Studies on Bacterial Concrete Exposed to Elevated Temperatures and Thermal Cycles

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Abstract - Although concrete is generally believed to be an excellent fireproofing material, it is susceptible to extensive damage or even catastrophic failure at high temperatures. At high temperatures, chemical transformation of the gel weakens the matrix bonding, which results in loss of strength of concrete. The behavior of concrete subjected to high temperatures depends on many factors such as member size, heating rate, peak temperatures, dehydration of C–S–H gel, phase transformations, and thermal incompatibility between aggregates and cement paste. This paper investigates the effect of sustained elevated temperature on residual compressive strength and percentage weight loss of Controlled Concrete and Bacterial Concrete mixes of ordinary grade (M20), standard grade(M40) and high strength grade (M60 and M80) after exposing to 200ºC, 400ºC and 600ºC for 2 hrs, 4hrs and 6 hrs duration and also the effect of thermal cycles on compressive strength and weight loss of Controlled Concrete and Bacterial Concrete mixes of above mentioned grades at temperature of 50 º C and 100 º C. Bacterial concrete is a special type of concrete in which microorganisms are induced to enhance the strength and durability properties. Bacteria used in this study are Bacillus subtilus (JC3). To be able to predict the response of bacterial concrete structures during and after exposure to high temperature, it is essential that the residual strength properties of bacterial concrete subjected to high temperatures should be clearly understood. This study quantifies the influence of a rise in temperature from ambient to 600ºC on the mechanical and physical properties of the concrete.

Keywords - Elevated Temperature, Thermal Cycles, Bacterial Concrete, fire resistance, residual compressive strength

I. INTRODUCTION

Concrete can be exposed to elevated temperatures during fire or when it is close to furnaces and nuclear reactors. The mechanical properties of concrete, such as strength, elastic modulus and volume deformation, decrease remarkably upon heating which results in a decrease in the structural quality of concrete. High temperature is one of the most important physical deterioration processes that influence the durability of concrete structures and may result in undesirable structural failures. Porosity, moisture content, its thermal properties, density etc determines the fire resistivity of the concrete. At high temperatures, Portland cement concretes undergo important changes in their properties, due to the degradation of its internal structure. The concrete structures could be exposed to high temperatures due to different reasons. Mainly during exposure to fire; another one could be when the structure or its elements are a part of industrial installations. Special applications such as nuclear reactor vessels, missile launching pads, turbo jet runways, and aircraft engine test cells require enduring higher temperatures. At elevated temperatures, ordinary concrete losses strength due to formation of cracks between cement paste and aggregate and associated thermal incompatibility between the two gradients. In most of the cases, the concrete remains intact with minor damages only due to its low thermal conductivity at high temperature and also limits the depth of penetration of fire damage. The distress in concrete due to fire manifests in the form of cracking and spalling of the concrete surface. But when the concrete is subjected to high temperature for long duration, the deterioration of concrete takes place and the compressive strength of concrete decreases. As the use of high-strength concrete becomes common, the risk of exposing it to high temperatures also increased. The behavior of high strength concrete under elevated temperatures differs from that of normal strength concrete. When concrete is exposed to elevated temperatures, it begins to experience dehydration reactions in the hydrated cement paste, possible thermal incompatibilities between paste and aggregate and eventual physiochemical deterioration of the aggregate. Typically, such degradation is accompanied by a decrease in the compressive strength, and weight of the concrete. Moreover, repeated thermal cycling due to fluctuating temperatures reduces the peak strength and could loosen the bond between the cement and aggregate. The thermal gradients and induced thermal stresses could trigger micro cracking, crumbling and spalling of the concrete.

II. PHYSICAL AND CHEMICAL TRANSFORMATIONS IN CONCRETE AT HIGH TEMPERATURES

When exposed to high temperature, the chemical composition and physical structure of the concrete change considerably. Dehydration, including the release of chemically bound water from calcium silicate hydrate, becomes significant above 100ºC. The dehydration of the matrix and the thermal expansion of the aggregate give rise to internal stresses, and beginning at 300ºC, micro-cracks begin to pierce through the material. $Ca(OH)_2$, one of the compounds in cement paste, dissociates at 400-600°C into CaO and H_2O resulting in the shrinkage of concrete. Although there are significant differences between normal and high strength concretes in fire performance, their thermal damages (crack formation, explosive spalling, and degradation of mechanical/durability properties) are similar and mainly arise from (i) thermal mismatch, (ii) decomposition of hydrates, and (iii) pore pressure.

When a concrete member is exposed to fire, the temperature gradient across the depth of the section will be built up. The thermal expansion of the outer layer of concrete under a high temperature is partially restrained by the inner layer of concrete under a lower elevated temperature, and this generates tensile thermal stresses in the concrete. The steeper the temperature gradient, the higher will be the thermal stresses. Another situation is that even a concrete member is subjected to an ideal uniform temperature field across its thickness; thermal stresses can still be developed because of the incompatibility of the coefficients of thermal expansion of the constitutive materials in concrete. Consequently, in the concrete matrix, the cement paste is under hydrostatic compression, and the granite aggregates are under biaxial compression and tension. As the temperature further increases, over 400 ºC, the thermal strain of the cement paste changes to negative (shrinking) due to chemical changes, whereas the granite continues to expand.

