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# Investigation of reinforced concrete beams behavior of steel fiber added lightweight concrete

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## HIGHLIGHTS

▶ Steel fibers added lightweight concrete and its effects on prismatic beams.
▶ Steel fibers increased bearing strength and ductility of reinforced concrete beams.
▶ Steel fiber addition increased toughness and ductility of prismatic concrete beams.
▶ The weight of the beam decreased by 42% with use of lightweight concrete.
▶ The significant role of fibers is resisting the formation and growth of cracks.

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## ABSTRACT

Use of structural lightweight concrete is preferred since the dead load of concrete buildings is enormous. A lower density of the lightweight concrete decreases the weight of the building. Statically, it decreases the earthquake loads, minimizes the sizes of the load bearing structural members and contributes into more economical solutions of the foundation problems. Lightweight concrete, having a lower module of elasticity, has a faster rate of crack development in reinforced concrete members. However, steel fibers are employed as an additive to the concrete in order to increase the energy absorption capacity and to control the crack development. Based on these ideas, steel fibers were added to the lightweight concrete and their effects on the behaviors of concrete and reinforced concrete beams were investigated. For this purpose, lightweight concrete and reinforced concrete beam specimens were produced with the addition of steel fibers in different strengths and ratio. The specimens were tested on four points through loading experiments and their utility for building members was investigated. As a result of the study, it is found that steel fiber addition increased the toughness capacity of prismatic concrete beams and their ductility. It also increased bearing strength and ductility of the reinforced concrete beams. Through this experimental study, the performance of the reinforced concrete beams was increased with the addition of steel fibers. It was also concluded that the decrease in the dead load with steel fiber added lightweight concrete can be considered for reinforced concrete beam designs.



## 1. Introduction

High density of the concrete increases the dead loads of the buildings. In accordance with the selected bearing systems for the buildings, dead load may be higher than the load to be borne. Therefore, the earthquake and foundational loads of the building increase. In order to eliminate this drawback of the concrete, the density needs to be decreased on condition that certain strength levels and behaviors are provided. One of the concrete types produced for this aim is the lightweight concretes. Lightweight concrete, having a lower density, not only is a fire resistant material, but also insulates sound and heat. By using lightweight concrete in a building, dead load and earthquake forces decrease. This outcome, which is statically positive, minimizes the sections of the building members, makes the foundational problems more economical and decreases the cost of the building [1–3]. A lower elasticity module in the lightweight concrete accelerates the development of cracks. Therefore, using lightweight concrete in the reinforced concrete may have an adverse effect on the behavior. However, recently with the aid of various additives, the strength levels and other mechanical characteristics of concrete materials may be improved. For the improvement of the concrete characteristics, steel fibers in varying sizes as well as chemical additives are used. Studies related to fiber added lightweight concrete structural member is not widespread in literature.

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Researching on effect of fiber added lightweight concrete structural member increases importance of the study. Because lightweight concrete provides a decreasing effect on dead load steel fiber added lightweight concrete on structural behavior was investigated experimentally in this study.

The ability of the steel fibers to control the cracks especially in concrete, demonstrates its importance and interestingness for its usage in the reinforced concrete. The concretes with steel fibers have wide range of usage thanks to their obvious advantages over ordinary concretes. The significant role of fibers is resisting the formation and growth of cracks. In addition, it enhances flexural strength, fatigue strength of reinforced concrete [4,5]. The concretes with steel fiber as additive are used widely in highways, tunnel linings, concrete pipes, reinforced concrete frames, reinforced concrete beam members, shell roof systems, skyscrapers and prestressed concretes, light shell constructions, domes and folded plates in recent years [6,7].

With steel fibers as additive to the lightweight concretes, its loading capacity is increased, the cracks are controlled and it shows a great resistance to dynamic and sudden loadings while decreasing the crack width. Furthermore, it also increases the resistance of the concrete against deformation and increases the tensile strength [8].

By adding steel fibers into lightweight concrete, it is stated that the strength of ordinary concretes are neared, it increases the concrete's tensile strength, toughness, flexural strength, permanent strength, resistance to disintegration and breaks, strength against blast effects and ability to deform and economical solutions are reached by decreasing the weight of the building [9]. It is found that adding steel fibers into the lightweight concrete mixtures increases the compressive strength of the concrete by 20%, tensile strength by 80% and flexural strength by 90% [10].

Today, the number of the multi-storey buildings increases rapidly with the developments in technology. Statically, as the sectional actions in the multi-storey buildings increase, it has raised the question of the sizes of the structural systems which increase the cost and their foundation solutions. In such kind of buildings, the dead load is aimed to be decreased by using structural lightweight concrete [11]. As an alternating solution, in the 40-storeyed Bank Tower building in Omaha–Nebraska, the dead load was decreased by using lightweight concrete for only floors [12].

