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Steel fiber reinforced concretes behaviour under biaxial flexure

Fehmi ÇİVİCİ, Şerif SAYLAN
Balıkesir University Faculty of Architecture and Engineering,
Department of Civil Engineeering, Cagis Campus, Balikesir.

Özet

En çok kullanılan yapı malzemelerinden biri olan beton gevreklik özelliği ile bilinir. Betonun gevreklik özelliğinin iyileştirilerek betona sünek davranış kazandırabilme çalışmalarına son günlerde ağırlık verilmiştir. Bu çalışmalardan bir kısmını da, beton içine liflerin katılması oluşturmaktadır. Kullanılan lifler çelik, cam, sentetik ve ahşap esaslı olabilir. Beton içine liflerin homojen bir şekilde karıştırılması ile elde edilen lifli beton park sahaları, havaalanı kaplamaları, erozyona maruz yüzeyler, köprü tabliyelerinde yoğun bir şekilde uygulanmaktadır. Bu çalışmada, iki eksenli eğilmeye maruz çelik lifli ve lifsiz plak numunelerin davranışları deneysel olarak incelenmiştir. Her bir numunenin deneyinden elde edilen yük-sehim eğrilerinden yararlanarak iki eksenli eğilmeye maruz çelik lifli ve lifsiz plak numunelerin davranışları karşılaştırılmıştır.

Anahtar Kelimeler: *Lif, eğilme,çelik,beton*

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Abstract

Concrete which is one of the most used structural material is recognized with brittle characteristics. Recently, the study of gaining ductile feature on concrete has been studied. One of these works is to add fibers in concrete. Fibers in concrete have different types such as steel, glass, synthetic and wood. Fiber concrete which is obtained by a mixture of cement, water, aggregate and fibers is often used in construction of bridge decks, airport pavements, parking areas subjected to cavitation and erosion surfaces. In this study, plain and steel fiber reinforced plate specimens' behaviour subjected to biaxial flexure is examined experimentally. To compare plain and steel fiber reinforced plate specimens behaviour, the load-displacement curve of each specimen was obtained by experiments.

Keywords: *Fiber, flexure, steel, concrete*

1. Introduction

Fiber concrete is often applied in construction of bridge decks, airport pavements, parking areas, subjected to cavitation and erosion surfaces. Fiber reinforced concrete is preferred to conventional concrete because of its toughness, high impact strength, cavitation resistance and tensile strength.

Research has been conducted on fiber reinforced concrete which is obtained by adding fiber [l-3-6-8]. It causes significant improvements on ductility, toughness, tensile strength etc. of fiber reinforced concrete. However, there is still a lack of information on fiber reinforced concrete. It was stated that using fibers on concrete for ductility increases, energy absorbing capacity and flexural strength and also for it reduces cracking[l]. Pull-out tests with various loading-rates were conducted on cement mortar matrix by Gokoz and Naaman[2]. Toughness measurement methods were introduced by Gopalaratnam et al.[3] Toughness is defined as the area under load-displacement curve. Notched and unnotched specimens with various fiber volumes were tested. Experimental results show that toughness is affected by specimen size, loading rate and test setup as parameters. Five steel fibers with different cross-sections were examined using wet-mix shotcrete affecting concrete compression and tension characteristics by Banthia,Trottier and Beaupre[4]. It was found that both compression and tension strength capacity are increased by fibers. In another study, seven different fibers' performance was measured according to EFNARC[5] using two-way slab bending test by Matthew and Clements [6]. Investigation of steel fiber reinforced concrete usage experimentally was performed in order to measure ductility on beam-column joint region during an earthquake excitation by Filiatrault, Ladicani and Massicotte[7]. It was concluded that steel fiber on beam-column joint region replaces stirrups. Another study presents the results of an experimental program and analytical assessment of the influence of addition of fibers on mechanical properties of concrete [8]. Ozcan et. al. studied experimental and finite element analysis of three SFRC beams[9]. Banthia and Sappakittipakorn investigated whether the toughness of FRC with large diameter crimped fibers can be enhanced by hybridization with smaller diameter crimped fibers while maintaining workability, fiber dispersability and low cost[10]. Effects of aspect ratio and volume fraction of steel fiber on compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity of steel fiber reinforced concrete were investigated by Yazıcı et. al.[11]