The mechanical properties of concrete depend largely on the hydration products (calcium silicate hydrate gel, calcium hydroxide, and ettringite) formed during the hydration reaction between the cementituous constituents and water. When concrete is exposed to a fire attack, free water in the concrete matrix will firstly be removed through a physical process such as evaporation at a lower elevated temperature. As the temperature further increases, disintegration of hydrates and loss of chemically bounded water will take place. 374°C is critical point of water when no free water is possible. The pore size and porosity of the hydrate matrix will increase, and the mechanical properties (strength and elastic modulus) of the hydrates will be weakened. Moreover, at 573 ºC, the crystal structure of quartz in a siliceous aggregate transforms from a low temperature α-phase to a high temperature β-phase. Such transformation is accompanied by an approximately one percent volume increase, which accelerates the disintegration process of the hydrates resulting gradual spalling. It is one of the main causes for which the siliceous aggregate based concrete show the lowest resistance to high temperature. At 700-800°C de-carbonation of calcium carbonate $CaCO_3$ into CaO and CO_2 occurs in cement paste and aggregates and at 1350°C melting of concrete starts. So mechanical properties of a heated concrete (in a macro-scale) are temperature-dependent.

The pore pressure developed in a heated concrete is derived from the evaporation of water within the porous media (free water) and from the decomposition of C-S-H gel and calcium hydroxide (chemically combined water). The highest pore pressure occurred between 220 ºC and 240 ºC in high strength concrete (HSC) and between 190 ºC and 210 ºC in normal strength concrete (NSC). The magnitude of the pore pressure depends on (i) the moisture level (degree of saturation), (ii) the permeability of concrete, and (iii) the heating rate. Low permeability and dense microstructure of HSC are probably the causes for creating high pore pressure that has been considered as a key factor for spalling of concrete. Explosive spalling failure occurs more in HSC than in NSC specimens. The reported temperature range when explosive spalling occurs is from 300°C to 650°C. Factors that influence spalling include original compressive strength, moisture content of concrete, concrete density, heating rate, and specimen dimensions and shape. Concrete with dense pastes due to the addition of silica fume are more susceptible to explosive spalling. Likewise, HSC made with lightweight aggregate appears to be more prone to explosive spalling than HSC made of normal weight aggregate concretes. HSC specimens heated at higher heating rates and larger specimens are more prone to spalling than specimens heated at lower rates and of smaller size. The failure of HSC is more brittle than NSC at temperatures up to 300°C. A temperature of 300°C marks the beginning of a higher rate of decrease in modulus of elasticity for all concretes. Mechanical damage of concrete is primarily caused by its sharp heating or cooling. In case of unsteady heat flow in concrete, the temperature is distributed in non-linear manner resulting in uneven distribution of thermal strain, causing thermal stress. As mentioned when concrete exposed to high temperature evaporates free (capillary) water. In the process, steam appears in concrete pores; the higher the moisture content of concrete and the faster the heating, the higher is the amount of steam. In M20 and M40 grade concretes, steam may move relatively freely and in the result its pressure does not reach higher levels. In dense concretes like M60 and M80 grades, the migration of steam is more difficult, hence its pressure can reach much higher values. Once high temperature begins to affect concrete, the location of the maximum concentration of steam in concrete pores gradually moves away from the surface of the element towards its inside. In temperatures from approximately 200°C to 300°C, a so-called "water plug" develops in concrete pores, making it difficult for steam to get through. Concrete which is outside the maximum pore pressure zone is pushed away from the centre of the element. Therefore, the concrete suffers tensile stress caused by pore pressure. Most frequently, such stress is directed approximately perpendicularly to the external, heated surface of the element. In addition to stress caused by steam pressure, the concrete may also suffer tensile stress caused by uneven distribution of temperature in the cross-section, or stress directed perpendicularly to the external surfaces of the element, related to the presence of high compressive stress which is most commonly parallel to the surface and generated by external load. When resultant tensile stresses reach the concrete tensile strength, an external fragment of concrete can chip away. This phenomenon is called thermal spalling. In some cases, the release of energy of the pressurized steam and energy of deformation of stressed concrete can shoot a fragment of structure away. This phenomenon is called explosive thermal spalling. In some cases, thermal spalling is replaced with gradual scaling of the surface. Thermal spalling is expected when the moisture content of concrete is high. Structures in dry environment generally do not suffer thermal spalling. Thermal spalling should be expected in case of fast heating of the element. In porous concretes, thermal spalling seems to be sporadic, while in high strength concrete, which has compact structure, the probability of thermal spalling seems to be very high.

III. OBJECTIVES AND EXPERIMENTAL PROGRAMME

The objectives of the current research work are to study the following properties:

1. Evaluation of residual compressive strength of controlled concrete and bacterial concrete mixes of ordinary grade (M20), standard grade (M40) and high strength grade (M60 and M80) exposed to 200ºC, 400ºC and 600ºC temperature for 2 hrs, 4hrs and 6 hrs duration .
2. Weight loss of controlled concrete and bacterial concrete mixes of ordinary grade (M20), standard grade (M40) and high strength grade (M60 and M80) exposed to 200ºC, 400ºC and 600ºC temperature for 2 hrs, 4hrs and 6 hrs duration.
3. Pulse Velocity of controlled concrete and bacterial concrete mixes of ordinary grade (M20), standard grade (M40) and high strength grade (M60 and M80) exposed to 200ºC, 400ºC and 600ºC temperature for 2 hrs, 4hrs and 6 hrs duration to determine quality after exposure.
4. Evaluation of residual compressive strength of controlled concrete and bacterial concrete mixes of ordinary grade (M20), standard grade(M40) and high strength grade (M60 and M80) when subjected to 7, 14, 21, 28 thermal cycles at temperature of 50 º C and 100 º C .

