0.4%
	ST2	0.7%
	ST3	1%
	ST4	0.1%
	ST5	0.3%

Sample preparations

The test specimens for compressive strength was 150mm cube and modulus of elasticity, Split tensile strength, carbonation test were150mm diameter with 300mm height cylindersand that for Flexural strength test was 150mmX 150mm X 700mm beam. All specimens were cast in a standard manner. The test specimen for sorptivity was 100mm diameter and 50mm height cylinder. The entire specimens were cast and compacted in accordance with BIS and ASTM standards. After casting, the samples were wrapped first with polyethylene sheet then after 24 hour water curing were practiced. The maximum curing age was 365 days.

Testing procedure

Compressive strength and Split tensile strength were determined at the age of 7, 28 and 90 days. Modulus of Elasticity was determined at the age of 28 days. Flexural strength was determined at the age of 7 and 28 days. Compressive strength tests, Split tensile strength, Modulus of Elasticity, Flexural strength test were carried out according to the Indian standard. Water absorption test, sulphate attack test, seawater test, carbonation test and sorptivity were determined at the age of 28, 56 and 90 days. The test specimen for durability water absorption test, sulphate attack test, seawater test, carbonation test and sorptivity test were carried out according to the ASTM standards. The absorption test was carried out according to ASTM C642.

RESULTS AND DISCUSSIONS

Compressive strength

Compressive strength results at 7 and 28 days arepresented in Figures 2 and 3.

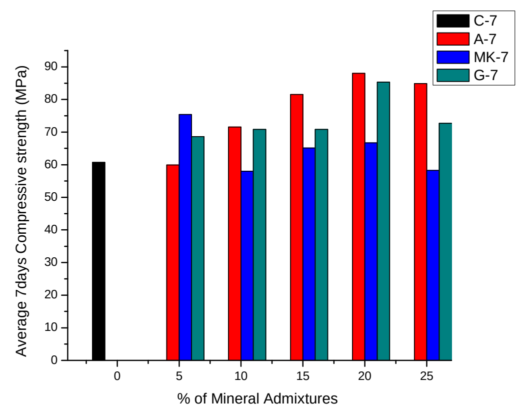

Figure-2. Compressive strength Vs Percentage of mineral admixtures at 7 days.

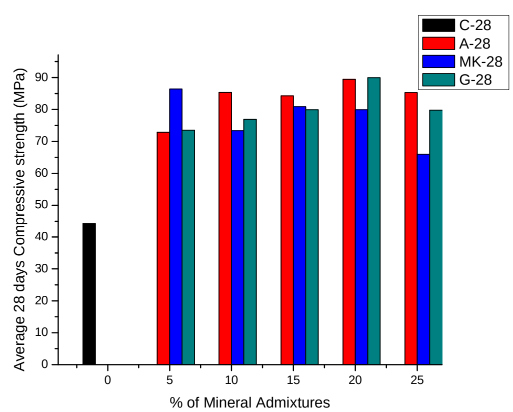

Figure-3. Compressive strength Vs Percentage of mineral admixtures at 28 days.

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From the test results, it is observed that, for Alccofine 1203, the maximum compressive strength of 87.99 MPa and 89.45 MPa is obtained at7day and 28 days respectively. Similarly for Metakaolin, the maximum compressive strength 75.37MPa and 86.51 MPa is obtained at5% replacement of cement. For GGBS, the maximum compressive strength of 85.3MPaand 89.93MPais obtained at 20% replacement of cement.The compressive strength of control mix at 28 day is found to be 60.69 MPa and 44.18 Mpa at 7 and 28 days.The reason for reduction in strength at 28 day age is due to the excess formation of calcium hydroxide, which will increase the volume and formation of internal cracks.Increase in compressive strength using metakaolin may be possibly due to an improved transition zone. Metakaolin removes calcium hydroxide from the system and accelerates the OPC hydration. At higher replacement levels, compressive strength is reduced possibly due to dilution effect i.e. the amount of metakaolin is in excess to react with Ca $(OH)_2$. This extra metakaolin produce dilution effect, such that the water-binder ratio is reduced. Test results may vary depending on the purity of metakaolin and Portland cement composition (C- Control Mix, A- Alccofine 1203, MK- Metakaoline, G- Ground granulated blast furnace slag).

