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STRENGTH AND PERMIABILITY OF HIGH PERFORMANCE CONCRETE WITH POLYPROPYLENE FIBRE

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ABSTRACT

The paper presents a comparison of mineral admixtures, Alccofine 1203 (AF), Metakaoline (MK) and Ground Granulated blast furnace slag (GGBS), on the Mechanical and durability properties of polypropylene fibre reinforced high-performance concrete. Assessment of the mechanical properties of concrete mixes was based on compressive strength, split tensile strength, flexural strength and durability tests like water absorption, seawater test, sulphate attack test, sorptivity and carbonation test of concrete. Measurements were carried out after first 24 hour warped curing and 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 and fibre type.

KEYWORDS: Durability, High Performance Concrete, Nokrack, Sorptivity, Strongcrete

INTRODUCTION

High Performance Concrete (HPC) is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. High performance and durable concrete structures have been studied in various aspects. The increasing use of HPC in conventional structures has been demanding from all over the world. The common cause of degradation in concrete is the corrosion of reinforcement. The steel is amenable to corrosion in the presence of chloride ions. The transport of fluids into concrete depends on its permeation characteristics of concrete. As the permeability of concrete decreases, its durability performance increases. The main degradation of concrete means carbonation, corrosion of reinforcement, sulphate attack, alkali-aggregate reaction etc. as a result of reaction between an external agent and the ingredients of concrete, and some physical effects, such as frost attack, can be greatly reduced by reducing the permeation of concrete.

In order enhance the properties of HPC, here added polypropylene fibre to the concrete and studying the combined behaviour of fibre and concrete. The use of blended cements or supplementary cementing materials decreases the permeability, thereby increasing the resistance of concrete to deterioration [1,2].

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EXPERIMENTAL PROGRAMME

Materials

The Ordinary portland cement of 53 grade confirming to IS 12269.1987 is used in the experimental programme. Three types of mineral admixture are used Alccofine 1203, Ground-granulated blast-furnace slag (GGBS), Metakaoline. Chemical Admixture: super plasticizer- MasterGlenium SKY 8233were used. polypropylene fibres were used in this experiment shown in Figure 1. The Properties of fibres obtained from the manufactures are shown in Table 1

Figure 1: a) Strongcrete b) Nokrack

Table 1: Properties of Fibres

Properties	Nokrack	Strongcrete
Length	Multiples of 10mm	Graded (20mm)
Construction	Combination of straight + fibrillated mesh fibre	Fibrillated mesh fibre
Acid Resistance	High	High
Alkali Resistance	Completely resistant	Full

Mix Proportions

A M80 grade was designed and the same was used to prepare the test samples. The design mix Proportion is shown in Table 2 and Table 3 gives the different percentage polypropylene fibre respectively considered for the trial mix.

Sample Preparations and Testing Procedure

Table 2: 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 % for metakaolin and 20 % for GGBS and Alccofine 1203 (fixed as per previous study)
High-range water reducers, (Percentage of cementitious content)	0.35 to 1
Fibres(Percentage of volume of concrete)	0.1 to 1

The test specimen for compressive strength was 150mm cube and modulus of elasticity, Split tensile strength, carbonation test were 150mm diameter with 300mm height cylinders and Flexural strength test was 150mm X 150mm X

700mm beam. All specimens were cast in a standard manner. The entire specimen were cast and compacted in accordance with BIS and ASTM standards. After casting, the samples were wrapped first with polyethylene sheet then after 24 hr water curing were practiced. The maximum curing age was 365 days. 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. British standard was followed to determine dynamic modulus of elasticity. Water absorption test, sulphate attack test, and were determined at the age of 28, 56 and 90 days. The test specimen for durability water absorption test, sulphate attack test and seawater test were carried out according to the ASTM standard. The absorption test was carried out according to ASTM C642

Table 3: Percentage of Polypropylene Fibre for Design Mix

Fibre Type	Notation	Percentage of Fibre (Percentage Volume of Concrete)
Strongcrete (fibrillated polypropylene fibre)	SG1	0.4%
	SG2	0.7%
	SG3	1%
	SG4	0.1%
	SG5	0.3%
Nokrack (combination of straight and fibrillated polypropylene fibre)	N1	0.4%
	N2	0.7%
	N3	1%
	N4	0.1%
	N5	0.3%

RESULTS AND DISCUSSIONS

In stage 1 study the effect fibres in compressive strength of concrete. The corresponding graph of test results shown in Figure 2. Variation in compressive strength for Strongcrete fibre concrete at 0.1%, 0.3%, 0.4%, 0.7% and 1% addition of fibres are 1.7%, -30.08%, -8.64% and -11.69% respectively.

