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# Compressive and Split Tensile Strengths of Steel Fiber Reinforced Concrete Exposed to Temperature

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*Abstract*— **Compressive and split tensile strengths of steel fiber reinforced concrete (SFRC) subjected to temperature (20, 100, 200, 400 and 600 ºC) were experimentally investigated in this study. Four different volume percentages (0, 0.25, 0.5 and 0.75% by volume of concrete) of steel fibers were used. Concrete specimens were cured in water for 28 days and then allowed to dry for three days at laboratory temperature before subjected to heat for 2 hours in an electric furnace. After the completion of heating period, specimens were cooled down for 1 day at laboratory conditions and then tested for determining their compressive and split tensile strengths as well as ultrasonic pulse velocity (UPV). The relation between concrete strengths and temperature for steel fiber reinforced concrete (SFRC) were also discussed. The test results show that the compressive and split tensile strengths of steel fiber reinforced concrete are less affected by temperature as compared to those of control concrete (without fiber). The results of statistical analysis show a good linear relation between: 1) Compressive strength and temperature; 2) Split tensile strength and temperature for SFRC.**

*Index Terms*: **steel fiber reinforced concrete, temperature, compressive strength, split tensile strength, ultrasonic pulse velocity.**

## I. INTRODUCTION

Exposure of concrete to high temperatures lead to cracks and destruction of the cement paste structure, which as a result causes reduction in its mechanical properties [1,2]. The effect of temperature on concrete strength is well documented [3-7]. The work conducted by Nneka & Ikemefuna [3] showed that concrete heated to 300ºC had 36% losses in its compressive strength in relation to its original, while the reduction in compressive strength of concrete subjected to 400°C was about 46%. According to results reported by Kumar et al.,[4], there were a gradual decrease in the compressive strength of concrete when the temperature increased up to 400ºC.

The reduction in its strength at 600, 800 and 1000ºC were 60, 80 and 90%, respectively, compared to its original strength. Peng & Huang [1] state that under high temperatures, concrete experienced the change of pore structure, known as the 'microstructure coarsening effect', which is believed to be one of the reasons for the strength loss at temperatures below 600°C.

Steel fiber may be included into concrete mixtures because of its ability to restrict the growth of cracks and thus changing the brittle mode of concrete to a strong matrix with superior crack resistance, improved ductility and distinctive post-cracking behavior prior to breakdown [8-16].

Several studies have been conducted in order to investigate the effect of temperatures on properties of steel fiber reinforced concrete [17-21]. Sideris et al.,[17] reported that the addition of steel fibers does not significantly influence the behavior of residual strength in steel fiber reinforced normal strength concrete. The residual compressive strength is linearly reduced up to 700 ºC. Bezerra et al.,[18] concluded that the use of steel fibers in concrete-based materials significantly enhances their fire and heat-resistant characteristics.

In this experimental study, the effect of temperature on compression and split tensile strengths as well as ultrasonic pulse velocity of steel fiber reinforced concrete (SFRC) were investigated. Four different volume percentages (0, 0.25, 0.5 and 0.75% by volume of concrete) of hooked end steel fibers were used. Statistical analysis were also done in order to evaluate the relations between temperature and strengths of SFRC.

## II. EXPERIMENTAL PROGRAM

### *A. Materials Used*

Steel fiber reinforced concrete (SFRC) mixes were made of Ordinary Portland Cement, crushed limestone aggregates, sand, and hooked-end steel fibers. Cement type CEM I (42.5 N), manufactured by Helwan Company-Egypt, conforming to the requirement of BS EN 197-1: 2011 was used. Coarse aggregates with maximum size of 20 mm were used in this investigation. The apparent specific gravity, absorption, impact value and crushing value of the coarse aggregate are 2.68, 0.68%, 19.7% and 26.3%, respectively. Natural sand with an apparent specific gravity of 2.73 and absorption

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of 0.65% was used. The sieve analysis results of the aggregates are given in Table 1. Hooked-end steel fibers (Harex 01-32) (Figure 1) with 32 mm length and 3.8 mm width were used in the study. Three different steel fiber volumes of 0.25, 0.5 and 0.75% (by volume of concrete) were added (i.e. 19.63, 39.25 and 58.88 kg/m$^3$).