2. Research significance

Nowadays, concrete is a popular structural material. Thus, A method to develop concrete characteristics is to add a small quantity of fibers into an ordinary concrete mix. Composite material which is named as fiber concrete has been applied in various applications extensively. In this study, steel fiber reinforced concrete was examined under biaxial flexure and its characteristics were determined. Also, one of our aims is to contribute choosing design method appropriately. Since steel fiber reinforced concrete is often applied to bridge decks, airport pavements, parking areas, subjected to cavitation and erosion surfaces, behaviour of plate in these applications must be determined in detail. Because experimental standard related to concrete and steel fiber reinforced concrete under biaxial flexure behaviour can't be determined accurately, steel fiber reinforced concrete behaviour can be determined in detail by a comparison in between biaxial and current uniaxial flexural tests. Additionally, in this study steel fibers were added into concrete mix using a new method. The effect of a new method was examined on steel fiber reinforced concrete performance. In Turkey, there are numerous applications of steel fiber reinforced concrete. Beksa Corporation has produced steel fibers. Tests were performed on plate and beam specimens depending on related standards. Limits were taken for each test separately.

3. Experimental Program

3.1 Materials

Aggregates were secured from a ready-mix plant in Balikesir. These aggregates were named as No. 1, No. 2 and sand. Table 1 shows tests on aggregates. In this study, campus net water and portland cement was used. Hooked-end steel fibers of trademark Dramix RC 80/60 were utilized. RC 80/60 fibers are 60 mm in length and 0.75 mm in diameter and have a strength of about 1100 MPa. Hooked-end steel fibers were glued to each other and packed in an original bag.

Table 1. Tests on aggregates

Aggregate Number	Compacted Bulk Density(kg/m^3)	Loose Bulk Density(kg/m^3)	Water Absorption Ratio (%)
No. 1	1509.4	1415	1.09
No.2	1537.5	1433.9	0.75
Sand	1551.8	1273.5	5

First, the sieve analysis of aggregates was performed. According to test results as shown in Figure 1., A1 grading curve was chosen. According to curve for No. 1, No.2 and sand ratios in the mix were determined as 0.30,0.30 and 0.40 respectively. Then, concrete mix design was carried out. Water, cement, aggregates and sand were first mixed for 2 min. Then, fibers were slowly added. The mixing time for SFRC was about 3 min. Concrete specimens were casted in three groups. These are plain, dispersed randomly and layered specimens. The fiber percentage values are 0.,1.,1.5 in specimens. Table 2 presents specimens characteristics. Vibration was used for compaction of cylinder and plate specimens.

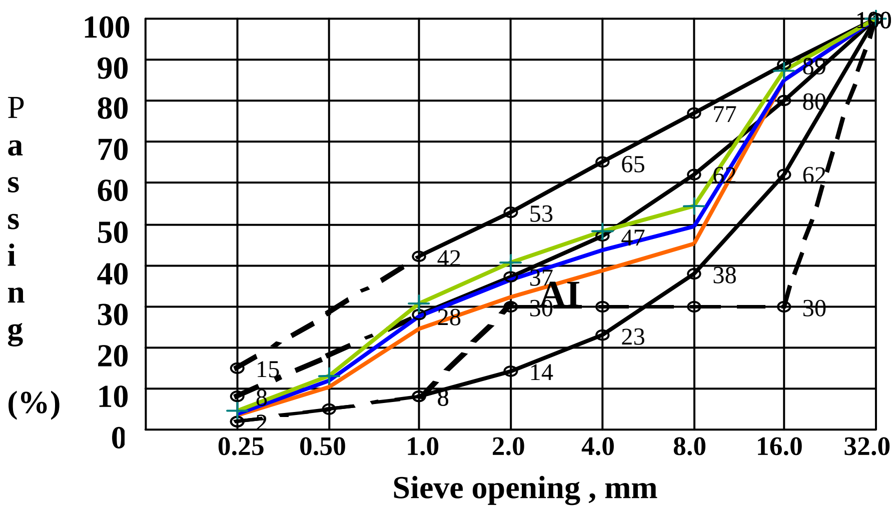

Figure 1. Grading curves

The specimens were cured for a week until demolding. After demolding, the specimens were kept at 20 ^{0}C and relative humidity until the date of the test.

