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Experimental and finite element analysis on the steel fiber-reinforced concrete (SFRC) beams ultimate behavior

D. Mehmet Özcan [a,*], Alemdar Bayraktar [a], Abdurrahman Şahin [a], Tefaruk Haktanir [b], Temel Türker [a]

[a] Karadeniz Technical University, Department of Civil Engineering, 61080 Trabzon, Turkey
[b] Erciyes University, Department of Civil Engineering, 38100 Kayseri, Turkey

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ABSTRACT

Steel fiber-added reinforced concrete (SFRC) applications have become widespread in areas such as higher upper layers, tunnel shells, concrete sewer pipes, and slabs of large industrial buildings. Usage of SFRC in load-carrying members of buildings having conventional reinforced concrete (RC) frames is also gaining popularity recently because of its positive contribution to both energy absorption capacity and concrete strength.

This paper presents experimental and finite element analysis of three SFRC beams. For this purpose, three SFRC beams with 250 × 350 × 2000 mm dimensions are produced using a concrete class of C20 with 30 kg/m^3 dosage of steel fibers and steel class S420 with shear stirrups. SFRC beams are subjected to bending by a four-point loading setup in certified beam-loading frame, exactly after having been moist-cured for 28 days. The tests are with control of loads. The beams are loaded until they are broken and the loadings are stopped when the tensile steel bars are broken into two pieces. Applied loads and mid-section deflections are carefully recorded at every 5 kN load increment from the beginning till the ultimate failure.

One of the SFRC beams modeled by using nonlinear material properties adopted from experimental study is analyzed till the ultimate failure cracks by ANSYS. Eight-noded solid brick elements are used to model the concrete. Internal reinforcement is modeled by using 3D spar elements. A quarter of the full beam is taken into account in the modeling process.

The results obtained from the finite element and experimental analyses are compared to each other. It is seen from the results that the finite element failure behavior indicates a good agreement with the experimental failure behavior.

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1. Introduction

It is a known fact that, aside from the mineral and chemical admixtures, the compressive strength and other mechanical properties of Portland cement concrete are improved with the addition of various ingredients to the concrete batch such as carbon fibers, silicon fibers, and steel fibers. Steel fiber added concrete (SFC) and steel fiber added reinforced concrete (SFRC) are being used in real-life applications at an escalating rate recently. The addition of standard size and shape steel fibers to concrete improves crack behavior, makes the concrete ductile, increases its tensile strength, and improves its durability appreciably. Because of these established facts, both SFC and SFRC have already become standard practice in many countries. A main advantage of SFC is its high energy absorption capacity and high toughness, due to its high ductility [1]. Mixing this standardized steel fiber (SF) to the fresh concrete during batching does not require radical changes in concreting practice, as they are somewhat like an additional fine aggregate group.

SFC is used in a wide range of fields such as mine and tunnel linings, slabs and floors, especially large slabs of factories and open squares, rock slope stabilization, shell domes, refractory linings, dam construction, composite metal decks, aqueduct rehabilitation, seismic retrofitting of all sorts of reinforced concrete buildings, repair and rehabilitation of marine structures, fire protection coatings, concrete sewer pipes, and even in conventional RC frames.

Dupont and Vandewalle [2] investigated the effect of SFs on cracks in RC beams and it was concluded that a SF dosage of 30–40 kg/m^3 was appropriate to have an appreciable improvement on cracks. Gopalaratnam et al. [3] studied the effects of dosage, shape, and texture of SFs, as well as the effects of the rate of loading, size of the specimens, and of the configuration of the setup on toughness of SFRC beams. Paine et al. [4] studied the contribution

* Corresponding author. Tel.: +90 462 377 40 17; fax: +90 462 377 26 06.
E-mail addresses: mozcan@ktu.edu.tr (D.M. Özcan), alemdar@ktu.edu.tr (A. Bayraktar), abdurrahmansahin@hotmail.com (A. Şahin), thaktan@erciyes.edu.tr (T. Haktanir), temelturker@ktu.edu.tr (T. Türker).

