Assessment of Post Fire Structural Strengths of Normal Strength Concrete Subjected to Cyclic Thermal Loadings

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Abstract
Concrete is a composite construction material consisting basically of a binder, aggregates, water and with or without admixture to modify either or both its physical and chemical properties. The rate at which concrete structures especially buildings are gutted by fire hazards is on the increase and this has adverse effect on the strength, hence, the need to assess the post fire structural strengths of Normal Strength Concrete(NSC). NSC of grade 50 was produced and cast into specimens of sizes 150mm cubes and 100mm x 100mm x 500mm reinforced concrete beams. The concrete cubes and beams were subjected to elevated cyclic thermal loadings after 7, 14 and 28 days of curing, while the rate of heating was maintained at $1^oC/min$ until the target temperature of (100, 130, 160, 200 and 250)^o C where attained and this was maintained for one hour and then allowed to cool at $1^oC/min$ to room temperature of 32^oC. Unstressed Residual Uniaxial Compressive Test (URUCT and Flexural Strength Test (FST) were conducted on the cubes and reinforced concrete beams, respectively. Direct Tensile Strength Test (DTST) was performed on the high yield ($460N/mm^2$) steel reinforcement. The result showed that the residual compressive strengths of concrete cubes decreases with increase thermal loadings. The expected strengths of 0.69 and 0.97 of the 28 days strength for 7 and 14 days respectively were met. The flexural strengths decrease with increase in thermal loadings. The flexural strength of the concrete beams at 28 days of $15.25N/mm^2$ at thermal loading of 32^oC was reduced to $8.16/mm^2$ at thermal loading of 160^oC; while the strength at 14 days of
$12.19\ N/mm^2$ at thermal loading of 32^oC was reduced to $7.62N/mm^2$ at thermal loading of 160^oC and finally, the strength at 7 days of $10.13N/mm^2$ at thermal loading of 32^oC was reduced to $5.82N/mm^2$ at thermal loading of 160^oC. All the results met the specification for high yield steel of 12% elongation at fracture. It was concluded that within the thermal loading range adopted, the tensile strength of the reinforcement was not impaired beyond the limit specified by the code.
Keyword: Normal Strength Concrete, Thermal loadings, Unstressed Residual Strength Test, Fire hazard.

1. Introduction

Post fire effect on strengths of Normal Strength Concrete (NSC) is an issue of great practical importance. Though, considerable research studies have been carried out using different test methods which revealed that concrete properties are greatly impaired (reduced) at elevated temperature which are more noticeable when the temperature is about 400^oC and above (Kaspar et al., 2009). Naus (2005) asserted that these changes in concrete properties are due to changes in the moisture condition of the concrete constituents and the progressive deterioration of the cement paste-aggregate bond. Among the noticeable changes that are exhibited by concrete exposed to elevated temperature are: tensile cracking, creep effects, yielding of reinforcement and deformation of the concrete. Kaspar et al. (2009) identifies four types of major damage mechanisms responsible for deterioration of concrete properties under high temperature to includes: phase transformations taking place in cement paste; phase transformations taking place in aggregate; thermal incompatibility between the cement paste and aggregate and spalling of concrete. The changes in properties of concrete structures exposed to thermal loadings resulted in loss of structural strengths/integrity. The study adopted Unstressed Residual Strength Test Method (URSTM) to accesses the residual compressive strength of the normal strength concrete cubes while Direct Tensile Strength Test (DTST) was performed on the steel reinforcement to access the tensile strength of the steel reinforcement. The main objective of the study was to access the post fire effect on the structural strengths of normal strength concrete cubes and beams with a view to determine the relationship that existed between compressive and flexural strengths and thermal loadings; relationship between tensile and yield strengths and thermal loadings; relationship between loss of strengths (compressive and tensile) and thermal loadings; the relationship between weight loss in post fire concrete cubes and beams and thermal loadings. Other mechanical properties of interest to the study includes the effect of post fire on the elongation, young modulus of elasticity and quality of steel reinforcement as contained in BS 4449:1998.

2. Experimental Procedure

The materials used and the method employed in preparing and testing the concrete specimens used for the various tests are discussed below.

2.1 Materials

The materials used for the study are: sharp sand (fine aggregate); granite (coarse aggregate) both aggregates are source from quarry site along Lagos - Ibadan expressway. The sand and gravel were then washed and clean with water several times, then it was spread out and left to dry in air, after which it were ready for use. The aggregate confirms to BS882 (1992). Ordinary Portland Cement OPC) complying with (BSEN206 -1: 2000) was used as the binding agent and it was sourced from Lafarge Cement Company, Ewekoro, Ogun State, Nigeria. Water used conforms to BS3148 (1980) and it was obtained from Lagos State Water Corporation. The steel reinforcement used was 16mm high yield steel reinforcement; it was free of seams, porosity, segregation and non-metallic inclusions. The reinforcement used conforms to BS4483: 1998.