The concrete specimens of size 100 x 100 x 100 mm cubes were cast and tested in compressive testing machine of 3000 kN after air cooling to the room temperature as per IS 516-1959. Ultra sonic pulse velocity Non-destructive test was also conducted as per IS: 13311- 1992 (Part-1) to determine quality after exposure. One thermal cycle constitute heating the specimens in a muffle furnace from room temperature to maximum temperature in about 2 hours, maintaining the maximum temperature for another 6 hours and then letting it cool down to the room temperature in another 16 hours.

IV. TEST RESULTS

Table 1: Residual Compressive Strength (MPa) of Controlled Concrete and Bacterial Concrete of different grades at different temperatures and exposure times

Type of Mix	Grade of Concrete	Room Temperature	Temperature(200ºC)			Temperature(400ºC)			Temperature(600ºC)		
			Exposure Time			Exposure Time			Exposure Time		
			2hrs	4hrs	6hrs	2hrs	4hrs	6hrs	2hrs	4hrs	6hrs
Controlled	M20	29.11	28.01	27.10	26.25	27.45	26.05	25.11	24.16	22.40	17.51
	M40	52.35	50.65	48.65	47.11	49.15	47.18	46.35	40.24	36.25	34.62
	M60	72.89	68.88	67.24	66.18	67.93	66.24	64.98	44.33	41.33	40.02
	M80	92.95	90.53	88.69	87.65	89.19	87.33	86.11	56.91	53.11	46.85
Bacterial	M20	33.52	32.56	31.97	31.25	31.75	30.66	30.07	30.05	25.19	23.84
	M40	60.58	59.21	58.99	58.62	58.11	57.98	57.31	46.01	43.82	38.14
	M60	93.56	91.11	91.03	90.58	92.06	92.40	91.26	83.57	81.03	79.65
	M80	117.9	116.4	115.96	115.70	115.19	114.88	114.60	99.08	97.10	90.77

Table 2: Percentage of loss in compressive strength (%) of Controlled Concrete and Bacterial Concrete of different grades at different temperatures and exposure times

Type of Mix	Grade of Concrete	Room Temperature	Temperature(200ºC)			Temperature(400ºC)			Temperature(600ºC)		
			Exposure Time			Exposure Time			Exposure Time		
			2hrs	4hrs	6hrs	2hrs	4hrs	6hrs	2hrs	4hrs	6hrs
Controlled	M20	-	3.78	6.90	9.82	5.70	10.51	13.74	17.00	23.05	39.85
	M40	-	3.25	7.07	10.01	6.11	9.88	11.46	23.13	30.75	33.87
	M60	-	5.50	7.75	9.21	6.80	9.12	10.85	39.18	43.30	45.10
	M80	-	2.60	4.58	5.70	4.05	6.05	7.36	38.77	42.86	49.60
Bacterial	M20	-	2.86	4.62	6.77	5.28	8.53	10.29	10.35	24.85	28.88
	M40	-	2.26	2.62	3.24	4.08	4.29	5.40	24.05	27.67	37.04
	M60	-	2.62	2.70	3.19	1.60	1.24	2.46	10.68	13.39	14.87
	M80	-	1.27	1.65	1.87	2.30	2.56	2.80	15.96	17.64	23.01

Table 3: Ultrasonic Pulse Velocity (km/sec) of Controlled Concrete and Bacterial Concrete of different grades at different temperatures and exposure times

Type of Mix	Grade of Concrete	Room Temperature	Temperature(200ºC)			Temperature(400ºC)			Temperature(600ºC)		
			Exposure Time			Exposure Time			Exposure Time		
			2hrs	4hrs	6hrs	2hrs	4hrs	6hrs	2hrs	4hrs	6hrs
Controlled	M20	4.26	4.15	3.95	3.91	3.56	3.45	3.20	3.44	3.18	2.81
	M40	4.49	4.33	4.18	3.99	3.82	3.66	3.58	3.65	3.35	2.99
	M60	4.89	4.69	4.48	3.95	4.55	4.28	4.11	3.76	3.40	3.09
	M80	5.13	4.52	4.45	4.32	4.45	4.28	4.19	3.90	3.54	3.17
Bacterial	M20	4.77	4.67	4.48	4.36	4.61	4.38	4.08	4.33	4.18	4.09
	M40	4.93	4.88	4.67	4.22	4.65	4.21	4.11	4.43	4.22	4.23
	M60	5.22	5.11	5.01	4.90	5.02	4.86	4.78	4.44	4.39	4.25
	M80	5.94	5.89	5.80	5.73	5.81	5.68	5.27	4.57	4.50	4.28

Table 4: Concrete quality and pulse velocity classification according to IS: 13311 (Part 1) –1992

Ultrasonic Pulse Velocity (km/second)	Concrete Quality
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Table 5: Weight (kg) of Controlled Concrete and Bacterial Concrete of different grades at different temperatures and exposure times

Type of Mix	Grade of Concrete	Room Temperature	Temperature(200ºC)			Temperature(400ºC)			Temperature(600ºC)		
			Exposure Time			Exposure Time			Exposure Time		
			2hrs	4hrs	6hrs	2hrs	4hrs	6hrs	2hrs	4hrs	6hrs
Controlled	M20	2.49	2.47	2.44	2.41	2.33	2.30	2.23	2.30	2.27	2.19
	M40	2.48	2.45	2.43	2.41	2.42	2.34	2.31	2.35	2.33	2.20
	M60	2.53	2.50	2.48	2.47	2.47	2.41	2.33	2.45	2.41	2.21
	M80	2.49	2.47	2.44	2.42	2.42	2.36	2.30	2.40	2.35	2.18
Bacterial	M20	2.53	2.51	2.47	2.43	2.41	2.37	2.30	2.38	2.33	2.19
	M40	2.58	2.56	2.49	2.45	2.42	2.39	2.37	2.36	2.33	2.17
	M60	2.51	2.50	2.46	2.46	2.43	2.39	2.33	2.40	2.33	2.17
	M80	2.54	2.52	2.49	2.50	2.43	2.38	2.33	2.43	2.31	2.21