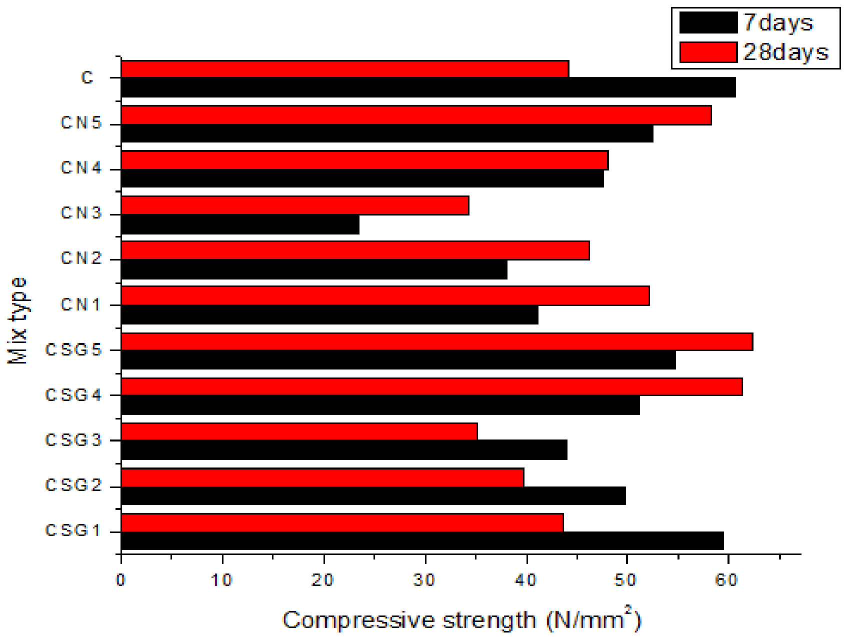

Figure 2: Relation of Percentage of Fiber in Concrete with Compressive Strength

Variation in compressive strength for Nokrack fibre concrete at 0.1%, 0.3%, 0.4%, 0.7% and 1% addition of fibres are 2.09%, -10.39%, -11.32% and -25.89% respectively. In both the fibres when the percentage varies from 0.1 to 0.3 there is an increase in compressive strength, on further increase in fiber percentage the compressive strength decreases. Among these, the maximum compressive strength is obtained at 0.3% addition of fibres shown in Figure 2. As the load is increased bond between 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 fibres, it is necessary to arrive at an optimum dosage (c-control mix).

Thus the optimum percentage of fibre addition was fixed as 0.3% of volume of concrete.

In stage 2 a study in conducted for the Mechanical and durability Properties of fibre reinforced high performance concrete (FRHPC), in which optimum percentage of stage 1 is used for the study. Table 4 represents the notation used for the concrete specimens.

Table 4: Notation Used for Specimens

Type of Specimen	Notation For Metakaoline	Notation For Alccofine 1203	Notation For GGBS
Cube	EMP/N – Metakaolin + Fibre	EAP/N - **Alccofine 1203** + Fibre	EGP/N - GGBS + Fibre
Beam	BM P/N – Metakaolin + Fibre	BAP/N - **Alccofine 1203** + Fibre	BGP/N - GGBS + Fibre
Cylinder	CM P/N - Metakaolin + Fibre	CAP/N - **Alccofine 1203** + Fibre	CGP/N - GGBS + Fibre
Beam	BM - Only Metakaolin	BA - Only **Alccofine 1203**	BG - Only GGBS
Cylinder	CM – Only Metakaolin	CA - Only **Alccofine 1203**	CG - Only GGBS
Sorptivity	SP/NM	SP/NA	SP/NG
Cylinder	CCM	CCA	CCG

* P-Strongcrete fibre, N- Nokrack fibre

Mechanical Property Test

Compressive strength

The results of tests conducted on hardened concrete are shown in Table 5. The compressive strengths generally increase from the age of 7 days to 365 days for all types of concrete specimens. The percentage increase of strength after 56 days of curing is less than 5%. The specimen with metakaoline shows better compressive strength of about 84.44MPa at 28 days and 90.23 MPa at 365 days of curing for strongcrete fibre sample and 81.28MPa at 28 days and 84.02 MPa at 365 days of curing for nokrack fibre sample shown in table 5

Tensile strength

The split tensile strength for HPC with metakaolin is 3.77MPa and 3.89MPa for Strongcrete and Nokrack fibre, the mix without fibre is 3.87 MPa. The GGBS concrete mix is 3.66MPa and 3.72MPa for Strongcrete and Nokrack fibre, mix without fibre is 3.94MPa. Similarly for alccofine 1203 concrete mix is 3.72MPa and 3.78MPa for Strongcrete and Nokrack fibre and for the concrete mix without fibre is 3.87MPa. In all the case Specimen of metakaoline mix with fibre shows higher tensile strength at 28 days of curing of about 4.37MPa shown in table 5