Table 1. Sieve analysis of used sand and coarse aggregate

| Sieve (mm) | Passing (%) | |
|---|---|---|
| | Coarse aggregate | Sand |
| 20 | 99.4 | - |
| 14 | 73.75 | - |
| 10 | 45.56 | - |
| 5 | 4.01 | 100 |
| 2.36 | - | 99.98 |
| 1.18 | - | 99.54 |
| 0.6 | - | 81.28 |
| 0.3 | - | 23.85 |
| 0.15 | - | 1.04 |

Figure 1 Steel fiber used in this study

## B. *Proportions and Mixing Procedure*

Mix design proportioning was performed by using weight-batching method and was designed in accordance with the Building Research Establishment (British method). Proportioning of concrete mixtures is shown in Table 2. All mixtures were mixed in a laboratory pan mixer with a volume capacity of 0.0607m$^3$. The mix ingredients placed in the mixer was in the following order; dry aggregates and cement were mixed in the mixer for 30 seconds. Then, steel fibers were added for 30 seconds and water was added gradually in 15 seconds and the mixing continued for 2 minutes. In order to avoid balling and interlocking between fibers, the fibers were added in small quantities during the mixing process. After mixing, the molds were filled with concrete and properly compacted by means of a vibrating table.

Table 2. Proportioning of concrete mixes

| Mix | Fiber (%) | (kg/m$^3$) | | | | |
|---|---|---|---|---|---|---|
| | | Fiber | Cement | Water | Sand | Coarse aggregate |
| 1 | 0 | 0 | 360 | 200 | 510 | 1310 |
| 2 | 0.25 | 19.63 | 360 | 200 | 510 | 1310 |
| 3 | 0.50 | 39.25 | 360 | 200 | 510 | 1310 |
| 4 | 0.75 | 58.88 | 360 | 200 | 510 | 1310 |

## C. *Curing of Test Specimens*

After casting, the specimens were left for 24 hours in the mould at laboratory conditions (20±2°C). Then, specimens were removed from the mould and kept in water for 28 days at 20°C.

## D. *Heating Procedure*

Electric furnace (Figure 2), with heat capacity up to 1200ºC, belong to the African Company in Benghazi – Libya was used to heat the concrete cubes and cylinders. Concrete specimens were taken from curing tanks and allowed to dry for 3 days at room temperature before exposed to heat in the furnace. The specimens were exposed to different temperature levels (100, 200, 400, and 600ºC) in the furnace for 2 hours duration. After achieving the required temperature and duration, specimens were exited from the furnace and allowed to cool down at room temperature for 24 hours. After that, the specimens transferred to the laboratory of civil engineering department for testing. For each temperature level, 12 concrete cubes and 12 concrete cylinders were tested for compressive and split tensile strengths, respectively.

Figure 2 Electric furnace used

## E. *Experiments*

The slump of freshly mixed concrete was measured according to BS1881: Part 102:1983. The standard cylinder of 100 mm diameter X 200 mm height was used for split tensile strength (BS 1881: Part 117:1983) and compressive strength was performed on 100 mm cube according to BS 1881:Part 116:1983.
Ultrasonic pulse velocity test was performed according to BS 1881: Part 203: 1986.

# III. RESULTS AND DISCUSIONS

## A. *Slump*

The results of slump is given in Figure 3. As the Figure shows, the slump decreases with the addition of steel fiber, and thus the workability decreases with increasing the steel fibers. This is because increasing the amount of fibers in the mix leads to better resistance against compaction. The lowest slump is obtained in mix with 0.75% fiber (mix 4). The reduction in slump is about 2.5 times lower compared to control concrete (without fiber) (mix 1).

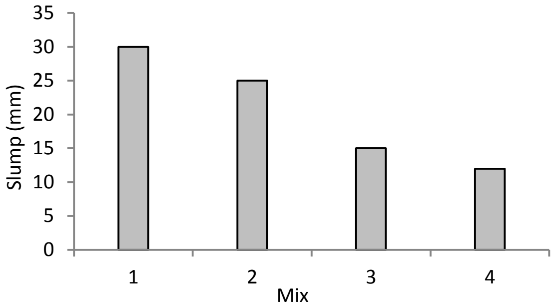



Figure 3 Slump test results

### B. *Compressive Strength*

Figure 4 shows the combined effect of temperature and fiber fraction on compressive strength of concrete specimens. In comparison to control concrete (without fiber), a slight increase in compressive strength with the addition of steel fiber is observed (Figure 4). An increase in compressive strength by about 2.4 % is observed with the addition of 0.75% fiber volume compared to control concrete. Elzaroug et al. [15] reported an increase in compressive strength by about 3.4% when steel fibers were used.

