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Analysis of Flexural Capacity of Fiber Reinforced Concrete Pavements

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Abstract: This paper aims to investigate and understand the effect of two different types of discrete fibers and various volumes on the mechanical properties of concrete by using the cylinder and beam specimens. Additionally, the excremental results were simulated by the Finite Elements Method (FEM) through the ANSYS software program. The mechanical properties for seven cases in this study related to Fiber Reinforced Concrete (FRC) included compressive strength, modulus of elasticity, break strength, modulus of rupture, and flexural toughness. The outcome of the study indicated that low volume fraction of the steel and Polyvinyl Alcohol (PVA) fibers have little effect on the flexural capacity of concrete pavement. However, steel fibers provide improvements that are more significant in toughness and residual strength than PVA fibers. Adding 0.4 and 0.6% steel fibers to concrete pavement provided flexural toughness up to 82 and 94 N.m, which is about 137 and 156 times, respectively. The analytical analysis by ANSYS software provided results that are close to experimental work with a comparatively safer design.

Keywords: *Concrete pavement, FRC, steel fiber, PVA fiber, modulus of rupture*

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I. INTRODUCTION

Pavements are usually either asphalt or concrete type, and it is playing significant to transmit the applied loads to the foundation. In recent decades, concrete pavements are preferred because of their low life-cycle cost, durability and low maintenance. Typically, concrete pavements are a better alternative to asphalt pavements for a highway under high traffic loads [1]. The concrete material is considered a high strength in compression and a weak in tension. Therefore, it needs to improve its performance in tension and flexure states. FRC fibers improve tension and flexural capacity of concrete by increasing toughness and ductility and controlling crack width [2, 3, 4, 5, 6, 7, 8]. In pavements or slabs on ground applications, discrete fibers have been used for several decades because of its ultimate increased capacity, toughness, load transfer efficiency at cracks, and decrease the crack width [9, 10, 11, 12, 13, 14].

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Steel discrete fiber the most common fiber type has been used in concrete applications and the amount has been utilized a range of (0.2-2.0%) [15] typically. Steel fibers have been used within several concrete applications such as pavements, slabs, columns, bridge decks, boxes, tanks, industrial floors, and repair techniques [16, 17, 18].

Synthetic fibers are human-made fibers resulting from several processes and development in the petrochemical field and textile industries. Synthetic fiber types, which have been used in concrete applications, are acrylic, aramid, carbon, nylon, polyester, polyethylene, and polypropylene [19, 20]. Among the many kinds of discrete synthetic fibers utilized in concrete applications, PVA fiber is a relatively new inclusion. PVA is developed by polyvinyl acetate that is hydrolyzed by treating an alcoholic solution with aqueous acid [21, 22]. This study aims to determine the flexural capacity of concrete pavements with different content of PVA or steel discrete fibers. Also, simulation of the excremental results by FEM through using the ANSYS software program.

II. BEHAVIOR OF FRC

The FRC response under compressive stress, which is prepared from the compressive test, shown in Fig. 1a. The first portion of the curve presents the elastic stage, and the slope of that portion presents the modulus of elasticity (E). The peak point of the curve presents the compression strength of concrete (fc') and peak strain (εc). The end of the curve presents the break strength and ultimate strain at failure (εu). The FRC response under flexural stress is shown in Fig. 1b. The first flexural parameter is the flexural capacity, which is called the Modulus of Rupture (MOR). MOR presents a primary design input and is the maximum strength of concrete before the failure happens. The second flexural property is the Flexural Toughness (FT), which is concrete's ability to absorb energy and plastically deform without fracturing. The concrete's toughness is a very important characteristic for all concrete mixtures, which are increased significantly by adding fibers. Even though toughness is not a design parameter, it indicates useful data since it contributes to load transfer across cracks. All those parameters determine as explained in the testing procedure sections.

