TENSILE BEHAVIOUR OF HIGH STRENGTH (M 90) AND NORMAL STRENGTH CONCRETE (M 30) SUBJECTED TO THERMAL CYCLES

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ABSTRACT : *The present study investigated the effect of thermal cycles on tensile strength of high strength and normal strength concrete. Tests were conducted on 150 mm diameter and 300 mm long cylindrical specimens and 100 mm X 100 mm X 500 mm beam specimens. This paper presents results on the study of residual tensile strength and weight loss of high strength concrete compared to normal strength concrete of age 28 days subjected to thermal cycles namely 1, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 apart from control concrete which is not subjected to thermal cycles. Specimens were exposed to temperatures from 100 to 400°C for 8 hours duration and subsequent air cooled for the remaining period of a day. Therefore, one thermal cycle means of 8 hours heating and 16 hours cooling. After heating, the specimens were tested for both splitting and flexural tensile strength. As there is insufficient fire test data for high strength concrete (HSC) subjected to thermal cycles, it is proposed to study the tensile properties of HSC compared to normal strength concrete (NSC).*

KEYWORDS: Cementitious material, tensile properties, thermal effect

1. Introduction

High temperature is one of the important factors for deterioration of the concrete linings of the industrial chimneys and nuclear reactors. The mechanical properties of concrete such as strength, elastic modulus and deformation decrease upon cyclic heating which results in deterioration of concrete. At high temperature, ordinary concrete loses its strength due to the formation of macro and micro cracks at the interface of cement paste and aggregate. In most of the cases, concrete acts as heat resisting material due to its low thermal conductivity when exposed to high temperature. But when the concrete is subjected to high temperature for long duration, the deterioration of concrete will be high and the strength decreases gradually on heating. As the use of high strength concrete is common, the risk of exposing to high temperatures is increasing. The behavior of high strength concrete under elevated temperatures differs from that of normal strength concrete due to its dense structure. However, repeated heating and cooling cycles of concrete reduces the peak strength and loses the bond between the cement and aggregate. These thermal changes lead to cracking and spalling of concrete. Hence it is necessary to study the tensile behaviour and weight loss of both high strength and normal strength concrete subjected to thermal cycles.

Many researchers[1-14] have observed that composition of concrete showed marked deterioration of mechanical properties when subjected to thermal cycles but the extent of deterioration was governed by the breakdown of bond between the aggregates and mortar. In addition, the loss of strength in the concrete with temperature is influenced by number of factors. The method of testing, that is, the rate of heating, the duration of heating, size and shape of the test specimen, cooling regimes, number of thermal cycles and the loaded condition (loaded or unloaded during testing) have a significant effect on the change of strength with temperature.

Concrete is weak in tension and strong in compression, due to the formation of cracks under tensile loads. The ratio of tensile strength to compressive strength for NSC is 10% while for HSC, the ratio is further reduced. Thus the tensile strength of concrete is neglected at ambient and elevated temperatures. However, it is an important property, because micro and macro cracking that occurs in the concrete is generally due to the tensile stresses. When concrete element exposed to heat up to 400°C, high internal stresses are developed in concrete which are caused by increase in pore pressure inside the element. This has lead to spalling of concrete surface.

There is an insufficient tensile strength data for high strength and normal strength concrete subjected to thermal cycles. In this paper it is restricted to study the behavior of high strength and normal strength concrete subjected to thermal cycles (namely 1, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50) exposed to temperature up to 400°C. The results obtained can be useful as guidelines for fire resistant design of the structures subjected to alternate heating and cooling cycles at elevated temperatures.

2. Experimental work

2.1 Materials used

The concrete used in this experimental work is made by mixing ordinary Portland cement with hard blue granite chips, sand, water, mineral admixture and chemical admixture. The properties of the individual materials are mentioned as follows.

2.1.1 Cement

Ordinary Portland cement of 53 grade conforming to IS 12269(1987) was adopted in this work. Its chemical and physical properties are given in Table 1

2.1.2 Fine aggregate

Locally available river sand was used. Fineness modulus and specific gravity of the sand are 2.85 and 2.66 respectively. The sand used conforms to grading Zone II of IS: 383(1970).

