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Behaviour of Reinforcement in Reinforced Concrete Beam Subjected To Fire on Tensile Strength

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ABSTRACT: *Fire is an extreme event, the occurrence of which affects the behavior of the structures significantly in terms of both serviceability and strength criteria; hence, provision of appropriate fire safety measures for structural members is an important aspect of structural design. However, the impact of fire on steel reinforcement at elevated temperature is analyzed by exposing the concrete beam to fire at an interval of time, the reduced in strength of the steel reinforcement for the 10mm and 12mm in diameter was found.*

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I. INTRODUCTION

Fire is a destructive force causing thousands of deaths and loss of property.Fire remains one of the serious potential risks to most building and structures.The extensive use of concrete as a structural material has led to the need to fully understand the effect of fire on reinforces concrete structures. Generally, concrete is thought to have good fire resistance, but the behavior of reinforced beams under high temperature affects the strength of concrete, the changes in the materials property and explosivespalling. Hence, the provision of fire resistance for reinforced concrete (RC) structures and components is treated in the structural design through the provision of building codes specified for buildings designed in the society.

The thermal properties like coefficient of thermal expansion, specific heat, density and thermal conductivity of concrete are important for evaluation of the performance concrete over the period of time (T Y Chuw 1978).

Thermal diffusivity is a measure of the rate at which temperature change within the mass take place. The larger the value of thermal diffusivity of a mass the faster the changes will occur. The value of thermal diffusivity is dependent on the aggregate type, moisture content, degree of hydration of the cement paste, and exposure to drying (K Hertz 1982).

Specific heat represents the heat capacity of concrete. It increases with the moisture content of concrete and is affected by the mineralogical character of the aggregate, specific heat increases with an increase in temperature and also increases with a decrease in the density of concrete (H Sager 1980). Specific heat varies only 8 percent for different types of aggregates. An increase in water content from 4 to 8 percent resulted in a 12 percent increase in specific heat. While an increase in temperature from 10 to 65°C resulted in increase in specific heat of 24 percent. Specific heat is the measure of the heat capacity of concrete. The type of aggregate has only a small effect on the specific heat of concrete, but it is greatly affected by the moisture content. This is due to the large difference between the values of specific heat of the concrete and water, 840 to 1170 J/kg °C and 4187J/kg°C respectively. This shows that a small change in the moisture content of the concrete causes a comparatively large change in the specific heat.

The effect of temperature up to about 400°C on the final strength and ductility of mild steel and hot-rolled high yield steel as from a practical point of view is negligible. This refers to strength and ductility after return to ambient temperature (Naus, D. J. (1980).

The effect of the elevated temperature on the steel under load and the disruptive effect of expansion must be given careful consideration. As the thermal expansion of the reinforcing steel is likely to be greater than the concrete bursting stresses and cracking of the concrete can occur around the steel, especially in heavily reinforced members. If the steel is subjected to design load stresses during the fire, deflection may occur due to the loss of strength at high temperature, also buckling of bars may occur due to compressive stresses induced by thermal expansion restraint(G A Khoury 1996).

Subjecting concrete to a higher temperature (e. g., due to accidental fire etc.) leads to severe deterioration and it undergoes a number of transformations and reactions, thereby causing progressive breakdown of cement gel structure, reduced durability, increased tendency of drying shrinkage, structural cracking and associated aggregate color changes (S E Pihlajavaara 1972).

Bond strength is defined as the maximum force that can be transmitted between bar and the concrete per unit area of a specified cylinder concentric with the bar axis. The surface of the reinforcing steel bar and concrete strength play an important role in bond strength of reinforced concrete members when subjected to elevated temperatures (G A Khoury2004).

Concrete when subjected to temperature over 550^0C induces distortion and residual thermal stresses. A restraint caused at the ends will lead to excessive deformations, such as twisting and distortion. The loading through self-weight and imposed loads present on the member during fire also will aggravate the situation. The reinforcing steel embedded in concrete can survive well if the concrete has not spalled off. On the other hand, when exposed to temperatures over 800°C, yield strength reduces and quenching of steel during fire fighting can cause embrittlement (Hirano, K. et al., 1994).