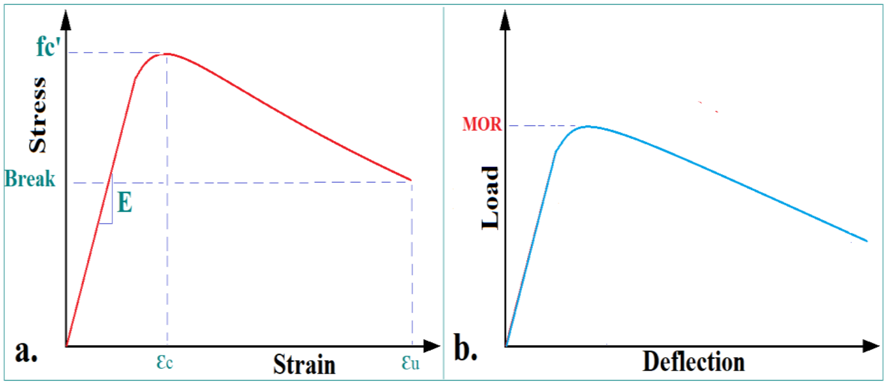

Fig. 1. Behavior of FRC under: a. Compression stress, and b. Flexural stress.

III. ANALYTICAL ANALYSIS

Concrete is composed of inhomogeneous and anisotropic materials; therefore, it is complicated to model. In this study, ANSYS 14 workbench [23] is used to simulate the experimental works. Solid65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar) and reinforced composites. The solid has the capability of cracking in tension and crushing in compression. The element has eight nodes with having three degrees of freedom at each node. Also, there are translations in the nodal x, y, and z directions.

IV. EXPERIMENTAL PROGRAM

A. *Testing Procedures*

The experimental testing program involved performing three different tests for seven cases of concrete mixtures, including [24, 25, 26, 27]. Table 1 summarizes laboratory testing methods, and types and sizes of testing specimens utilized in the experimental work.

TABLE 1
SUMMARY OF EXPERIMENTAL TESTING METHODS AND SPECIMENS

Testing Type	Testing Methods	Dimensions (mm)	Calculated Parameters
Compressive Strength	ASTM C39	Cylinder (100×200)	Compression Strength (fc')
Modulus of Elasticity	ASTM C469	Cylinder (100×200)	Modulus of Elasticity (E)
Flexural Strength	ASTM C78	Prism(150×150×560)	MOR
Flexural Performance	ASTM C1609	Prism (150×150×560)	FT

B. *Material Properties*

Seven different mixtures consisted of cement, sand, aggregate, water, and discrete fibers as shown in Table 2. All mixtures had the same water-to-cement (w/c) ratio of 0.45, and the maximum aggregate size was 19.0 mm. The properties of PVA and steel discrete fibers were used in the experimental work listed in Table 3.

TABLE 2
SUMMARY OF MIX PROPORTIONS (% BY VOLUME).

Case	Cement	Water	Sand	Aggregate	Fiber (P: PVA & S: Steel)
Plain	12.8	18.1	28.0	40.1	0
0.1% PVAFRC	12.8	18.1	27.0	40.0	0.04P
0.3% PVAFRC	12.7	18.0	27.9	39.9	0.12P
0.5% PVAFRC	12.7	18.0	27.9	39.9	0.2P
0.75% SFRC	12.7	18.1	27.9	39.9	0.3S
1.0% SFRC	12.7	18.0	27.8	39.7	0.4S
1.5% SFRC	12.6	17.9	27.8	39.4	0.6S

TABLE 3
PROPERTIES OF DISCRETE FIBBERS

Fiber Type	Configuration	Specific Gravity	Length, mm.	Diameter, mm.	Tensile Strength, MPa	Flexural Strength, GPa
PVA	Monofilament	1.3	0.25	0.001	1655	38
Steel	Mono Cold Drawn	7.8	1.5	0.035	1138	200

V. RESULTS OF EXCREMENTAL WORKS

A. *Results of Compression Tests*

Fig. 2 shows the compression strength of plain, PVAFRC, and SFRC. For both fibers, the general trend of the compression strength shows an increase in its value with the increase of the fiber dosage. The addition of the PVA fibers to concrete increases the compression strength by more than 9, 12, and 15% at 0.04, 0.12, and 0.2% contents, respectively. Steel fibers also improve compression strength by more than 23, 30, and 41% at 0.3, 0.4, and 0.6% contents, respectively.