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of SFs to the shear resistance of RC beams and determined that a SF dosage of 1–2% by absolute volume was ideal. Ganesan and Shivananda [5], after having performed experiments on SFRC beams with SF dosages of 0.5%, 1%, 1.5% by absolute volume, developed expressions relating the flexural crack width to the SF dosage. Alavizadeh-Farhang [6] applied static loading and heat simultaneously to SFRC beams manufactured with SFs of 30 mm long and 0.5 mm thick with a single dosage of 60 kg/m^3, and reported a significant increase in static load capacity of the tested beams. Hartman [7] manufactured and after 28 days of curing tested a total of 12 SFRC beams, in which the steel fibers known as Dramix RC-65/35-BN at two different dosages of 60 kg/m^3 and 100 kg/m^3 were used. Hartman reported that the ratio of the measured ultimate load to the theoretical load was higher for the 60 kg/m^3 SFRC beams. Bangash [8] studied numerical modeling and applications of concrete structures. Hemmaty [9] used the ANSYS finite element program [10] to study the modeling of the shear force transferred between cracks in reinforced and fiber-reinforced concrete structures. Huyse et al. [11] used the ANSYS program to study the finite element modeling of fiber-reinforced concrete beams. Wolanski [12] studied flexural failure of reinforced concrete and prestressed concrete beams by using ANSYS.

The objective of this paper is experimental and finite element analysis on the SFRC (steel fibers reinforced concrete) beams ultimate behavior. For this purpose, SFRC beams were tested in laboratory and finite element solutions were obtained by using ANSYS [10]. The experimental and finite element modeling results are compared numerically and graphically.

2. Experimental study

Five different C20 class concrete batches, four of them with steel fibers (SFs), coded Dramix-RC-80/0.60-BN, as additives in four different dosages of 30, 40, 50, 60 kg/m^3, and the fifth one without SFs are produced and six cylindrical specimens of 15×30 cm dimensions are taken from each batch. All the specimens are subjected to the standard crushing tests, a compressometer being mounted on each one, in a certified compression machine and load–displacement and stress–strain relationships of these specimens are precisely measured. Hence, the toughnesses, the ultimate compressive strengths, and the elasticity moduli of all the specimens are determined. The compressive strength and elastic modulus of 30 kg/m^3 steel fiber added (SFA) concrete drop 9% and 7% as compared to the reference C20 concrete without SFs, whereas the area under the load–displacement curve increases more than twofold. With higher SF dosage SFA concretes, these ratios are around 10% and the increase in toughness is about the same. Because the toughnesses of 30, 40, 50 and 60 kg/m^3 SFA concretes are close as the strength and elasticity modulus of the former are even slightly better than the latter, for economic reasons, the steel fiber dosage of 30 kg/m^3 is chosen to be the optimum recipe for SFA-reinforced concrete (SFARC). Six under-reinforced reinforced concrete (RC) beams of equal dimensions, all with the same tensile reinforcement, while three of them having SFA concrete with a SF dosage of 30 kg/m^3, are produced. The ultimate load causing the final failure of these beams tested in a conventional four-point loading bending configuration is measured to be 18% greater for the SFARC beams than the ordinary RC beams, and the top parts of the (load)–(mid-section displacement) curves prior to the ultimate failure of the SFARC beams are measured to be considerably longer than those of the ordinary RC beams.

The experimental studies were performed in two phases. In the first one, conventional workability and strength and deformation experiments were performed on five different concrete batches, the first one being an ordinary C20 class without any SFs, and the other four containing SFs of varying dosages again in the same C20 class concrete (Fig. 1). By investigating the resultant mechanical properties of the SFCs, the optimum SF dosage was decided on, and in the second phase of experiments, load–displacement experiments were performed on SFRC beams with the purpose of tangibly determining the effects of SF addition to reinforced concrete.

2.1. Experiments on SFCs

First, it was decided that a common class of structural concrete be chosen, and hence C20 class of concrete batches were worked

Fig. 1. Five different concrete batches, the first one being an ordinary C20 class without any SFs, and the other four containing SFs of varying dosages again in the same C20 class concrete.

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