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Mechanical Properties for High Performance Concrete Exposed to High Temperature

Saeed Ahmed Al.Sheikh
Lecturer, Civil Department, Faculty of Engineering, Modern University, Cairo, Egypt
saeedalsheikh56@yahoo.com

ABSTRACT

This paper deals with the development of engineering database on the changes in the mechanical properties of high performance concretes mixtures when exposed to high temperature up to 1000°C. The results of an experimental investigation in to the effects of high temperature on the residual compressive and tensile strengths for high performance concretes made with ordinary Portland cement are presented. Concrete specimens were heated in an electric furnace to varying temperatures up to 1000°C and the change in compressive and tensile strength, weight, ultrasonic pulse velocity and rebound number were determined. The heated specimens were subjected to sudden cooling in water and to slow cooling in air. The results showed that the compressive and tensile strengths, pulse velocity and rebound number were decreased with the increase in exposed temperature. The weight loss from concrete increased non- linearly with the maximum exposed temperature. Sudden cooling caused reduction in concrete strength.

Keywords: High performance concrete, cement type, compressive strength, tensile strength, pulse velocity, rebound number, high temperature, weight loss, cooling rate.

1. Introduction

Acceptance of high performance concrete by the construction industry contributed to the economical construction of high-rise buildings and long spans bridges. The use of high water reducing admixtures (HRWRA) and silica fume has resulted in producing workable high strength concrete, having the compressive strength over 100 MPa. Most specifications for high performance concrete require the desired strength at the ages of 56 or 90 days, instead of the conventional age of 28 days. This allows the concrete producers to utilize one or more of the supplementary cementing materials, such as fly ash, ground granulated blast furnace slag and silica fume in the high performance concrete mixtures. The risk of exposing high performance concrete structures to high temperatures increases with the increase in usage of high performance concrete by the construction industry. Therefore, it becomes necessary that the properties of high performance concrete subjected to high temperatures be clearly understood. The previous investigations reported that up to 300°C, concrete with the initial compressive strength of 52 MPa, retained more than 80% of its initial strength but after 300°C, the residual strength fell markedly. The porosity studies indicated an increase in the total pore distribution as well as in the pore dimensions. The concrete retained 46% of its initial strength when it was exposed to 600°C. Aim of this study was to evaluate the effects of high temperatures on the properties of high performance concrete, having the compressive strength of about 80 MPa. The parameters studied were maximum temperature up to 1000°C, ordinary Portland cement with 35% fly ash were used in the concrete mixtures. The following properties of concrete were determined before and after heating: water content, compressive strength, indirect tensile strength, ultrasonic pulse velocity and rebound number.

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2. Experimental Investigations

2.1 Material Preparation and Characterization

2.1.1 Portland Cement

Ordinary Portland cement, from Helwan Factory in Cairo were used, their physical properties and chemical analysis as follows in table 1

Table 1: Properties of used Portland cement

Description	
Physical Properties	
1- Specific Gravity	3.15
2- Fineness passing 90 µm%	90 %
3- Surface area m^2/kg	2250 cm^2/ gm
Chemical Analysis	
1-Lime Calcium Oxide (CaO)	60 : 67 %
2- Silicon Dioxide (SiO_2)	17 : 25 %
3- Aluminum Oxide (Al_2O_3)	3.0 : 8.0 %
4- Calcium Sulphate ($CaSO_4$)	0.50 : 6.0 %
5- Magnesium Oxide (MgO)	0.10 : 4.0 %
6- Sulphur trioxide (SO_3)	2.75 %
7- Alkalis	0.40 : 1.25 %
Compressive Strength (Cubes)	
1- Age 7 days MPa	29.2
2- Age 28 days MPa	35.7

2.1.2 Aggregates

Crushed dolomite (specific gravity of 2.65) having the maximum aggregate size of 10 mm was used as the coarse aggregate and local natural sand as fine aggregate (specific gravity of 2.62). To keep the grading uniform for mixtures, both the fine and the coarse aggregates were separated into different size fractions that were then recombined to a specific grading.