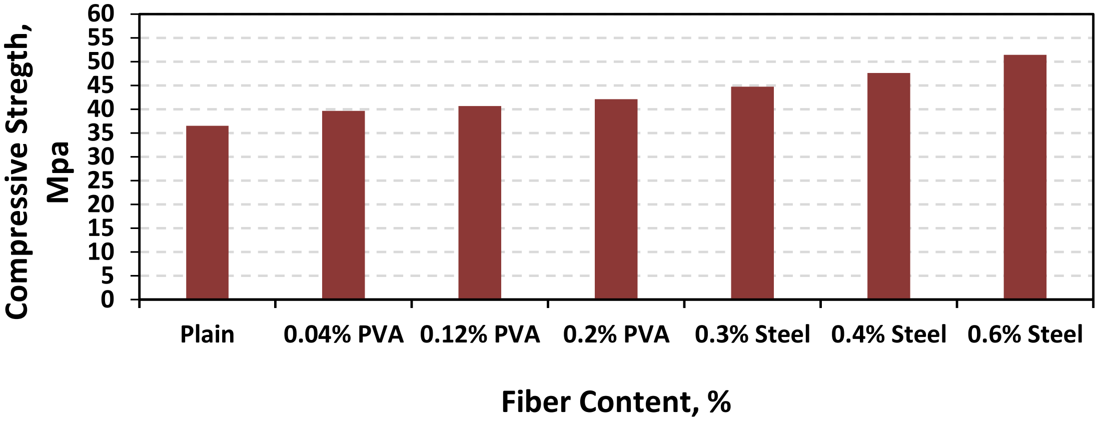

Fig. 2. Effect of fiber content on the compressive strength of concrete

Fig. 3 shows the modulus of elasticity of plain, PVA FRC, and steel FRC as a function of fiber content. From the Figure, it is noticeable that the addition of the fibers to concrete decreased the modulus of elasticity of the concrete. There was no specific correlation between fiber dosage and the modulus of elasticity. All the results of compressive strength and modulus of elasticity agreed with the results of the study of [28]. Fig. 4 shows the effect of discrete fiber on the break strength. The addition of PVA and steel fibers slightly increased the break strength of the plain concrete, which led to preventing the sudden failure of concrete structures.

