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(Research Article)



# Simulating the effect of elevated temperature on the compressive strength of steel fiber reinforced concrete (SFRC) using ANSYS workbench

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## Abstract

The behavior of concrete structures at elevated temperatures is of significant importance in predicting the safety of structures in response to certain accidents or particular service conditions. The behavior of M50 Steel Fiber Reinforced Concrete (SFRC) at 28-days strength subjected to elevated temperatures was simulated using ANSYS 2020 R2 Workbench, and results validated with experimental results from a referenced Journal. M50 concrete at 28-days was modelled along with steel fibers from 0 to 4% by weight of cement. Models were made and subjected at room temperature, 100, 200, 300, 400 and 500°C from ANSYS Workbench Static Structural module. The concrete matrix was modelled as solid body, while the steel fiber reinforcement as line bodies, the new ANSYS reinforcement workflow that allows for simulating proper bond between concrete and rebar was utilized. Compressive strength results were determined as Average Von-misses stress and results validates that obtained from the referenced literature. This work has developed results with variations compared to the experimental work largely below 5% and has given important reasons to assert that results obtained from experimental works can be obtained with FE simulations and that laboratory works can be simulated with FE programs to cut down on cost and time associated with the former. In other words ANSYS Workbench program is a good validatory tool for similar experimental research.

**Keywords:** Simulation; Finite Element; ANSYS Workbench; Elevated Temperature; Fiber Reinforced Concrete (FRC)

## 1. Introduction

Experimental study on the behavior of concrete subjected to compressive stress gives the exact behavior of the structure but is time consuming and expensive [3]. ANSYS works on finite element method. Finite element analysis is used for evaluation of the structures gives accurate and fast results compared to experimental study [4]. ANSYS is one of the tools used to determine the behavior of concrete structures subjected to stress. Finite element method is a numerical analysis method that divides the element into smaller parts and analyze the element under given loading conditions and hence evaluates the response of the material. The response of the element is represented in terms of finite number of degrees of freedom as the value of unknown function in set of nodal points. Most of the problems are non-linear in nature. Hence the non-linear analysis is an effective tool to obtain the exact solution [3]. Non-linear analysis is a method that stimulates the exact behavior of the material in inelastic range and to identify the potential of high load carrying capacity of the components through redistribution and shear strength [4]. Steel fiber reinforced concrete (SFRC) reduces the concrete brittleness and tensile capacity [2]. It contains short discrete fibers (steel fibers) that are uniformly distributed and randomly oriented. Concrete has excellent properties in regards of fire resistance compared to other materials and can be used to shield other structural material such as steel. ANSYS will aid engineers get a better understanding the exact behavior of the materials.

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## 2. Literature review

From the literature reviewed in this study a number of works has been done on the effect of elevated temperature on concrete mixes. Due to space limitations, some of the most relevant ones are presented below.

Shinkar1 et al., 2018 [6] work deals with the mechanical properties of concrete with steel fibers subjected to temperatures up to 500°C. The specimens were kept in oven for 1 hour. Different materials were used in the concrete mixes of M 50 have been designed along with crimped steel fibers from 0.5 to 4% by weight of ordinary Portland cement and river sand was used. Specimens were made and subjected to room temperature, 100, 200, 300, 400 and 500°C. In this study, the statically related (model) between compressive and tensile strength value is introduced. Regression analysis is used to obtain this type of relation. This investigation developed some important data on the properties of concrete exposed to elevated temperatures up to 500°C.

Tomasz et al., 2017 [5] researched on the evaluation of the changes of the physical and mechanical properties of HPC exposed to the effect of high temperature. The tests were carried out on three types of high-performance concrete: air entrained concrete, polypropylene fiber-reinforced concrete and reference concrete having constant water/cement ratio. The properties of hardened concrete including compressive strength, tensile splitting strength, flexural strength and E-modulus were studied. The latter tests were carried out both on concrete cured at 20°C and concrete subjected to high-temperature conditions at 300°C, 450°C and 600°C. The results enabled us to evaluate the effect of high-temperature conditions on the properties of high-performance concrete and compare the effectiveness of the two methods designed to improve the high-temperature performance of the concrete: addition of polypropylene fibers and entrainment of air.