2.2 Specimen Preparation

The research used Unstressed Residual Strength Test Method (URSTM) to access the compressive and flexural strengths of the concrete cubes and Direct Tensile Strength Test (DTST) to assess the tensile strength and yield stress of the reinforcement.

Normal Strength Concrete (NSC) of grade 50 was produced and cast into specimens of sizes 150mm cubes and 100mm x 100mm x 500mm reinforced concrete beams. The concrete cubes and beams were subjected to elevated cyclic thermal loadings after 7, 14 and 28 days of curing, while the rate of heating was maintained at 1^{o}C/min until the target temperature of $(100, 130, 160, 200 \text{ and } 250)^{o}$ C where attained and this was maintained for one hour and then allowed to cool at 1^{o}C/min to room temperature of 32^{o}C. Uniaxial Compressive Test (UCT) was performed on the concrete cubes and Flexural Strength Test (FST) was conducted on the reinforced concrete beams. Direct Tensile Strength Test (DTST) was performed on the high yield (460 N/mm^2) steel reinforcement.

2.3 TESTING OF SPECIMEN

2.3.1 Uniaxial Compressive Strength Test

The compressive strength of the specimens was determined by destructive test method conducted at Lagos State Material Testing Laboratory, Ojodu Berger, Lagos State. The test conducted was in accordance with BS 1881: Part 116, 1983. The compressive strength machine used is Tecnotest Modena – Italy, Model: 2007, Serial No F050 - TC, with capacity ranges from 500 - 2000KN. Three specimens were taken to the crushing machine to determine their compressive strengths. The control experiment were not heated but crushed at room temperature of 32^{o}C.

2.3.2 Flexural Test

The flexural strength test or modulus of rupture is a measure of the outer fiber tensile strength of a material. It was determined in accordance with BS 1881: Part 118: 1983. The machine used was electrically and hydraulically operated, the manufacturer name is ELE international Limited HP2 7HB, England with a maximum capacity of 70MN, serial, No: 154721029.

The beam specimens were all placed on the electrically and hydraulically operated flexural strength test machine. The third point loading of the machine was set-up, the actuator gradually releases the load steadily and without shock at 0.06 ± 0.04N/(mm^{2}s). The rate of loading was maintained without change until failure occurred. The results were read off from the analogue screen and tabulated. All the beam specimens were tested after heating and cooling except for the control specimens which were not heated. The flexural strength was calculated thus:

$$F_{cf} = \frac{F \times L}{d_1 \times d_2^2}$$

Where;
F_{cf}=Flexural strength
F = Breaking load (N)
d_1 & d_2^2 = Lateral dimension of the cross - section (mm)
L = Distance between the supporting rollers (mm)

2.3.3 Direct Tensile Strength Test

The direct tensile strength test was conducted on the 460N/mm^2 high-yield steel reinforcement. The specimens was of 16mm diameter with total length of 400mm and sectional- area of 201.062mm^2. The specimen was subjected to cyclic loadings of (100,130, &160) ^{o}C after which it was allowed to cool to room temperature of 32^{o}C. The loading was done by griping the specimen at its ends and pulling it apart in tension; stress pace of 20N/mm^2/s was maintained. The control specimen was not subjected to cyclic loading. The tensile strength is given by the failure load divided by the cross-sectional area of the specimen. The test was conducted in accordance with BS 4449: 1998. The tensile strength was computed as follows:

$$\sigma_t = \frac{P}{A}$$

Where:
σ_t =Tensile strength
P = Maximum load at failure (N)
A= Cross-sectional area of the specimen

3. Results and Discussion

The findings from the study are presented below.

3.1 Unstressed Residual Uniaxial Compressive Strength Test Analysis

Figure 1 showed the graphs of compressive strength with thermal loading (temperature) at 7, 14 and 28days. From the graphs it was evident that the strength of Normal Strength Concrete, NSC, decreases with increment in thermal loadings. The maximum strength developed by the concrete cubes at 32^{o}C was 24.89 N/mm^2 at 28 days. This was reduced to 18.22 N/mm^2 at thermal loading of 250^{o}C. The strength developed at 7 days and at 32^{o}C of 17.05N/mm^2 was reduced to 8.59N/mm^2 at thermal loading of 250^{o}C.