Table 6: Percentage of weight loss of Controlled Concrete and Bacterial Concrete of different grades at different temperatures and exposure times

Type of Mix	Grade of Concrete	Room Temperature	Temperature(200ºC)			Temperature(400ºC)			Temperature(600ºC)		
			Exposure Time			Exposure Time			Exposure Time		
			2hrs	4hrs	6hrs	2hrs	4hrs	6hrs	2hrs	4hrs	6hrs
Controlled	M20	-	0.8	2.0	3.2	6.4	7.6	10.4	7.6	8.8	12.0
	M40	-	1.2	2.0	2.8	2.4	5.6	6.9	5.2	6.0	11.3
	M60	-	1.2	2.0	2.4	2.4	4.7	7.9	3.2	4.7	12.6
	M80	-	0.8	2.0	2.8	2.8	5.2	7.6	3.6	5.6	12.4
Bacterial	M20	-	0.8	2.4	4.0	4.7	6.3	9.1	5.9	7.9	13.4
	M40	-	0.8	3.5	5.0	6.2	7.4	8.1	8.5	9.7	15.9
	M60	-	0.4	2.0	2.0	3.2	4.8	7.2	4.4	7.2	13.5
	M80	-	0.8	2.0	1.6	4.3	6.3	8.3	4.3	9.1	13.0

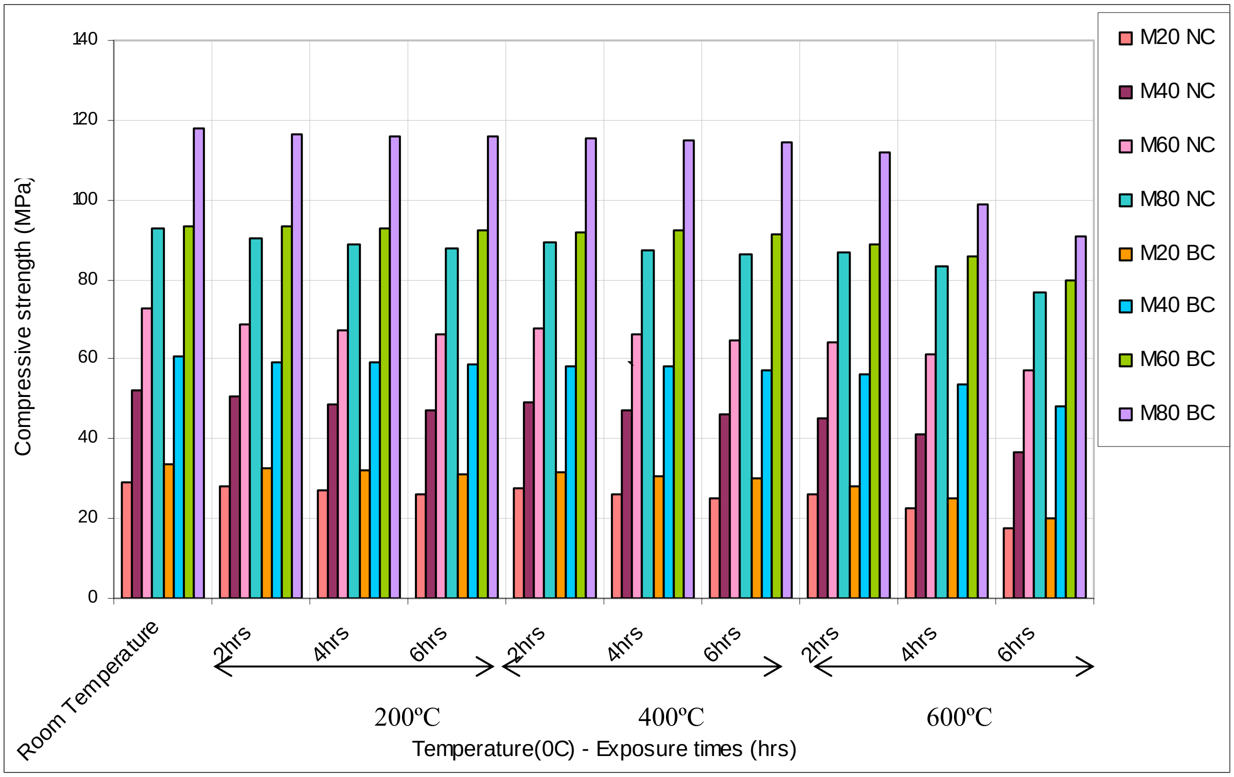

Fig 1: Graph showing variation of compressive strength at various temperatures and exposure durations for different grades of controlled and bacterial concrete

Table 7: Effect of thermal cycles on Compressive Strength of different grades of Controlled Concrete and Bacterial Concrete at 50 º C temperature