Figure-4 shows the variation of compressive strength for flat crimpled steel fibre. The percentages of the fibre selected for the study are 0.1%, 0.3%, 0.4%, 0.7% and 1% respectively. Flat Crimped steel fibre shows a maximum strength of 70.35 MPa obtained at 0.3% of fibre at 28 days. As the load is increased, bond between steel fibre and C-S-H gel is damaged easily, compared to bond between aggregate and C-S-H gel. To increase the enhancement effect of steel fibre, it is necessary to arrive at an optimum dosage.

Thus, optimum percentage of HPC M80 can be made with Metakaoline -5%,Alccofine 1203 20%, GGBS 20% replacement of cement by weight.Optimum percentage of fibre was fixed as 0.3% by volume.

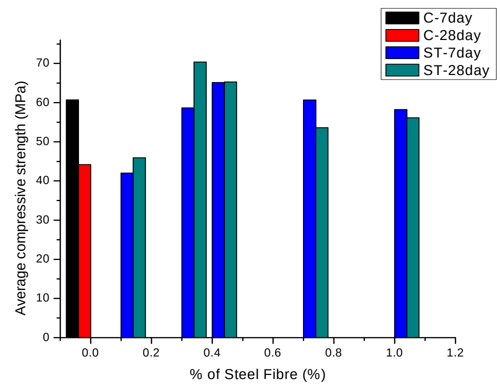

Figure-4. Compressive strength Vs percentage of fibre.

RESULTS AND DISCUSSIONS

In the second phase of experimentation, tests were conducted by combination of admixtures and steel fibre based on the optimum values of compressive strength at 7, and 28 days. The optimum percentage selected for metakaolin is 5%, Alcoofine 20% and that for GGBS at 20%. The optimum percentage for steel fibre is 0.3%. The notations of the specimen were presented in Table-6.

Table-6. Notation used for specimens.

Type of specimen	Notation for Metakaoline	Notation for Alccofine 1203	Notation for GGBS
Cube	EMS-5%Metakaolin + 0.3%Steel Fibre	EAS-20 % Alccofine 1203 + 0.3% Steel Fibre	EGS -- 20% GGBS +0.3% Steel Fibre
Beam	BMS-5%Metakaolin +0.3% Steel Fibre	BAS-Alccofine 1203 +0.3% Steel Fibre	BGS –20% GGBS + 0.3%Steel Fibre
Cylinder	CMS- Metakaolin + Steel Fibre	CAS- Alccofine 1203 + Steel Fibre	CGS- GGBS + Steel Fibre
Beam	BM - Only Metakaolin	BA - Only Alccofine 1203	BG - Only GGBS
Cylinder	CM - Only Metakaolin	CA - Only Alccofine 1203	CG - Only GGBS
Sorptivity	SSM	SSA	SSG
Cylinder	CCM	CCA	CCG

From the test results, it is observed that, the compressive strengths generally increase from the age of 7 days to 365 days for all types of concrete specimens. The specimen with metakaoline and steel fibre shows better compressive strength of about 93.20MPa at 28 days and 99.92 at 365 days of curing.The split tensile strength for HPC with metakaolin and steel fibre is 4.38 MPa and for the mix without fibre is 3.87 MPa. The tensile strength is improved by 11.64%. For GGBS concrete mix with fibre, the tensile strength is 4.12MPa and that for the concrete mix without fibre is 3.94MPa. Similarly for alccofine 1203 concrete mix with fibre is 4.37MPa and for the concrete mix without fibre is 4.004MPa, the tensile strength is improved by 4.3%.The test results were presented in Tables 7 and 8.

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Table-7. Compressive strength values with combination of admixtures and steel fibres.