TABLE 1 : CHEMICAL AND PHYSICAL PROPERTIES OF CEMENT			
S. No.	**Particulars**	**Test Results**	**Requirements as per IS:4031(1988)**
	Chemical requirements		
1.	Insoluble material (% by mass)	0.68	28.96 Maximum
2.	Magnesia (% by mass)	1.16	6.00 Maximum
3.	Sulphuric anhydride (% by mass)	1.73	3.00 Maximum
4.	Loss on ignition (% by mass)	1.15	5.00 Maximum
5.	Total chlorides (% by mass)	0.006	0.10 Maximum
	Physical requirements		
1.	Fineness as weight retained on IS 90 micron sieve	5.5%	10% Maximum
2.	Standard consistency (%)	30	
3.	Setting time		
	a) Initial (minutes)	155	30 Minimum
	b) Final (minutes)	225	600 Maximum
4.	Soundness		
	a) Le-chatelier method (mm)	1.0	10.0 Maximum
	b) Autoclave method (%)	0.026	0.8 Maximum
5.	Compressive strength (MPa)		
	at 3 days	39.61	27 Minimum
	at 7 days	50.05	37 Minimum
	at 28 days	63.60	53 Minimum

2.1.3 Coarse aggregate

In the present study the coarse aggregate was used after soaking in water for 24 hours and then completely air dried. The fraction of coarse aggregate passing through 20 mm and retained on 10 mm is taken as 2/3 of total aggregate. The remaining 1/3 fraction is aggregate passing from 10 mm and retained on 4.75 mm. For M 30 grade of concrete, both sizes of aggregates were used but for M90 grade of concrete aggregate passing through 10 mm was used in mix. The higher the targeted compressive strength, the smaller the maximum size of the coarse aggregate should be. The fineness modulus and specific gravity of coarse aggregate are 6.30 and 2.78 respectively.

2.1.4 Water

Water is the most important ingredient of concrete and a part of mixing water is utilized in hydration of cement to form the binding matrix and the remaining water acts as a lubricant to make the concrete readily in pouring state. Locally available potable water was used in this present work.

2.1.5 Superplasticizer

Chemical admixture based on second-generation poly carboxylic technology conforming to IS 9103-1999 with specifications light orange colour, specific gravity = 1.09, chloride content = Nil and solid content = 34% was used in this work.

2.1.6 Mineral admixture

The specific gravity of micro silica is 2.2. Specific surface area of micro silica was 19,000 m^2/kg (from manufacturer's data). The high surface area of micro silica would increase the water demand. The use of micro silica can reduce bleeding and improve cohesion of the mix. The cohesiveness of concrete containing micro silica is good for pumping and for underwater concrete.

2.2 Casting, curing and testing of specimens

The sequence of feeding ingredients in the pan mixer depends on the properties of mix and those of mixer. In this work, a small amount of water is fed first, followed by coarse aggregate in saturated surface dry condition and fine aggregate. These materials are mixed uniformly and cementitious material fed into the mixer. After attaining uniform mixture of all ingredients, water is added. The mix proportions were arrived after carrying out trial mixes and finally mix proportion were adopted for M 30 and M 90 grades of concrete according to IS:10262 (2009) and ACI 211.4R-08 respectively. The quantities of ingredient materials used in these mixes and workability results are shown in Table 2

TABLE 2: MIX PROPORTIONS

S.No.	Ingredient	Normal strength concrete M 30	High strength concrete M 90
1	Cement (OPC 53 grade)	370 kg/m^3	594 kg/m^3
2	Micro silica (10% of cementitious material)	Nil	66 kg/m^3
3	Fine aggregate	740 kg/m^3	650 kg/m^3
4	Coarse aggregate	1214 kg/m^3	1105 kg/m^3
5	Water	165 l/m^3	145 l/m^3
6	Superplastcizer	Nil	0.8% by weight of cementitious material
7	Workability	45 mm slump	0.85 compaction factor

Usually mixing is done in two different stages for HSC. Dry mixing is done before the addition of water and wet mixing is done after addition of water. After dry mixing of the ingredients for one minute, 60% of water is added to the ingredients and mixed uniformly. The remaining 40% of water is mixed with superplasticizer and is introduced into the mixer and ingredients are mixed for 3 minutes until the mix is uniform. The total mixing time is 4 minutes. After mixing, the concrete is poured on the pre wetted platform then filled into moulds. The cylindrical and beam moulds of size 150 mm diameter and 300 mm long and 500 mm x 100 mm x 100 mm respectively are used to prepare specimens. All moulds are retained for a period of 24 hours in a moist air. Then the specimens are demoulded, marked and cured in a curing tank with fresh water. They are cured for a period of 28 days. The specimen is heated without preload at a prescribed rate to a target temperature, which is maintained until a thermal steady state is reached within the specimen. The specimen is allowed to cool to a room temperature after subjecting to thermal cycles namely 1, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 apart from control concrete. Specimens were exposed to temperatures from 100 to 400°C for 8 hours exposure duration and subsequent air cooling for the remaining period of day. Load is applied at room temperature until the specimen fails according to IS: 5816 (1970) and IS: 516 (1959) for splitting and flexural tensile strength respectively. The results of this test are more suitable for assessing the post fire (residual) properties of concrete.