STATEMENT OF THE PROBLEM

The rise in temperature causes a decrease in the strength and modulus of elasticity for both concrete and steel reinforcement in most of the Nigerian buildings. However, the rate at which the strength and modulus decrease depends on the rate of increase in the temperature of the fire and the insulating properties of concrete. Most building structures fail as the high temperature affect the steel reinforcements. The research aims at testing the strength of steel after being exposed to fire for several hours. Note that concrete does not burn.

II. MATERIAL AND METHOD

Sampling of Material

Representative samples of the materials of concrete for use in the concrete construction work were obtained by careful sampling. Test samples of cement were made up of a small portion taken from each of a number of bags. Test samples of aggregate were taken from larger lots by quartering.

Preparation of Materials

All materials were brought to room temperature, preferably $27^0 \pm 3^0$C before commencing the tests.
The cement samples, on arrival at the laboratory, were thoroughly mixed dry in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material. Care being taken to avoid the intrusion of foreign matter. The cement were then stored in a dry place, preferably in air-tight metal containers.
Samples of aggregates for each batch of concrete were of the desired grading and were in an air -dried condition. In general the aggregate were separated into fine and coarse fractions and recombined for each concrete batch in such a manner as to produce the desired grading. IS Sieve 480 were used for separating the fine and coarse fractions, but where special grading were being investigated, both fine and coarse fractions were further separated into different sizes.

Proportioning

The proportions of the materials, including in concrete mixes used for determining the suitability of the materials available, were similar in all respects to those to be employed in the work. Where the proportions of the ingredients of the concrete as used in the laboratory were to be specified by volume, they were calculated from the proportion by weight used in the test rectangular mould and the unit weights of the materials.

Cutting and Fixing of Steel Reinforcements

The steel reinforcements of Y10 and Y12 bars were cut to an adequately required length, they were then fixed into the rectangular formwork for assemblage.

Weighing

The quantities of cement, each size of aggregate, and water for each batch were determined by weight, to an accuracy of 0·1 percent of the total weight of the batch.

Volume of rectangular mould= $0.150 \times 0.150 \times 0.750 = 0.016875m^3$
Density of concrete= 2400 kg/m^3
But, density = mass/volume
And mass= density $\times$ volume
Mass of mixture= $2400 \times 0.016875 = 40.500$ kg.
For 12 number of beams = $12 \times 40.500 = 486.000$ kg.
Adopting standard ratio 1:2:4 for the mixture.

For 100%
Mass ratio of Cement = (1 / 7) × 486
= 69.429 kg
Mass ratio of fine aggregate = (2/7) × 486
= 138.857 kg
Mass ratio of Coarse aggregate = (4/7) × 486
= 277.714 kg
5% waste was added
For Cement = (5/ 100) × 69.429
= 3.471 kg
For Fine aggregate = (5/ 100) × 138.857
= 6.943 kg
For Coarse aggregate = (5/ 100) × 277.714
= 13.886 kg
Total
Total amount of cement = 69.429 + 3.471
= 72.900 kg
Total amount of fine aggregate = 138.857 + 6.943
= 145.800 kg
Total amount of coarse aggregate = 277.714 + 13.886
= 291.600 kg

3.1.5 Mixing Concrete
The concrete were mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete are of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

Figure1: Mould used in the experiment

The test specimens were made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance. The concrete were filled into the mould in layers approximately 5cm deep, In placing each scoopful of concrete, the scoop was moved around the top edge of the mould as the concrete slides from it, in order to ensure a symmetrical distribution of the concrete within the mould. Each layer was compacted by vibrator. After the top layer has been compacted. The surface of the concrete was finished using a trowel, and was covered with a metal plate to prevent evaporation.

Curing

The test specimens were stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours ± l hour from the time of addition of water to the dry ingredients, After this period, the specimens marked and removed from the moulds and, unless required for test within 24 hours, immediatelysubmerged in clean, fresh water and kept there until taken out just prior to test.

