Elevated Temperature and Durability Studies on High Strength Concrete

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Abstract: **In this paper, an attempt was made to study the effect of elevated temperatures and durability studies on fifty one numbers of ten centimeter high strength concrete cubes prepared with ultrafine mineral admixture, Alccofine 1203. Trials were made with 0%, 5%, 10% and 15% replacement of cement with Alccofine. Optimum percentage of replacement of cement by Alccofine was found to be 10%. The maximum compressive strength achieved was 79.93MPa. Elevated temperature, Non-Destructive test and Durability studies were conducted. The percentage loss in weight was found to be decreased with the temperature increase from 100^{0}C to 900^{0}C. Similar trend was observed for Compressive strength also with the temperature increase. But compressive strength was increased at 300^{0}C. The weight and compressive strength was increased when immersed in Sulphate solution, Chloride solution, Alkali solution and Sea water.**

Index Terms: **Compressive strength, Weight, Elevated Temperatures, Sulphate Attack, Chloride Attack, Alkali Attack, Sorptivity.**

I. Introduction

A. High Strength concrete(HSC)

HSC is characterized by high compressive strength. HSC is more durable because the low water-to-cementitious materials ratio results in very low porosity. The main advantage of HSC is its high compressive strength. Other advantages include improved microstructure and homogeneity, high flexibility with the addition of fibers. Due to the high strength of the concrete, the thickness of concrete elements will be reduced, which results in materials saving and cost saving.

B. Alccofine 1203

Alccofine1203 is a new generation slag of high glass content with high reactivity obtained through the process of controlled granulation having Ultra-fineness with optimized particle size distribution. Alccofine1203 is much finer than other hydraulic materials like cement, fly ash, silica etc. The use of Alccofine1203 leads to a reduction of the size of the crystalline compounds, particularly calcium hydroxide which results in a reduction of the thickness of the interfacial transition zone (ITZ). It also reduces the free lime (CH) to C-S-H. This, in turn, strengthens the interfacial transition zone width with C-S-H structures occupying the CH crystal spaces. Thus, allowing the concrete to sustain higher loads without cracking. The physical and chemical parameters are presented in Table I and Table II.

TABLE I.
PHYSICAL PARAMETERS OF ALCCOFINE1203

Specific gravity	Bulk Density (kg/m^3)	Fineness (Cm^2/gm)	Specific Gravity	Particle size distribution (μ)		
2.9	680	12000	2.86	D10	D50	D90
				1-2	4-5	8-9

TABLE II.
CHEMICAL PARAMETERS OF ALCCOFINE1203

CaO	Al_2O_3	SiO_2	Fe_2O_3	SO_3	MgO	Glass content
34.0%	24.0%	35.0%	1.20%	0.13%	8.20%	>90%

II. Literature Review

High strength concrete was prepared using foundry slag as a partial substitute for fine aggregate in varying proportions. Alccofine was used in an optimum amount of 15% as a partial substitute for Portland pozzolana cement. Results showed increase in Ultrasonic pulse velocity and rebound number with increase in foundry slag content and age [1]. Durability tests were conducted on high performance concrete made with Alccofine and Fly ash. Alccofine enhanced the durability of concretes and reduced the chloride diffusion. Due to the more compactness and less permeability of concrete, effect of chloride attack was reduced [2]. Strength and durability performance of concrete with Alccofine as partial replacement was studied and observed that 20% replacement of cement with Alccofine increased the strength and durability of concrete at all the ages [3]. The behavior of high performance of concrete with Alccofine as a supplementary cementitious material was studied. It was observed that 10% replacement of cement with Alccofine gave an increase in the compressive strength and flexural strength [4]. Performance of concrete was studied by replacing the cement with supplementary cementitious material Alccofine. Under sulphate attack, it was found that the weight loss decreased with the increase in Alccofine addition [5].The behavior of Alccofine concrete was studied at different high range water reducing dosages with low water/binder ratios. The cost of concrete mix prepared with Alccofine was lesser than the concrete prepared without Alccofine [6]. Effect of elevated temperatures on compressive strength, Split tensile strength

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and Flexural strength was studied between the temperatures 50^0C to 250^0C. Compressive strength, Split tensile strength and Flexural strength were found to be decreased with the increased temperature [7].