3. Results and discussions

3.1 Effect of temperature on tensile strength

Residual tensile strength is the tensile strength of heated specimen expressed as the percentage of 28 day strength of the control concrete (reference concrete). The residual tensile strength of concrete reduces gradually when subjected to thermal cycles.

Strength reduction occurs in specimens when exposed to elevated temperatures due to dehydration of absorbed water from capillary pores, leading to formation of vapours and these vapours tend to escape creating internal stresses. In turn, these internal stresses lead to minute cracking and strength reduction. Further with increase in temperature, the same phenomenon is observed in small pores i.e chemically bound water trying to escape creating thermal stresses. Loss of moisture is not only the major fact of strength loss at elevated temperature but there are several other factors responsible. At high temperature, macro and micro cracks result in thermal incompatibility between the cement paste and the aggregate which affects the interfacial bond between them. This results in reduction in tensile strength.

3.1.1 Effect of thermal cycles on residual split tensile strength

1. Fig 3.1 shows the variation of residual split tensile strength with the number of thermal cycles for the concrete specimens of M 30 grade exposed to a specific temperature. At 100°C, for M 30 grade

concrete residual split tensile strength increased by 6.45% at first thermal cycle and reduced gradually to 58.6% after 50 thermal cycles with respect to control concrete. This was not so in case of other temperatures (i.e 200, 300 and 400°C). This is due to the slow transport of water and water vapour in the concrete specimens which may lead to elevated pore pressure levels. These pore pressures may be a cause of damage in the concrete.

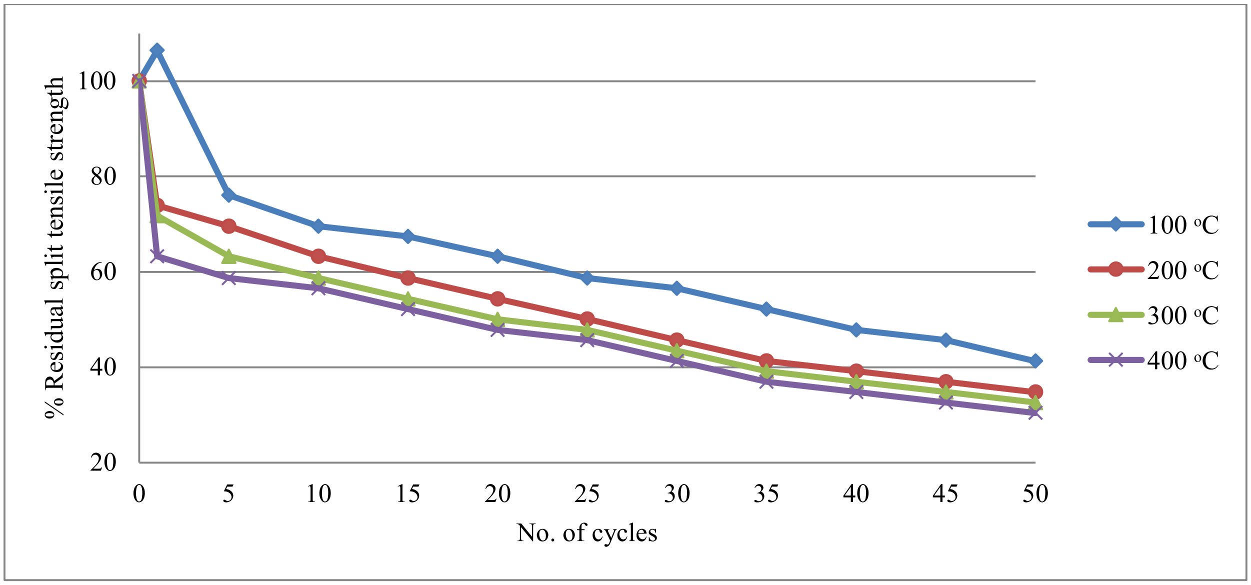

Fig. 3.1 Variation of % residual split tensile strength of M 30 specimens with number of cycles when exposed to different temperatures

The decrease in tensile strength of normal strength concrete (NSC) with temperature can be attributed to weak micro structure of NSC allowing initiation of micro cracks. At 100°C, concrete loses about 62% of its initial tensile strength after exposed to 50 thermal cycles. When subjected to high temperatures, the tensile strength of NSC decreases at a rapid rate due to a more pronounced thermal damage in the form of micro cracks and reaches to about 30% of its initial strength at 400°C after 50 cycles of exposure.

2. Fig 3.2 shows the variation of residual split tensile strength with the number of thermal cycles for the concrete specimens of M 90 grade exposed to a specific temperature. For high strength concrete, higher rates of strength loss, as much as 63% of the original strength was observed at 100°C and 75% strength loss at 400°C after 50 thermal cycles. At high temperatures, the first thermal causes a bulk loss in strength except at 100°C. This may be due to complete evaporation of free water in concrete. Low permeability and dense microstructure of HSC are probably the causes for creating high pore pressure making concrete brittle.