Figure: Sample specimen under curing

The water or solution in which the specimens were submerged were renewed every seven days and were maintained at a temperature of 27° ± 2°C. The specimens were not be allowed to become dry at any time until they have been tested. The beams are then cured for 21 and 28 days for testing [i.e 3 beams from Y10 and 3 beams from Y12 cured for 21 days separately and again for 28 days separately.]

Test for Steel Strength Before Used

The strength of steel specimens of Y10 and Y12 were tested before they were used for the beam casting, however same methodology for tensile strength test was applied for the steel specimen after being exposed to fire.

Figure 3: Tensile strength test machine

BEAMS EXPOSURE TO FIRE

After the beams [6 numbers Y10 and 6 numbers Y12] were cured for 21 days and 28 days. Three beams from each specimen were exposed to fire at 21 days of curing and similarly at 28 days of curing three beams from each specimen were exposed to fire. After the beams were exposed to fire, the steel reinforcements from each beam were brought out by cutting inside the beam and removing the steel reinforcement out for tensile strength test.

RESULT PRESENTATION

Control Sample Calculations

Calculation of Area of Steel Used:

For Y12, area = $\pi d^2/4$ $\quad \pi = \frac{22}{7}$

Area = $\frac{22}{7} \times 12^2 \div 4 = 113\ mm^2$

For Y10, area = $\pi d^2/4$ $\quad \pi = \frac{22}{7}$

Area = $\frac{22}{7} \times 10^2 \div 4 = 79\ mm^2$

Table1: Specification for control sample

Diameter (mm)	Nominal Size (mm)	Gauge Length (mm)	Yield Load (KN)	Ultimate Load (KN)	Reduction in Diameter (mm)	Elongation (mm)
Y12	400	200	54.000	55.000	11.000	28.000
Y10	400	200	36.000	38.000	9.5000	28.000

Calculation of Area Reduction

Table 2: Results (control specimen)

Diameter (mm)	Area (mm^2)	Elongation (mm)	% elongation (%)	Diameter reduction (mm)	% reduction in area (mm^2)	Yield strength (N/mm^2)	Ultimate strength (N/mm^2)
Y12	113	28	14	11.000	16	477.900	486.700
Y10	79	28	14	9.500	37	455.700	481.000

PRESENTATION AND ANALYSIS OF RESULT (21 DAYS) AFTER EXPOSURE TO FIRE

Table 3: Test Data of steel for 21 days

Diameter (mm)	Norminal Size (mm)	Gauge Length (mm)	Yield Load (KN)	Ultimate Load (KN)	Reduction in Diameter (mm)	Elongation (mm)	Burning Time (mins)
12	400	200	51.000	54.500	11.000	31.000	20.000
10	400	200	32.000	34.000	8.300	23.000	20.000
12	400	200	43.000	45.000	9.500	29.000	40.000
10	400	200	27.000	29.000	6.400	27.000	40.000
12	400	200	42.000	44.000	8.300	22.000	60.000
10	400	200	26.000	28.000	6.400	22.000	60.000

Table 4: Results of tested steel (21 Days)

Diameter (mm)	Area (mm^2)	Elongation (mm)	% elongation (%)	Diameter reduction (mm)	% reduction in area (%)	Yield strength (N/mm^2)	Ultimate strength (N/mm^2)	Time (min)
12	113	31.000	15.500	11.000	16	451.3	482.3	20
10	79	23.000	11.500	8.300	52.2	405.1	430.4	20
12	113	29.000	14.500	9.500	37	380.5	398.2	40
10	79	27.000	13.500	6.400	59.3	341.8	367.1	40
12	113	22.000	11.000	8.300	52.2	371.7	389.4	60
10	79	22.000	11.000	6.400	59.3	341.8	354.4	60