No of thermal cycles	Compressive strength at 50º C							
	Controlled Concrete				Bacterial Concrete			
	M20	M40	M60	M80	M20	M40	M60	M80
0	28.5	51.6	71.5	92.8	32.7	59.2	94.0	112.9
7	27.1	50.7	70.2	91.9	31.4	58.3	92.4	111.9
14	23.0	48.9	65.0	85.4	28.7	56.2	90.5	108.1
21	22.7	45.1	63.8	83.1	28.0	54.5	88.9	107.0
28	22.1	44.8	62.7	82.3	27.9	54.1	88.2	106.7

Table 8: Effect of various thermal cycles on Compressive Strength of Different Grades of Controlled Concrete and Bacterial Concrete at 100 º C temperature

No of thermal cycles	Compressive strength at 100º C							
	Controlled Concrete				Bacterial Concrete			
	M20	M40	M60	M80	M20	M40	M60	M80
0	28.5	51.6	71.5	92.8	32.7	59.2	94.0	112.9
7	25.1	48.7	68.3	90.3	31.0	56.9	91.2	111.0
14	21.6	43.5	64.2	77.1	28.4	52.8	85.6	104.2
21	19.8	40.1	57.1	72.0	25.9	51.2	84.0	101.9
28	17.6	38.3	55.9	71.2	24.1	50.4	82.7	100.8

Table 9: Percentage decrease of Compressive strengths of Controlled Concrete and Bacterial Concrete of Different Grades subjected to thermal cycles at 50ºC temperature

No of thermal cycles	Percentage Decrease in Compressive strength at 50ºC							
	Controlled Concrete				Bacterial Concrete			
	M20	M40	M60	M80	M20	M40	M60	M80
0	-	-	-	-	-	-	-	-
7	4.9	1.7	1.8	1.0	4.0	1.7	1.5	1.0
14	19.3	5.2	9.1	8.0	12.2	5.1	3.7	4.3
21	20.4	12.6	10.8	10.5	14.4	7.9	5.4	5.2
28	22.5	13.2	12.3	11.3	14.7	8.6	6.2	5.5

Table 10: Percentage decrease of Compressive strength of Controlled Concrete and Bacterial Concrete of Different Grades subjected to thermal cycles at 100ºC temperature

No of thermal cycles	**Percentage Decrease in Compressive strength at 100ºC**							
	Controlled Concrete				Bacterial Concrete			
	M20	M40	M60	M80	M20	M40	M60	M80
0	-	-	-	-	-	-	-	-
7	11.9	5.6	3.8	3.1	5.2	3.9	3.0	1.7
14	24.2	15.7	40.0	16.9	13.1	10.8	8.9	7.7
21	30.5	22.3	20.1	22.4	20.8	13.5	10.6	9.7
28	38.2	25.8	23.3	21.8	26.3	14.9	12.0	10.7

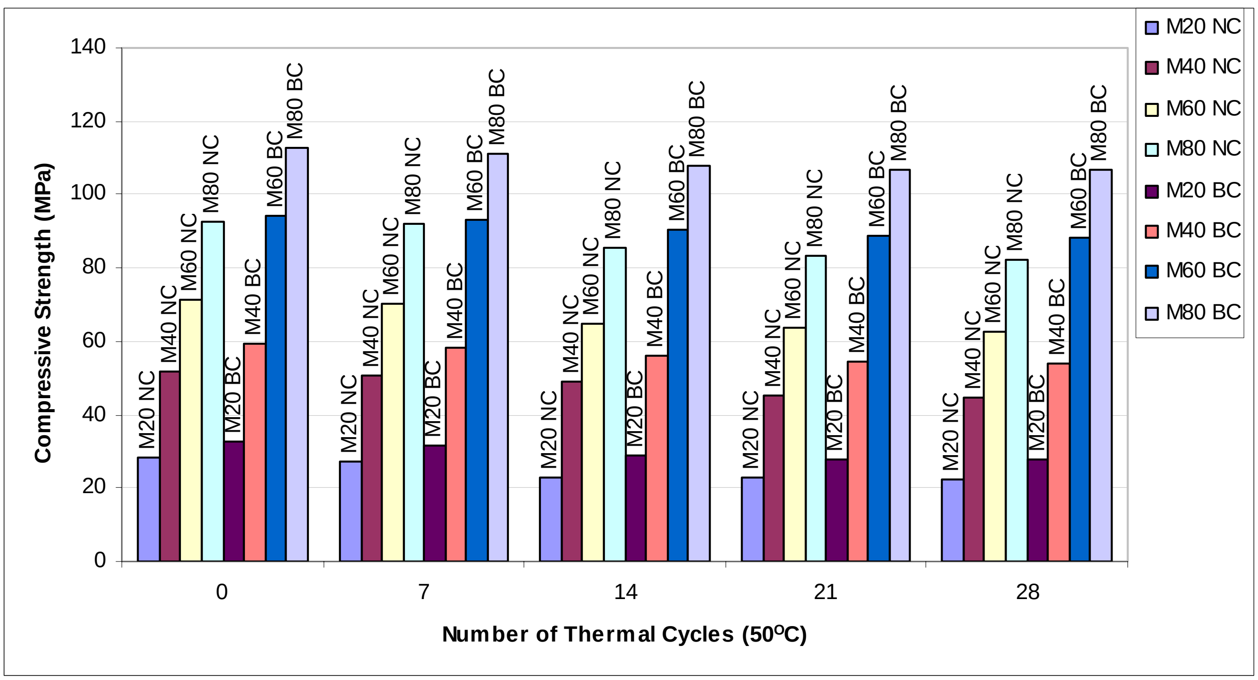

Fig 2: Graph showing Compressive strength of Controlled Concrete and Bacterial Concrete of Different Grades subjected to number of thermal cycles of 50ºC temperature