Table 2: Physical Properties of used aggregates

Description	
Dolomite	
1-Specific Gravity	2.65
2- Absorption	0.67
Natural Sand	
1-Specific Gravity	2.62
2- Absorption	0.81

2.1.3 Fly Ash

The physical properties and chemical analysis as follows in table 3

Table 3: Properties of used fly ash

Description	
Physical properties	
1- specific Gravity	2.68
2- Fineness passing 45µm%	81.7
3- Surface area m^2/kg	306
Chemical analysis	
1- Silicon Dioxide (SiO_2)	40.9
2- Aluminum Oxide (Al_2O_3)	18.6
3- Ferrio Oxide (Fe_2O_3)	28.9
4- Calcium Oxide (CaO)	1.87
5- Magnesium Oxide (MgO)	1.01
6- Sodium Oxide (Na_2O)	0.56
7- Potassium Oxide (K_2O)	1.44
8- Phosphorous Oxide (P_2O_5)	< 0.9
9- Titanium Oxide (TiO_2)	0.85
10- Sulphur trioxide (SO_3)	0.87
Pozzolance Activity with reference Portland Cement	
1- Water requirement %	91
2- Activity Index at 7 days %	89.7
3- Activity Index at 28 days %	94.1

2.1.3 Super Plasticizer

A commercially available type-high range water reducing super-plasticizer was used. This type is dark brown in color and has 40% solids content in an aqueous solution. It is consisting of a salt of naphthalene sulphonate formaldehyde condensate.

2.2 Heating Equipment

A ventilated oven was used to heat the concrete specimens to a temperature up to 100°C. For the temperature of 200°C and above, an electrically heated furnace designed for a maximum temperature of 1200°C was used. The furnace was heated by means of exposed heating elements laid on the refractory walls of the inside chamber, which was approximately 400 × 400 × 800 mm in dimension. The test specimens were stacked with sufficient space between two adjacent specimens to obtain a uniform heating in each specimen. Since the chamber had a limited volume the concrete specimens were heated in batches.

2.3 Concrete Mixtures

The graded coarse and fine aggregates were weighted in room dry condition, the coarse aggregate was then immersed in water for 24 hours, the excess water was decanted and the water retained by the aggregates was determined by the mass difference. A predetermined amount of water was added to the fine aggregate that was then allowed to stand for 24 hours. The water to cementitious materials ratio and the quantities of cement, water and fly ash were kept constant 35%, also the quantity of ordinary Portland cement was kept constant 900 kg/m^3. Fly ash was kept also constant 300 kg / m^3 .The target slump was 150 mm but due to the variation in materials properties, the superplasticizer dosage was adjusted resulting in slump of 100 to 200 mm. the mixture proportions of the concretes as follows in table 4

Table 4: Mix. Design

Mix No	$\frac{W}{C+F}$	Quantities kg / m^3					
		Cement	Fly Ash	Water	C.A	F.A	S.P
M	35%	600	300	315	1280 gravel	640 sand	7.0

$\frac{W}{C+F}$ = Water to (cement + fly ash ratio)

- C.A: coarse aggregate
- F.A: fine aggregate
- S.P : superplasticizer
- G : gravel
- D : dolomite
- B : basalt

The required specimens were included 150 × 300 mm cylinders, 150 × 150 ×150 mm cubes. The specimens were cast in two layers; an internal vibrator was used for compaction. After casting, all the molded specimens were covered with plastic sheets and were left in the casting room for 24 hours. Afterwards, they were remolded and transferred to the moist curing room at 100% relative humidity until required for testing and stored in water at 20°C till the age of 28 days.