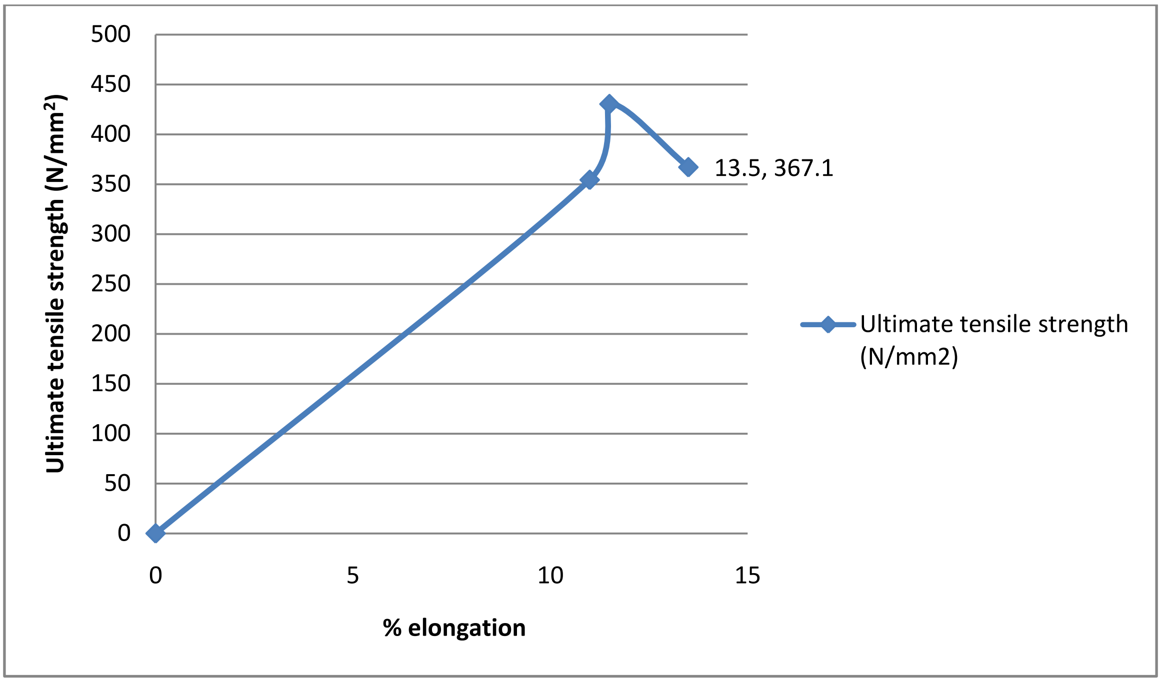

Figure 4: Graph of tensile strength against % elongation of Y10 at 21 days

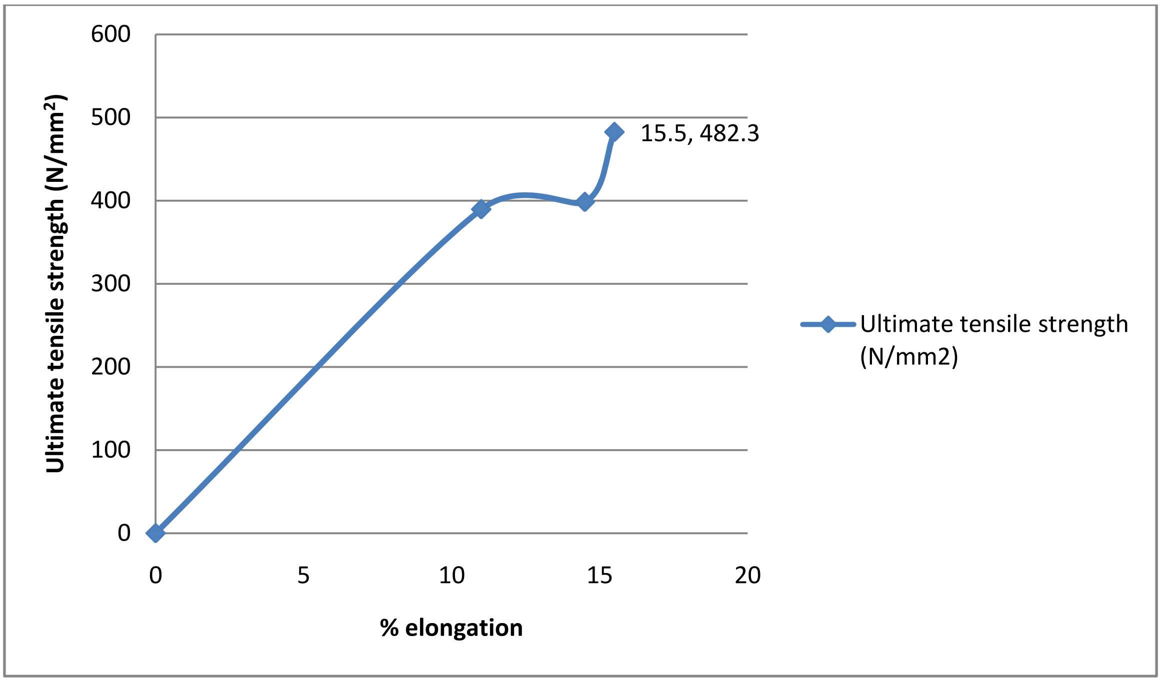

Figure 5: Graph of tensile strength against % elongation of Y12 at 21 days

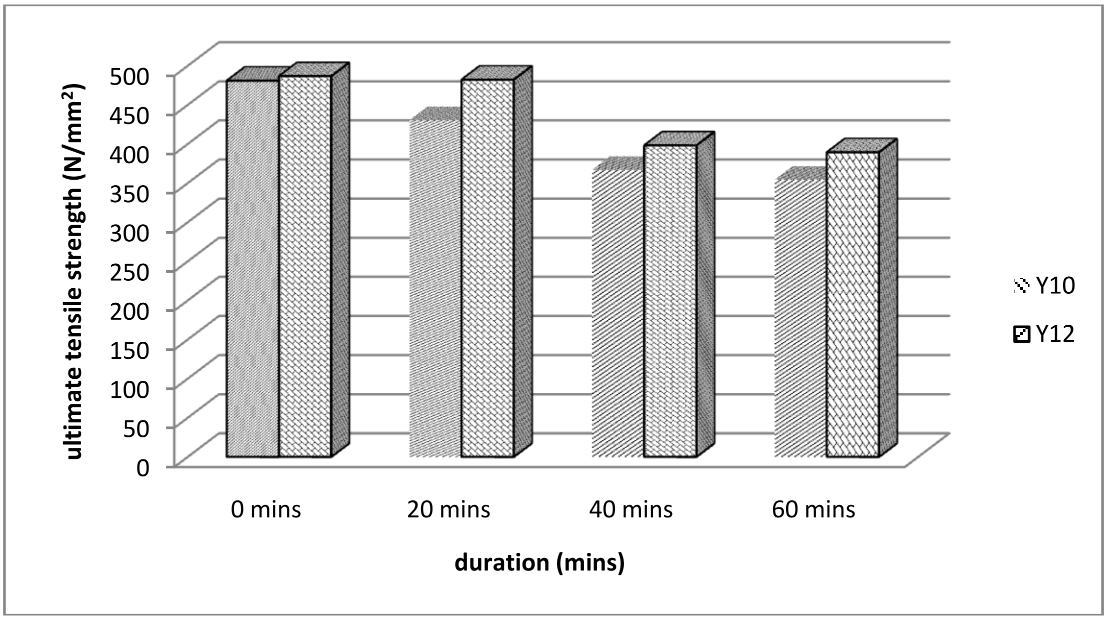

Figure 6: Graph of tensile strength with duration of fire (21 days)

PRESENTATION AND ANALYSIS OF RESULT (28 DAYS) AFTER EXPOSURE TO FIRE

Table 5: Test Data of steel for 28 days

Diameter (mm)	Norminal Size (mm)	Gauge Length (mm)	Yield Load (KN)	Ultimate Load (KN)	Reduction in Diameter (mm)	Elongation (mm)	Burning Time (mins)
12	400	200	50.000	51.000	8.300	30.000	20.000
10	400	200	31.000	32.000	6.400	20.000	20.000
12	400	200	43.000	45.000	9.500	28.000	40.000
10	400	200	27.000	29.000	6.400	25.000	40.000
12	400	200	40.000	42.000	9.500	24.000	60.000
10	400	200	25.000	26.000	6.000	24.000	60.000