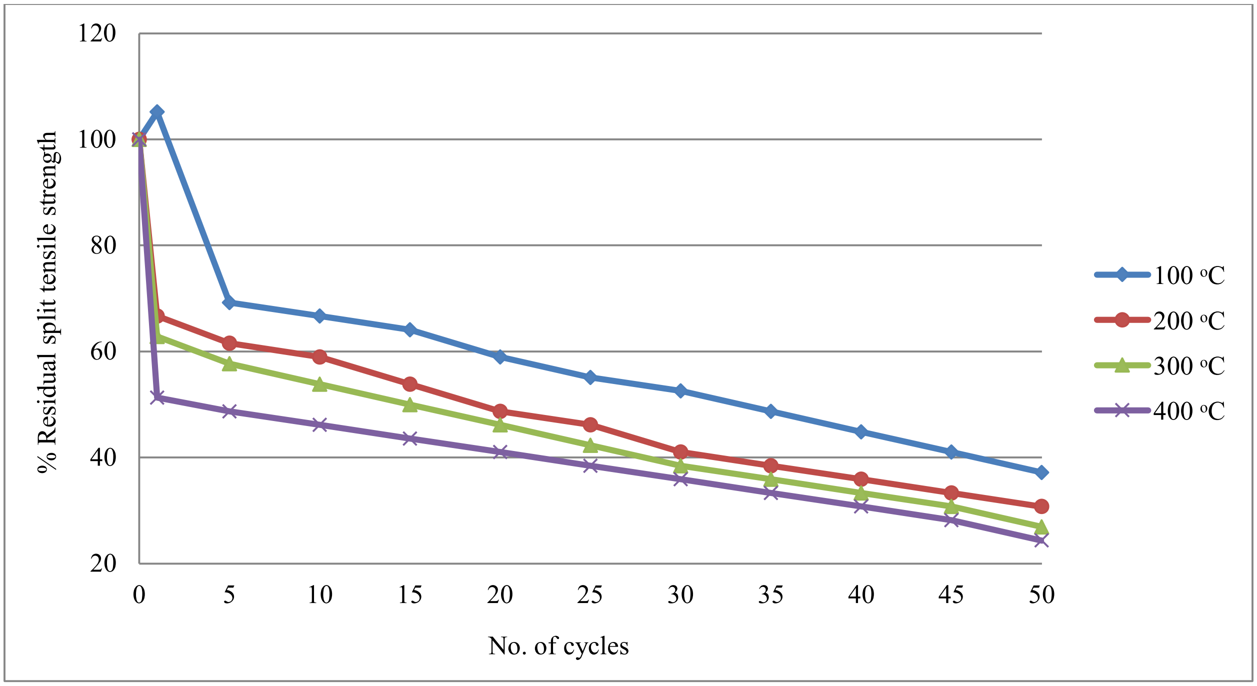

Fig. 3.2 Variation of % residual split tensile strength of M 90 specimens with number of cycles when exposed to different temperatures

3.1.2 Effect of thermal cycles on residual flexural tensile strength

1. Fig 3.3 shows the variation of residual flexural strength with the number of thermal cycles for the concrete specimens of M 30 grade exposed to a specific temperature. At 100°C, for M 30 grade concrete residual flexural strength increases at first thermal cycle and reduces gradually as number of thermal cycles increases. Increase in strength was observed at first cycle due to accelerated hydration of cement during heating cycle. At 100°C, concrete loses about 40% of its initial tensile strength and reaches to about 45% of its initial strength at 400°C after 50 cycles of exposure. M 30 grade of concrete retained at least 50% of its original strength even after 50 thermal cycles of exposure up to 300°C. But at 400°C, its residual strength was reduced to 45% of its initial strength.
2. Fig 3.4 shows the variation of residual flexural strength with the number of thermal cycles for the concrete specimens of M 90 grade exposed to a specific temperature. The strength loss 44.44% of the original strength was observed at 100°C and 58.33% strength loss at 400°C after 50 thermal cycles. As the temperature increases, there is a loss of free moisture followed by absorbed water and finally chemically bound water of hydrated cement products causing progressive strength loss. When M 90 grade of concrete exposed to 100 and 200°C, it retains 50% of its initial strength even after 50 cycles of exposure. But at 300 and 400°C, the strength reduced beyond 50% of its original strength after 45 and 30 thermal cycles respectively.

