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ENHANCEMENT OF FIRE RESISTANCE OF REINFORCED CONCRETE BEAMS USING STEEL FIBERS

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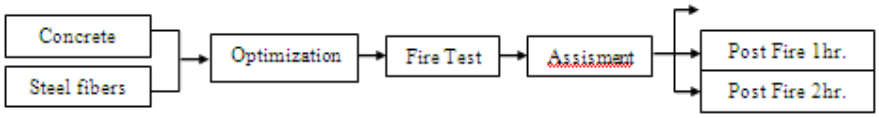
HIGHLIGHTS

- Application of crimped steel fibers in concrete with different volume fractions.
- Mechanical characteristics of steel fibers reinforced concrete (SFRC).
- The specimens were tested pre and post exposure to elevated temperatures (500°C) for one hour and two hours.
- (SFRC) improve the ductility at high temperature and at room temperature.
- (SFRC) enhance the ultimate tensile and flexural strength and have slight impact ultimate compressive strength.

GRAPHICAL ABSTRACT



ABSTRACT

In the last two decades recent interest has been shown in the use of steel fibers reinforced concrete (SFRC), since the tensile strength of the composite is higher than that of plain concrete and the use of fibers may lead to reduction in the amount of cracking under serviceability conditions. This paper investigated the application of crimped steel fibers in concrete with different volume fractions (0.5%, 1%, 1.5% and 2%). Standard specimens in forms of cubes, cylinders and beams were cast from each mix and tested in compression, tension and flexure at ages of 7 and 28 days. Tested specimens were subjected to elevated temperatures (500°C for one hour and two hours) and the results were compared and showed the enhancement level obtained due to utilizing steel fibers. The obtained results show that the addition of steel fibers has contributed to significant improves the ductility behavior of the concrete mixes for both pre and post elevated temperature testing. In addition, after 2 hrs. exposure to elevated temperature the experimental results show that each addition of steel fibers (by 0.5% volume fractions) enhances the ultimate compressive load for cubes specimens (by 10 to 15% from the control cubes). The ultimate splitting tensile load improved (by 25 to 37% from the control cylinders). The ultimate flexural load improved (by 36 to 39% from the control beams).

Keywords: concrete, steel fibers, ductility, strength, thermal effect.

1. INTRODUCTION

In the last two decades, steel fibers have been used for strengthening structural members of reinforced concrete structures exposed to elevated temperature. Previous investigation shows that steel fibers reinforced concrete (SFRC) resists high temperature more than plain concrete and SFRC with 1% hooked end fibers has a superior behavior after exposure to high temperature [1,10]. Also the inclusion of steel fibers in concrete reduces the amount of strength loss due to heating; the degree of strength deterioration depends on the fibers content and high temperatures, and the bulk flexural strength lose occurs within two hours of heat exposure [2, 9]. The compressive strength at elevated temperatures of steel-fibers-reinforced concrete is higher than that of plain concrete [3]. It is concluded that the mechanical properties of fibers-reinforced concrete are more beneficial to fibers resistance than those of plain concrete [11, 13]. Concrete mixes reinforced with steel fibers exposed to 600° and 800°C, retained, respectively, 45% and 23% of their compressive strength, on average [4]. The results also show that after the concrete was exposed to the elevated temperatures, the loss of stiffness was much quicker than the loss in compressive strength, but the loss of energy absorption capacity was relatively slower. Steel fibers approximately doubled the energy absorption capacity of the unheated concrete. The compressive strength and modulus of elasticity of plain and steel fibers reinforced concrete decreased after high temperatures exposure [5]. While other authors summarizes their research on fibers reinforced concretes at high temperatures and after heating and cooling down the concrete, that the fibers prevent concrete spalling [6, 12]. Also [7, 14] study the effect of fire flame exposure on compressive strength and splitting tensile strength of plain and fibers reinforced high strength concrete. The results obtained from this study indicated that damage of concrete caused by exposure to fire depends on the temperatures range and the duration of exposure to fire.