Average compressive strength (MPa)					
Specimen	**7 Days**	**28 Days**	**56 Days**	**90 Days**	**365 Days**
EAS	71.11	87.80	90.30	93.45	95.38
EMS	82.96	93.20	94.32	95.35	99.92
EGS	79.19	87.16	92.45	95.15	95.45

Table-8. Split tensile strength values with combination of admixtures and steel fibres.

Average split tensile strength (MPa)					
Specimen (with steel fibre)	**7 Days**	**28 Days**	**Specimen** (without steel fibre)	**7 Days**	**28 Days**
CAS	3.43	4.004	CA	3.73	4.37
CMS	3.42	4.38	CM	3.23	3.87
CGS	3.15	4.12	CG	3.02	3.94

Flexural strength

Table-9 presents the values of flexural strength and Modulus of elasticity for concrete combined with optimum percentage of admixture and steel fibre.

Table-9. Flexural strength values with combination of admixtures and steel fibre.

Flexural strength MPa					
Specimen (with steel fibre)	**7 Days**	**28 Days**	**Specimen** (without steel fibre)	**7 Days**	**28 Days**
BAS	4.99	6.37	BA	4.89	6.58
BMS	4.89	6.62	BM	5.56	7.56
BGS	4.93	6.21	BG	4.09	6.38

Flexural strength for metakaoline mix with fibre is 6.62 MPa and that for mix without fibre is 7.56MPa at 28 days. Flexural strength for GGBS concrete mix with fibre is 6.21 MPa and that for mix without fibre is 6.3MPa.Flexural strength for alccofine 1203 concrete mix with fibre is 6.37 MPa and that for mix without fibre is 6.58 MPa at 28 days. Thus there is no significant influence for these fibres to bending resistance. Also the metakaoline mix specimen shows higher flexural strength at 28days of curing.

Modulus of elasticity

From Table-10, the values of Modulus of elasticity can be observed. The obtained values of modulus of elasticity at 28 days are70 to 80 GPa which is within the allowable limits as per the ACI codes.

As per ACI 363, $E = 3320\sqrt{f_{ck}} + 6900$

For f_{ck}in between 21Mpa – 83Mpa

Or

$E = 40{,}000\sqrt{f_{ck}} + 10^6$ psi

As per IS 318, $E = 4730\sqrt{f_{ck}}$

As per ACI 363, E = 38985.7MPaor 38,999MPa

As per IS 318, E = 45712.5MPa

The modulus of elasticity of HPC should be greater than 40GPa (ASTMC 469). High value may be due to the presence of steel fibre in the specimen, which ultimately reduced the strain and thereby increased the modulus of elasticity value.

Table-10. Modulus of elasticityvalueswith combination of admixtures and steel fibre.

Modulus of elasticity (GPa)	
Specimen	**28 Days**
BAS	75.00
BMS	85.05
BGS	70.86

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Durability tests

Water absorption test

The absorption test was carried out according to ASTM C642. The determination of water absorption, specified in Table-11.

Table-11. Water absorption test results.

Specimen	S. No.	Wet weight (Kg) W_1	Oven dry weight(Kg) W_2	W.A = (W_1-W_2)*100/W1	Average
EAS**(28 days)**	1	8.409	8.326	0.99%	0.83%
	2	8.361	8.307	0.65%	
	3	8.381	8.309	0.86%	
EMS**(28 days)**	1	8.285	8.262	0.29%	0.32%
	2	8.336	8.308	0.34%	
	3	8.334	8.306	0.34%	
EGS**(28 days)**	1	8.500	8.400	1.18%	1.23%
	2	8.357	8.248	1.30%	
	3	8.400	8.298	1.21%	
EAS**(56 days)**	1	8.328	8.012	3.79%	4.09%
	2	8.377	7.978	4.76%	
	3	8.356	8.046	3.71%	
EMS**(56 days)**	1	8.505	8.262	0.46%	0.47%
	2	8.55	8.507	0.50%	
	3	8.558	8.515	0.50%	
EGS**(56 days)**	1	8.435	8.327	1.28%	1.29%
	2	8.439	8.360	1.29%	
	3	8.442	8.354	1.04%	
EAS**(90 days)**	1	8.356	8.332	0.29%	0.28%
	2	8.375	8.352	0.27%	
	3	8.405	8.382	0.28%	
EMS**(90 days)**	1	8.53	8.519	0.13%	0.11%
	2	8.429	8.421	0.09%	
	3	8.495	8.486	0.11%	
EGS (90 days)	1	8.425	8.409	0.19%	0.13%
	2	8.435	8.430	0.06%	
	3	8.456	8.445	0.13%	