Figure 2 showed the graphs of percentage loss of compressive strength with thermal loading (temperature) at 7, 14 and 28days. The graphs revealed that Normal Strength Concrete, NSC, cubes losses more of its strength at early days; equivalent of 49.62% strength loss was recorded at 7 days, 34.77% at 14 days and 26.80% at 28 days all at thermal loading of 250^{o}C. This establish the fact that loss of compressive strength experienced by normal strength concrete are caused by increment in thermal loading and are reduced as the age of the concrete increases. Sangluaia et al (2013) studied the behavior of reinforced concrete slab subjected to fire. The study showed that mechanical properties of concrete decrease drastically for temperature above 300 ^{o}C; this was attributed to microstructure transformations occurring in the cement paste and aggregates and the volume changes induced by thermal stresses.

3.2 Flexural Strength Test Analysis

Figure 3 showed the graphs of flexural strength with thermal loading at 7, 14 and 28days. From the graphs it was deduced that the flexural strength of Normal Strength Con crete, NSC, beams decrease with increment in thermal loadings. The flexural strength of the concrete beams at 28 days of 15.25N/mm^2 at thermal loading of 32^{o}C was reduced to 8.16/mm^2 at thermal loading of 160^{o}C; while the strength of the concrete beams at 14 days of 12.19 N/mm^2 at thermal loading of 32^{o}C was reduced to 7.62N/mm^2 at thermal loading of 160^{o}C and finally, the strength of the concrete beams at 7 days of 10.13N/mm^2 at thermal loading of 32^{o}C was reduced to 5.82N/mm^2 at thermal loading of 160^{o}C.

Figure 4 showed the graphs of percentage loss of flexural strength with thermal loading (temperature) at 7, 14 and 28days. From the graphs it was deduced that percentage loss of flexural strength of the concrete beams at 28 days was 26.82%, at 14 days was 37.49% and at 7days was 42.54% all at thermal loading of 160^{o}C. This clearly show that the loss of strength decrease with age of concrete. Sheng-Jin Chen (1986) researches into the effect of cyclic loading on reinforced concrete slab and beam. In this contribution the researcher asserted that distributed cracks and plastic deformation were developed when floor slab are subjected to cyclic loading; the research concluded that cyclic loading caused reduction in strengths of concrete and displacement capacity of the floor panel.

Mohammed (2014) adopted residual stressed test method to evaluate the effect of fire on reinforced concrete structures. The research showed that the load-deflection relation of the rigid beam specimen is almost linearly proportional for temperature exposure of (400 and 750)^{o}C. The study identified three (3) distinct cracks development exhibited during burning of reinforced concrete beam which are: thermal cracks, flexural cracks and inclined cracks. Thermal cracks developed due to the release of moisture and resulted into differential shrinkage; flexural cracks developed due to loading in the mid-span region at about 400 ^{o}C which resulted to spalling of concrete cover while the inclined cracks are caused due to the presence of increasing shear stresses as the load and temperature increases at about 750 ^{o}C.

3.3 Direct Tensile Strength Test Analysis

Figure 5 is the graph of elongation with the thermal loading. Deduction from the graph showed that maximum elongation developed by the steel reinforcement subjected to thermal loading increases with increment in thermal loading (temperature)

Figure 6 showed the graph of tensile strength with thermal loadings (temperature) for the target temperature of (100, 130 and 160)^{o}C. Thermal loading of 32^{o}C was used as the control temperature. Deduction from the graph showed that tensile strength decreases as the thermal loading increases.

Figure 7 showed the graph of yield strength with thermal loading (temperature) for the target temperatures. It was evident that the yield strength of the steel reinforcement decreases as the temperature increases.

Figure 8 showed remarkably that the young modulus of elasticity attained by each steel reinforcement subjected to elevated thermal loading reduces with increase in thermal loading. The research conducted by Sangluaia et al (2013) concluded that at about 400 ^{o}C there is significant reduction in the physical strength of materials of concrete; high temperature resulted in loss of strengths (both yield and ultimate strengths) and stiffness (moduli of elasticity). The results corroborated the result of the research study under investigation.

Figure 9 showed the graph of ratio of tensile strength to the yield strength with the thermal loading (temperature) for the target temperature of (32, 100, 130 and 160)^{o}C from the graph it was affirmed that ratios of tensile strength to the yield stress of reinforcement subjected to elevated cyclic temperature met the specification for high yield steel (12% elongation at fracture, 460N/mm^2 yield stress).