III. Experimental Programme

A. Materials

Cement, fine aggregate, coarse aggregate and water were used for the preparation of desired strength of concrete mix. In addition, Supplementary Cementitious Material (Alccofine 1203) was used to increase the strength of the concrete. Chemical admixture (ACE 30 JP) was also used to produce high workability in fresh concrete and to reduce water-cement ratio

B. Cement

Ordinary Portland Cement of 53 grade conforming to IS:8112-1989 was used in the present Project work. Specific gravity of cement was 3.10 and the cement was tested according to IS:1489-1991 (Part-I).

C. Fine Aggregate

Natural river sand was used as fine aggregate. Specific gravity of fine aggregate was 2.65. Fineness modulus is 2.87. Bulk density is 1778.26 kg/m^3.Testing of fine aggregate conforms to IS: 383-1970.

D. Coarse Aggregate

Coarse aggregate passing through 20mm sieve and retained on 10mm sieve and 4.75mm sieve was taken in 60% and 40% respectively. Specific gravity of Coarse aggregate was 2.70. Testing of coarse aggregate conforms to IS:383-1970.

E. Water

Potable water was used in the preparation of concrete. Water used conforms to IS:456-2000.

F. Superplasticizer

Superplasticizer used in the present study was Master Glenium BASF ACE30JP. Dosage of superplasticizer used was 1.27% by weight of binder. Chemical Admixture BASF ACE30JP is conforms to IS: 9103-1999.

G. Mineral Admixture

Alccofine1203 conforming to IS:12089-1987, IS:456-2000 (Clause No:5.2.2) and ASTM C989-99 [9] was used as a supplementary cementitious material. Its particle size is much finer than the cement particle size.

H. Compressive Strength

Mix proportions 1:0.556:1.629:0.25 and 1:0.617:1.644:0.25 were taken from the literature and trial castings were made to produce high strength concrete. Concrete cubes of 100mm x100mm x100 mm size were cast. Forty-eight hours after casting, cubes were demoulded and water cured for 28 days and tested using 3000kN Computerized Compression Testing Machine at right angle to the direction of casting for compressive strength of concrete as per IS: 516-1959 [10] as presented in Fig. 1.

Figure 1. Cube testing under computerized Compression Testing Machine

Mix proportion 1:0.556:1.629:0.25 with 10% Alccofine 1203 yielded high strength compared to 1:0.617:1.644:0.25 mix proportion. The results obtained from the compressive strength of concrete with mix proportions 1:0.556:1.629:0.25 was presented in Table III.

TABLE III.
MIX PROPORTIONS AND COMPRESSIVE STRENGTH DETAILS OF 1:0.556:1.629:0.25

Mix Proportion	Alccofine 1203	Avg.Compressive Strength (MPa)
1:0.556:1.629:0.25	5%	69.71
1:0.556:1.629:0.25	10%	79.93
1:0.556:1.629:0.25	15%	63.55

I. Ultrasonic Pulse Velocity (UPV)

In the present work, pulse velocity was measured on 100 mm cubes according to IS 13311 (Part 1):1992 [8] by using PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) Lab plus apparatus as presented in Fig. 2. Higher velocities were obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. The test results before and after removing from high temperature furnace are presented in Fig. 3.