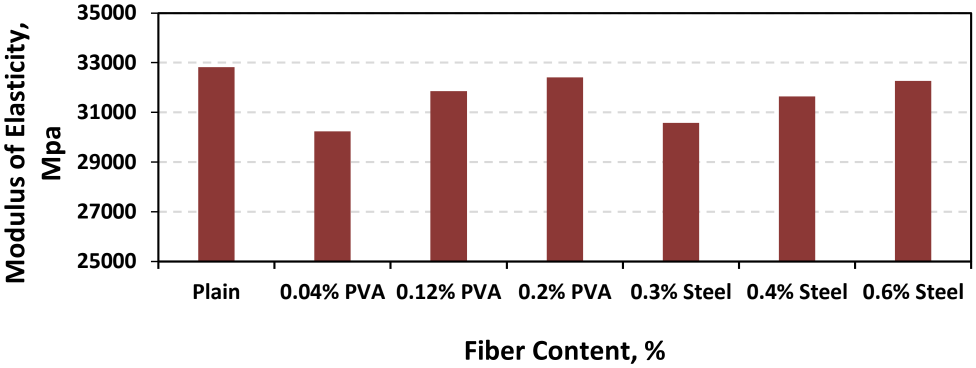

Fig. 3. Effect of fiber content on the modulus of elasticity of concrete

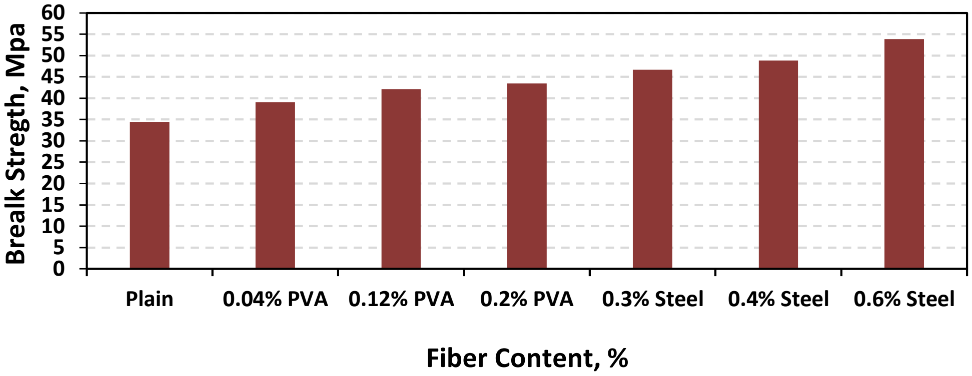

Fig. 4. Effect of fiber content on the compressive strength of concrete

The impact of type and content of discrete fiber on the stress-strain curve of the concrete under compression stress are shown in Figures 5 and 6. Clearly, adding fiber to plain concrete changes failure response from brittle to ductile. Adding 0.2% PVA increases the ultimate strain by more than 40%. Using 0.6% of steel fibers within concrete includes improved the ultimate strain by more than 60%.