Deduction obtained from the result depicted that within the thermal loading range adopted the steel quality level are not impaired even after the steel being subjected to thermal loading (temperature) up to 160^{o}C as specify in BS4449:2005.

Borst and Peeters (1989) adopted numerical techniques approach rather than simulating the behavior in scale test to predict the behavior of structures under extreme thermal loadings. In this contribution an algorithm was developed which treats the material properties of concrete at elevated temperature. The model developed was tested against some tests on plain concrete specimen and the results obtained compared with an experiment on a one-way reinforced concrete slab. The research concluded that axial stress is a function of the temperature and the nonlinear of material properties as function of the temperature.

4. Conclusion

From the results of the various test conducted the following conclusion can be drawn: Both the unstressed residual uniaxial compressive strength test values and the flexural strength test values of the normal strength concrete cubes and beams decreases as the thermal loading (temperature) increases for the target temperature; the loss of compressive and flexural strength are caused by increment in thermal loading and these values decreases as the age of concrete increases; the tensile and yield strengths of the steels decrease after being subjected to increase thermal loadings (temperature); while the maximum elongation attained by each steel subjected to elevated thermal loadings increases with increase in thermal loadings.

Finally, the result showed that the strength of the steel reinforcement are not impaired beyond the limit specific by the code when subjected to the target temperature used for the research study.

5. Recommendation

Based on a close investigation into the assessment of post-fire effects on strengths of normal strength concrete, of grade 50 concrete cubes and beams and the conclusions arrived at the following recommendations are made: thermal loading (temperature) reduces the strengths of normal strength concrete, hence adequate measures must be put into place to prevent fire hazards which can leads to this kind of situation under study.

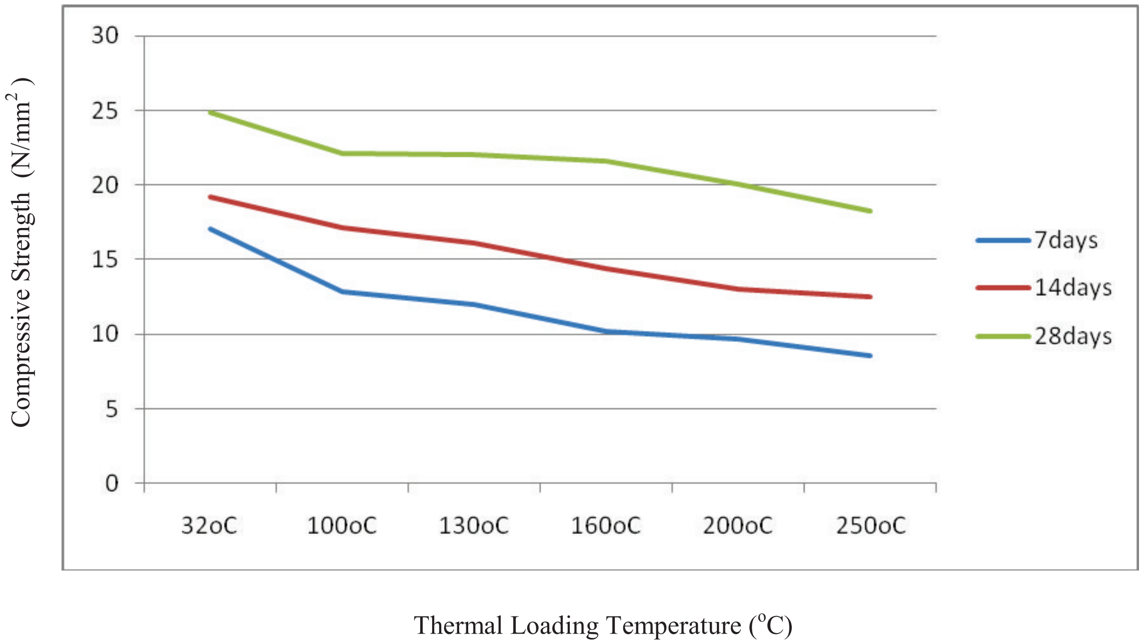


Figure 1: Graph of Compressive Strength with Thermal Loadings (Temperature)