Modulus of Rapture

Flexural strength for for HPC with metakaolin is 8.19 MPa and 7.78MPa for Strongcrete and Nokrack fibre, the mix without fibre is 7.56 MPa. The GGBS concrete mix is 7.93MPa and 7.58MPa for Strongcrete and Nokrack fibre, mix without fibre is 6.38MPa. Similarly for alccofine 1203 concrete mix is 7.24MPa and 7.50MPa for Strongcrete and Nokrack fibre and for the concrete mix without fibre is 6.58MPa. In all the case Specimen of metakaoline mix with strongcrete fibre shows higher tensile strength at 28 days of curing of about 8.19MPa and also we can saw that fibres had a significance contribution in the increase of flexural strength shown in table 6. Using strongcrete fibre flexural strength increase is around 10-20% and for Nokrack fibre is around 15-20% than specimen without fibres.

Table 5: Average Strength Test Results

Average Compressive Strength (MPa)						Split Tensile Strength (MPa)					
Specimen	7 DAYS	28 DAYS	56 DAYS	90 DsAYS	365 DAYS	Specimen (with fibre)	7 Days	28 Days	Specimen (without Fibre)	7 Days	28 Days
EAP	72.00	79.78	83.24	84.56	84.45	CAP	3.23	3.72	CA	3.73	3.87
EMP	76.44	84.44	88.85	89.26	90.23	CMP	3.64	3.77	CM	3.23	4.37
EGP	71.33	78.14	82.33	83.56	84.23	CGP	3.32	3.66	CG	3.02	3.94
EAN	70.00	78.86	80.54	81.56	81.95	CAN	3.80	3.78			
EMN	71.78	81.78	83.66	84.22	84.02	CMN	3.77	3.89			
EGN	66.67	77.56	79.69	80.85	80.45	CGN	3.56	3.72			

Table 6: Average Test Results

Modulus of Rupture (MPa)						Modulus of Elasticity (GPa)	
Specimen (with Fibre)	7 Days	28 Days	Specimen (Without Fibre)	7 Days	28 Days	Specimen	28 Days
BAP	6.62	7.24	BA	4.89	6.58	BAP	75.00
BMP	7.41	8.19	BM	5.56	7.56	BMP	85.05
BGP	7.06	7.93	BG	4.09	6.38	BGP	70.86
BAN	7.15	7.50				BAN	72.06
BMN	7.50	7.78				BMN	82.36
BGN	7.50	7.58				BGN	68.45

Modulus of Elasticity

The obtained value of modulus of elasticity is 70 to 80 GPa which is within the allowable limits as per the ACI codes.

As per ACI 363, $E = 3320\sqrt{f_{ck}} + 6900$ 2

For f_{ck} in between 21Mpa – 83Mpa

Or

$E = 40{,}000\sqrt{f_{ck}} + 10^6$ psi 3

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

As per ACI 363, E = 38985.7MPa or 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 polypropylene fibre in the specimen, which ultimately reduced the strain and thereby increased the modulus of elasticity value.

Durability Test

Water Absorption Test

The absorption test was carried out according to ASTM C642. The determination of water absorption, specified in table 7. Water absorption values obtained is less than 5% as per ASTM C-642 and can be regarded as low absorption type. In all the sample, mix with metakaoline shows better result ie., only 0.57% for Strongcrete and 0.38% for Nokrack at 90 days test.

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Table 7: Water Absorption Test Result

Specimen	Sl No:	Oven Dry Weight (Kg) W_2	Wet Weight(Kg) W_1	W.A = $(W_1 – W_2)$*100/W1	Average
EAP**(28 days)**	1	8.006	8.033	0.34	0.97
	2	7.866	7.994	1.60	
	3	8.106	8.185	0.96	
EMP**(28 days)**	1	8.049	8.084	0.43	0.46
	2	8.216	8.255	0.47	
	3	8.156	8.195	0.48	
EGP**(28 days)**	1	8.092	8.171	0.97	1.53
	2	7.994	8.136	1.75	
	3	7.956	8.109	1.88	
EAP**(56 days)**	1	7.855	7.941	1.08	0.87
	2	7.996	8.036	0.50	
	3	7.905	7.988	1.03	
EMP**(56 days)**	1	8.187	8.220	0.40	0.53
	2	7.763	7.815	0.66	
	3	8.028	8.070	0.52	
EGP**(56 days)**	1	7.934	8.084	1.86	1.29
	2	8.147	8.229	1.00	
	3	8.105	8.189	1.02	
EAP**(90 days)**	1	7.863	7.926	0.79	0.56
	2	7.939	7.971	0.40	
	3	7.928	7.967	0.49	
EMP**(90 days)**	1	8.310	8.358	0.57	0.57
	2	8.039	8.094	0.68	
	3	8.156	8.195	0.47	
EGP**(90 days)**	1	8.015	8.053	0.47	0.53
	2	8.037	8.082	0.56	
	3	8.029	8.075	0.57	
EAN**(28 days)**	1	7.615	7.997	4.78	2.73
	2	8.003	8.132	1.59	
	3	8.056	8.205	1.82	
EMN**(28 days)**	1	7.978	8.000	0.28	0.75
	2	7.936	8.050	1.42	
	3	7.901	7.945	0.54	
EGN**(28 days)**	1	8.010	8.188	2.17	2.81
	2	7.903	8.164	3.20	
	3	7.955	8.205	3.05	
EAN**(56 days)**	1	8.162	8.204	0.51	0.51