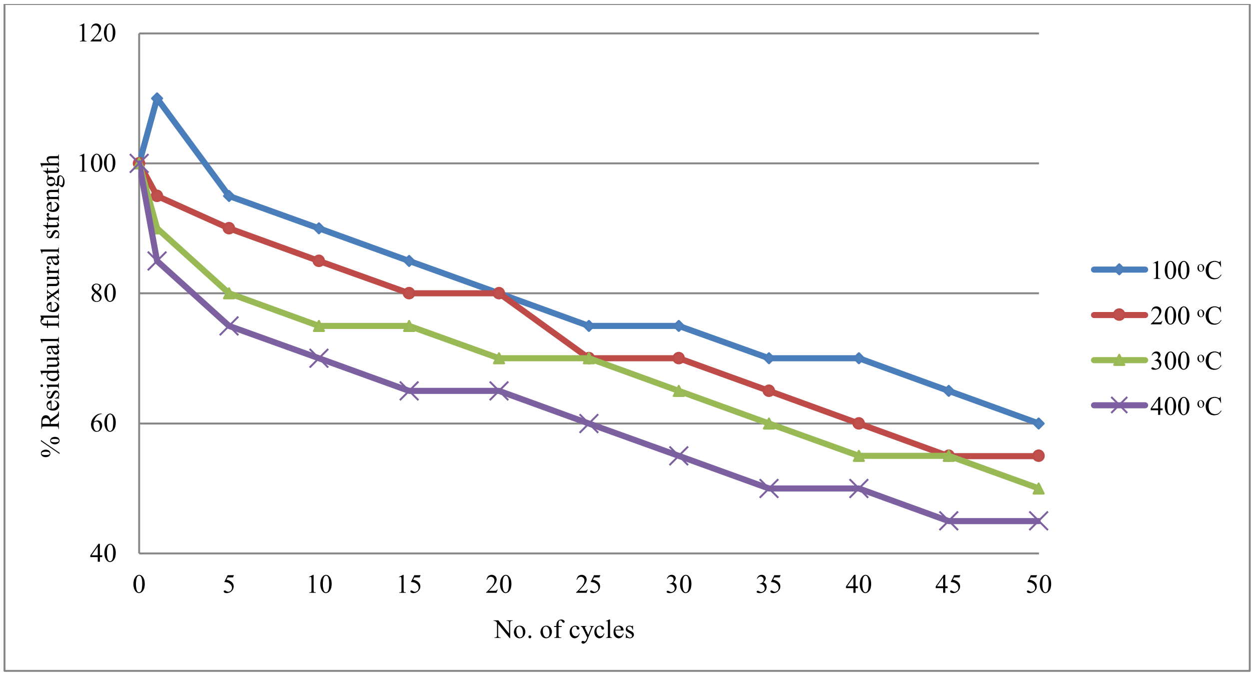

Fig. 3.3 Variation of % residual flexural strength of M 30 specimens with number of cycles when exposed to different temperatures