Rajwanlop et al., 2016 [7] presents the finite-element procedure for fatigue evaluation of reinforced concrete bridge deck under the application of truck wheel load. The approach is based on the smeared crack concept with the introduction of the fatigue tests of concrete and reinforcing steel available in the literature and the Palmgren-Miner linear criterion of cumulative damage in the analysis. The models are validated with the fatigue test of 1/6.6-scale AASHTO bridge deck under the application of fixed-point repetitive loading presented in previous study. Results are in good agreement. Significant contribution of the developed approach to the fatigue evaluation of bridge deck is a series of S-N relations which can be simulated at any desired levels of damage. This permits the investigation of the deterioration of bridge deck which is appeared to be useful information for highway agencies to prolong the life of their bridge decks. S-N relations are simulated at crack areas of 10%, 20%, 30%, and 40% of the bottom surface area of the deck slab to represent the propagation of crack. Deterioration of bridge deck subjected to passages of five-axle double-unit trucks in Thailand is investigated to demonstrate the application of the simulated S-N relations.

## 3. Description of the fiber reinforced concrete cube model

Experimental analysis is widely carried out to study individual component members under uniformly distributed load spread through the top of the cube. This method provides the actual behavior of the structure, but it is time consuming and expensive. The development in the software modelling and analysis of structural elements has become simple. The finite element analysis is one of such tools.

### 3.1. Geometry of the FRC Cube

Dimensions of the FRC cube considered for this study is (100mm x100mm x 100mm and 40mm long steel fiber). The cube is fixed at the bottom end. Loads are uniformly applied at the top end of the cube. The details of the FRC cube are shown in Figure 1.

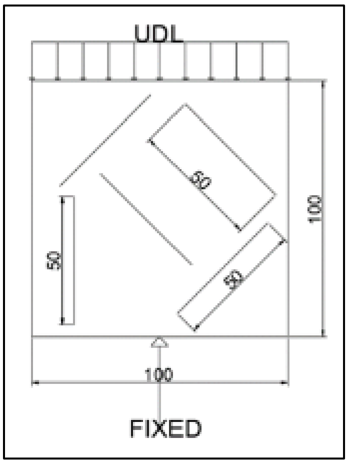


**Figure 1** FRC Cube section details

### 3.2. Material Properties Model:

The grade of concrete used for the FRC cube was M50, elastic modulus was 30000MPa and poison's ratio was 0.18 whereas the steel fiber used has Elastic modulus of 200000MPa, poison's ratio of 0.3 and an average aspect ratio of 50 as sourced from the reference Journal [1]

The material properties where modeled and simulated from the ANSYS Engineering data module available in the Work bench platform (Figure 2)