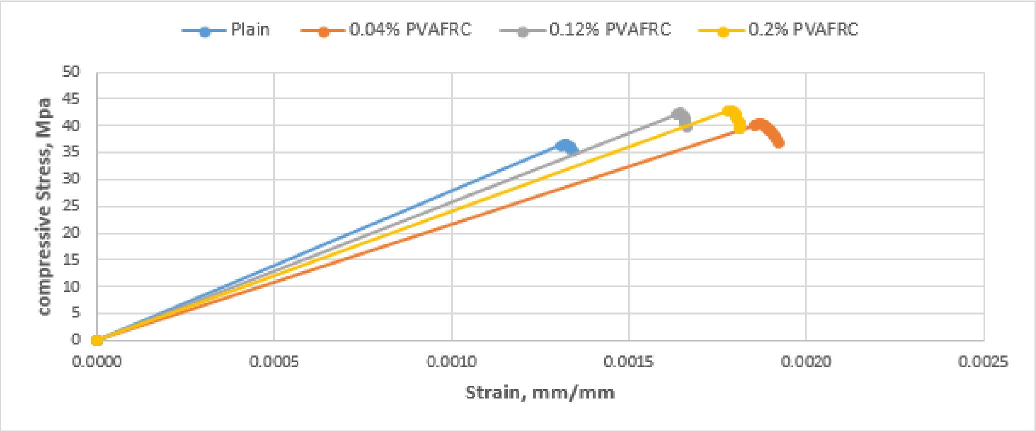

Fig. 5. Compressive stress-strain curve of PVAFRC

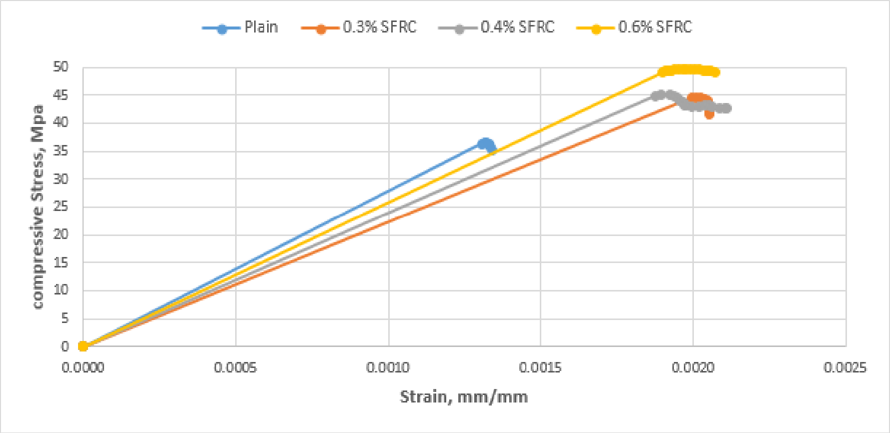

Fig. 6. Compressive stress-strain curve of SFRC

B. *Results of Flexural Tests*

The impact of the content of each fiber type on flexural properties of concrete has been found to correlate very well with the results of the experimental work presented. Fig. 7 and 8 summarize the load-deflection data of the flexural test of plain, PVA FRC, and steel FRC, which were used to determine the flexural parameters. It is noted that increasing fiber content improved the state of concrete failure from brittle to ductile material. Furthermore, the steel fibers improve concrete ductility of plain concrete more than PVA.

