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Effect of Elevated Temperature and Aggressive Chemical Environment on Compressive Strength of M-30 Grade of Concrete Composite.

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Abstract
The present paper reports result of an experimental program conducted to study the behavior of M-30 grade of concrete at elevated temperature on the basis of physical appearance, weight loss and residual compressive strength test. The concrete cubes(M-30) of 150×150×150 mm were cast with a ratio of 1:1.26:2.8 by weight. Three cubeswere tested for compressive strength at the age of 7 days and 28 days by universal testing machine. Then the specimen were subjected to the elevated temperature 200^{o}c, 400^{o}c, 600^{o}c, 800^{o}c and 1000^{o}c in an electric air heated muffle and after cooling were tested for the compressive strength. Six cubes were immersed in each solution of sodium sulphate, sulfuric acid, and sodium chloride for 30 days and 60 days. The testreveal the properties of M-30 concrete and its applicability at elevated temperature and against aggressive environment such as acid attack, sulphate attack and chloride attack.
Keywords: Elevated temperature, Residual strength, Aggressive chemical environment, M-30 concrete

I. INTRODUCTION

Concrete is the second highest consumed material after water in the world, plays a vital role in the construction field because of the versatility in its use, Developments during the last two decades have shown a marked increase in the number of structure involving the long time heating of concrete. After the 9-11 attack on the world trade centre, interest in the assessment of structure for fire greatly increased. Fire is one of the hazards that may result in death, injury or property damage. One of the burning topic in fire research today is assessment of the residual strength of concrete after exposure to fire. The knowledge of the strength of concrete may be required for different practical condition of exposure. In case of fire, the exposure to the high temperature is only of a few hours duration but the heat flux is large and so is the mass of concrete subjected to it. The extensive use of concrete as a structural material for the high rise buildings, nuclear power reactors, pressure vessels, storage tank for hot crude oil, hot water and coal gasification & liquefaction vessels increases the risk of concrete is most suitable to resist high temperatures because of its low thermal conductivity and high specific gravity[1]. It was investigated that the loss in structural quality of concrete due to rise of temperature is influenced by its degradation through changes induced in basic process of cement hydration and hardening of the binding system in the cement paste of concrete[1].

Concrete is generally well resistant to chemical attack,provided anappropriate mix is used and concrete is properly compacted. There are some exceptions. Concrete containing Portland cement, being highly alkaline is not resistant to attack by strong acids or compounds which may convert to acids. Consequently, unless protected, concrete should not be used when this form of attack may occur.

Chemical attack of concrete occur by way of decomposition of the products of hydration and formation of new compound which, if soluble may be leached out and if not soluble may be disruptive in situ. The attacking compounds must be in solution. Te most vulnerable cement hydrate is $Ca(OH)_2$, but C-S-H can also be attacked. Calcareous aggregates are also vulnerable[2].

Solid salt do not attack concrete but, when present in solution they can react with hydrated cement paste. Particularly common are sulfates of sodium, potassium, magnesium and calcium which occur in soil or in groundwater. Because of solubility of calcium sulfate is low, groundwater with a high sulfate content contain the other sulfates as well as calcium sulfate. Te significance of this lies in the fact that those other sulfates as well as calcium sulfates react wit te various products of hydration of cement and not only with $Ca(OH)_2$[3].

II. EXPERIMENTAL PROGRAM

2.1 Materials

The material used in present investigation were locally available in Sindri, Dist-Dhanbad(Jharkhand) and physical properties were found through various laboratory tests conducted in Concrete and Road material lab, B.I.T Sindri.

2.1.1 Fine aggregate

Ordinary sand available in Sindri, Dhanbad (Damodar river sand) having the following characteristics has been used.

Specific gravity : 2.67
Fineness modulus : 2.42
Unit weight : 1.674 gm/cc
Water absorption : 0.44%
Bulking : 26%

Sand after sieve analysis (Table 1.1) confirm to zone – II as per IS 383-1970.

Table 1. Sieve analysis of fine aggregate

IS Sieve (mm)	Wt.Retained (Kg)	Cum. Wt. (Kg)	% Retained	% Passing	Remarks
4.75	0.034	0.034	3.4	96.6	Sand Zone II As per IS: 383-1970 CLAUSE 4.3 TABLE 4
2.36	0.026	0.060	6	94	
1.18	0.140	0.200	20	80	
600	0.162	0.362	36.2	63.3	
300	0.425	0.787	78.7	21.3	
150	0.185	0.972	97.2	2.30	

2.1.2 Coarse aggregate

Locally available black crushed stone (Pakur stone) in Sindri with maximum nominal size of 20 mm and 10 mm have been used as coarse aggregate. The physical properties for the coarse aggregate as found through laboratory test according to IS 2386-1963 is resulted as:

Aggregate crushing value =24%
Aggregate impact value = 29%
Specific gravity = 2.64
Water absorption = 0.94%
Unit weight = 1.60gm/cc
Fineness Modulus = 6.15

Sieve analysis of the locally available coarse aggregate is given in Table 2 and 3.