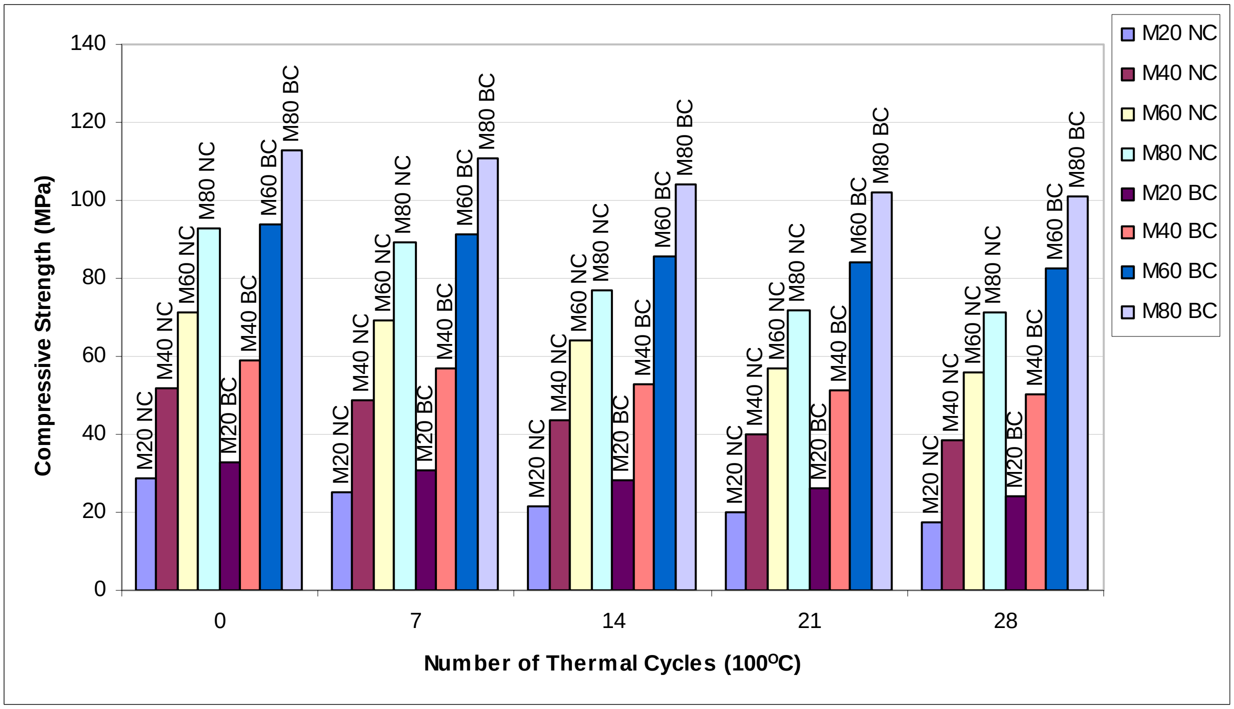

Fig 3: Graph showing Compressive strength of Controlled Concrete and Bacterial Concrete of Different Grades subjected to number of thermal cycles of 100ºC temperature

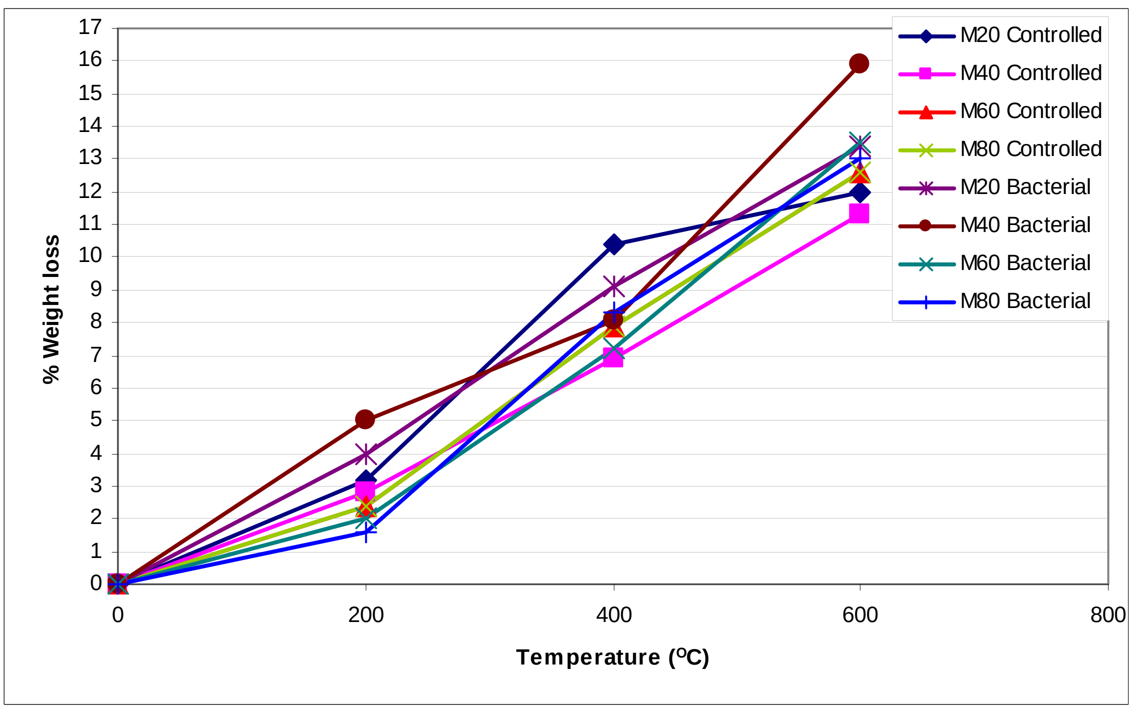

Fig4: Graph showing variation of % Weight Loss at various temperatures for different grades of controlled and bacterial concretes

Fig 5: Electric Muffle Furnace

V. DISCUSSIONS

When specimens are subjected to unstressed residual strength test, heating without any preload then cool down to room temperature, and load them to failure, there is a decrease in compressive strength of controlled and bacterial concrete mixes of different grades when exposing to elevated temperatures of 200ºC, 400ºC and 600 ºC for 2 hrs, 4hrs and 6 hrs duration as shown in Table 1.