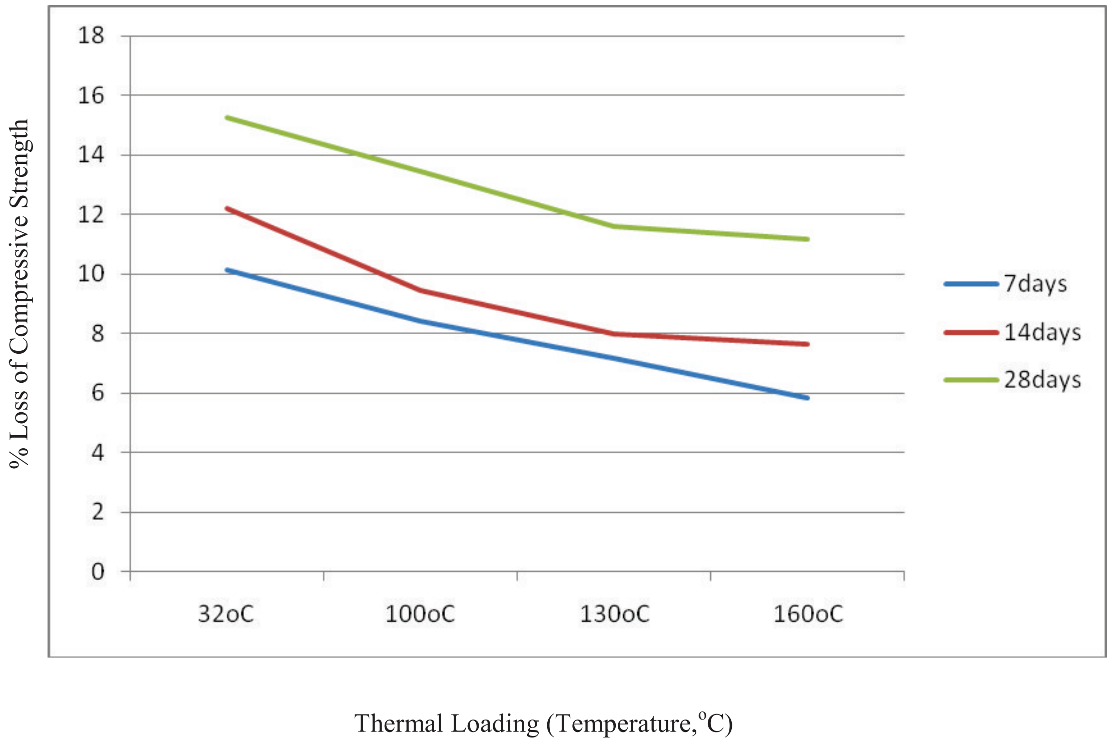
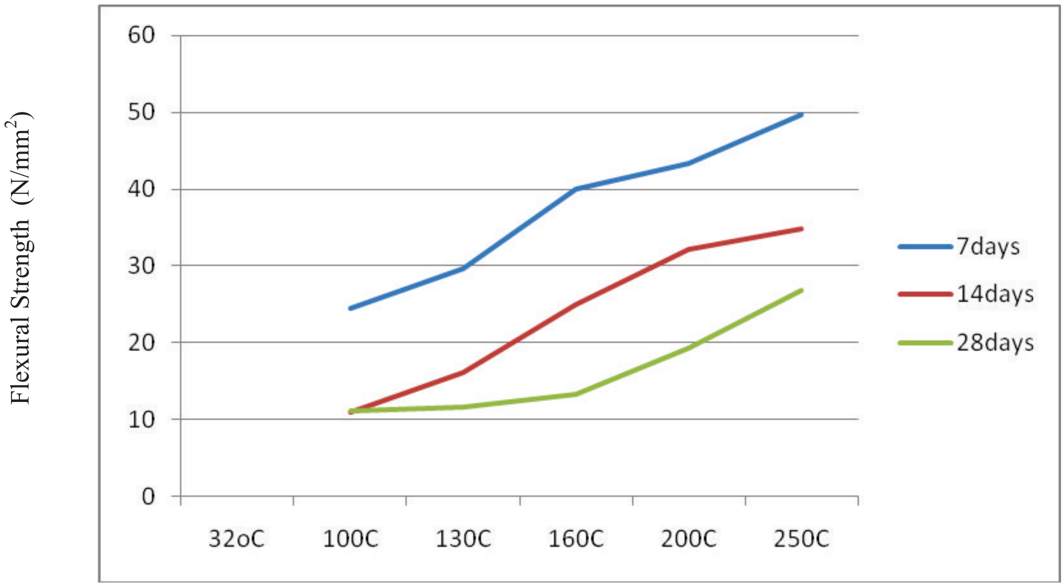
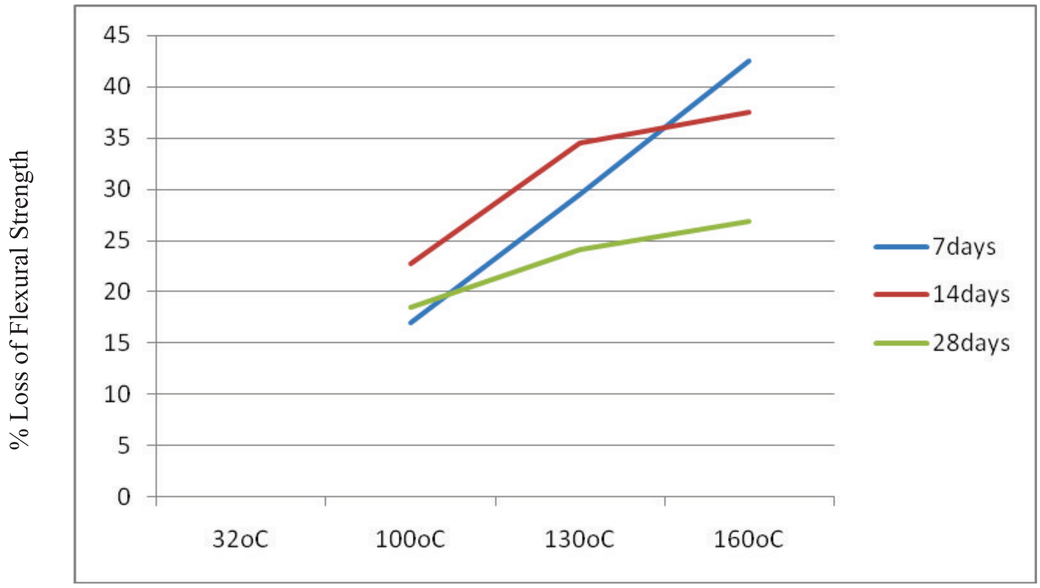