2. EXPERIMENTAL PROGRAM

2.1 Experimental materials

The materials used for preparing the test specimens are local available materials and the process of manufacturing is simulated as closely as common way of practice of concrete construction in Egypt, all the working technicians are experts and work by the Egyptian specification code, all the used apparatus are calibrated every year. The cement used in this study was Ordinary Portland Cement (OPC- CEM I). The fine aggregate used was medium graded sand, the coarse aggregate used was graded, mixed crushed stone no. 1 and 2, and Tap water was used for mixing and curing of all concrete specimens in this work. Superplasticizer ASTM C494 Type G, High Range Water Reducer (HRWR), and retarding admixtures are used to reduce the amount of water by 12% to 30%, while maintaining a certain level of consistency and workability and to increase workability for reduction in w/cm ratio and to compensate the loss of workability due to the use of steel fibers in the mix. The dosage was 0.8 liters per 100 Kg of cement. Crimped steel fibers were used in this investigation and the properties of these fibers are presented in Table-1 and Figure-1 show the shape of used steel fibers. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed volume fraction (V_f). V_f typically used percentages was (0.5, 1.0, 1.5 and 2.0%). Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). The workability decreases with increasing aspect ratio, in practice it is very difficult to achieve a uniform mix if the aspect ratio is greater than about 100. If the modulus of elasticity of the fibers is higher than that of the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material.

Table-1. Properties of steel fibers.

Density (kg/m^3)	**Tensile strength** (MPa)	**Length** (mm)	**Diameter** (mm)	**Aspect ratio** (l/d)
7840	1100	50	1	50

Figure-1. Crimped steel fibers.

2.2 Mixing of concrete

Mixing process was performed by using revolving drum tilting mixer of 0.1 m3 capacity. The aggregate used is in saturated surface dry condition. Coarse aggregate, sand and were primary placed in the mixer and they were dry mixed for about 1minute, the water and super-plasticizer were mixed apart to each other and then they were added to the mix and mixed for about 30 seconds. After that the cement was loaded to the mixer and mixed for about 5 minutes until the mix became homogeneous and finally the steel fibers is added by spreading over the mixture during a period of about one minute using a sieve and mixed for about another two minutes, this method of mixing is recommended in the ACI committee report 544 [8].

2.3 Preparation of specimens

Steel moulds were prepared include cubic specimens with internal dimensions of 150x150x150 mm for compressive strength, cylindrical specimens of 150×300 for splitting tensile strength, prismatic specimens of 150×150×600 mm for flexural strength. Control specimens were prepared from the same mix of plain (without fibers) and steel fibers reinforced concrete for each specimen. The beam and control specimens were covered with polyethylene sheet for about 24 hours, and then demoulded and prepared for curing.

2.4 Curing of specimens

After 48 hours from casting, the specimens were totally immersed in water, then the water was heated with slow rate (20°C per hour) until it reaches 60°C to prevent the formation of micro cracks in concrete. The temperature of the curing water remains constant at 60°C during 28 days. After curing the specimens were kept in the laboratory till the time of testing. The tested beams and the control specimens were immersed in the same curing pool and two automatic control heaters were fixed in the pool to heat the water and to keep its temperature approximately constant during the curing period.

2.5 Testing of specimens

After the specimens were removed from water and wipe out excess water from the surface, then the specimen was placed in the machine and the load was

applied gradually and continuously until the specimen fails. The maximum load was recorded. Due to difficulty in applying tension to concrete specimen, the tensile strength of the concrete is determined by indirect test method (split cylinder test), which varies between 1/8 to 1/12 of the cube compressive strength. The flexural test was performed for the concrete beam specimens; the beam was loaded at mid span line. The load was applied continuously until the specimen fails. The maximum load was recorded; some specimens were heated using computer-controlled electric furnace, see Figure-2, with peak temperature maintained at 500°C for 1 and 2 hours. Reading of temperature inside electric furnace was carried out by means of two thermocouples attached to the sides of the furnace. After letting the specimens to cool naturally to room temperature, heated specimens in forms of cubes, cylinders and beams were tested along with the non-heated specimens. The specimens were tested in compression, tension and flexure. The results show that the addition of steel fibers has contributed to decrease the brittle behavior of cement based materials, both at high temperature and at room temperature. In addition, the steel fibers have contributed to increase the ultimate tensile and flexural strength and slightly enhance ultimate compressive strength. It is now well established that one of the important properties of steel fibers reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, Fibers composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the Fibers are able to hold the matrix together even after extensive cracking.

Figure-2. Computer-controlled electric furnace.

2.6 Modes of failure

The following photos are shapes of failure of cubes, cylinders and beams specimen with and without steel fibers heated for 2 hr. shown in Figures 3 and 4. The specimens were tested in compression, tension and flexure. The results were compared and showed the enhancement level obtained by including steel fibers. Effect of fibers is significant since it allows transmission across cracks by bridging mechanism they offer. Steel fibers approximately doubled the energy absorption capacity of the unheated concrete. They were effective in minimizing the degradation of compressive strength for the concrete after exposure to the elevated temperatures.