Calculation of Percentage Elongation

$$= \frac{elongation}{original\ \ length} \times 100$$

Calculation of Yield Strength

Yield Strength = $\frac{Yield\ \ Load\ \ in\ \ Newtons}{Cross-sectional\ \ Area\ \ in\ \ mm2}$

Calculations of Tensile Strength

Tensile Strength = $\frac{Load\ \ Taken\ \ To\ \ Break\ \ The\ \ Wire\ \ in\ \ Nwtons}{Cross-sectional\ \ Area\ \ in\ \ mm2}$

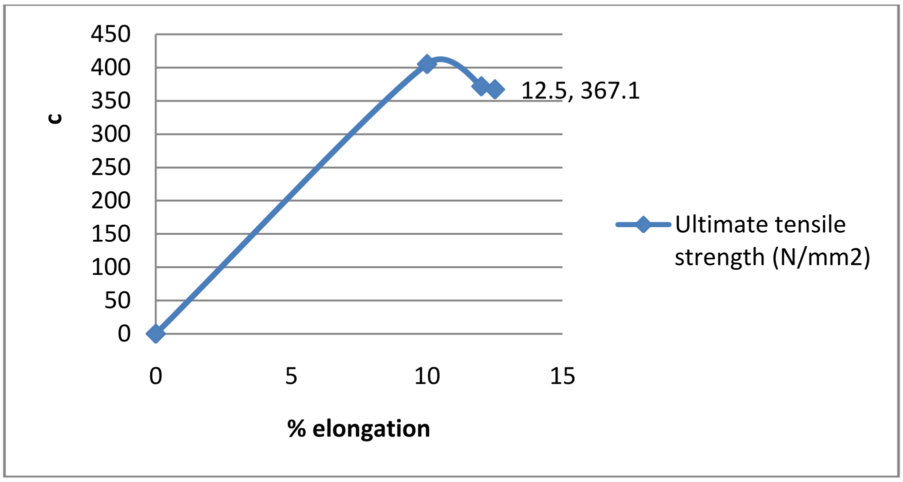

Figure 7: Graph of tensile strength against tensile strain of Y10 at 28 days

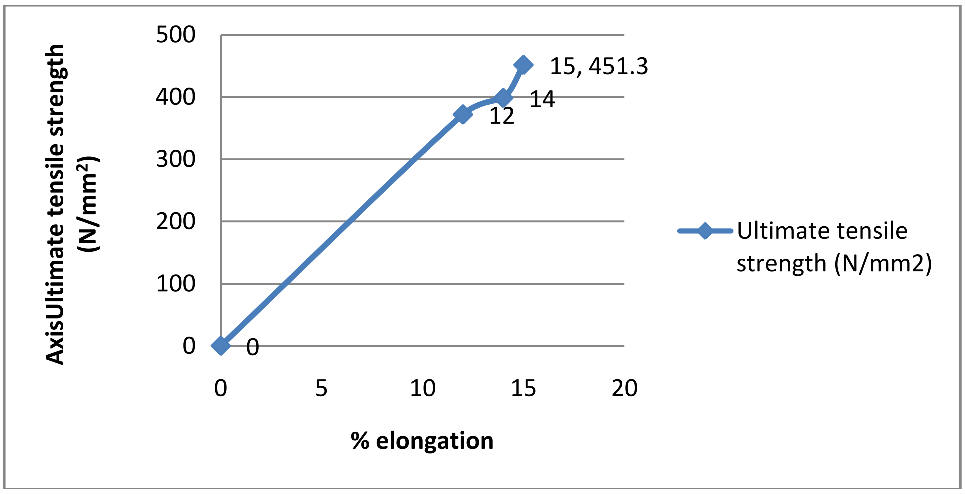

Figure 8: Graph of tensile strength against tensile strain of Y12 at 28 days

Table6: Results of tested steel (28 Days)