Figure 2. Ultrasonic Pulse velocity measurement of cubes

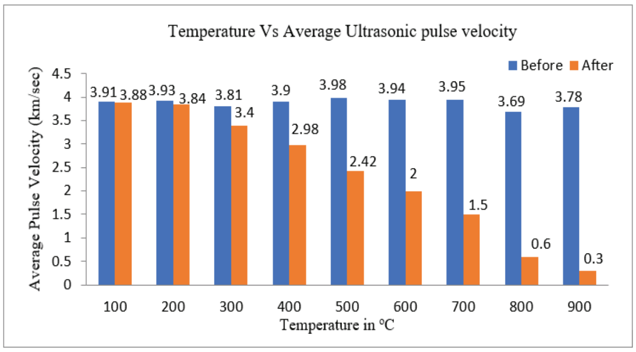

Figure 3. Average Ultrasonic pulse velocity of cubes before and after temperature studies.

J. Elevated Temperature Studies

Fire accidents, sabotages or natural hazards are the situations where concrete is likely to get exposed to elevated temperatures. Exposure to elevated temperature causes Physical changes including large volume changes due to thermal dilations, thermal shrinkage and creep related to water loss. The volume changes can result in large internal stresses and lead to micro-cracking and fracture. Elevated temperatures also cause chemical and micro-structural changes such as water migration, increased dehydration, interfacial thermal incompatibility and the chemical decomposition of hardened cement past and aggregate. All these changes decrease the stiffness of concrete and increase the irrecoverable deformation.

In the present work, Cubes cast were kept in high temperature furnace for 02 hours duration at different temperatures from 100^0C-900^0C as presented in Fig .4. After 02 hours duration, cubes were taken out of the furnace and the Ultrasonic pulse velocity of cubes was measured using Portable Ultrasonic Non-destructive Digital Indicating Tester. The Percentage loss in weight of cubes and Residual compressive strength of the cubes were evaluated.

K. Percentage loss in weight

The percentage of weight loss of cubes after taking out from high temperature furnace is presented in Table IV.

TABLE IV.
AVERAGE PERCENTAGE OF WEIGHT LOSS OF CUBES AFTER TAKING OUT FROM HIGH TEMPERATURE FURNACE

Temperature (^{O}C)	Specimen designation	Weight of specimen before placing in HTF (W1) kg	Weight of specimen after taking out from HTF (W2) kg	Average percentage of weight loss = ((W1-W2)* 100) /W1
100	10 BT	2.41	2.40	
	18 BT	2.46	2.36	
	19 BT	2.48	2.47	1.63
200	2 BT	2.55	2.50	
	3 BT	2.41	2.35	
	24 BT	2.46	2.41	2.02
300	6 BT	2.49	2.40	
	20 BT	2.44	2.33	
	22 BT	2.45	2.35	4.06
400	1 BT	2.46	2.33	
	12 BT	2.45	2.32	
	25 BT	2.47	2.35	5.28
500	7 BT	2.41	2.27	
	17 BT	2.47	2.35	
	21 BT	2.45	2.30	5.73
600	9 BT	2.47	2.33	
	23 BT	2.46	2.29	
	26 BT	2.47	2.32	6.09
700	11 BT	2.49	2.32	
	15 BT	2.46	2.33	
	4 BT	2.49	2.32	6.45
800	13 BT	2.43	2.25	
	16 BT	2.48	2.33	
	27 BT	2.44	2.27	6.93
900	8 BT	2.50	2.32	
	73 BT	2.48	2.30	
	77 BT	2.50	2.33	7.22
*HTF- High Temperature Furnace				

The percentage loss in weight of cubes was found to be increased up to 900^0C. It was observed that there was an increase in percentage of weight loss with respect to increase in temperature.

L. Compressive Strength

The compressive Strength of cubes before placing and after removing from high temperature furnace are presented in Table V.