2.4 Testing of Specimens

At the age of 28 days, the concrete specimens were removed from water and dried in air for 24hrs at the laboratory conditions with a mean relative humidity and temperature of 65% and 25°C respectively. Then the specimens were placed in a ventilated oven at 60°C for 24hrs before subjecting them to high temperatures in the electric furnace. This step was found to be necessary to avoid the explosion of the concrete specimens in the furnace due to the formation of steam. The rate of heating was maintained at 200°C/hr. Once the required maximum furnace temperature was reached, the temperature was maintained until the specimens were removed. For all concrete specimens, the total duration in the furnace was 8 hrs. The maximum furnace temperatures were 200, 400, 600, 800 and 1000°C.

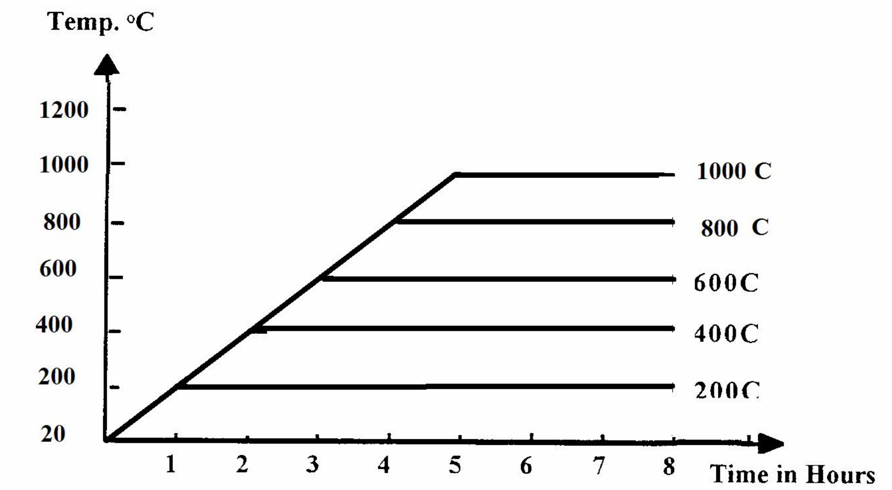

Figure 1: Furnace Temperature Histories

Two cooling methods were employed for the heated concrete specimens. At the end of the sustained periods at the corresponding maximum temperatures, the specimens were removed from the furnace. Some of the heated specimens were quenched in water at 20°C in a very large water tank and kept in water for 48hrs prior to strength testing. The remaining specimens were cooled in air at the laboratory conditions for 24hrs, followed by placing in water for 24hrs prior to strength testing. Both water quenched and air cooled concrete specimens were tested in either compression or in direct tension. The specimens were weighted at different stages of heating and cooling. Both the ultrasonic pulse velocity and rebound number were determined using the cube specimens. All specimens for the compression testing were capped with sulphur before testing.

2.5 Tests Results and Discussion

2.5.1 Weights Loss for High Performance Concrete on Heating

The weight loss from high performance concrete increase with the increase in the maximum exposed temperatures due to accelerated drying. Up to the temperature of 100°C, concrete specimens lost between 1.5 and 1.7 % of either initial weight due to the evaporation of free water. When the temperature was increased to 200°C, the weight loss was 4.00 %, and when the temperature was increased to 400°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 800°C the weight loss was 9.75 % while at 1000°C the weight loss arrived to 11.8 %. The relationship between the weight loss and maximum temperature is non- linear.