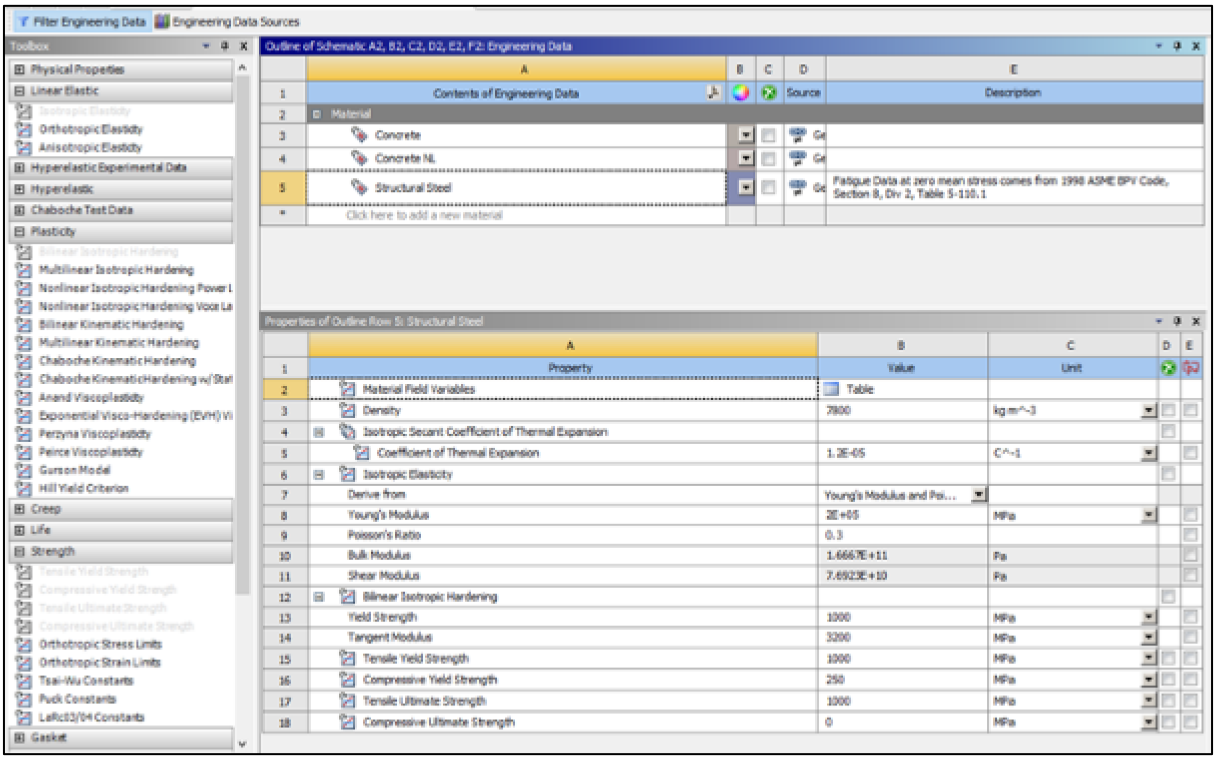


**Figure 2** Concrete and SFR material properties model in ANSYS Engineering data

### 3.3. 3D-Modelling/ Element Type

The Design Modeler in ANSYS workbench is where the actual 3D modeling was performed. The Design Modeler was used to model the 100x100x100mm concrete cube which generated a solid body as well to incorporate the randomness of the fiber in concrete cube and to also add cross-section to the steel fiber.

Line bodies were created on different planes of the modelled concrete cube and patterned in different directions to in cooperate the randomness of the fiber in the concrete matrix in the Design Modeler. The finite element model is shown in Figure 3. The dimensions for the FRC cube are presented in Table 1.

The ANSYS design modeler was used for 3D modelling of the concrete cube as well as to incorporate the randomness of the steel fiber. The concrete is capable of cracking in tension and crushing in compression [4]. The geometry and node locations for this element are shown in Figure 2. The default element coordinate system is along global directions.

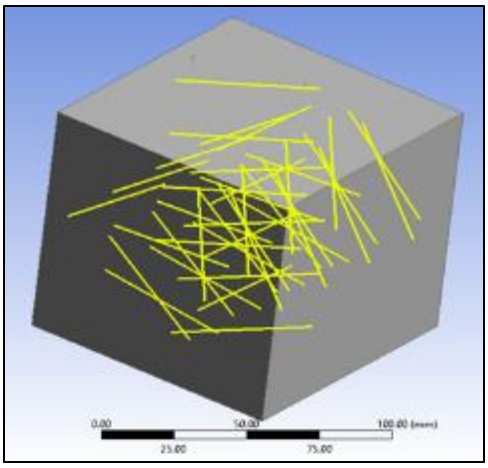


**Figure 3** SFRC Cube 3D Matrix and Fiber Model

### 3.4. Meshing

**Table 1** Dimension for SFRC Cube

| ANSYS | Concrete (mm) | Steel fiber (mm) |
|---|---|---|
| X1, X2, X-coordinates | 100 | 50 |
| Y1, Y2, Y-coordinates | 100 | 50 |
| Z1, Z2, Z-coordinates | 100 | 50 |

In other to obtain a close result to the experimental results, mesh refinement technique was employed. The SFRC cube was meshed using the body sizing option such that it was considered a tetrahedral element of size 5mm.