Exposure to heat causes reduction in compressive strength of concrete cubes, but this reduction decreases with the addition of steel fiber, as Figure 4 shows. For control concrete exposed to 600ºC, the reduction is about 65% compared to control concrete at 20ºC. While, the decrease in compressive strength is about 57% for concrete with 0.75% steel fiber and exposed to 600ºC compared to concrete with 0.75% steel fiber stored at 20ºC. The reduction in compressive strength of heated concrete specimens can be attributed to the induced microcracks which is restricted by fiber addition.

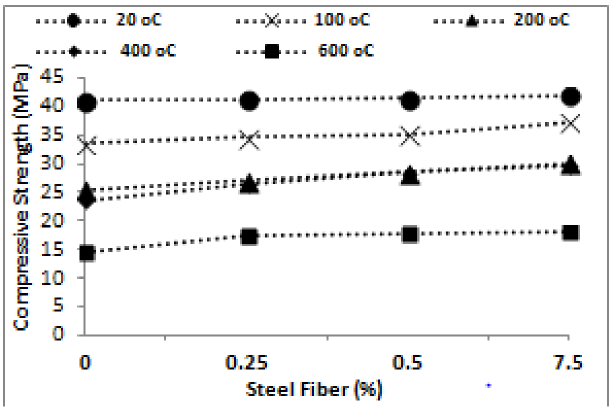



Figure 4 Compressive strength results

### C. *Split Tensile Strength*

The combined effect of temperature and steel fiber on split tensile strength of concrete is shown in Figure 5. The graph shows that increasing fiber volume fraction leads to increase the split tensile strength compared to control concrete (without fiber). The maximum increase in concrete split tensile strength is about 28% by adding 0.75% steel fiber compared to control concrete stored at 20ºC. Figure 5 shows decrease in split tensile strength of concrete cylinders when subjected to heat. This reduction decreases as fiber fraction increases in concrete mixes. For control concrete (without fiber), exposure to 600ºC causes a 80% reduction in split tensile strength compared to those stored at 20ºC, but the decrease in split tensile strength is only about 46% for concrete with 0.75% steel fiber and subjected to 600ºC compared to control concrete stored at 20ºC. Steel fibers increase the tensile strength because they bridge the end of formed cracks.

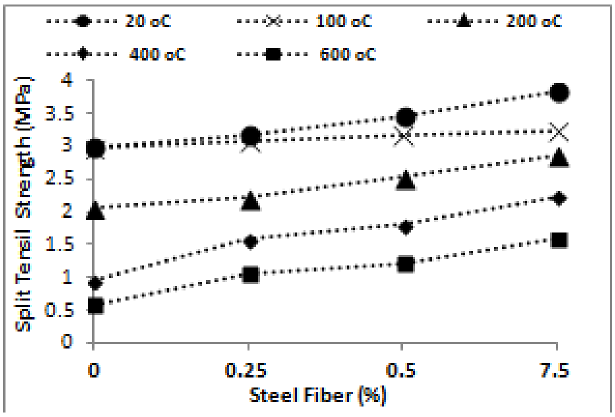



Figure 5 Split tensile strength results

### D. *Ultrasonic Pulse Velocity*

Figure 6 shows the combined effect of temperature and fiber fraction on ultrasonic pulse velocity (UPV) of concrete specimens. It can be clearly seen from the graph that exposure to heat causes reduction in pulse velocity of concrete specimens. For control concrete specimens exposed to 600ºC, the reduction is about 61% compared to those stored at 20ºC. The reduction in pulse velocity is due to initiation of cracks in concrete specimens.

Concrete specimens contain steel fibers and subjected to heat shows lower reduction in UPV compared to control concrete specimens. The reduction is about 58% for concrete with volume fraction of 0.75% steel fiber and exposed to 600ºC compared to concrete with 0.75% steel fiber and stored at 20ºC. Generally, the addition of steel fibers lead to a slight increase in the values of pulse velocity (Figure 6).