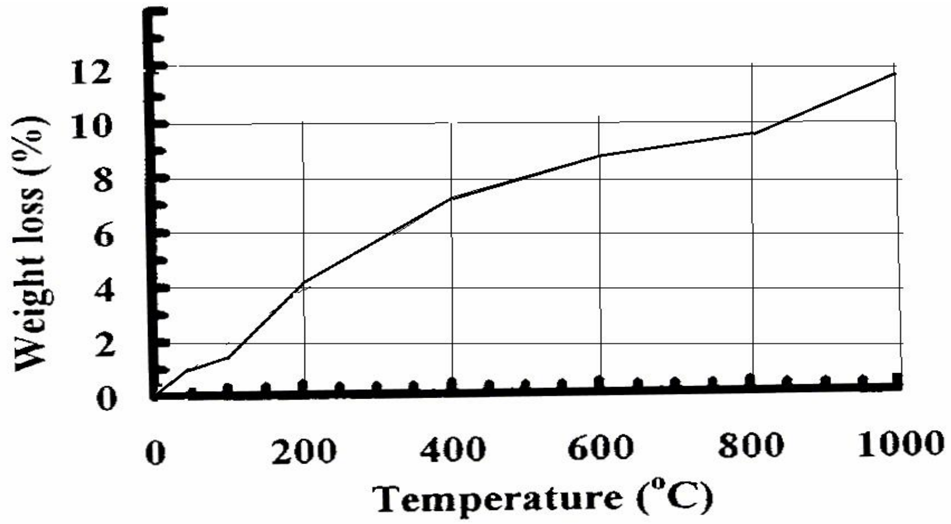

Figure 2: Effect of temperature on weight loss for high strength concrete

2.5.2 Water Absorption of High Performance Concrete on Heating

Weights of the concrete specimens were taken for a period up to 48hrs after they placed in water. The specimens that were air- cooled for 24hrs were placed in water for 24hrs; the water-quenched specimens were kept in water for a period of 48hrs. The results showed that nearly all the weight losses on heating were recovered by the concrete specimens when they were placed in water. Some specimens gained more weight than they lost on heating. The water absorptions for the concrete specimens on water quenching were more than that for the corresponding air- cooled concrete specimens. Sudden cooling of heated concrete may have created additional micro- cracks leading to increased water absorption. For heated concrete specimens and subjected to water quenching, the water content of concrete after saturation was between 0.93 and 1.02 of the water content prior to drying. The corresponding value for air cooled concrete was between 0.79 and 0.88. The specimens heated to 1000^{o}C showed the largest value for water absorption in relation to the water loss on heating. These differences in water content indicate that the pore structure and hydration products are affected by the factors such as maximum temperature, cement type and method of cooling.

2.5.3 Ultrasonic Pulse Velocity of High Performance Concrete on Heating

The pulse velocity was taken in 100 mm air- cooled cube specimens. The results showed that pulse velocity decreased substantially with the increase of exposed temperature. The pulse velocity decreased by 20% at 400^{o}C, 37% at 600^{o}C, 50% at 800^{o}C and 76% at 1000^{o}C. The high performance concrete has a low water to cement ratio, the pore volume is lower than that for the medium strength concrete. Removal of water from the pores in the concrete system produced a smaller reduction in pulse velocity for the high performance concrete than the corresponding reductions for medium strength concrete. In addition, the amount of aggregate – cement paste cracks due to high temperature may be lower in high performance concrete than that for the medium strength concretes due to the combined effects of lower aggregate to cement ratio, smaller maximum aggregate size and better cement paste matrix strength.

Table 5: Effects of Heating on Pulse Velocity and Cylinder Strength

Temperature ^{o}C	Pulse Velocity	V_t /V_o	F_t/F_o
20	5.1		
100	4.9	0.97	0.98
200	4.5	0.89	0.87
400	4.1	0.80	0.60
600	3.72	0.73	0.56
800	2.55	0.50	0.40
1000	1.22	0.24	0.25

V_o & V_t are the pulse velocity of the control (unheated) and the heated specimens to ^{o}C
F_o & F_t are the cylinder strength for the control (unheated) and the heated specimens to ^{o}C

2.5.4 Rebound Number for High Performance Concrete on Heating

The results obtained with the concrete specimens subjected to high temperatures followed by air-cooling, rebound number was reduced with the increase of concrete temperature. Between 20 and 400^{o}C, the rebound number was reduced from 43 to 38 and between 20 and 1000^{o}C, the rebound number was reduced from 43 to 25. In relative terms, both concretes lost 21% in their rebound number values compared to those corresponding values, prior to heating. The reduction in rebound number is lower than the relative loss of the pulse velocity. The results indicate that high temperatures have a lesser effect on the hardness of the concrete surface than that on the internal changes within the concrete specimens.