Table 2. Fiber content in 600x600x100 mm plate specimens.

Specimen Number	Fiber Content(%)	Specimen Number	Fiber Content(%)	Specimen Number	Fiber Content(%)	Specimen Number	Fiber Content(%)
P1	0	P10	0	P19	0	P28	0
P2	1	P11	0	P20	1.5	P29	1
P3	1	P12	1.5(k)	P21	1.5	P30	0
P4	1	P13	1.5(k)	P22	1.5	P31	0
P5	1	P14	0	P23	0	P32	1
P6	0	P15	1.5(k)	P24	1.5	P33	0
P7	1	P16	1.5(k)	P25	0		
P8	1	P17	0	P26	0		
P9	0	P18	1.5(k)	P27	1.5		

Concrete strength, flexure strength and static elastic modulus tests were carried out on concrete specimens. Table 3 and 4 presents results obtained from these tests.

3.2. Test Setup

Bending tests on 600x600x100 mm plate and 150x150x500 mm beam specimens were carried out at 28 th.day in Balikesir University, Structural Laboratory of Civil Engineering Department by using a loading frame with a capacity of 300 kN. The loading frame is shown in Picture 1 in detail. Loading on bending test specimens was applied by a hydraulic jack with a capacity of 300 kN. Tests of plate specimens were performed according to recommendation of the EFNARC[5], and beam tests were performed according to ASTM C1018[8]. Plain and steel fiber reinforced concrete plates were supported on its 4 edges and a center point load was applied through a contact area of 100x100 mm. For each 0.25 second, displacements under the plate center point were measured by means of LVDT(Linear Variable Displacement Transducer) and loads by means of load-cells.

Table 3. Averaged compression strength and elastic modulus at 28 days.

Specimen number	Averaged compression strength at 28 days $f_{ck,28}$ (kgf/cm^2)	Averaged elastic modulus at 28 days E_{28} (kg/cm^2)
C1,C2,C7	226.6	
C3,C4,C9	240.6	214900
C5,C6,C8	238.7	
C10,C11	330.4	227690
C12,C13	250.4	242350
C14,C15	318.1	278480
C16,C17,C18	228.4	
C19,C20,C21	243.3	
C22,C23,C24	245.9	203040
C25	206.5	
C26,C27	233.4	
C28,C29	225.2	
C30,C31	276.4	250190
C32,C33	276.3	

Table 4. Flexural Strenght in 150x150x500 mm beams

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Specimen Number	$\sigma E_{ç}\,(kgf/cm^2)$	Specimen Number	$\sigma E_{ç}\,(kgf/cm^2)$	Specimen Number	$\sigma E_{ç}\,(kgf/cm^2)$
B1	37.96	**B6**	41.04	**B11**	33.84
B2	34.88	**B7**	33.84	**B12**	53.34
B3	30.78	**B8**	29.74		
B4	18.464	**B9**	33.84		
B5	32.82	**B10**	34.88		

3.3. Test Results

As shown in Figure 2-5, first-crack load values obtained from load-displacement curves of steel fiber reinforced concrete plates are higher than plain concrete plate specimens.

Plain concrete plate specimens failed in brittle. Thus, the reducing branch of load-displacement curve after maximum load wasn't obtained using the current test method.

After the specimens were tested, a study on specimens using crack microscope was performed. Consequently, it was noted that plain concrete plate specimens had higher crack-width than steel, It was observed that steel fiber reinforced concrete plate specimens had higher crack-width and fiber reinforced concrete plate specimens are in compression zone. However, in tension zone, it is denser than plain concrete plate specimens. Capillary cracks weren't observed on plain concrete specimens around, the crack vicinity.

Picture 1. The loading frame with a capacity of 300 kN.