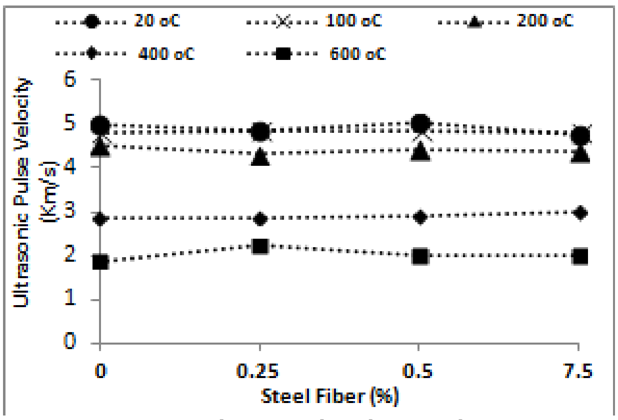



Figure 6 Ultrasonic pulse velocity results

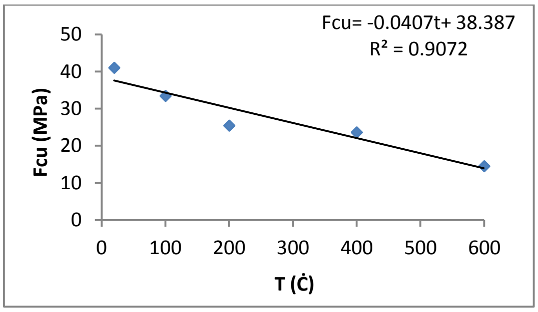
## E. Statistical Analysis

A regression analysis was done in order to evaluate the correlation between: 1) Compressive strength (Fcu) and temperature (T) and; 2) Split tensile strength (Fspl.) and temperature (T) for different fiber content. From Figures 7 and 8, it is clear that there are a good linear relations between concrete strengths and temperature for SFRC. Therefore, a linear regression was obtained by using the following equations;

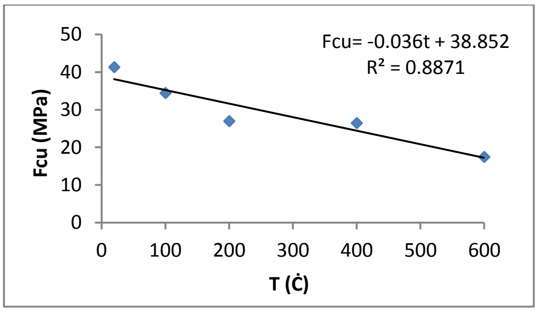
$$F_{CU} = A\,(T) + B. \qquad (1)$$

$$F_{spl.} = c\,(T) + d. \qquad (2)$$

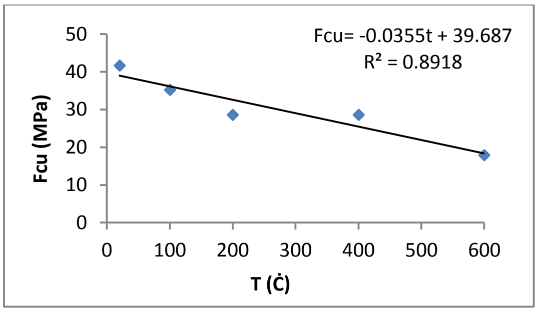
Where; a, b, c and d are regression coefficients. The results of regression analysis are as given in Tables 3 and 4 in terms of regression coefficients (a, b, c and d) and correlation coefficient (R2). From correlation coefficient values, it can be said that regression analysis gives good results for SFRC subjected to high temperature up to 600°C.