Table 6: Rebound Number according to Temperature Degrees

Temperature °C	Rebound No.	R_t /R_o
20	43	
100	42	0.98
200	40	0.93
400	38	0.88
600	34	0.79
800	30	0.70
1000	25	0.34

R_o & R_t are the rebound number for the control (unheated) and the heated specimens to °C

2.5.5 Residual Strength in Compressive after Heating

The residual compressive strength decreased with the increase in the maximum temperature and was affected by the method of cooling and the cement type used. Increasing temperatures actives a series of reaction in the hardened cement paste, complete desiccation of the pore system followed by the decomposition of hydration products and the destruction of the gel structure in hydrated cement paste.

Table 7: Effect of Temperature Changes on Compressive Strength

Temperature °C	Compressive Strength		Compressive Strength reduction%	
			Water Cooling	Air Cooling
20	780			
100	717	741	0.92	0.95
200	655	686	0.84	0.88
400	608	624	0.78	0.80
600	523	553	0.67	0.71
800	335	413	0.43	0.53
1000	241	273	0.31	0.35

2.5.6 Residual Strength in Tensile after Heating

The residual tensile strength decreased with the increase in the maximum temperature and was affected by the method of cooling and the cement type used. Increasing temperatures actives a series of reaction in the hardened cement paste, complete desiccation of the pore system followed by the decomposition of hydration products and the destruction of the gel structure in hydrated cement paste.

Table 8: Effects of Effect of Temperature Changes on Tensile Strength

Temperature °C	Tensile Strength		Tensile Strength reduction%	
			Water Cooling	Air Cooling
20	68			
100	63	65	0.92	0.95
200	54	62	0.79	0.91
400	39	44	0.58	0.65
600	33	37	0. 48	0.54
800	29	35	0.43	0.52
1000	18	24	0.27	0.35