Water absorption values obtained is less than 5% as per ASTM C-642 and can be regarded as low absorption type. In all the samples, mix with metakaoline shows better result ie, only 0.11% at 90 days test

Sorptivity

The sorptivity (ASTM C-1585) can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used as the test fluid. The cylinders after casting were immersed in water for 90 days curing. The specimen size 100mm dia x 50 mm height after drying in oven at temperature of 100 + 10 °C were drowned with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating. The quantity of water absorbed in time period of 30 minutes was measured by weighting the specimen on a

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top pan balance weighting up to 0.1 mg, surface water on the specimen was wiped off with a dampened tissue and each weighting operation was completed within 30 seconds. Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. Table-12gives the Acceptance criteria for sorptivity. Table-13 shows the sorptivity values at 28day and 56day. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t) $I=S.t^{½}$ therefore

$S=I/ t^{½}$

Where
S=Sorptivity in mm,
t = Elapsed time in mint.
$I=\Delta w/Ad$
Δw = Change in weight = W_2-W_1
W_1 = Oven dry weight of cylinder in grams
W_2= Weight of cylinder after30 minutes capillary suction of waterin grams.
A = Surface area of the specimen through which water penetrated.
d = Density of water

Table-12. Acceptance criteria for sorptivity.

Acceptance criteria		**OPI** (log scale)	**Sorptivity**(mm/h)
Laboratory concrete		>10	< 6
As-built Structures	Full acceptance	> 9,4	< 9
Conditional acceptance		9,0 to 9,4	9 to 12
Remedial measures		8,75 to 9,0	12 to 15
Rejection		< 8,75	>15

Sorptivity value at 28, 56 and 90 days is less than maximum i.e., 6mm/h. Alcoofine 1203 specimen shows a little higher sorptivity value at 56days, later at 90 days it decreases. The porous nature of concrete reduces at later stage. Out of all the specimens, the specimen with metakaoline mix shows lesser sorptivity value 1.26 at 90 days.

Table-13. Sorptivity Test results.

Specimen	**S. No.**	**Oven dry weight W1** (Kg)	**Weight after 30min Capilarysuction W2**(Kg)	**Δw = W2 - W1** (g)	**I = Δw/Ad** (mm)	**S = I/√T (mm/ h)**	**Average** (mm/h)
SSA (28 days)	1	1.110	1.111	1	0.127	0.180	0.180
	2	1.066	1.067	1	0.127	0.180	
	3	1.088	1.089	1	0.127	0.180	
SSM (28 days)	1	1.077	1.078	1	0.127	0.180	0.180
	2	1.074	1.075	1	0.127	0.180	
	3	1.068	1.069	1	0.127	0.180	
SSG (28 days)	1	1.101	1.103	2	0.254	0.360	0.360
	2	1.103	1.105	2	0.254	0.360	
	3	1.102	1.104	2	0.254	0.360	
SSA (56 days)	1	1.015	1.032	17	2.16	3.06	3.180
	2	1.093	1.112	19	2.42	3.42	
	3	1.022	1.039	17	2.16	3.06	
SSM (56 days)	1	1.088	1.089	1	0.127	0.181	0.296
	2	1.071	1.073	2	0.25	0.354	