The mesh statistics showed the number of Nodes and elements as 36,061 and 8,160 respectively. The meshing of the SFRC cube is shown in Figure 4.

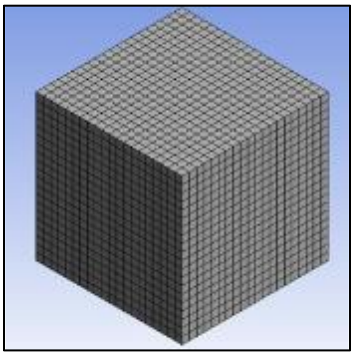

**Figure 4** SFRC Cube 3D Mesh

### 3.5. Loads and Boundary Conditions

Displacement conditions were needed to constraint the model to get a unique solution. The base of concrete cube was fixed to replicate a flat surface and the force applied at the top in the Y-axis direction. The failure loads as deduced from the experimental work were applied uniformly over the top of cube as forces. The loading and boundary conditions of the cube is shown in Figure 5. The failure loads for the various percentages of fiber and different temperature are presented in Table 2.

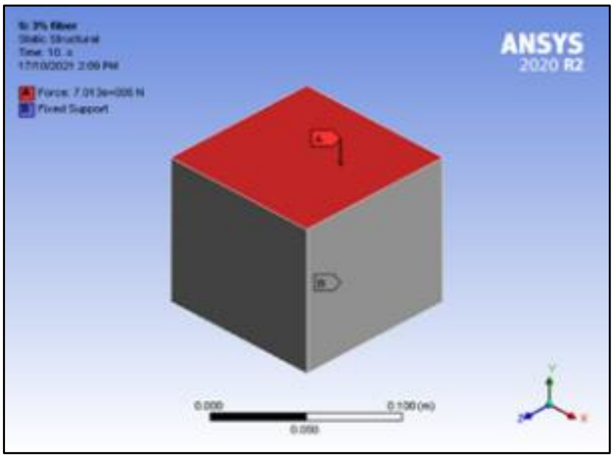


**Figure 5** Boundary condition on 3D Model

### 3.6. Temperature effect

The effect of elevated temperature on the concrete cube was achieved by raising the environmental temperature of the static structural interface, which simulates various ranges at which the experimental model was heated.

### 3.7. Analysis Type and Settings

ANSYS Static Structural analysis was performed from the ANSYS workbench platform. A Non-linear analysis was done to account for non-linearity that might exist in the material and Models geometry.

**Table 2** Test failure loads

| | | | **Failure loads (N)** | | | |
|---|---|---|---|---|---|---|
| **Temperature(C)<br>% Steel Fibre** | **27** | **100** | **200** | **300** | **400** | **500** |
| 0 | 582700 | 754200 | 721300 | 652000 | 572000 | 349800 |
| 1 | 624000 | 804000 | 784000 | 748000 | 603100 | 374200 |
| 2 | 690200 | 842700 | 838200 | 792000 | 636000 | 414200 |
| 3 | 349800 | 349800 | 349800 | 349800 | 349800 | 406200 |
| 4 | 651100 | 793300 | 758200 | 716000 | 598200 | 361300 |

## 4. Results and discussion

While modelling the SFRC cube for the compressive strength test, the cubes were modelled to simulate laboratory works. Using the data obtained from the numerical analysis of the SFRC cube, average equivalent Von-Misses stress values in the cubes were obtained. The results obtained from ANSYS analysis as well as the obtained results from the laboratory work were summarized in Table 3. Figures (6 -11) showed Equivalent Von-Misses contour plots of models for only 0 to 4% Fibers at 100°C, while Figure 12 showed a plot of the Compressive Strengths of the SFRC cubes over various ranges of Temperatures considered in the research Simulation.