Table 2. Sieve analysis of coarse aggregate 20 mm

Sieve size (mm)	Weight retained(Kg)	Cum.wt (Kg)	Percent retained	Percentage passing	Remarks
40	0.000	0.000	0	100	60%
20	0.470	0.470	9.4	90.6	
12.5	3.461	3.931	78.62	21.38	
10	0.463	4.393	87.88	12.12	
4.75	0.562	4.956	99.12	0.88	

Table 3. Sieve analysis of coarse aggregate 10 mm

Sieve size (mm)	Weight retained (Kg)	Cum.wt (Kg)	Percent retained	Percentage passing	Remarks
40	0.000	0.000	0	100	40%
20	0.000	0.000	0	100	
12.5	0.000	0.000	0	100	
10	1.400	1.40	28.00	72	
4.75	3.304	4.704	94.08	5.92	

2.1.3 Cement

Commercially available Portland slag cement confirming to IS 455: 1989[5]with brand name "ACC CEMENT" was used for casting of M-30 grade of concrete.

The physical properties of the cement are given as follows:

Initial setting time (minute) : 145
Final setting time (minute): 230
Specific surface (m^2/Kg) : 325
Specific gravity: 3.15
Residue on 200 μm (%) : 1.00
Normalconsistency (%) : 28
28 days compressive strength (MPa) : 49
Le-Chatelier expansion (mm) : 0.5

Table 4.Chemical properties of cement.

Material	Cement
CaO	58.80
SiO_2	21.70
Al_2O_3	6.10
Fe_2O_3	3.60
SO_3	3.60
MgO	3.00
K_2O	0.72
Na_2O_3	0.45
LOI*	1.50

* Loss of ignition.

2.1.4 Water

Tap water was used throughout the test procedure which is available in concrete laboratory.

2.2 Mix design of concrete

Using Indian Standard recommended guidelines for mix design of concrete of grade M-30 as per IS 10262-2009. The mix proportion is calculated and the value of different ingradients for one cubic meter concrete by mass is given as

Water (kg/m3)	Cement (kg/m3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)
191.58	433.0	545.0	1210.0
0.442	1	1.26	2.80

2.3 Mixing and casting procedure

The specimen were prepared according to IS 516-1959. Mixing of all the material were done manually in the laboratory at room temperature as shown in figure(2.1).

Figure(2.1). Mixing of concrete material

The coarse aggregates, fine aggregates and cement were weighed and placed on the mixing floor, moistened in advance and mixed homogeneously. After mixing these ingradient, weight the water and placed on the dry mix. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in colour. Fresh concrete was castin steel mould and each cube specimen was cast in three layers by compacting manually(as shown in fig 2.2) as well as by using vibration table as shown in fig.(2.3). Each layer received 35 strokes of compaction by standard compaction rod for concrete, followed by further compaction on the vibration table.The cube specimens of size 150×150×150 mm size were used for compressive strength determination after demoulding at one day, the specification were cured in water at 20^oc until 28 days age and then cured in air with a temperature of 20^oc and 50% relative humidity.

After the feeding operation, each of the specimen was allowed to stand for 24 hours before demoulding, stored in fresh tap water at 20 ± 2^oc for 28 days and the removed and kept at room temperature until the time of the experiment.

Figure (2.2) compaction of concrete manually.

Figure(2.3) Compaction on vibrating table.

III. TESTING METODOLOGY

Three cubes each was tested for compressive strength at 7 days and 28 days of curing using universal testing machine.

3.1 Testing at elevated temperature

Specimens were heated in an electric furnance (AIMIL) at a heating rate of 10^oc/min to target temperature as shown in figure(3.1).

Figure (3.1) Electric Muffle

Five target temperatures namely 200^oc, 400^oc, 600^0c, 800^oc, and 1000^oc were used. At each target temperature, the specimens were maintained for two hours. The temperature measured by Type K thermocouple. After each exposure cycle, the specimen were allowed to cool in muffle at room temperature for 24 hours and were then tested to assess the residual strength and weight loss. For each data point of test, three identical specimens were used to guarantee repeatability in all tests. The change in color of specimen due to different elevated temperature is shown in figure 3.2

Figure 3.2 concrete cube at different elevated temperature

3.2 Testing method for aggressive chemical environmental

Six cubes of M-30 was immersed in 10% concentration ofsulfuric acid, sodium sulfate solution and sodium chloride solution for test period of 30 days and 60 days. The solution were stirred every 7thday to avoid deposition at the bottom of container. After test period the specimen were taken out of solution and were left at room temperature for 3 days and heat cured for 2 hours in heat curing chamber to dry the specimens. The specimens were tested for change in compressive strength and change in mass.