In this study, the behaviors of prismatic concrete beams (PCB) and reinforced concrete beams (LWRCB) made of lightweight concrete with steel fibers were studied. The development of cracks in the concrete and reinforced concrete to which steel fibers were added and its effects on the behavior were determined. The performance calculation of the reinforced concrete that took crack development into consideration will provide a more correct demonstration of the member and building capacity.

## 2. Experimental study

### 2.1. Experimental specimens

In this study pumice origin aggregate supplied from Erciyes Mountain in Turkey was used in lightweight concrete mixes. Dry bulk specific gravities of sand and course aggregates were determined as 1.156 and 0.907 gr/cm$^3$ respectively. To fabrication of structural beams, ∅8, ∅12, ∅16 dimensions of rebars were used. Mechanical properties of the rebars were measured 422.7 N/mm$^2$ for ∅8, 430.8 N/mm$^2$ for ∅12, and 442.9 N/mm$^2$ for ∅16. As to lightweight concrete mixes with three various cement dosage were designed. Amount of used materials in lightweight concrete are given Table 1.

In describing steel fibers, "length-to-diameter" ratio is used. This ratio, the division of the fiber length by fiber diameters, is defined as slenderness. In the concrete reinforcement, generally round, cross sectioned, hooked steel fibers are used. Peeling behavior of the steel fibers which are produced with hooked ends are more positive compared to ordinary ones [13]. In the study, Dramix RC 80/0.60 BN type steel fibers with 60 mm length, 075 mm diameter, and with a 80 slenderness value were employed. The tensile strength of the steel fibers was 1050 N/mm$^2$ at minimum. The steel fibers were added in the transmixer with 20 kg/min. rate and to secure a homogenous mixture and the mixture was spun for 5 min at maximum speed [14].

**Table 1**
Concrete mixing materials.

| Materials | Amount (kg) | | |
|---|---|---|---|
| | LWC 350 | LWC 400 | LWC 450 |
| Water | 360 | 375 | 370 |
| Cement CEM II/B-M 42.5R | 350 | 400 | 450 |
| Pumice sand | 343 | 335 | 327 |
| Pumice coarse aggregate | 343 | 335 | 327 |
| Chemical additive | 3.5 | 4 | 4.5 |

In order to distribute steel fibers in the concrete regularly, the optimum steel fiber dosage should be determined. The selected dosage is also significant for the concrete to display a behavior of a homogenous material. The fibers in the concrete should resist the effective loads without any break or failure. The occurrence and development of a crack is more orderly and the cracks kept under control. The steel fibers distributed in the concrete counterbalanced the forces in the crack ends. With steel fibers, these forces were transferred to the other side of the crack [13].

In the experiments the specimens were produced in two groups in order to examine the effects of the steel fiber additives on the behaviors of lightweight concrete. The resulting outcomes would supply a better assessment of the behaviors by the reinforced concrete. The first group specimens were prismatic concrete beams (PCB) and the second group specimens were the reinforced concrete beams made of lightweight concrete (LWRCB). PCB and LWRCB specimens were produced in three different cement dosages as 350, 400 and 450 and three different steel fiber proportions as 0, 30 and 60 kg/m$^3$. The PCB specimens were $1 \times 3 \times 3$ pieces in total and LWRCB specimens are $2 \times 3 \times 3$ pieces in total. The sizes of the PCB specimens were $150 \times 150 \times 750$ mm and the sizes of LWRCB were $300 \times 300 \times 2000$ mm conforming to the standards.

### 2.2. Experimental setup

The concrete and reinforced concrete beam specimens were loaded on four points under a simple bending effect. In the experiments, the displacement brace and mid-span values of the beams were measured. The measuring in the displacement regions were done in order to control the brace movements in the experiment. The mid-span displacements and force–displacement curves of the beams were drawn. The points where the loading setup and displacement values were taken are given in Fig. 1.

## 3. Test results and discussion

### 3.1. Prismatic concrete beam experiments

Mechanical properties of cylindrical concrete mixes are given in Table 2. The prismatic concrete beam (PCB) experiments are carried out to identify the effects of steel fiber additives on the behavior of the lightweight concrete. The resulting outcomes would provide a better assessment of the reinforced concrete behavior.

PCB specimens which had been kept under the cure conditions for 28 days following the production were tested by loading on four points with bending experiment [16]. In PCB experiments, a 250 kN loading capacity of frame with deflection control and feedback was employed. The displacement values during the loading of prismatic beams were recorded automatically on computer.

The area under the mid-point load–displacement curve and flexural strengths of the PCB specimens were assessed. This area value obtained for the prismatic beam specimens is an indicator of the specimen's energy absorption capacity [15–17]. The load–displacement curves according to different steel fiber ratio for the PCB specimens are given in Fig. 2.

In the PCB specimens with steel fibers, the value in which the first crack occurred is defined as the first crack displacement. In the steel fiber reinforced concrete, elastic deformations were assessed through indexes. Elastic transformation indexes are obtained from the division of the field under the curve that extended to the defined deflection by the field until the first crack.