**Table 3** Experimental and Simulated 28-days Compressive Strengths of SFRC

| **28 days compressive strength** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T(⁰C) SF(%)** | **27** | | **100** | | **200** | | **300** | | **400** | | **500** | |
| | Expt. | ANSYS | Expt. | ANSYS | Expt. | ANSYS | Expt. | ANSYS | Expt. | ANSYS | Expt. | ANSYS |
| 0 | 58.27 | 56.47 | 75.42 | 73.62 | 72.13 | 69.19 | 65.20 | 62.84 | 57.20 | 55.48 | 34.98 | 34.06 |
| 1 | 62.40 | 61.75 | 80.40 | 79.61 | 78.40 | 77.63 | 74.80 | 74.07 | 60.31 | 59.64 | 37.42 | 36.71 |
| 2 | 69.02 | 70.22 | 84.27 | 86.25 | 83.82 | 85.78 | 79.20 | 80.92 | 63.60 | 64.40 | 41.42 | 40.93 |
| 3 | 70.13 | 73.11 | 83.11 | 87.49 | 81.33 | 85.52 | 78.80 | 82.71 | 65.96 | 68.42 | 40.62 | 40.39 |
| 4 | 65.11 | 66.30 | 79.33 | 81.49 | 75.82 | 77.77 | 71.60 | 73.29 | 59.82 | 60.45 | 36.13 | 35.75 |

From figure 12, it was generally observed that, the in cooperation of Steel Fibers in Concrete showed a progressive increase of Concrete compressive Strength from 0% (Control) up to 3% Fiber. However, at 4% Fiber, the Strength decreased an indication that 3% is the Optimum addition.

Figure 12 also showed clearly that between 27°C (Room Temperature) and 100°C, SFRC compressive strength increases for all percentages of Steel Fibers in cooperated, but beyond 100°C, a progressive decrease in the Strengths were observed. However the result indicated that SFRC can withstand temperatures up to 400°C without compromising its design strength (i.e. M50 at 28-days), because the graph clearly showed that only at 500°C the SFRC compressive strength dropped below the design strength.

Finally, it was also observed that the ANSYS Simulated results are closely correlated with those obtained from the laboratory Experiment as shown in both Table 4 and Figure 12. The curve pattern of the Strength and Temperature plots for the SFRC are Similar and Table 4 summarizes the degree of deviation of the simulated values from the Experimental results.