TABLE V.
COMPRESSIVE STRENGTH OF CUBES SUBJECTED TO ELEVATED TEMPERATURE STUDIES

Temperature (^{O}C)	Average compressive strength before placing in HTF (MPa)	Average residual compressive strength after taking out from HTF (MPa)	Average percentage loss in compressive strength
100	78.06	63.06	19.34
200	78.69	56.93	27.72
300	77.55	91.9	-18.55
400	78.86	68.3	11.74
500	77.39	62.1	19.71
600	78.52	57.4	26.809
700	77.83	52.76	32.15
800	77.98	37.36	52.06
900	79.44	23.96	69.83

Figure 4. Cubes in High High Temperature Furnace

Figure 5. Cube after 02 hrs.in Temperature Furnace at 100^0C

Figure 6(a). Cube after 02 hrs. in High Temperature Furnace at 200^0C

Figure 6(b). Cube after 02 hrs. in High Temperature Furnace at 300^0C

Figure 7(a). Cube after 02 hrs. in High Temperature Furnace at 400^0C

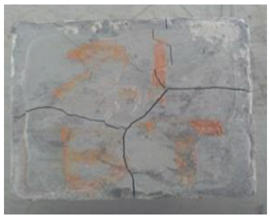

Figure 7(b). Cube after 02 hrs. in High Temperature Furnace at 500^0C

Figure 8(a). Cube after 02 hrs. in High Temperature Furnace at 600^0C

Figure 8(b). Cube after 02 hrs. in High Temperature Furnace at 700^0C

Figure 9(a). Cube after 02 hrs. in High Temperature Furnace at 800^0C

Figure 9(b). Cube after 02 hrs. in High Temperature Furnace at 900^0C

No visible cracks and spalling were found up to 300^0C as presented in Fig. 5, Fig. 6(a) and Fig. 6(b) respectively. Cracks were observed in the specimens tested to 400^0C and 500^0C as presented in Fig. 7(a) and Fig. 7(b). Cracks were observed as pronounced in the specimens subjected to 600^0C, 700^0C, 800^0C and 900^0C respectively as presented Fig. 8(a), Fig.8(b), Fig. 9(a) and Fig.9(b) respectively. Above 700^0C, large crack widths and depths were observed in the specimens. The variation in color was observed with respect to the temperature increase. Up to 600^0C, the concrete colour doesn't change noticeably. When the temperature was increased to 700^0C, the color of cube was changed from normal to pink or red as presented in Fig. 8(b). When the temperature was increased above 700^0C, the color of cube was changed to whitish grey as presented in Fig. 9(b).

M. Durability Studies - Sulphate Attack Test

Sulphate attack test was carried out on 100 mm x100 mm x100 mm concrete cubes. Total 03 cubes were casted and cured in water for 28 days. After 28 days curing, cubes were taken out and allowed for drying for 24 hours at 50^0C and weights were taken before placing in the sulphate solution (2.5% Na_2SO_4 and 2.5% $MgSO_4$ by weight of water) as presented in Fig. 10. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the sulphate solution after the prescribed period of continuous soaking and the surface of the cubes was cleaned, weighed & the average percentage of loss in weight was calculated at 7, 14, 28 and 56 days as presented in Fig. 11 and tested in the compressive testing machine at the end of 56 days and the compressive strength of the concrete cubes was calculated as per IS: 516-1959 [10].

Figure 10. Cubes immersed in $MgSo_4$ & Na_2So_4

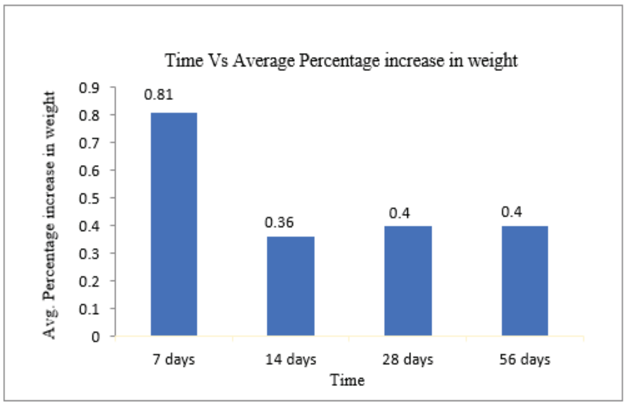

Figure 11. Variation of average percentage increase in weight of cubes taken out from $Mgso_4$ and Na_2so_4