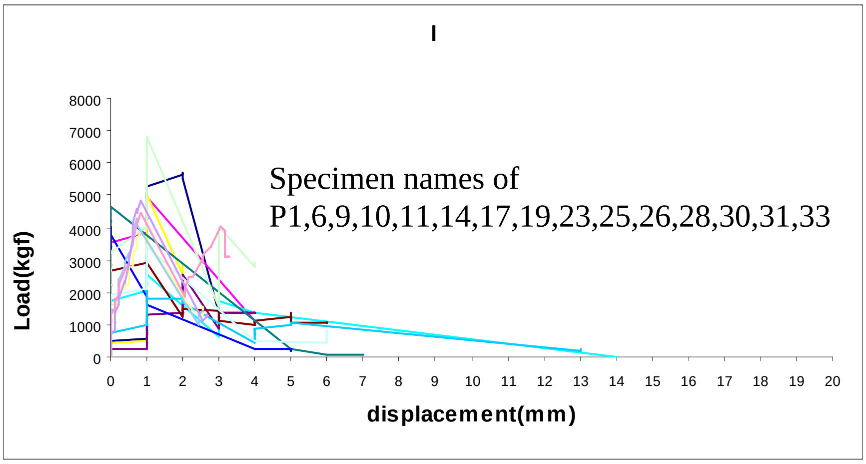

Figure 2. Load-displacement curves of plain concrete plate specimens.

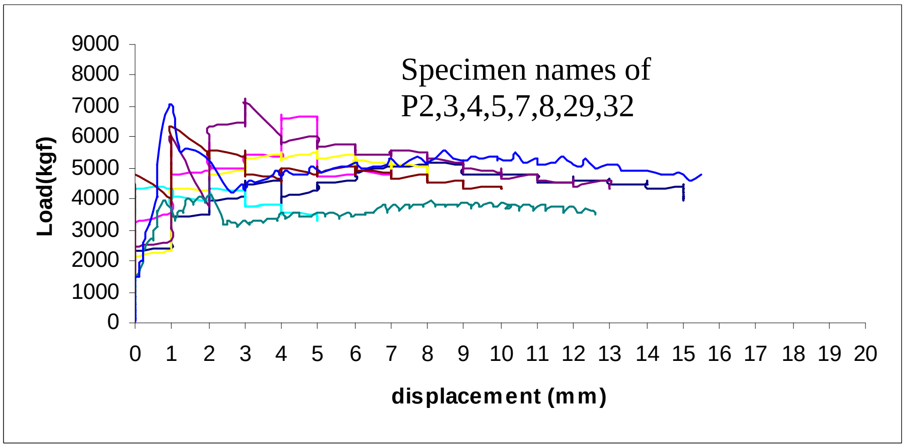

Figure 3. Load-displacement curves of steel fiber reinforced concrete plate specimens, fiber percentage % 1.

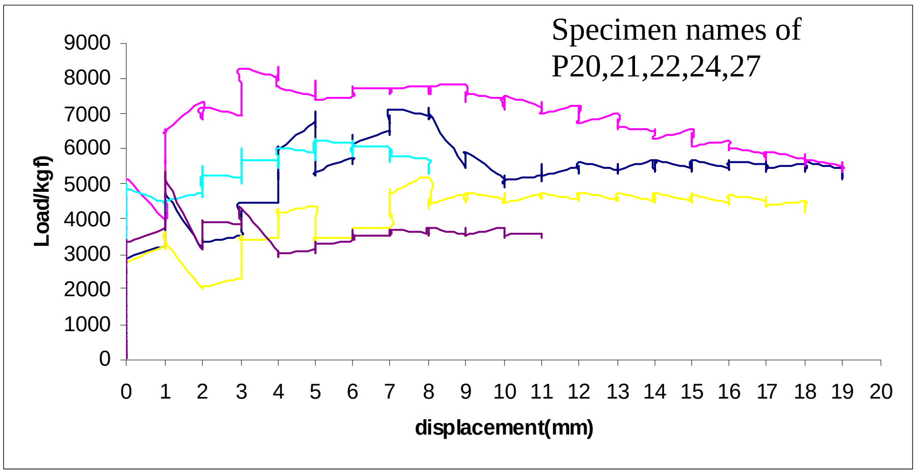

Figure 4. Load-displacement curves of steel fiber reinforced concrete plate specimens, fiber percentage % 1.5