IV. RESULTS AND DISCUSSION

The experimental results are presented and discussed. Each of the compressive strength test data plotted in Figures or given Tables corresponds to the mean value of the compressive strengths. The effects of elevated temperature and aggressive chemical environment on the compressive strength of M-30 concrete composite are discussed.

Finally at end discussion on weight loss of the M-30 concrete composite.

4.1 Compressive strength at elevated temperature

Compressive strength of concrete is directly determined with the help of universal testing machine in concrete and road material laboratory, BIT Sindri. As the temperature increases the compressive strength of the concrete decreases gradually upto temperature 400^0 C, after 400^{o}C the rapid decrease in temperature is observed. The compressive strength for different conditions is given in table 4.1

Table 4.1 Compressive strength at elevated temperature

Elevated Temperature (in degree centigrade)	Residual compressive strength (in MPa)
25	44.44
200	39.99
400	31.99
600	18.14
800	10.59
1000	5.18

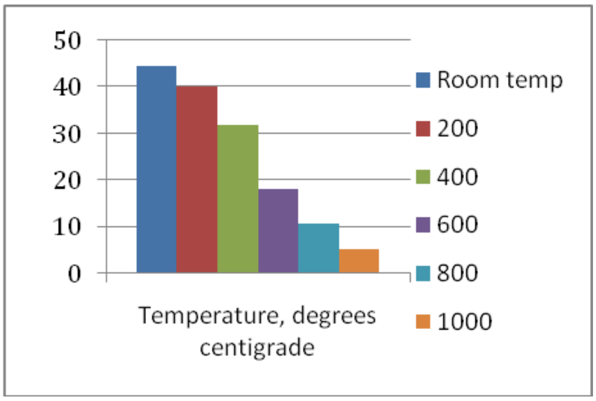


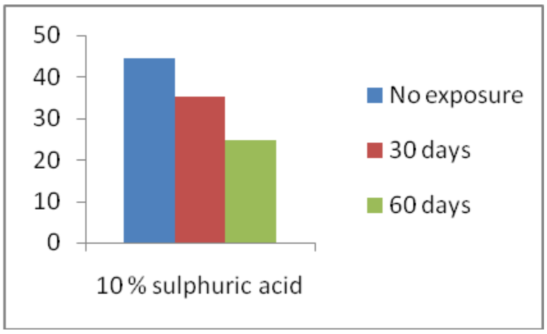
Figure 4.1 Change in compressive strength of specimen at elevated temperature

4.2 Compressive strength against aggressive environment

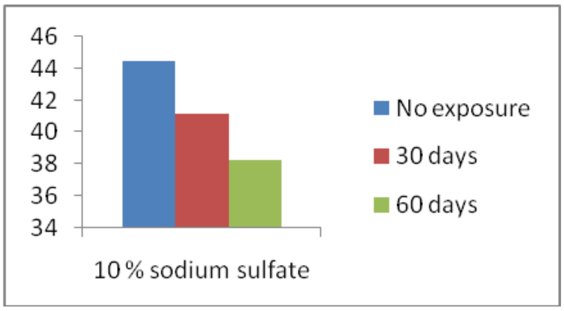
Three numbers of specimens in each acid, sulfate and chloride solution were tested for compressive strength after curing time and unit weight of specimens was noted before the test. Sulphuric acid attacks to lead to deposition of a white layer of a gypsum crystal on the acid exposed surface of the specimen. The average test results are presented in table 4.2 and corresponding diagram is plotted as shown in fig 4.2 for M-30 grade of concrete.

Table 4.2 Compressive strength at aggressive chemical environment

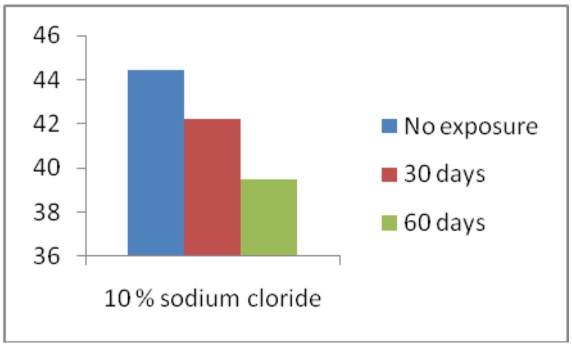
	Compressive strength no exposure (in MPa)	Compressive strength after 30 days exposure (in MPa)	Compressive strength after 60 days exposure (in MPa)
10 % sulphuric acid	44.44	35.11	24.62
10 % Sodium sulfate	44.44	41.20	38.29
10 % Sodium chloride	44.44	42.41	39.46



Figure(4.2): Change in compressive strength of specimen against acid attack.