N. Chloride Attack Test

Chloride resistance test was carried out on 100 mm x100 mm x100 mm concrete cubes. Total 03 cubes were casted and cured in water for 28 days. After 28 days curing, cubes were taken out and allowed for drying for 24 hours at 50^0C and weights were taken before placing in the sodium chloride solution (5% of Nacl by weight of water) as presented in Fig. 12. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the sodium chloride solution after the prescribed period of continuous soaking and the surface of the cubes was cleaned, weighed & the average percentage of loss in weight was calculated at 7, 14, 28 and 56 days as presented in Fig. 13 and tested in the compressive testing machine at the end of 56 days and the compressive strength of the concrete cubes was calculated as per IS: 516-1959.

Figure 12. Cubes immersed in Nacl

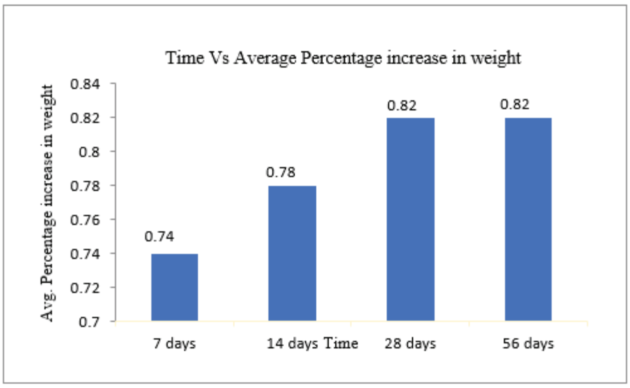

Figure 13. Variation of average percentage increase in weight of cubes taken out from Nacl

O. Alkali Attack Test

Alkali attack test was carried out on 100 mm x100 mm x100 mm concrete cubes. Total 03 cubes were casted and cured in water for 28 days. After 28 days curing, cubes were taken out and allowed for drying for 24 hours at 50^{0}C and weights were taken before placing in the sodium hydroxide solution (5% of sodium hydroxide solution by weight of water) as presented in Fig.14. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the sulphate solution after the prescribed period of continuous soaking and the surface of the cubes was cleaned, weighed & the average percentage of loss in weight was calculated at 7, 14, 28 and 56 days as presented in Fig.15 and tested in the compressive testing machine at the end of 56 days and the compressive strength of the concrete cubes was calculated as per IS: 516-1959.

Figure 14. Cubes immersed in NaoH

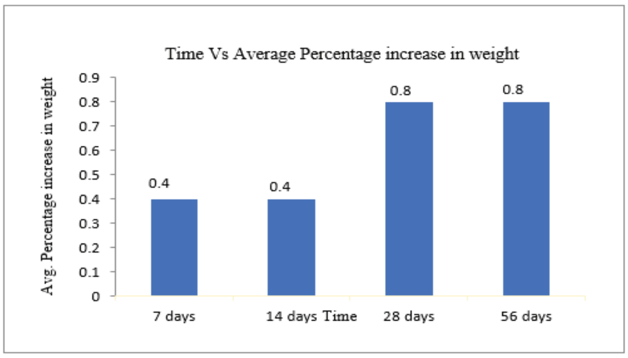

Figure 15. Variation of average percentage increase in weight of cubes taken out from NaoH

P. Sea Water Test

Sea water was brought from Bay of Bengal and test was carried out on 100 mm x100 mm x100 mm concrete cubes. Total 03 cubes were casted and cured in water for 28 days. After 28 days curing, cubes were taken out and allowed for drying for 24 hours at 50^{0}C and weights were taken before placing in the sea water (5% of Sea water solution) as presented in Fig.16. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the sulphate solution after the prescribed period of continuous soaking and the surface of the cubes was cleaned, weighed & the average percentage of loss in weight was calculated at 7, 14, 28 and 56 days as presented in Fig.17 and tested in the compressive testing machine at the end of 56 days and the compressive strength of the concrete cubes was calculated as per IS: 516-1959.