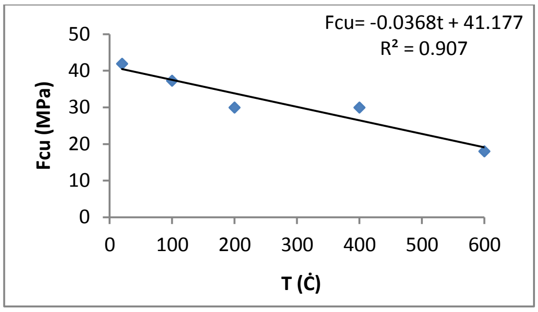

*Concrete cubes with 0% Steel Fiber*




*Concrete cubes with 0.25% Steel Fiber*

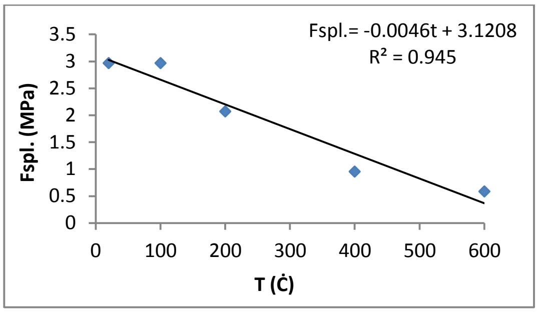



*Concrete cubes with 0.5% Steel Fiber*

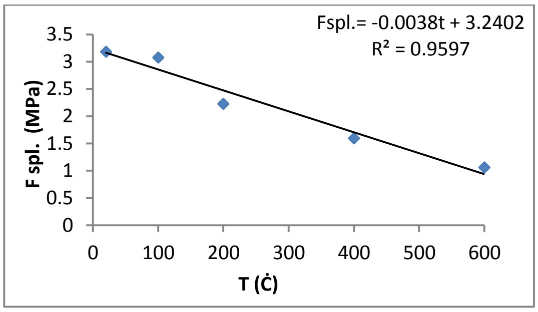



*Concrete cubes with 0.75% Steel Fiber*

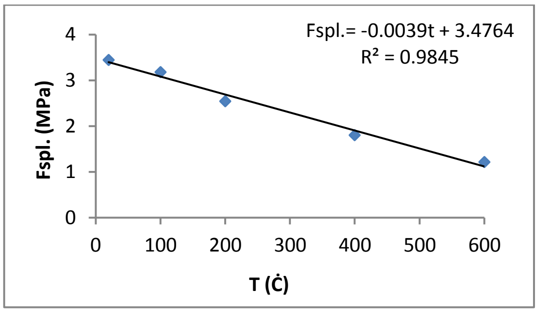
Figure 7 Relation Between Compressive Strength ($F_{cu}$) and Temperature (T) for SFRC



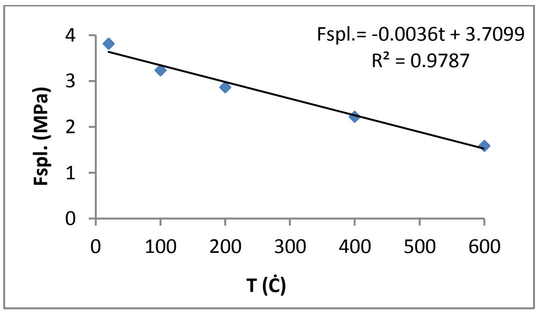

*Concrete cylinders with 0% Steel Fiber*




*Concrete cylinders with 0.25% Steel Fiber*




*Concrete cylinders with 0.5% Steel Fiber*




*Concrete cylinders with 0.75% Steel Fiber*

Figure 8 Relation Between Split Tensile Strength ($F_{spl.}$) and Temperature (T) for SFRC

Table 3. Regression analysis results for compressive strength ($F_{cu}$) with temperature (t)

| Steel Fiber (%) | Regression Coefficient | | Correlation Coefficient ( $R^2$ ) |
|---|---|---|---|
| | a | b | |
| 0 | -0.0407 | 38.387 | 0.907 |
| 0.25 | -0.036 | 38.852 | 0.887 |
| 0.5 | -0.0355 | 39.687 | 0.892 |
| 0.75 | -0.0368 | 41.177 | 0.907 |

Table 4. Regression analysis results for split tensile strength ($F_{spl.}$) with temperature (t)

| Steel Fiber (%) | Regression Coefficient | | Correlation Coefficient ( $R^2$ ) |
|---|---|---|---|
| | c | d | |
| 0 | -0.0046 | 3.1208 | 0.95 |
| 0.25 | -0.0038 | 3.2402 | 0.96 |
| 0.5 | -0.0039 | 3.4764 | 0.98 |
| 0.75 | -0.0036 | 3.7099 | 0.98 |

# IV. CONCLUSIONS

The following findings can be drawn from the obtained results:

- The slump decreases with the addition of steel fiber which is related to the improvement in compaction resistance.
- The addition of steel fiber has slight effect on compressive concrete strength. However, split tensile strength of concrete show noticeable improvement with the addition of steel fiber. The maximum increase in split tensile strength is about 28% by adding 0.75% steel fiber. This can be attributed to arresting cracks by the addition of steel fiber, which changes the mode of failure of concrete from brittle to ductile when the steel fiber presents in the concrete mix.
- Exposure to high temperature causes significant reduction in compressive and split tensile strengths of concrete. Control concrete (without fiber) exposed to 600ºC showed 65% and 80% reduction in compressive and split tensile strengths, respectively compared to those stored at 20ºC. The reduction in strengths due to exposure to temperature for concrete reinforced with steel fibers are less compared to non-reinforced concrete.
- A regression analysis provides a good linear relation between concrete strengths and temperature for steel fiber reinforced concrete.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