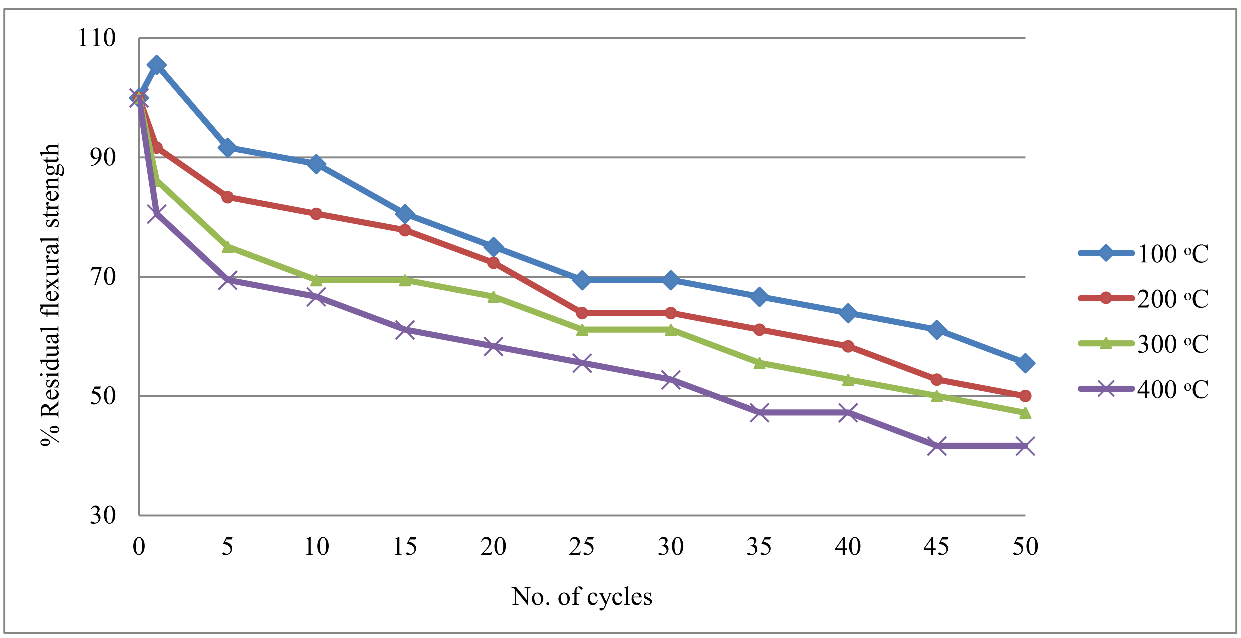

Fig. 3.4 Variation of % residual flexural strength of M 90 specimens with number of cycles when exposed to different temperatures

It was observed that the concrete has higher tensile strength in direct tensile test (flexural strength) than the indirect tensile test (split tensile strength). An interesting feature was also observed in control specimens of high strength concrete (reference specimens), which failed with a loud explosion indicating high dissipation of energy whereas the failure of heated specimens was gentle.

3.2 Effect of thermal cycles on weight loss

When the temperature in the oven increased, the evaporable water started expelling out from the capillary pores of concrete. This leads to increase in strength when exposed up to 100°C due to accelerated hydration of unhydrated cement during heating cycle. Beyond 100°C, all evaporable water gets evaporated depending on the duration of exposure. The chemically combined water i.e hydrated water and physically absorbed water are lost gradually when exposed to high temperatures. These hydro thermal changes result in change of pore structure of concrete where initially free moisture is lost, followed by physically absorbed water and finally chemically combined water of hydrated cement products causing progressive weight loss.

Weight loss is a continuous non-reversible process to represent moisture migration 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. The study of weight loss of the concrete specimens will estimate the durability of concrete. Weight loss of concrete at high temperatures depends on the composition, age of concrete, heating temperature and duration of exposure. Higher heating temperature always led to a higher weight loss which makes the concrete less durable.

Fig. 3.5 and 3.6 show the variation of % weight loss with the number of thermal cycles for the concrete specimens of M 30 and M 90 grade heated from ambient temperature to elevated temperature. At first thermal cycle, M 30 grade concrete specimens suffered 3.12% weight loss at 100°C and 4.21% at 400°C. After 50 cycles of exposure, the specimens suffered 4.69% weight loss at 100°C and 6.1% at 400°C. In the case of M 90 grade, specimens suffered 1.87% weight loss at 100°C and 3.06% at 400°C after first thermal cycle. After 50 cycles of exposure, the specimens exhibited 3.63% weight loss at 100°C and 5.04% at 400°C.

This implies that weight loss increases with increase in temperature. Normal strength concrete (M 30) shows more loss in weight due to high porosity than high strength concrete (M 90). The moisture present in the pores gets evaporated when heated to elevated temperature forming voids which results in weight loss. Hence normal strength concrete is less durable than high strength concrete.