Figure 2: Graph of % Loss of Compressive Strength with Thermal Loadings (Temperature)



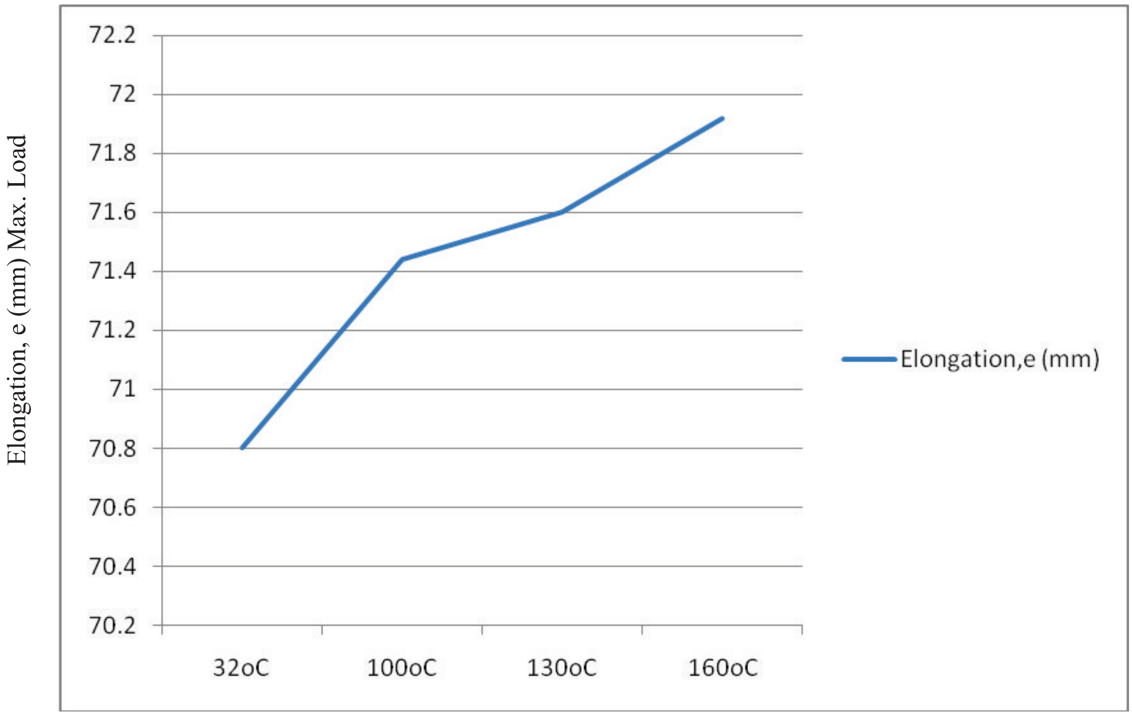
Thermal Loading (Temperature,^{o}C)