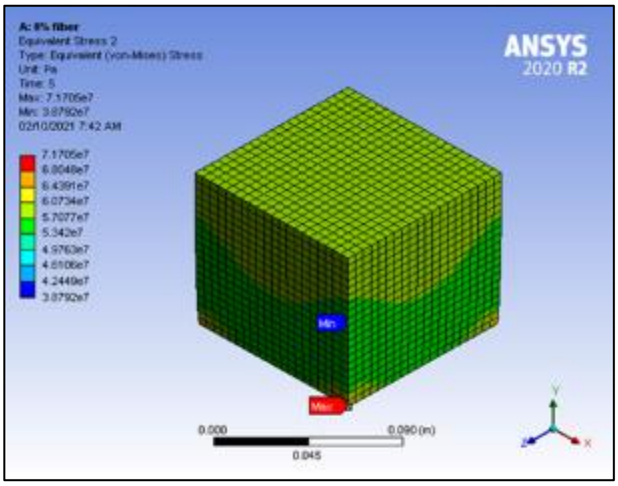


**Figure 6** Equivalent Stress Contour at 0% Fibre-27°C

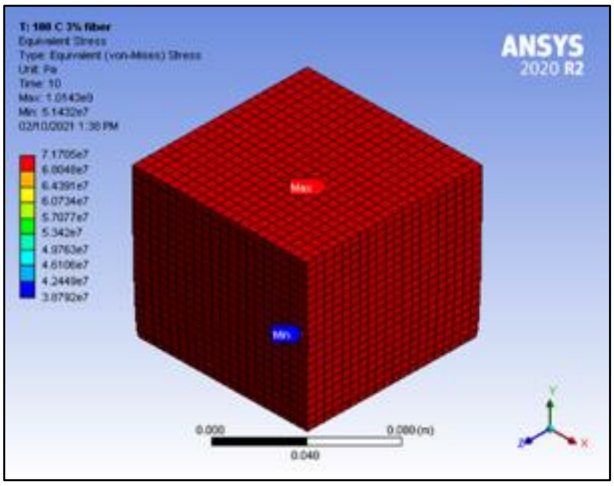


**Figure 7** Equivalent Stress Contour at 1% Fibre-100°C

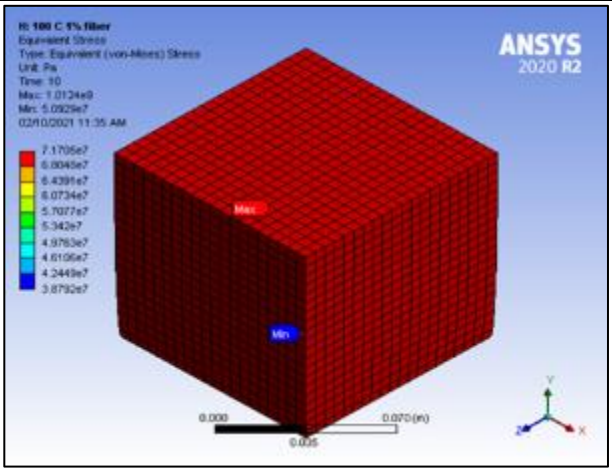


**Figure 8** Equivalent Stress Contour at 2% Fibre-100°C

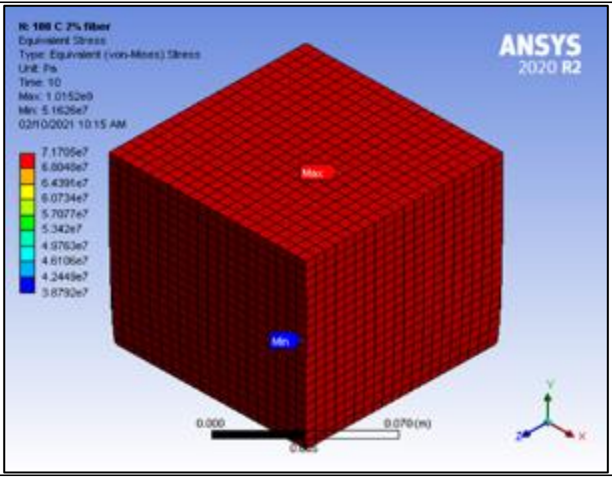


**Figure 9** Equivalent Stress Contour at 3% Fibre-100°C

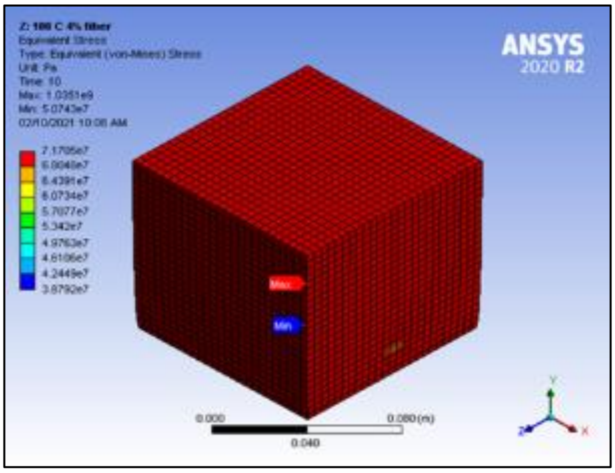


**Figure 10** Equivalent Stress Contour at 4% Fibre-100°C

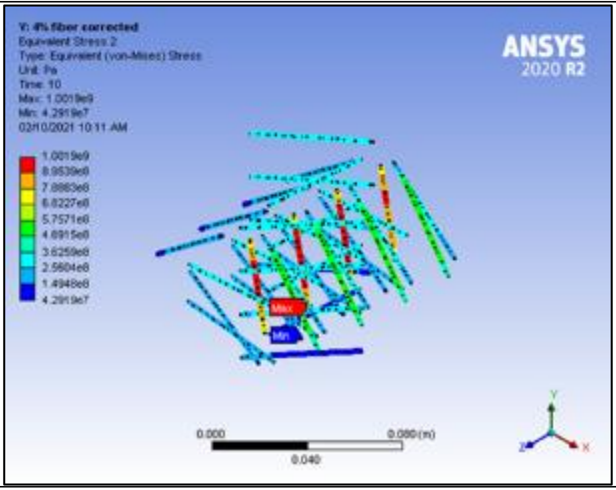


**Figure 11** Equivalent Stress Contour at 4% Fibre-100°C (Showing Fibre Stress)

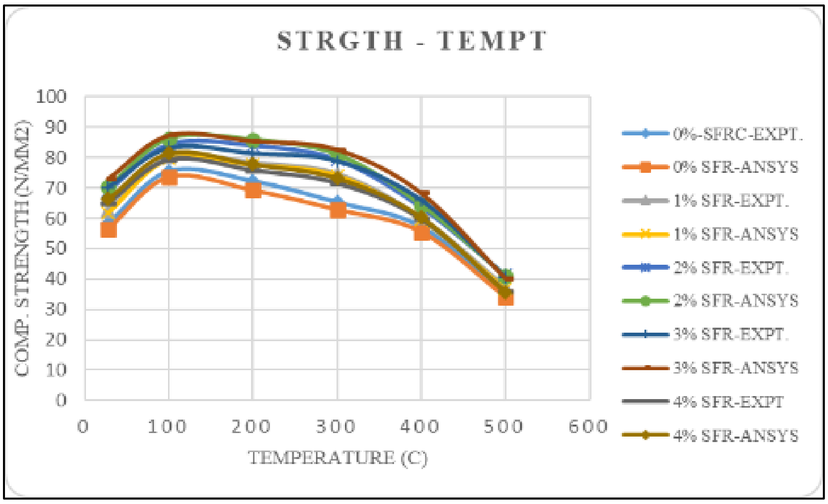


**Figure 12** Strength and Temperature relationships at varying SFR

### 4.1. Percentage Error

The percentage error between the laboratory work and the ANSYS analysis results were also computed and tabulated in Table 4. From the various percentage error calculated, it was visible that the results obtained are within acceptable limits as greater percentages of the samples have percentage error less than 5% which signifies 95% confidence with ANSYS result.

**Table 4** Standard Error between Experimental and Simulated 28-days Compressive Strengths of SFRC

| | | | **Error (%)** | | | |
|---|---|---|---|---|---|---|