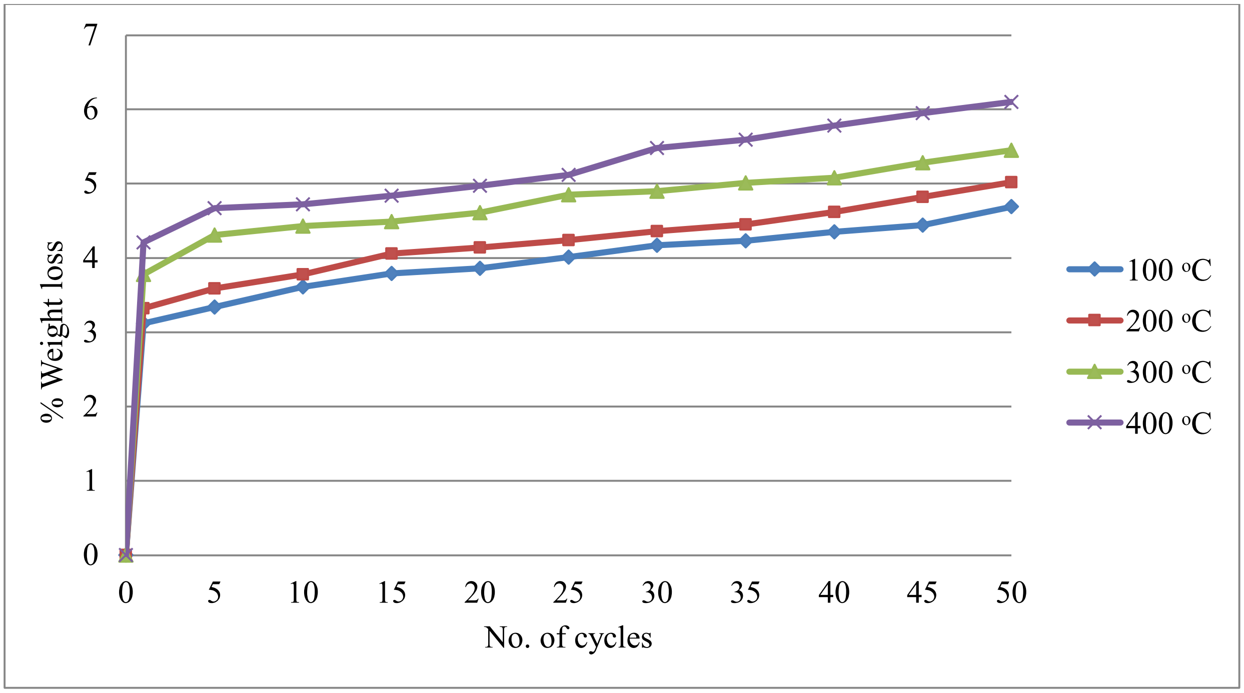

Fig. 3.5 Variation of % weight loss of specimens of grade M 30 with number of cycles when exposed to different temperatures

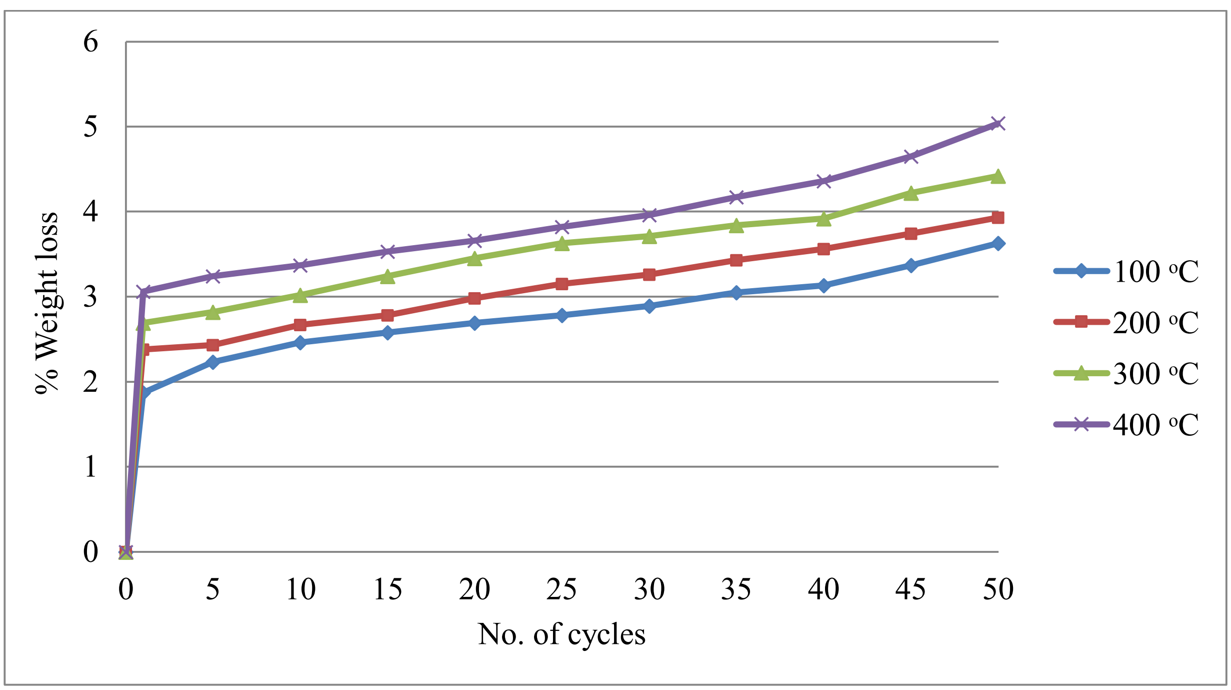

Fig. 3.6 Variation of % weight loss of specimens of grade M 90 with number of cycles when exposed to different temperature

4. Conclusions

Based on the investigations conducted on HSC and NSC subjected to thermal cycles, the following conclusions are drawn.

1. The percentage decrease of tensile strength is higher for higher exposure temperature irrespective of grade of concrete.
2. The tensile strength of concrete was affected more significantly as the temperature increases. It decreases with an increase in thermal cycles except at first cycle.
3. Tensile strength of concrete (both HSC and NSC) increase at 100°C at first cycle as it loses its free water (water not chemically bound) which results in acceleration of unhydrated core in concrete.
4. Thermal cycles have adverse effect on tensile strength of HSC and NSC. At high temperature around 200°C and 300°C, the first thermal cycle causes a large percentage of damage.
5. Normal strength concrete was observed to perform better than high strength concrete by retaining a greater percentage of tensile strength.
6. A gradual loss in weight was found with increase in temperature from 100 to 400°C with repeated heating. The effect is more pronounced in the case of NSC than HSC which affects the durability of concrete.
7. The mode of failure of heat cycled HSC concrete is altered from that of unheated concrete, as the failure of heated concrete is more gradual due to its brittleness.