Figure 3: Graph of Flexural Strength with Thermal Loadings (Temperature)



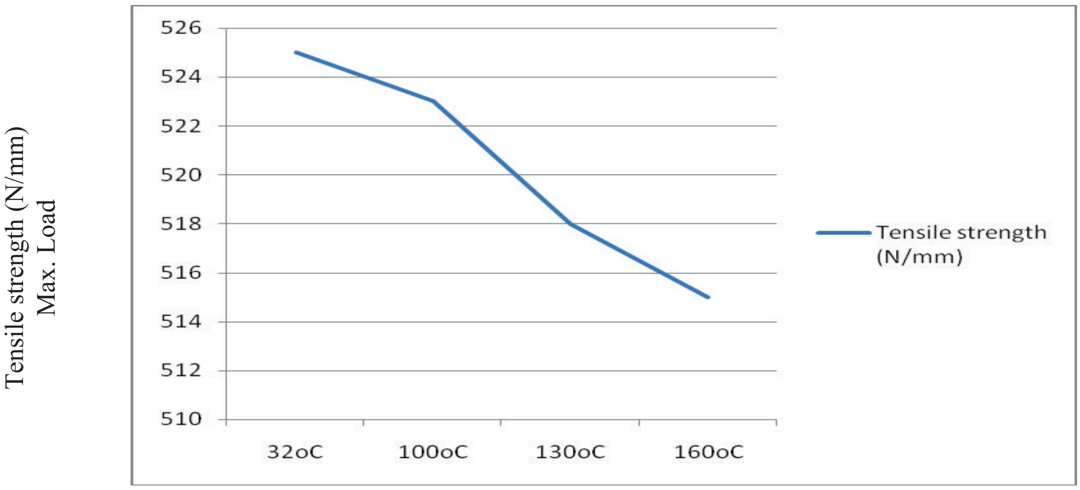
Thermal Loading (Temperature,^{o}C)

Figure 4: Graph of % Loss of Flexural Strength with Thermal Loadings (Temperature)



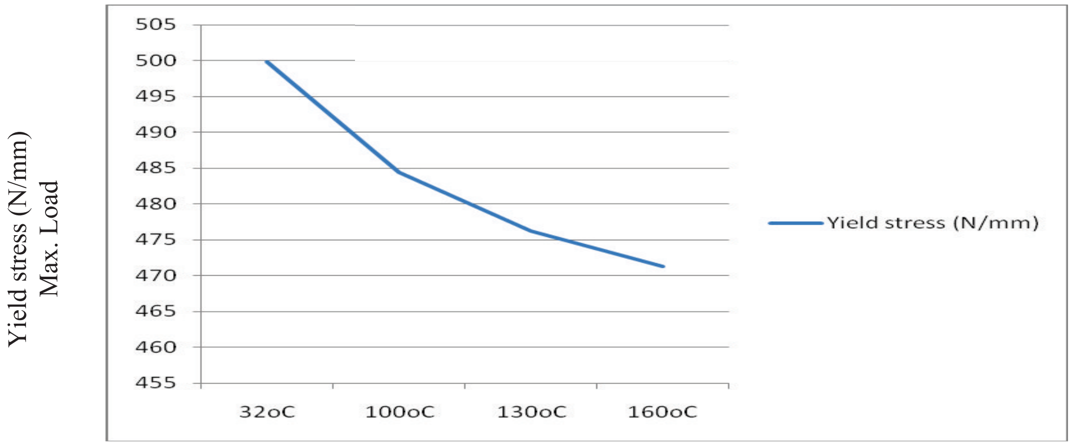
Thermal Loading (Temperature,^{o}C)

Figure 5: Graph of Elongation with Thermal Loadings (Temperature)