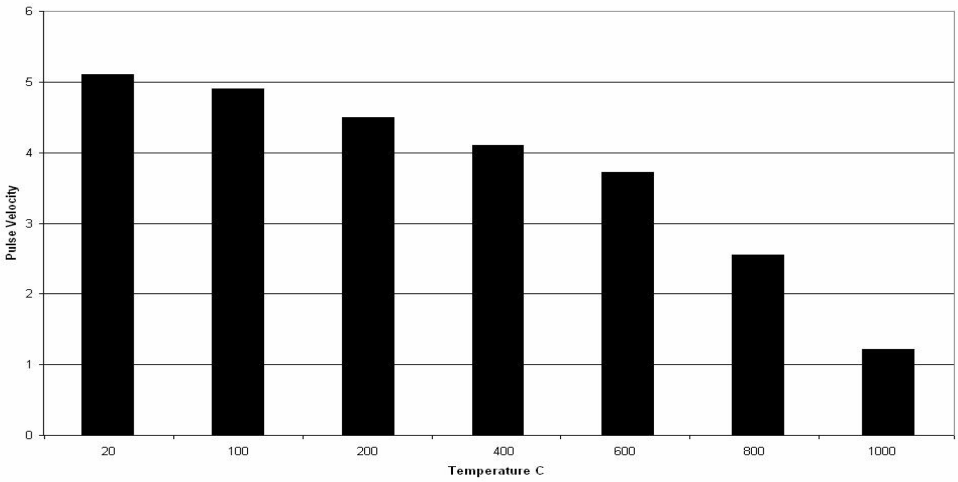

Figure 3: Relationship between temperatures and Pulse Velocity

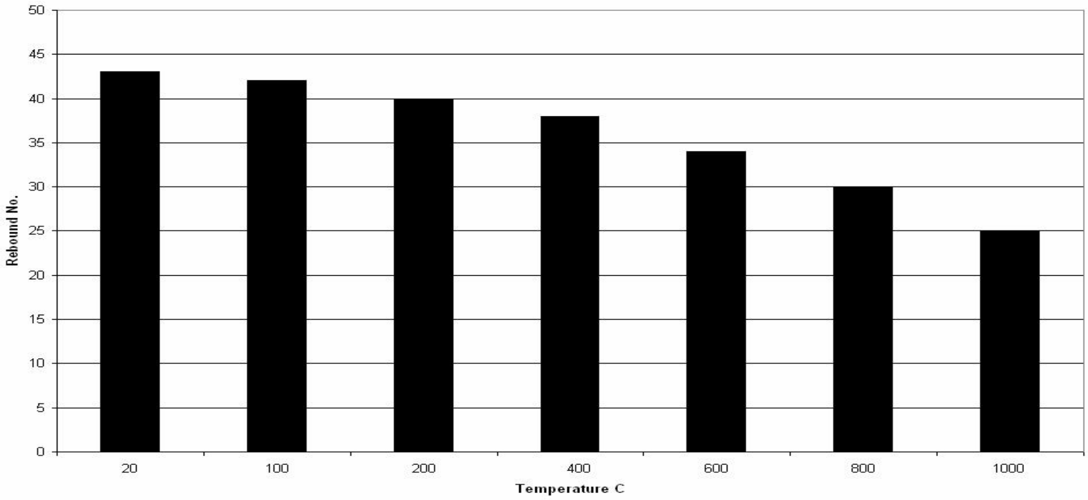

Figure 4: Relationship between temperatures and Rebound Number

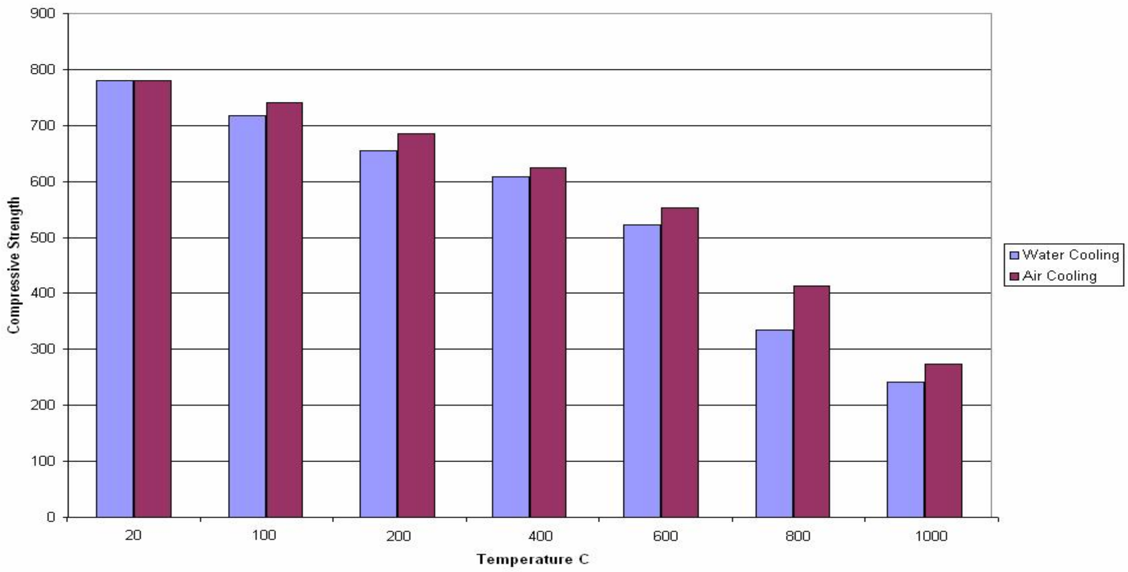

Figure 5: Relationship between temperatures and Compressive Strength

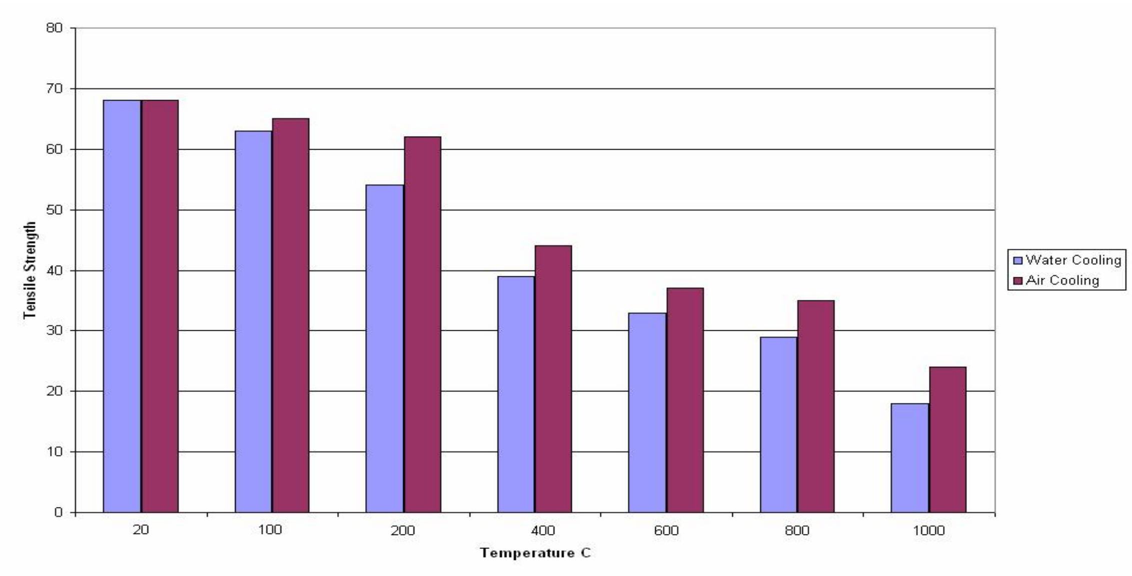

Figure 6: Relationship between temperatures and Tensile Strength

3. Conclusion

1. The experimental investigation confirms that:
2. Loss of weight increased with temperature at a decreasing rate for high performance concrete at 1000oC , weight loss was about 12%
3. High performance concrete showed deterioration in its properties when exposed to temperatures above 200oC
4. High performance concrete showed reduction in strengths in compression and tension when exposed to high temperatures. This reduction was about 69% and 73% in compressive and tensile strengths respectively.
5. Sudden cooling concrete caused additional strength loss for high performance concrete
6. Ultrasonic pulse velocity and rebound number with the increase in temperature and were not affected by the type of cement used.

4. References

1. Burnett,I.D (Aug.1990), "High Performance Concrete " National ready mixed association of Australasia, Melbourne