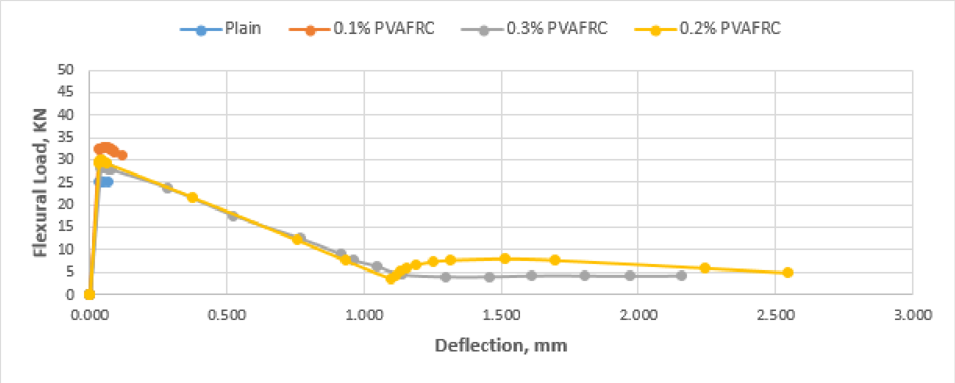

Fig. 7. Flexural load-deflection curve of PVAFRC

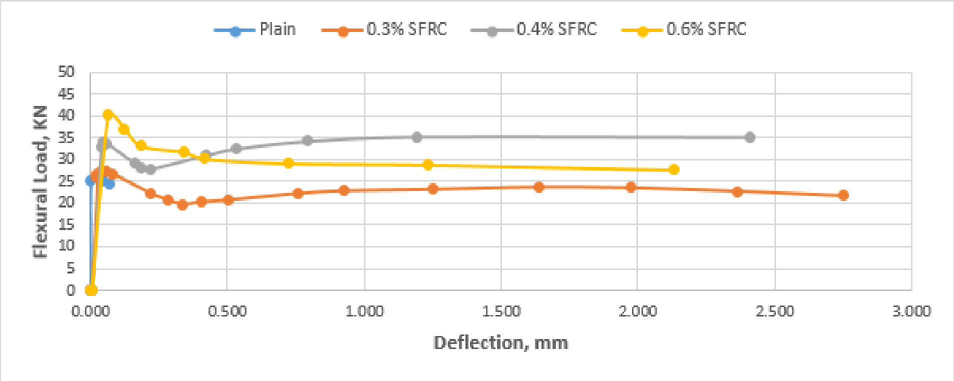

Fig. 8. Flexural load-deflection curve of SFRC

The results of the flexural capacity are presented in Fig. 9. Clearly, discrete fibers have been found to have little impact on flexural capacity since the fiber role starts after concrete matrix cracks, which does not take into account the formula of MOR. Fig. 10 shows the flexural toughness results, which were conducted from the load-deflection curve of FRC under flexural stress. All fiber types and dosages more than 0.3% increase the FT when compared to the plain concrete, but the degree of improvement varied significantly. Adding 1.0 and 1.5% of steel fiber increased the flexural toughness of plain concrete by factors of 137 and 156 times, respectively.

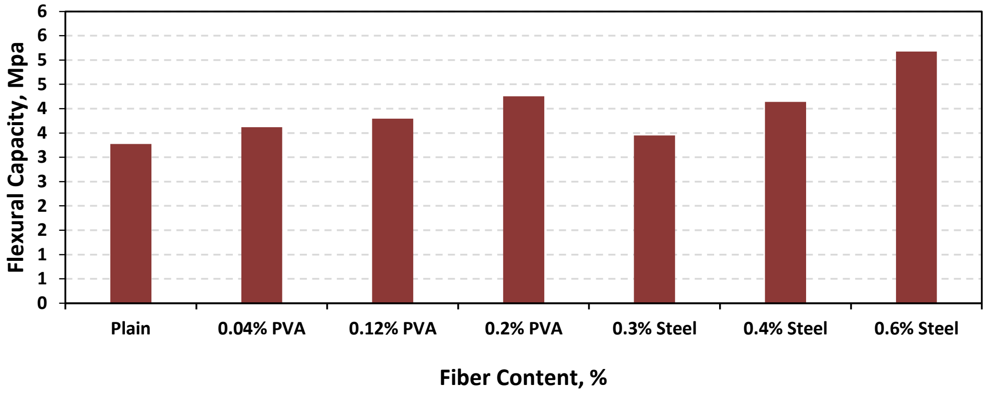

Fig. 9. The flexural capacity of FRC

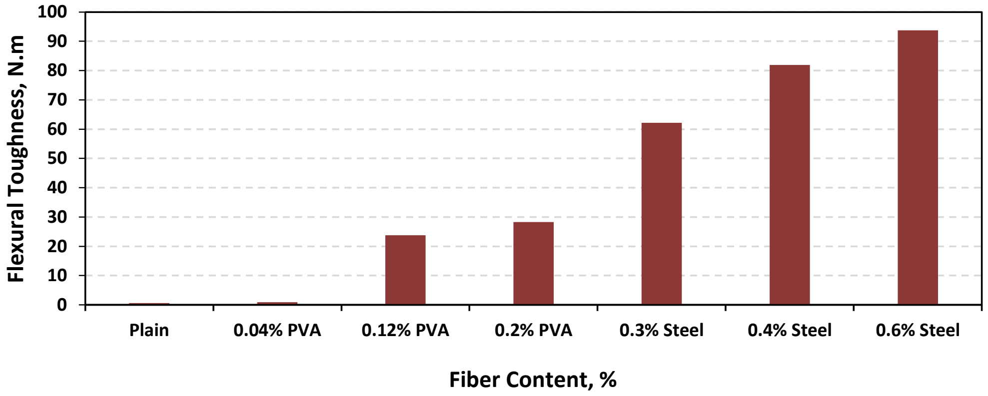

Fig. 10. The flexural capacity toughness of FRC

VI. RESULTS OF ANALYTICAL WORKS ANALYSIS

In this section, a non-linear FEM by incorporating the maximum tensile stress and maximum displacement of the plain, PVAFRC, SRFC obtained was developed to compare the results of experimental works with FEM results as shown in Table 4. Figures 11 and 12 show the analytical analysis of the experimental work by ANSYS. From these results, it was noted that the maximum computed tensile stresses and maximum displacements using FEM tend to underestimate the actual stress.