Figure-3. Shape of failure of specimens heated for 2 hr. without steel fibers (Control).

Figure-4. Shape of failure of specimens heated for 2 hr. with steel fibers (2%).

3. TEST RESULTS AND DISCUSSIONS

The Mechanical behavior of the concrete cubes, cylinders and beams containing crimped steel fibers with different volume fractions (0.5%, 1%, 1.5% and 2%) and heated to 5000C for one hour and two hours is studied in this investigation. After 7 days the experimental results show that each addition of steel fibers (by 0.5% volume fractions) slightly enhances the ultimate compressive load for cubes specimens (by 6 to 7% from the control cubes). While the ultimate splitting tensile load increased (by 15 to 20% from the control cylinders) and the ultimate flexural load increased (by 14 to 19% from the control beams) as shown in Figure-5. After 7 days adding 2% steel fibers increase flexural and splitting strength by (62 and 71% resp.), while this enhancement was limited to 24 % in compression.

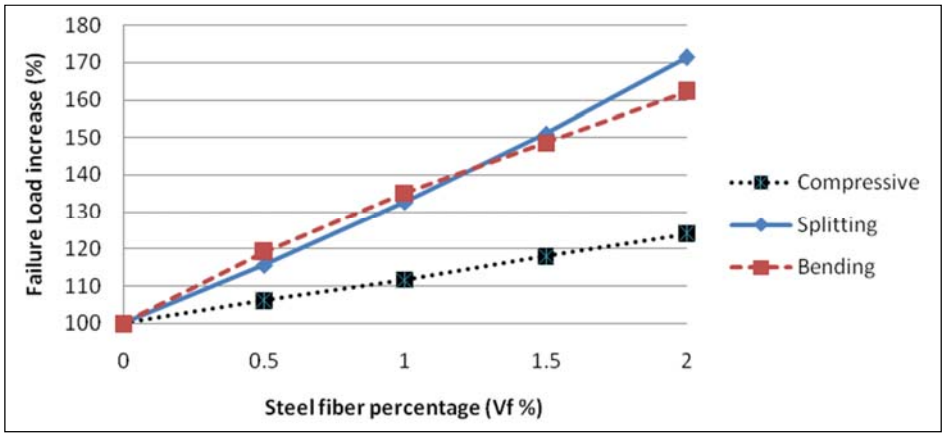


Figure-5. Failure loads after 7 days.

After 28 days the experimental results show that each addition of steel fibers (by 0.5% volume fractions) slightly enhances the ultimate compressive load for cubes specimens (by 4 to 5% from the control cubes). While the ultimate splitting tensile load increased (by 14 to 15% from the control cylinders) and the ultimate flexural load increased (by 12 to 15% from the control beams) as shown in Figure-6. Using 2% steel fibers increase flexural and splitting ultimate strength by (53 and 59% resp.), while this enhancement was limited to 15 % in compression.

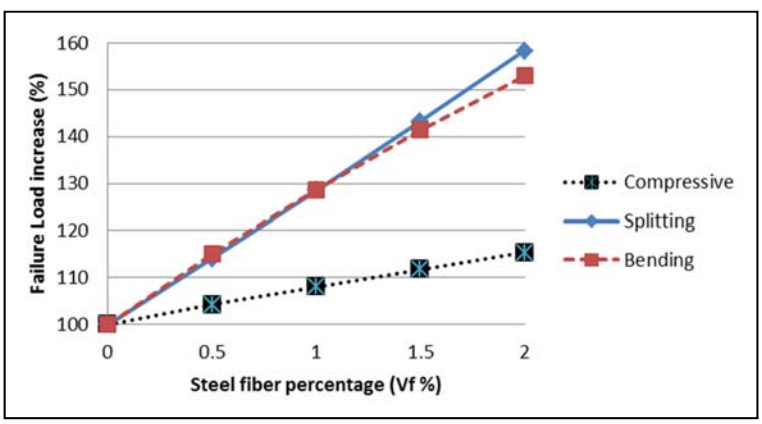


Figure-6. Failure loads after 28 days.