Diameter (mm)	Area (mm^2)	Elongation (mm)	% elongation (%)	Diameter reduction (mm)	% reduction in area (mm^2)	Yield strength (N/mm^2)	Ultimate strength (N/mm^2)	Time (min)
12	113	30	15	8.3	52.2	442.5	451.3	20
10	79	20	10	6.4	59	392.4	405.1	20
12	113	28	14	9.5	37	380.5	398.2	40
10	79	25	12.5	6.4	59	341.8	367.1	40
12	113	24	12	9.5	37	354	371.7	60
10	79	24	12	6.0	64	316.5	329.1	60

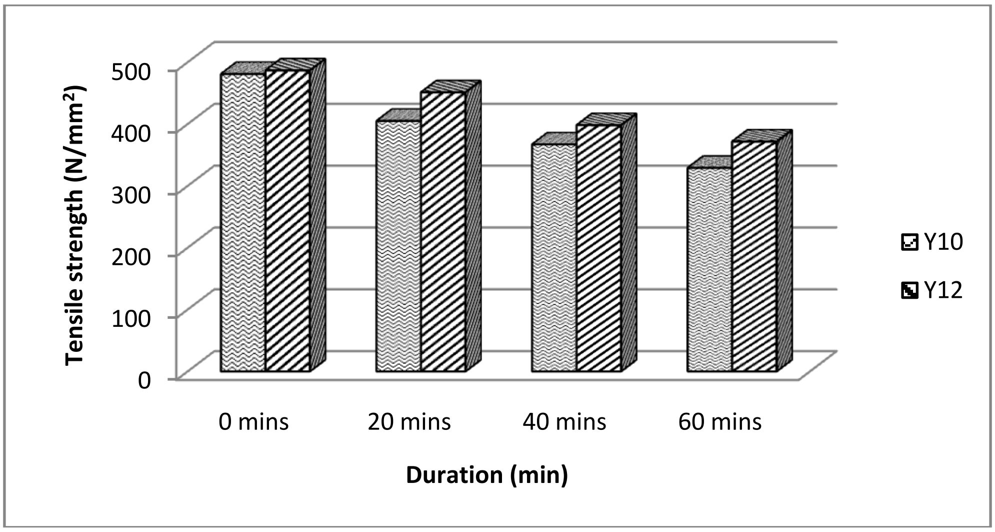

Figure 9: Graph of tensile strength with duration of fire (28 days)

Figure 4.4 and 4.5 shows the relationship between stress and % elongation (strain) of steel (Y10 and Y12) which is a linear relationship and later brakes. Also figure 4.6 is a bar representation of the steel ultimate tensile strength of control specimen, Y10and Y12 at various duration as seen above.

III. CONCLUSION

The project was conducted in order to test and understand the strength of steel reinforcements in reinforced concrete beam when exposed to fire. The strength of the reinforcement reduces as their time of exposure to fire increases. During the test, the following were ascertained:

- At the first 20 minutes of exposure to fire, no cracks appeared on the structure, hence the whole structure resist the temperature rise.At 40 minutes, cracks began on the beam.At 60 minutes of exposure to fire, spalling and cracks continued until the beam was removed from fire.
- The tensile strength of steel reduces as the time of exposure to fire increases for both the sample (Y10 and Y12 bars).
- Comparison of strength of control and tested specimen is given below:

Parameters	Tensile Strength of Y12 (N/mm^2)	Tensile Strength of Y10 (N/mm^2)
Control Specimen	486.7	481.0
21 Days of Curing (average)	423.3	384.0
28 Days of Curing(average)	401.3	367.1

However, a major advantage of steel is that it is incombustible and it can fully recover its strength following a fire, most of the times. During the fire steel absorbs a significant amount of thermal energy. After this exposure to fire, it returns to a stable condition after cooling to ambient temperature. During this cycle of heating and cooling, the steel members inside the beam became slightly bent and some got damaged, without affecting the stability of the whole member.

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