Figure(4.3): Change in compressive strength of specimen against sulfate attack.



Figure(4.4): Change in compressive strength of specimen against chloride attack.

4.3 Loss of weight due to elevated temperature

The weight loss from M-30 concrete composite increase with the increase in the maximum exposed temperatures due to accelerated drying. Up to the temperature of 100^{o}C, concrete specimens lost 1.6 % of either initial weight due to the evaporation of free water. When the temperature was increased to 200^{o}C, the weight loss was 4.00 %, and when the temperature was increased to 400^{o}C, the weight loss was 7.3%. The increased weight loss is probably due to the dehydration of the hydration products and the loss of water from the fine pores in the cement paste and aggregate particles. At 600^{o}C the concrete lost 8.45% of its weight. At 800^{o}C the weight loss was 9.77 % while at 1000^{o}C the weight loss arrived to 11.8 %. The relationship between the weight loss and maximum temperature is non- linear.

Table 4.3 Loss of weight at elevated temperature

Elevated Temperature (in degree centigrade)	% loss of weigth of concrete.
Room Temp.	0
200	4
400	7.5
600	8.45
800	9.77
1000	11.8

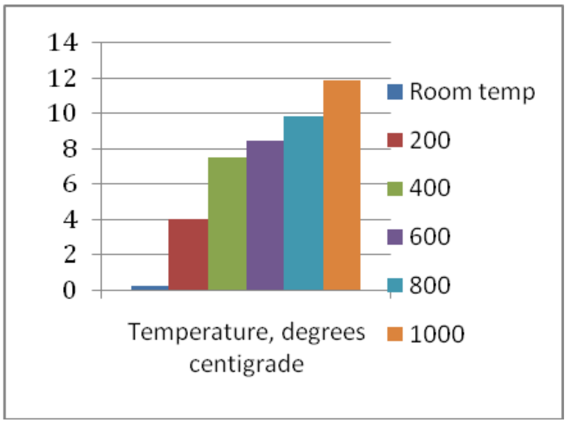


Figure 4.5 Percentage loss of weight due to elevated temperature.

4.4 Loss of weight due to aggressive environment

OPC (M-30) cubes were immersed in 10% concentration of sulphuric acid, 10% sodium sulfate solution and 10% sodium chloride for test period of 30 days and 60 days. All the exposed specimen recorded weight loss and it was observed that the weight loss in case of acid attack was more as compared to sulfate and chloride attack. The results of change in weight is presented in Table 4.4

Table 4.4 Loss of weight due to aggressive environment

Aggressive Environment	% loss of Weight (30 days exposure)	% loss of Weight (60 days exposure)
10 % H_2SO_4	10.59	16.47
10 % Na_2SO_4	7.15	12.88
10 % NaCl	4.14	7.99

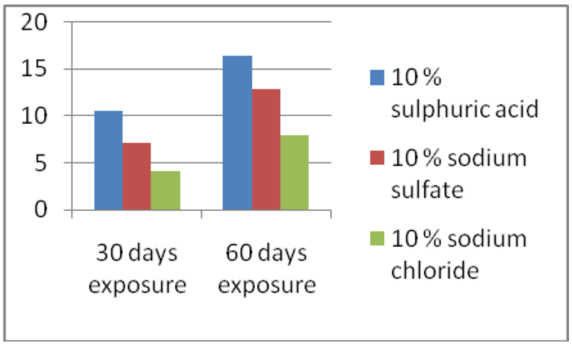


Figure 4.6 Percentage loss of weight due to aggressive chemical environment.

V. CONCLUSIONS

The experimental investigation confirms that:

- Loss of weight increased with increase in elevated temperature, weight loss was about 12% at 1000^{0}C.
- M-30 concrete composite showed deterioration in its properties when exposed to temperatures above 200^{0}C.
- M-30 concrete showed reduction in strengths in compression when exposed to high temperatures. This reduction was about 10%, 28.01%, 59.18%, 76.17% and 88.34 % at 200^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C and 1000 ^{o}C degree respectively.
- Loss of weight due to acid, sulfate and chloride attackis 10.59 %, 7.15 % and 4.14 % respectively after exposure of 30 days.
- Loss of weight due to acid, sulfate and chloride attack is 16.47 %, 12.88 % and 7.99 % respectively after exposure of 60 days
- Sulphuric acid attacks lead to more loss of weight and also deposition of a white layer of a gypsum crystal on the acid exposed surface of the specimen.
- M-30 concrete showed reduction in strengths in compression when exposed to different aggressive chemical environment. This reduction was about 20.99%, 7.29% and 4.57% after 30 days exposure and 44.6%, 13.83 % and 11.20 % after 60 days exposure to acid, sulfate and chloride solution respectively.

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VI. ACKNOWLEDEMENTS

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