| **Temperature(C) % Steel Fibre** | **27** | **100** | **200** | **300** | **400** | **500** |
| 0 | 3.09 | 2.39 | 1.45 | 3.61 | 3.00 | 2.64 |
| 1 | 1.04 | 0.99 | 0.98 | 0.97 | 1.11 | 1.89 |
| 2 | 1.73 | 2.35 | 2.34 | 2.17 | 1.26 | 1.18 |
| 3 | 4.25 | 5.27 | 5.15 | 4.97 | 3.72 | 0.56 |
| 4 | 1.83 | 2.73 | 2.57 | 2.35 | 1.06 | 1.05 |

## 5. Conclusion

In this research work, the effect of elevated temperature on the Compressive Strength of SFRC was studied using ANSYS and results validated with results of a laboratory work sourced from a published Journal source. After modelling, simulating and analyzing results from ANSYS and Comparing with the referenced results, the following conclusion were drawn:

Steel Fiber reinforced concrete can be modelled with fibers randomly distributed within the concrete matrix with the help of the ANSYS Design Modeler.

From the analysis, results of Compressive Strength at different temperatures range can be obtained as Average Von-Misses Stresses in ANSYS Work bench Static Structural module.

From the results obtained after comparison, it was clear that ANSYS was capable of simulating the effect of elevated temperature on SFRC as such, the aim of the research was achieved.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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