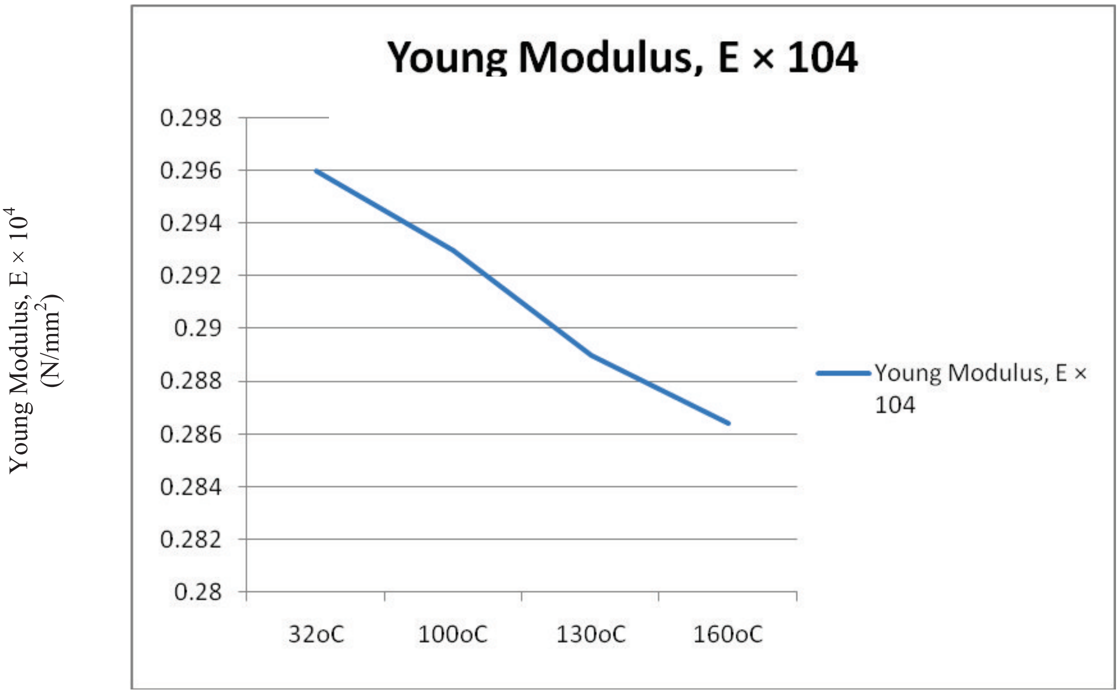
Thermal Loading (Temperature,^{o}C)

Figure 6 Graph of Tensile Strength with Thermal Loadings (Temperature)



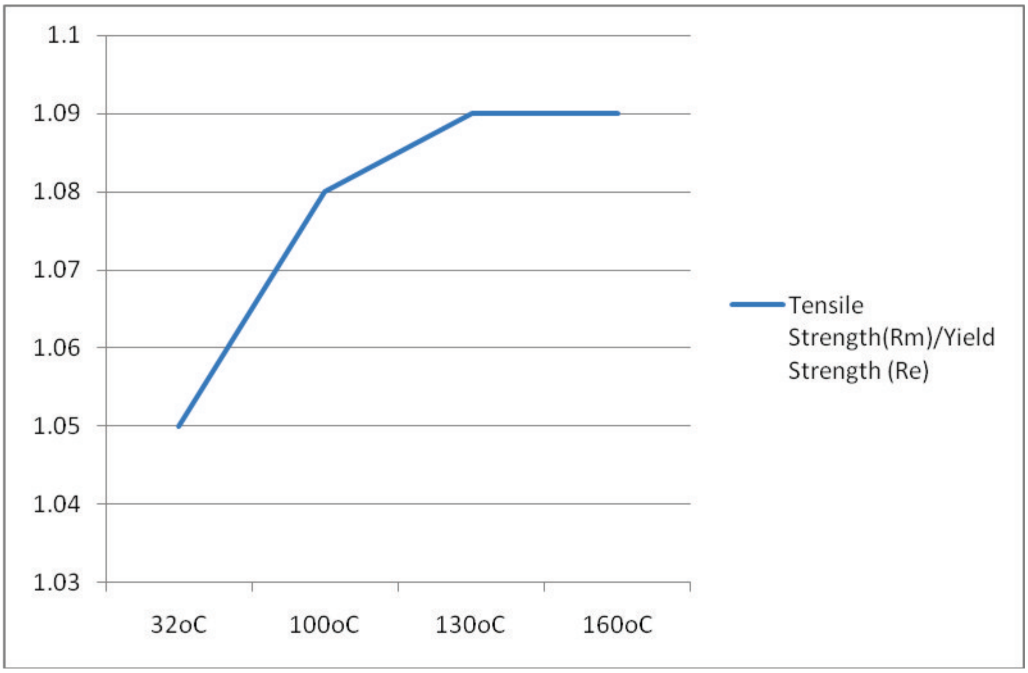
Thermal Loading (Temperature,°C)

Figure 7: Graph of Yield Stress with Thermal Loadings (Temperature)



Thermal Loading (Temperature,°C)

Figure 8: Graph of Young Modulus with Thermal Loadings



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R_m/R_e

z

Thermal Loading (Temperature,^{o}C)

Figure 9: Graph of ratio of Tensile Strength (R_m) to Yield Strength (R_e) with Thermal Loadings

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