Figure 16. Cubes immersed in Sea Water

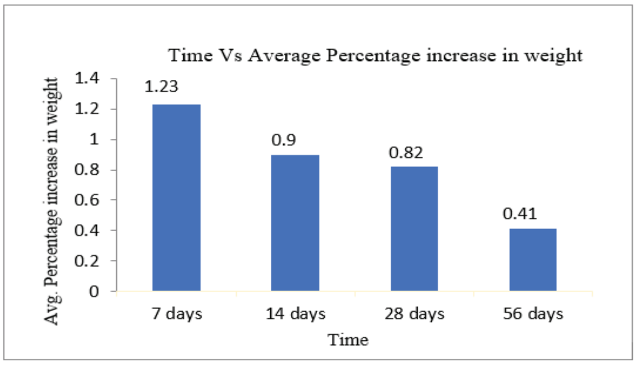

Figure 17. Variation of average percentage increase in weight of cubes taken out from Sea Water

Q. Percentage Increase in Weight

The Percentage increase in weight for Nacl, NaoH, $MgSo_4$ & Na_2So_4 and Sea Water as presented in Fig.18.

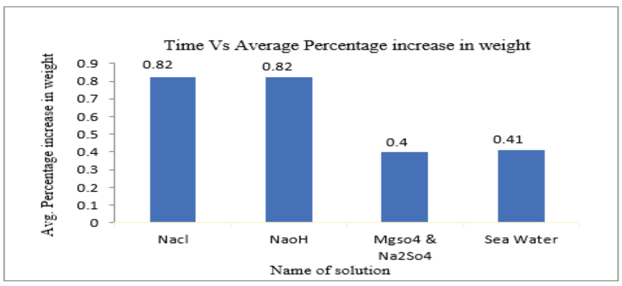

Figure 18. Comparison of percentage Increase in weight of cubes for different solutions at 56 days

R. Compressive Strength

The Average Compressive Strength before placing and after removing from Nacl, NaoH, $MgSo_4$ & Na_2So_4 and Sea Water and percentage increase in compressive strength are presented in Table 6.

TABLE VI.
PERCENTAGE INCREASE IN COMPRESSIVE STRENGTH OF CUBES AT 56 DAYS

Name of Solution	Average Compressive Strength when cured in potable water (MPa)	Average Compressive Strength after taking out from the chemical solutions (at 56days) (MPa)	Percentage Increase in Compressive strength
Nacl	69.71	91.83	31.73
NaoH	79.93	94.6	18.35
$MgSo_4$ & Na_2So_4	63.55	86.93	36.78
Sea Water	78.40	89.10	13.64

S. Sorptivity Test

Sorptivity is the absorption and transmission of water through capillary action.

Before the specimen is placed in contact with water it was kept in oven at temperature of 50^0C for 03 days [9]. Cubes (10 cm) were placed as presented in Fig.19.

The absorption (I) due to capillary action is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water as in (1). The units of 'I' are mm.

$$I = \left(\frac{m_t}{a * d} \right) \quad (1)$$

Where, I = absorption

Δw= change in weight = W2-W1

W1 = Oven dry weight of cube in grams

W2 = Weight of cube after the prescribed time due to capillary suction of water in grams.

m_t = change in specimen mass (in grams, at time t)

a = exposed area of the specimen through which water penetrated (mm^2)

d = density of the water (g/mm^3)

Sorptivity was calculated using the expression presented in (2).

$$\text{Sorptivity, } S = I/t^{1/2} \quad (2)$$

Where, S = Sorptivity in $mm/min^{1/2}$

t = elapsed time in min.