In order to investigate effect of elevated temperature on mixes, concrete cubes, cylinders and beams were subjected to elevated temperature at (500°C), in an electric oven, for one and two hours. Specimens were taken out of the furnace and cooled in ambient air. After 1 hr. exposure to elevated temperature the experimental results show that each addition of steel fibers (by 0.5% volume fractions) slightly enhances the ultimate compressive load for cubes specimens (by 10 to 13% from the control cubes). While the ultimate splitting tensile load increased (by 25 to 30% from the control cylinders) and the ultimate flexural load increased (by 30 to 33% from the control beams) as shown Figure-7 and 9 to 14. After 1 hr. exposure to elevated temperature the addition 2% steel fibers increase flexural and splitting ultimate strength by (124 and 111% resp.), while this enhancement was limited to 45 % in compression.

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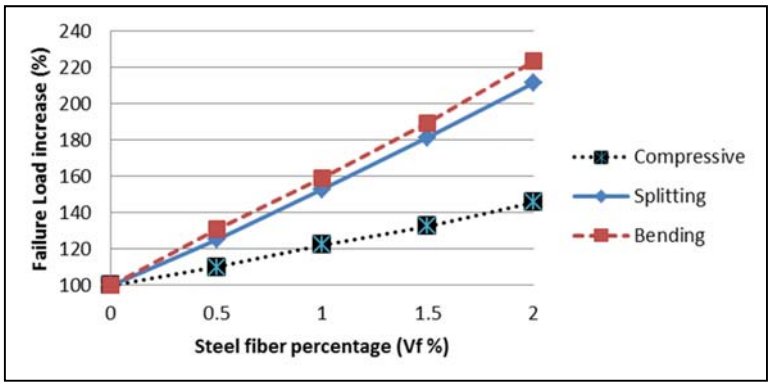

Figure-7. Failure loads after 1 hrs. exposure to elevated temperature.

After 2 hrs. exposure to elevated temperature (500°C) the experimental results show that each addition of steel fibers (by 0.5% volume fractions) slightly enhances the ultimate compressive load for cubes specimens (by 10 to 15% from the control cubes). While the ultimate splitting tensile load increased (by 25 to 37% from the control cylinders) and the ultimate flexural load increased (by 36 to 39% from the control beams) as shown in Figures 8 to 14.

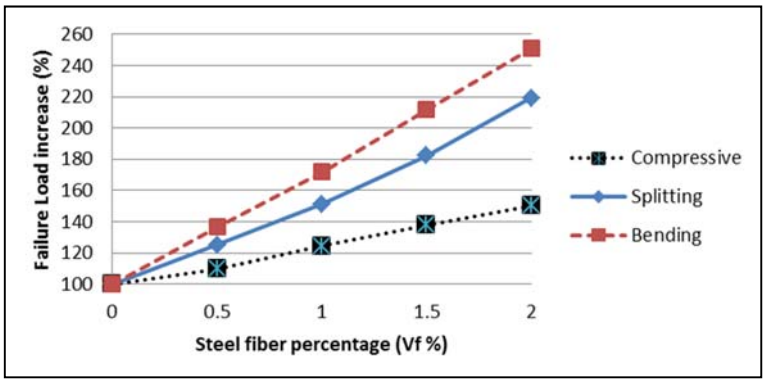

Figure-8. Ultimate loads after 2 hrs. exposure to elevated temperature.

After 2 hr. exposure to elevated temperature the addition 2% steel fibers increase flexural and splitting ultimate strength by (150 and 119% resp.), while this enhancement was limited to 50 % in compression.

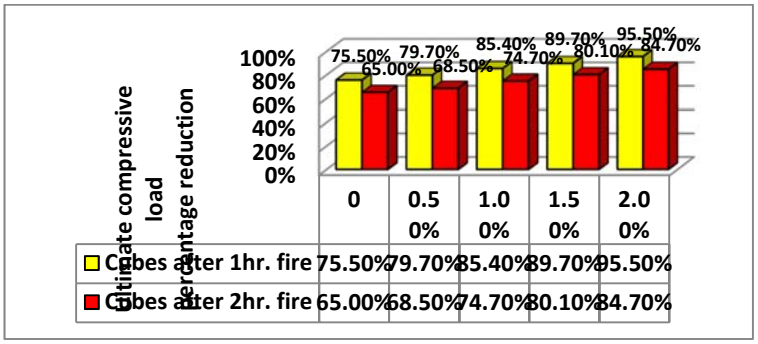

Figure-9. Reduction of ultimate load for cubes due to exposure to 5000 C.