As temperature increases from 200ºC to 600ºC with exposure durations from 2 to 6 hrs, there is loss of compressive strength of controlled concrete and bacterial concrete mixes of ordinary grade (M20), standard grade(M40) and high strength grade (M60 and M80). Bacterial concrete specimens exhibited much better resistance to temperature than Controlled Concrete when exposed till 400ºC but over 400ºC bacterial concrete specimens' loss in compressive strength is drastically increased as shown in Table 2.

At elevated temperatures, M20 and M40 grades of controlled and bacterial mixes losses strength due to formation of cracks between cement paste and aggregate. The percentage decrease in compressive strength of M60 and M80 grade Controlled Concrete and Bacterial Concrete mixes is high beyond 400ºC when compared with Controlled Concrete and Bacterial Concrete mixes of ordinary grade (M20) and standard grade (M40).` The reason may be due to high brittleness and dense micro structure of high grade concrete.

The occurrence of gradual spalling in high-strength (M80) grade concrete specimens at temperature 600ºC is observed. The high-strength concrete loses a significant amount of its compressive strength above 400ºC and the strength loss is about 45-50% at 600 ◦C. The loss of strength, for M60 and M80 grade Bacterial Concrete mixes, at temperatures of 200 ºC and 400ºC is marginal. The average residual compressive strength of concrete produced with silica fume decreased sharply at high temperature. Over 400 ºC, as the temperature further increases, the thermal strain of the cement paste changes to negative (shrinking) due to chemical changes, and results in scaling of surface in M60 and M80 of controlled and bacterial mixes. Since specimen sizes are small and rate of heating is gradual, the effect is less but at higher heating rates and larger specimens they are more prone to explosive spalling than gradual spalling.

The reduction in pulse velocity is observed as temperature increases from 200ºC to 600 ºC with exposure durations from 2 to 6 hrs as shown in Table 3. This may be due to deterioration of concrete at elevated temperatures. The increase in pulse velocity is observed in the case of bacterial concrete specimens over controlled concrete specimens which indicate that bacterial concrete more resistance to higher temperatures. The effect of temperatures is related to either the weaker formation of cement paste hydrates or the differential thermal expansion of matrix components.

The microstructures of the specimens that were used in the study deteriorated due to increasing temperature, resulting in decreasing UPV values, especially at 600^{o}C. This decrease in UPV values observed in concrete samples exposed to high temperatures has been explained as follows:

Degeneration of the C-S-H gel at temperatures above 600°C increases the amount of air voids in the specimens and decreased the transmission speed of sound waves through the specimens. This decrease results from the formation of a more porous structure due to the decomposition of the C-S-H gel, which is more abundant in samples containing Silica Fume. The massive changes in the morphology of the concrete exposed to `600°C is probably due to the predominance of micro cracks, the increased porosity of the concrete due to voids, the deformation of $Ca(OH)_2$ crystals, and finally disrupted C-S-H phase boundaries. Therefore, the loss of strength observed at higher temperatures may be attributed to the loss of bound water, increased porosity, and consequently, the increased permeability. At 200ºC pore water is lost due to evaporation along with the release of chemically bound water from calcium silicate hydrate induces thermal stresses and micro-cracks begin to appear, at 400ºC gel-like hydration products are decomposed and at 600ºC Ca(OH)2 is de-hydroxylated resulting in the shrinkage of concrete.

High strength concrete (M60 and M80) appears to be more prone to spalling in a fire than normal strength concrete (M20 and M40). For M60 and M80 grade concrete the spalling started when temperature reached to 600ºC. This is due to two effects: a physical effect due to reduced Van der Waals' forces as water expands upon heating, and a chemical effect whereby detrimental transformations can take place under hydrothermal conditions. The internal vapour pressure may be the leading reason of concrete spalling. This is mainly attributed to the dense, low permeability structure of M60 and M80 grade concretes which does not readily allow moisture to escape from the heated concrete, thus resulting in high pore pressures and the development of micro cracks. The potential spalling increased in M80 than M60 because of lower w/c and high silica fume content. The addition of silica fume gives highly densified pore structure for concrete, which can result in spalling owing to the build-up of pore pressure by steam, and thus the rates of strength loss are significantly higher in M60 and M80 concretes than M20 and M40 grade concretes when exposed to high temperature. So it is proved that the use of 6% to 10% silica fume in concrete creates high risk of spalling.

The decrease in compressive strength of controlled concrete and bacterial concrete mixes of ordinary grade (M20), standard grade(M40) and high strength grade (M60 and M80) when subjected to 7, 14, 21, 28 thermal cycles at temperature of 50 º C and 100 º C is observed as shown in Table 7 -10.