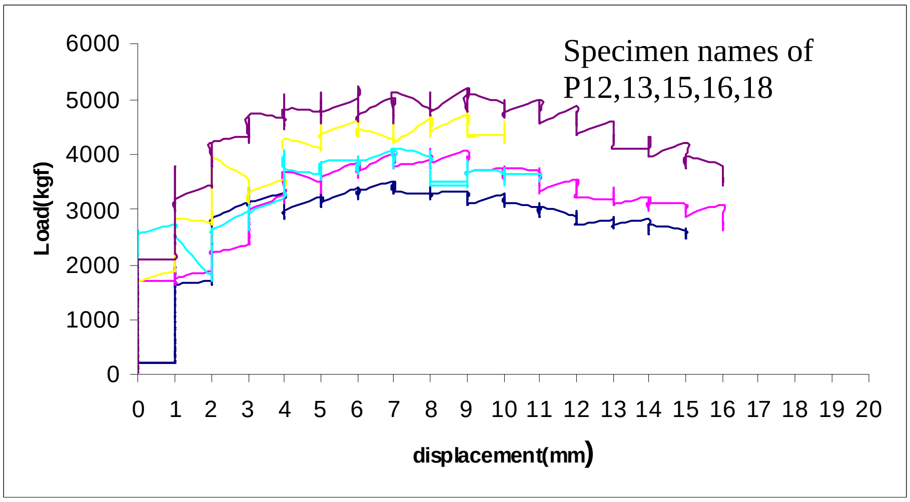

Figure 5. Load-displacement curves of layered steel fiber reinforced concrete plate specimens

During steel fiber reinforced concrete plate tests, it was noted that specimens' sides were risen opposite to displacement direction. It was observed that in steel fiber reinforced concrete tests subjected to biaxial flexural, crack lines formed perpendicular to plate sides. Plain concrete plate specimens failed instantaneously. A layered steel fiber reinforced concrete plate specimen subjected to biaxial flexure deformation capability was better than the conventional concrete.

4. Conclusions and recommendations

This paper presents behaviour of plain and steel fiber reinforced concrete. The following conclusions can be drawn from this study:

It was shown that steel fiber reinforced specimens failed as ductile elements, but plain concrete specimens failed in brittle. At a displacement of 15 mm, steel fiber reinforced concrete plates didn't fail, but in plain concrete specimens as soon as the load reaches its peak, cracks occur immediately. These specimens failed at low load values than steel fiber reinforced concrete plates. Using steel fiber in structural members provides extra durability. It was observed that steel fibers don't break out from obtained test results. Due to steel fibers' contributed on concrete strength as much as its bond strength. Fracture patterns of plain concrete plates developed randomly. These reason is errors of test setup and concrete compressive strength isn't homogenous. In this context, cracks of steel fiber reinforced concrete plates developed at center-points of plate sides. This is be cause steel fibers provide a stress-transmission on concrete. The load-displacement curves of specimens are drawn. The basic difference between the plain concrete and fiber reinforced concrete is observed in their toughness. Toughness is considered as compressive, tensile or flexural. Usually,the flexural toughness is determined according to ASTM C 1018[12], JSCE-SF 4[13] and ACI[14] recommendations.

Layered steel fiber reinforced concrete specimens subjected to biaxial flexure deformation capability are better than conventional SFRC. After cover concrete had been casted in molds, steel fibers were spread out on the cover concrete. These steel fibers act as reinforcement. To spray fibers on cover concrete needs labor.

However this labor is less than needed to settle down classical tension reinforcement. If fiber content varies optimally in steel fiber reinforced concrete, attractive solutions will be obtained. Thus, ductile elements are manufactured. Also, ductile behaviour can be obtained during a shock or an earthquake.

In additional, nonlinear behaviour of specimens must be examined using crack analysis. To obtain modest results, more data must be recorded on test specimen . Loading must be carried out by an automated machine. Also, test setup with displacement control must be used. In further analysis, plain and steel fiber reinforced concrete tension strength can be determined from simple tension tests and fiber length can be examined.

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