2. Zolders, N.G (Aug 1996) "Effect of high temperature on the compressive strength" Magazine of Concrete Research, 8(3), pp 85-94

3. Davix, H.S (oct.1997), "Effects of high temperature exposure on concrete" Materilas Research& Standards, , pp 452- 459

4. Giaccio and G.M (1998), "Concrete Incorporating High Volumes of ASTM Class F Fly Ash" ASTM Cement, Concrete and Aggregates, 10(12), pp 88-95

5. Langley, W.S., Carette, G.G.and Malhotra, V.M (1999), “Structural Concrete Incorporating High Volume of ASTM Class F Fly Ash”, ACI Materials Journal , 86(5), pp 507-514

6. Sivasundaram, V.Carette and G.G (1999), “Properties of Concrete Incorporating Low Quantity of Cement anD High Volumes of Low Calcium Fly Ash” ACI Special Publication SP-114, 1, pp 45-71

7. Sri Ravindrarajah, R (Jan/Feb 1999), "Strength evaluation of High strength concrete by ultrasonic pulse velocity method" Non destructive Testing , 29(1), pp 6-9

8. J. Randall Lawson, Long T. Phan, Frank Davis (2000), Mechanical Properties of High Performance Concrete After Exposure to Elevated Temperatures, NISTIR 6475, United States Department of Commerce Technology Administration National Institute of Standards and Technology, 1, pp 2-12.