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	3	1.075	1.073	2	0.25	0.354	
SSG (56 days)	1	1.062	1.072	10	1.27	1.79	0.188
	2	1.073	1.084	11	1.40	1.98	
	3	1.074	1.085	11	1.40	1.98	
SSA (90 days)	1	1.109	1.117	8	1.018	1.44	1.38
	2	1.107	1.115	8	1.018	1.44	
	3	1.105	1.112	7	0.891	1.26	
SSM (90 days)	1	1.104	1.11	6	0.764	1.08	1.26
	2	1.106	1.114	8	1.018	1.44	
	3	1.109	1.116	7	0.891	1.26	
SSG (90 days)	1	1.121	1.128	7	0.891	1.26	1.38
	2	1.089	1.097	8	1.018	1.44	
	3	1.108	1.116	8	1.018	1.44	

Sulphate attack

Cube specimens after 28days of water curing were taken out and dried in air and then kept immersed in $MgSO_4$ solution and sea water for a period of 28, 56 and 90 days according to ASTM-C-452 and ASTM-C-1012.The concentration of solutions used is 25000ppm for $MgSO_4$. Residual compressive strengths of the specimen were found out. Compressive strength after immersion in sulphate solution is shown in Table-14.

Table-14. Sulphate attack test result.

Specimen	**Average compressive strength** (MPa)		
	28 Days	**56 Days**	**90Days**
EAS	93.78	92.44	81.86
EMS	95.62	99.12	88.36
EGS	93.45	95.62	83.12

The compressive strength at the 28 days and 56 days sulphate curing doesn't have any significant reduction. But in 90 days of sulphate curing specimens, Alccofine 1203 shows 12.4% reduction in strength, Metakaoline shows 11.5% reduction in strength and GGBS shows 12.9% reduction in strength comparing with 90days water cured specimens. In all the three, metakoline specimen shows better resistive capacity under sulphate attack. Also the compressive strength of all mix doesn't go below the characteristic strength.

Sea water attack

Sea water (ACI 201.2) was collected from Thirumullavaram beach, Kollam. Cube specimens after 28days of water curing were taken out and dried in air and curing in sea water for a period of 28, 56 and 90 days according to ACI 201.2.Table-15 shows the result of chlorine content of sea water. Residual compressive strengths of the specimen were found out shown in Table-16.

Table-15. Chloride content of sea water.

Sample	**T.No.**	**Burette reading**		**Amount of silver nitrateconsumed**(ml)	**Chloride content**(ppm)	**Actual chloride content**(ppm)
		Initial (ml)	**Final** (ml)			
Sea water	1	12.5	27.1	14.6	53.48	21393.3
Blank	1	27.1	31	3.9		

The compressive strength at the 28 days and 56 days seawater curing doesn't have any significant reduction expect for alccofine 1203 specimens. But in 90 days of seawater curing specimens, alccofine 1203 shows 12.4% reduction in strength, metakaoline shows 11.5% reduction in strength and GGBS shows 12.9% reduction in strength comparing with 90days water cured specimens. In all the three, metakoline specimen shows better resistive capacity under sulphate attack. Also the compressive strength of all mix doesn't go below the characteristic strength.

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Table-16. Compressive strength of specimen sea water.

Specimen	**Average compressive strength** (MPa)		
	28 Days	**56 Days**	**90Days**
EAS	95.56	90.22	88.26
EMS	98.81	100.41	89.86
EGS	90.12	92.32	81.23

CONCLUSIONS

From the present study, the following conclusions were drawn

a) The concrete mixes with containing 5% metakaoline shows higher compressive strength and a viable level of performance achieved, when economical and environmental benefits are concerned.
b) The compressive strength of concrete mix with metakaoline, as mineral admixture was higher compared to GGBS and Alccofine 1203.
c) The concrete specimens incorporated with metakaoline produced greater strengths from the age of 7 days. This indicated that significant acceleration of pozzolanic reaction of admixture at early age.
d) The flat crimped steel fibre showed that it has an influence in increasing in compressive and tensile strength of concrete, but in flexural strength it doesn't have any effect.
e) The specimens with metakaoline show better resistivity to chemical attack like sulphate and chlorine ions. The non-porous nature of specimen help to resist the attack from chemicals, thus prevent degradation of structures and corrosion of reinforcement

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