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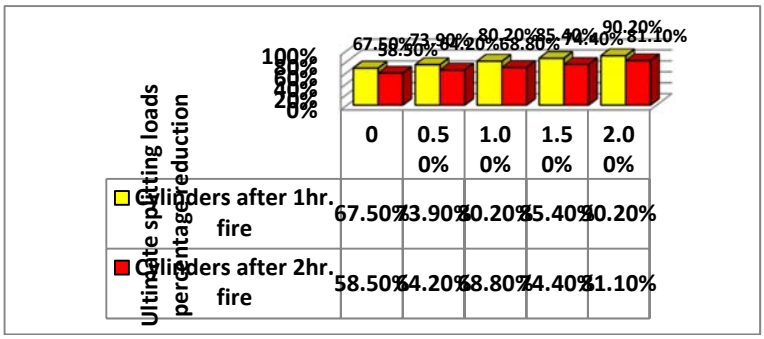

Figure-10. Reduction of ultimate load for cylinder due to exposure to 5000 C.

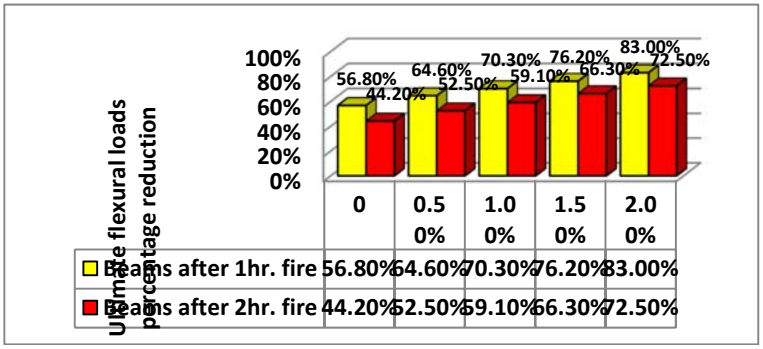

Figure-11. Reduction of ultimate load for beams due to exposure to 5000 C.

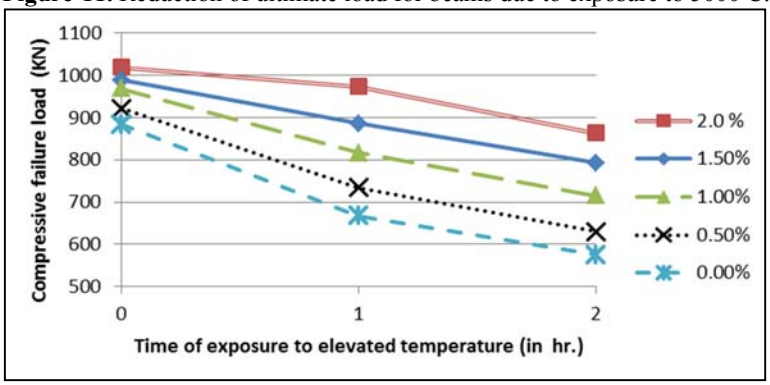

Figure-12. Decrease of compressive failure load due to expusure to elevated temp.

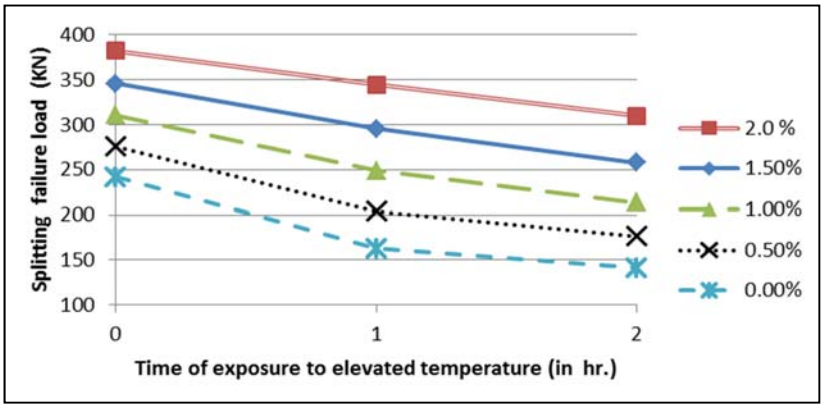

Figure-13. Decrease of splitting failure load due to expusure to elevated temp.