	2	8.043	8.085	0.52	
	3	8.105	8.145	0.49	
EMN**(56 days)**	1	8.039	8.152	1.39	1.74
	2	8.126	8.282	1.88	
	3	8.095	8.225	1.94	
EGN**(56 days)**	1	7.859	7.964	1.32	1.17
	2	8.055	8.142	1.07	
	3	7.945	8.035	1.12	
EAN**(90 days)**	1	8.001	8.048	0.58	0.48
	2	8.212	8.242	0.36	
	3	8.075	8.115	0.49	
EMN**(90 days)**	1	8.265	8.297	0.39	0.38
	2	8.176	8.207	0.38	
	3	8.215	8.245	0.36	
EGN**(90 days)**	1	8.041	8.072	0.38	0.36
	2	8.078	8.110	0.39	
	3	8.060	8.085	0.31	

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 & 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 were shown in Table 8.

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 ie., alccofine 1203 shows 17.61% reduction in strength for Strongcrete & 3.34% reduction in strength for nokrack, metakaoline shows 11.98 % reduction in strength for Strongcrete & 8.57% reduction in strength for nokrack and GGBS shows 2.5 % reduction in strength for Strongcrete & 1.45% reduction in strength for nokrack comparing with 90days water cured specimens. In all the three, GGBS specimen shows better resistive capacity under sulphate attack. But the compressive strength of most of the mix go below the characteristic strength.

Table 8: Sulphate Attack Test Result

Specimen	Average Compressive Strength (MPa)		
	28 Days	**56 Days**	**90 Days**
EAP	70.78	78.33	69.67
EMP	76.78	80.78	78.56
EGP	75.44	84.11	81.45
EAN	78.33	83.22	79.22
EMN	80.78	82.56	77.00
EGN	73.89	81.67	77.67

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 9 shows the result of chlorine content of sea water. Residual compressive strengths of the specimen were found out shown in table 10.

Table 9: Chloride Content of Sea Water

Sample	Trial no	Burette Reading		Amount of Silver Nitrate Consumed (ml)	Chloride Content (ppm)	Actual Chloride Content (ppm)
		Initial (ml)	Final (ml)			
Sea water	1	12.5	27.1	14.6	53.48	21393.37
Blank	1	27.1	31	3.9		

Table 10: Compressive Strength of Specimen Sea Water

Specimen	Average Compressive Strength (MPa)		
	28 Days	56 Days	90 Days
EAP	77.56	78.89	72.89
EMP	83.78	79.56	76.89
EGP	79.11	78.22	78.00
EAN	71.78	72.89	78.89
EMN	77.56	79.33	79.33
EGN	66.89	75.11	74.56

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 ie., alccofine 1203 shows 13.81% reduction in strength for Strongcrete & 3.27% reduction in strength for nokrack, metakaoline shows 13.85 % reduction in strength for Strongcrete & 5.81% reduction in strength for nokrack and GGBS shows 6.65 % reduction in strength for Strongcrete & 7.81% reduction in strength for nokrack comparing with 90days water cured specimens. In all the six, GGBS and metakaoline specimen shows better resistive capacity under sulphate attack, in which metakaoline-Nokrack specimen is more resistive to sulphate. But the compressive strength of most of the mix go below the characteristic strength

CONCLUSIONS

The main conclusion which can be drawn from the investigation, are given below

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.

The compressive strength of concrete mix with metakaoline as mineral admixture was higher compared to GGBS and alccofine 1203 and the specimen with Strongcrete fibre shows better compressive strength than nokrack fibre

By using Strongcrete and Nokrack fibre in HPC there is no significant improvement in compressive and tensile strength, when comparing with HPC without fibre.

On increase the percentage of fibre its compressive strength reducing and balling effect at the time mixing.

Compared to the days of curing, after 28 days the strength increment of specimens is less than 10%. This suggests that curing of specimen after 28days doesn't have much effect in strength.

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.

The Strongcrete fibre flexural strength increase is around 10-20% and for Nokrack fibre is around 15-20% than specimen without fibres. So there is a significant contribution of flexural strength when we use both fibres in HPC concrete.

The specimens with metakaoline as admixtures shows better resistive to chemical attack like from 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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