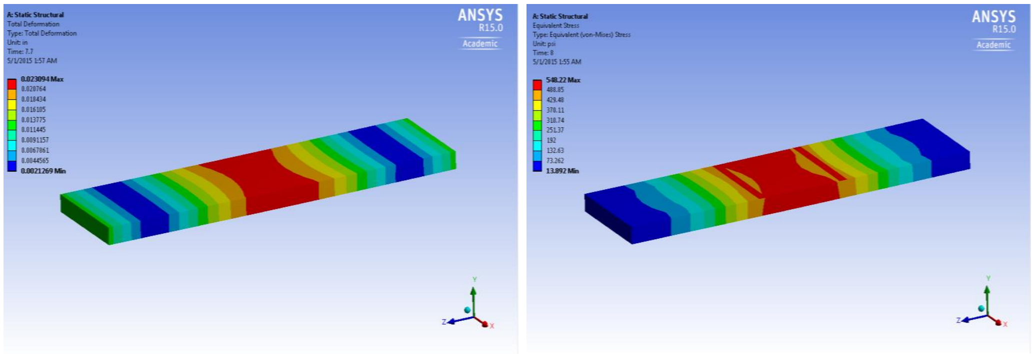

Fig. 11. ANSYS results of PVAFRC, a. Deformation, and b. Stress.

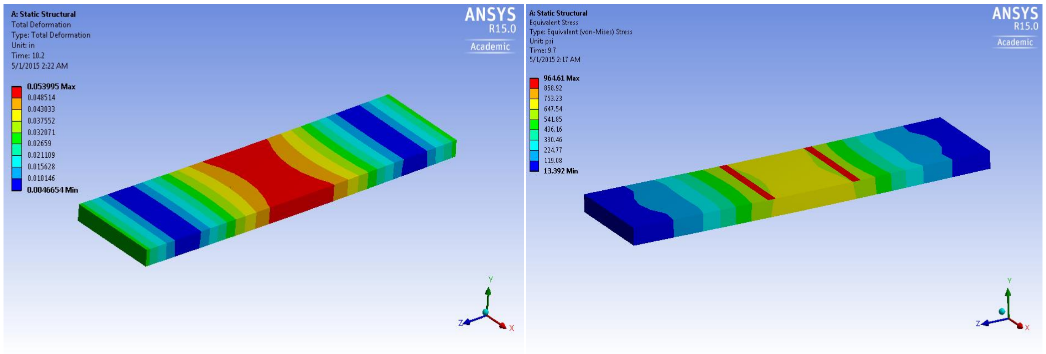

Fig. 12. ANSYS results of SFRC, a. Deformation, and b. Stress

TABLE 4
COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL WORKS

Fiber Type	Displacement, mm		Max. Tensile Stress, Mpa	
	ANSYS	Experimental	ANSYS	Experimental
PVA	0.59	0.66	3.8	4.0
Steel	1.37	1.70	6.6	7.2

VII. CONCLUSION AND RECOMMENDATIONS

Based on the observed test results, the following conclusions can be drawn:

1. Fiber type and content have a significant effect on compressive strength, compressive break strength, flexural toughness, and flexural deflection of FRC.

2. Steel fibers provide more significant improvements in toughness and residual strength than synthetic fibers, and both parameters are proportional to dosage rate for any fiber used.

3. Steel and PVA discrete fibers have been found to have little effect on flexural capacity (modulus of rupture) of concrete.

4. Flexural toughness presents a good indicator of the improved flexural performance of FCR.

5. Adding 0.4 and 0.6% steel fibers to concrete provided flexural toughness up to 82 and 94 N.m, which is about 137 and 156 times, receptively.

6. The analytical analysis by ANSYS software provided underestimate the actual tensile stresses and displacements.

Declaration of Conflicting Interests

There are no conflicting interests.

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