Figure 19. Cubes under Sorptivity test

Sorptivity coefficient is calculated as 1.5873×10^{-4} $mm/min^{0.5}$ from the graph presented in Fig.20.

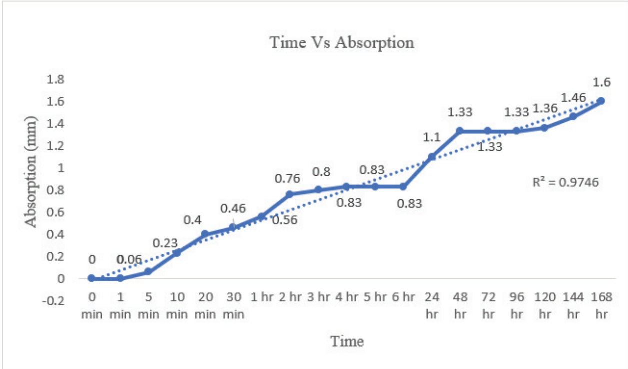

Figure 20. Variation of water absorption of cubes with respect to time

IV. DISCUSSIONS AND CONCLUSIONS

The quality category of cubes before temperature studies as per IS:13311 (Part-I) was 'Good'. The Ultrasonic pulse velocity of high strength concrete cubes as per IS:13311 (Part-I) between 100^0C-900^0C in an interval of 100^0C was found to be 'Good' quality for 100^0C, 200^0C and 'Medium' quality for 300^0C and 'Doubtful' quality for 400^0C, 500^0C, 600^0C, 700^0C, 800^0C and 900^0C. Due to the weakened cohesion between the mixture constituents, path length of the Ultrasonic pulse velocity might have been increased and thereby decreasing the velocity. This might be the reason for the decrease in quality category of concrete cubes from 'Good' to 'Doubtful'.

The effect of elevated temperatures on weight of concrete cubes was studied between 100^0C-900^0C in an interval of 100^0C. The percentage loss in weight of cubes was found to be increased from 100^0C to 900^0C. This may be attributed to the continuous evaporation of moisture from the concrete cubes which might have weakened the bonding between the binder and the course aggregate.

The percentage difference in compressive strength between 100^0C to 900^0C in an interval of 100^0C was 19.34, 27.72, -18.55, 11.74, 19.71, 26.80, 32.15, 52.06, 69.83. The increase in strength at 300^0C might be attributed to the increase in surface forces between gel particles (Vander Waal forces) due to the removal of moisture content. The decrease in compressive strength at 800^0C may be attributed to decomposition of the cementing compound C-S-H with its different phases, dehydration of calcium hydroxide (CH) into free lime. These changes would have affected the volume occupied by these cementitious products and when combined with the weakened cohesion between the mixture constituents due to the different expansions experienced by each of them. The decrease in compressive strength at 900^0C may be attributed to the decomposition of calcium carbonate through the loss of CO_2 and all the free water might have lost.

The percentage variation in average weight of 10cm concrete cubes after 56 days of immersion in Nacl solution, NaoH solution, $Mgso_4$ plus Na_2so_4 solution and Sea water was found to be 0.82, 0.80, 0.40 and 0.41 respectively. The percentage variation in weight of cubes is very less and this might be due to the error in taking the measurements.

The percentage increase in compressive strength after taking out from the chemical solutions Na_2SO_4 and $MgSO_4$, Nacl, NaoH and Sea water at 56 days was found to be 31.73, 18.35, 36.78 and 13.64 respectively. The concentration of these solutions was not sufficient enough to affect the Compressive strength of concrete cubes.

More absorption of water due to capillary action might be attributed to the precondition of the concrete cubes at a temperature of 50^0C for 03 days as per ASTM:C1585-04.

Based on the above discussions, the use of Alccofine 1203 is recommended as a mineral admixture to prepare a concrete of high strength and durability.

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