There is gain in strength after cooling in all grades of controlled and bacterial concretes may be due to the absorption of moisture from the surrounding medium which leads to extra hydration. The moisture content has a significant bearing on the strength of concrete. At elevated temperatures, the dehydration of the cement paste results in its gradual disintegration. Since the paste tends to shrink and aggregate expands at high temperature, the bond between the aggregate and the paste is weakened, thus reducing the strength of the concrete. The type of aggregates and mixture proportions influence the degradation in the strength of heated concrete.

Weight reduction takes place in the specimens at all temperatures of exposure due to the release of water. Because of the release of bound water from the cement paste, air voids are formed in the concrete. The structural integrity of the specimens deteriorates as confirmed by the increase in weight reduction with increased temperature. The reduction in weight confirms the loss of mass by the concrete material and the increase in the proportion of air voids

Finally, a sharp reduction in relative strength occurred beyond that point due to the loss of crystal water, leading to the reduction of the $Ca(OH)_2$ content and changing the morphology and formation of micro cracks. The decomposition of calcium hydroxide does not generally occur below 350°C. The conversion of calcium hydroxide into lime and water vapor during heating is not critical in terms of loss of strength. But this conversion may lead to serious damage due to the expansion of lime during the cooling period.

As temperature increases color of concrete changes, at 300ºC the concrete colour doesn't change noticeably. But when temperatures are increased up to 400ºC – 600ºC concrete colour slightly changes to dust colour or brownish/ yellowish grey. Certain colours correspond with specific temperature ranges, this is an important indicator of the maximum temperature, and the structure is exposed to.

The behavior of M60 and M80 grades of controlled and bacterial mixes under elevated temperatures differs from that of M20 and M40 of controlled and bacterial mixes. Rate of heating, size of specimen and moisture content are responsible for high damage of concrete at elevated temperatures. This phenomenon of scaling of surface is not observed in M20 and M40 grades of controlled and bacterial mixes may be due to more porous nature of them than M60 and M80 of controlled and bacterial mixes.

VI. CONCLUSIONS

(1) The percentage decrease of compressive strength is higher for higher exposure temperature and time.

(2) A gradual loss in weight was found with increase in temperature from 200ºCto 600ºC for duration of 2, 4 and 6 hours in controlled and bacterial concrete mixes. The effect is more pronounced in the case of

Controlled Concrete of ordinary grade (M20), standard grade (M40) than high strength grade (M60 and M80).

(3) Up to 400ºC the reduction in compressive strength of Bacterial Concrete mixes of all the grades is less but at 600ºC the loss in strength is observed more due to spalling in M60 and M80.

(4) The drastic reduction in ultra sonic pulse velocity values between 400 ºC and 600 ºC indicates that the physical state of the M60 and M80 grade bacterial concrete samples deteriorated rapidly beyond 400ºC when compared to M20 and M40 grades.

(5) The bacterial concrete specimens of all grades retains their original strength up to a temperature of 400°C for all durations of exposure but the rate of decrease in compressive strength is drastic in the range of 400°C to 600°C.

(6) A critical combination of porosity and degree of micro cracking may not be the result of exposure to a certain temperature alone but may also be dependent on the heating rate and exposure duration so it is considered equally possible that under high/low heating rate and long/short temperature duration that critical combination may happen at temperatures below or above 400°C.

(7) High strength concrete with dense structure is less resistant to high temperature than ordinary strength concrete. Due to thermal inertia of concrete, temperature may continue to rise inside structural elements for some time after the end of fire, which may further decay the residual strength of concrete.

VII. REFERENCES

[1]. Castillo C, Durrani A J. "Effect of transient high temperature on high-strength concrete" [J]. ACI Material Journal, 1990, 87(1): 47−53

[2]. Chakrabarti, S.C., K.N.Sharma and Abha Mittal: "Residual strength in Concrete after exposure to elevated temperature" Indian Concrete Journal, December, 1994 pp 713 – 717.

[3]. Diederichs, U., Jumppanen, U.M. and Penttala, V. (1989). "Behavior of high strength concrete at high Temperatures." Report No. 92, pp. 76, Helsinki University of Technology, Helsinki, Finland.

[4]. Fukujiro, Furumura, Takeo, Ave and Yasuji, Shinohara (1993). "Mechanical Properties of High Strength Concrete at High Temperatures." Report of Research Laboratory of Engineering Materials , Tokyo Institute of Technology, Japan.

[5]. Felicetti, R., and Gambarova, P.G., "Effects of High Temperature on the Residual Compressive Strength of High-Strength Siliceous Concretes", ACI Materials Journal, Vol. 95, No. 4, July-Aug. 1998, pp. 395-406.

[6]. Hirashima T, Tokoyoda M, Toyoda K, Yamashita H, Shinohara K, Uesugi H. "Experimental study on mechanical properties of concrete at elevated temperature [C]// Summaries of Technical Papers of Annual Meeting AIJ. Tokai, Japan, 2003: 135−137.

[7]. Khoury, G.A. (1992). "Compressive Strength of Concrete at High Temperatures." Magazine of Concrete Research, 291-306.

[8]. Potha Raju M, Srinivasa Rao K, Raju P S N. Compressive strength of heated high-strength concrete [J]. Magazine of Concrete Research, 2007, 59(2): 79−85.

[9]. Phan LT, Carino NJ., 2003, Code Provisions for High Strength Concrete Strength Temperature

[10]. Relationship at Elevated Temperatures, *Material Structure,* 36(256): 91– 98

[11]. Sancak YE, Sari D, Simsek O. Effects of elevated temperature on compressive strength and weight loss of the light-weight concrete with silica fume and superplasticizer, ACI Materials Journal, No. 4, (2008) 395-406.

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