REFERENCES

1. *Al-Tayyib A J, Baluch M H, Al-Farabi M Sharif and Mahamud M M, " The effect of Thermal cycling on the durability of the concrete made from local materials in the Arabian Gulf countries", Cement and concrete research, Vol.19, (1989),pp131-142.*
2. *Bairagi N K and Dubal N S, "Effect of thermal cycles on the compressive strength, modulus of rupture and dynamic modulus of concrete," The Indian Concrete Journal, August, (1996) 423-426.*
3. *Campbell Allen D and Desai P M, "The influence of aggregate on the behavior of concrete at elevated temperatures," Nuclear Engineering and Design, No 6, (1967) 65-77.*
4. *Campbell Allen D and Low E W E, "An investigation on the effect of elevated temperatures on concrete for reactor vessels," Nuclear Structural Engineering, No 2, (1965), 382-388.*
5. *Carette G G, Painter K E, and Malhotra V M, "Sustained High Temperature Effects on Concretes Made with Normal Portland Cement, Normal Portland Cement and Slag, or Normal Portland Cement and Fly Ash", Concrete International, July, 4(7), (1982), pp. 41–51.*

6. *Defigh-Price C, "Effects of Long-Term Exposure to Elevated Temperature on the Mechanical Properties of Hanford Concrete", Report RHO-C-54, Construction Technology Laboratories, Portland Cement Association (1981), Skokie, Illinois.*
7. *Defigh-Price C, "Effects of Long-Term Exposure to Elevated Temperature on Mechanical Properties of Concrete", ACI Symposium on Concrete and Cementitious Materials for Radioactive Waste Management (1984), New York.*
8. *Farhat F and Assadi S, "The effect of hot-dry environment on reinforced concrete beams", 32nd Conference on Our World in Concrete & Structures, 28-29th August, (2007).*
9. *Haddad H Rami and Abendeh M Raed, "Effect of thermal cycling on bond between reinforcement and fiber reinforced concrete", Cement and Concrete Composites 26, (2004), 743-752.*
10. *Kanazu T, Matsumura T, and Nishiuchi T, "Changes in the Mechanical Properties of Concrete Subjected to Long-Term Exposure to High Temperatures", Report No. U95037, Abiko Research Laboratory, Central Research Institute of Electric Power Industry (1996), Japan.*
11. *Kanellopoulos A, Farhat A F, Nicolaides D and Karihaloo B, "Mechanical and fracture properties of cement-based bi-materials after thermal cycling, Cement and Concrete Research (2009), 39, 1087-1094.*
12. *Kasami H, Okuno T, and Yamane S, "Properties of Concrete Exposed to Sustained Elevated Temperature", Paper H1/5 in Proc. 3rd International Conference on Structural Mechanics in Reactor Technology, Elsevier Science Publishers, (1975), North-Holland, Netherlands.*
13. *Shokrieh M M, Heidari-Rarani, Shakouri M and Kashizadeh E, "Effect of thermal cycles on mechanical properties of optimized polymer concrete", Construction and Building Materials, 25, (2011) 3540-3549.*
14. *Srinivasa Rao P and Seshadri Sekhar T, "Experimental investigation on the effect of thermal cycles on the strength properties of glass fibre SCC", The Indian Concrete Journal, September, (2015), 69-74.*
15. *Indian standard IS 4031-88: Methods of physical tests for hydraulic cement, Bureau of Indian Standards, New Delhi, India.*
16. *Indian standard IS 9103-99: Concrete Admixtures- Specifications, Bureau of Indian Standards, New Delhi, India.*
17. *Indian standard IS 3025-86 (parts 22 and 24): Methods of sampling and tests (chemical and physical) for water and waste water, Bureau of Indian Standards, New Delhi, India.*
18. *Indian standard IS 516-59: Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India.*

19. *Indian standard IS 10262-09: Recommended guidelines for concrete mix design, Bureau of Indian Standards, New Delhi, India.*
20. *Indian standard IS 12269-89: Specifications for 53 grade ordinary Portland cement, Bureau of Indian Standards, New Delhi, India.*
21. *Indian standard IS 383-70: Specifications for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi, India.*
22. *American Concrete Institute ACI 211.4R-08: Guide for selecting proportions for high strength concrete using Portland cement and other cementitious materials, ACI Committee Report, American Concrete Institute, Farmington Hills, MI, USA.*