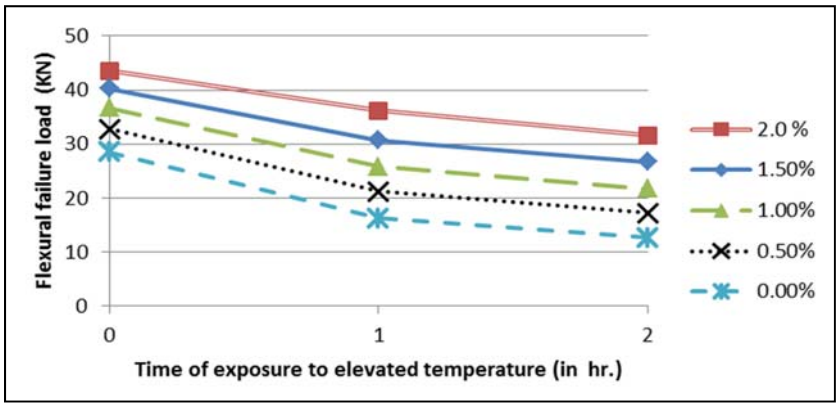

Figure-14. Decrease of flexural failure load due to expusure to elevated temp.

Using steel fibers in concrete significantly improved flexural and splitting strength behavior on exposure to elevated temperature (500º). This enhancement reached (28 and 23 % resp.) after 2 hours of fire exposure compared to control. While the compression strength improvement reached (20%).

4. CONCLUSIONS

The following are the main obtained conclusions:

1. Inclusion of fibers improves significantly heat resistance of concrete samples.
2. Elevated temperature affected most flexural strength, then splitting, then compression.
3. **7 days results** show that each addition of steel fibers by 0.5% enhances:
   - The ultimate compressive load increased (by 6 to 7% from control cubes).
   - The ultimate splitting tensile load increased (by 15 to 20% from control cylinders)
   - The ultimate flexural load increased (by 14 to 19% from control beams)
4. **28 days results** show that each addition of steel fibers by 0.5% enhances:
   - The ultimate compressive load increased (by 4 to 5% from control cubes).
   - The ultimate splitting tensile load increased (by 14 to 15% from control cylinders)
   - The ultimate flexural load increased (by 12 to 15% from control beams)
5. **After 1 hr. exposure to elevated temperature** the experimental results show that each addition of steel fibers by 0.5% volume fractions enhances:
   - The ultimate compressive load increased (by 10 to 13% from control cubes).
   - The ultimate splitting tensile load increased (by 25 to 30% from control cylinders)
   - The ultimate flexural load increased (by 30 to 33% from control beams)
6. **After 2 hrs. exposure to elevated temperature** the experimental results show that each addition of steel fibers by 0.5% volume fractions enhances:
   - The ultimate compressive load increased (by 10 to 15% from control cubes).
   - The ultimate splitting tensile load increased (by 25 to 37% from control cylinders)
   - The ultimate flexural load increased (by 36 to 39% from control beams).
7. **After 1 hr. exposure to elevated temperature** the experimental results show that
   - The ultimate compressive strength loss decreased from control cubes 24.5% to (20.30%, 14.60%, 10.30%, and 4.50%) for percentages (0.5%, 1.0%, 1.5% and 2.0%) steel fiber respect.
   - The ultimate splitting tensile strength loss decreased from control cylinders 32.5% to (26.10%, 19.80%, 14.60% and 9.80%) for percentages (0.5%, 1.0%, 1.5% and 2.0%) steel fiber respect.
   - The ultimate flexural strength loss decreased from control beams 43.2% to (35.40%, 29.70%, 23.80% and 17.00%) for percentages (0.5%, 1.0%, 1.5% and 2.0%) steel fiber respect.
8. **After 2 hr. exposure to elevated temperature** the experimental results show that
   - The ultimate compressive strength loss decreased from control cubes 35.0%to (31.50%, 25.30%, 19.90%, and 15.30%) for percentages (0.5%, 1.0%, 1.5% and 2.0%) steel fiber respect.
   - The ultimate splitting tensile strength loss decreased from control cylinders 41.5% to (35.80%, 31.20%, 25.60% and 18.90%) for percentages (0.5%, 1.0%, 1.5% and 2.0%) steel fiber respect.
   - The ultimate flexural strength loss decreased from control beams 55.8% to (47.50%, 40.90%, 33.70% and 27.50%) for percentages (0.5%, 1.0%, 1.5% and 2.0%) steel fiber respect.

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