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Experimental investigation of mechanical properties of hybrid fiber reinforced concrete samples and prediction of energy absorption capacity of beams by fuzzy-genetic model

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HIGHLIGHTS

- Hybrid fibers effects were exhibited on prismatic and cylindrical samples.
- Hybrid fiber addition increased compressive strength of cylindrical samples.
- Hybrid fiber addition increased toughness and ductility of prismatic samples.
- S1.50/P0.15 and S2.00/P0.20 additions are suggested as the optimum fiber addition.
- Fuzzy-genetic model showed a satisfactory performance in predicting data.

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ABSTRACT

There have been a great number of studies aiming to improve the mechanical qualities of concrete material which is a basic component of reinforced concrete bearing systems. Attempts to reinforce the concrete through fiber addition have an important place among these studies. This study is an experimental research on the mechanical features of hybrid fiber added concretes which are obtained using steel fibers and polypropylene (PP) fibers together in certain proportions. Test specimens consist of 180 cylindrical samples (150×300 mm) and 90 prismatic ($150 \times 150 \times 750$ mm) beams produced in C40 concrete class. The specimens were exposed to temperatures ranging from room temperature to 100, 200, 400, 600 and 800 °C in a certain order following their cure periods of 7, 28 and 90 days. It was observed that hybrid fiber addition has a significant contribution into the compressive strength, flexural strength and energy absorption capacity of the concrete. Significance of hybrid fiber addition was put forward for the increase in ductility of the concrete which displays a brittle behavior when forced to bending.

In the experimental studies with a numerous test specimens, losing of data due to some reasons and being unable to receive data was considered as a problem to be solved. Therefore, a fuzzy-genetic model was suggested to predict not only the experimental gaps, but also the untested value ranges of experimental parameters. Model was taken consideration in three different applications and it showed a satisfactory performance in predicting data.

1. Introduction

In many countries, reinforced concrete structures compose of a large portion of the available construction stock. Thus, there is a quite widespread usage field of concrete which constitutes the constructional elements of these constructions. There are strong and weak properties of concrete which constitutes these constructional elements that are exposed to sectional effects resulting from various load effects during their economical lifetime. Different studies or practices are researched in order to improve these weak properties of concrete and thus to avoid behaviors caused by unexpected effects in constructional elements. Among these practices, addition of different kinds of fibers into concrete is one of the popular researches. Fibered concrete is a construction material that has a composite combination of water and discontinuously and randomly distributed fibers in concrete, hydraulic cement and aggregation. This material can be obtained by adding only one type of fiber in the mixture or by adding two or more fibers with different features as well. The concretes produced through the addition of more than one type of fibers are called mixed or hybrid fibered concretes.

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Steel and polypropylene fibers are the most preferred fiber types used in concrete. These fibers are used to improve the weak properties of concrete such as tensile strength, energy absorption capacity, corrosion resistance and weathering resistance resulting from impact load effects [1–3]. Besides, it is aimed to reduce the adverse effects of such environmental factors on the mechanical features as plastic cracks, freezing-thawing or high temperatures, etc.

1.1. Steel fiber-reinforced concrete

Steel fiber (SF) is a material that is produced in circular section usually but in rectangular sections sometimes, without any coverings, with lower carbon ratio and prestressed without any heat treatment in room temperature [4]. Steel fibers have begun to be used in concrete since the early 1960s. Today it has become a technology used in a wide range of fields with the development of various steel fiber types by the studies and practices in many areas.

Three dimensional reinforced construction material is obtained by enabling the distribution of steel fibers added to the concrete mixture in the mortar. It depends on some parameters that this composite material can exhibit the desired behavior under service loads. These parameters can be listed as fiber ratio, enabling the fibers to be distributed homogeneously in the mixture, fiber type, fiber size-fragility ratio (length/diameter) and the method by which the fibers are added to the mixture.

Steel fibers (SFs) act as a bridge between the micro-cracks forming in the fresh concrete, spreading the internal stress due to shrinkage throughout the concrete. In this way, SFs increase the crack resistance and impermeability by avoiding crack development and expansion under service loads. However, their most important contribution into concrete used in construction members is that SFs increase the bending strength and ductility.

One of the important parameters of the practice is to determine the best fiber ratio to improve the desired mechanical property. When the fiber ratio is too low, the effect of fiber remains lower or when it is too high, a homogeneous distribution may not be obtained. This adversely affects the performance of concrete.

1.2. Polypropylene fiber-reinforced concrete

Polypropylene fibers (PP) are polymer structured materials which enable a micro-reinforcement system within concrete. It has been a focus of many different studies on preventing the weakening of the concrete especially due to exposure to environmental effects (freezing-thawing, temperature, etc.) [5].

PPs were originally designed as a substitute for reinforcements like steel, mash, etc. The most important advantages of PP fibers are that they are not affected by corrosion, they are resistant to salt and alkalies, they are easy to be blended in mixture, they do not chemically react to other components of concrete, they have a higher tensile strength, they do not change the amount of water used in the mixture since they do not absorb water, they do not increase the unit volume weight of the mixture significantly and they decrease the air pore within significantly due to their microfiber structure.

PP fibers prevent the formation of micro-cracks to a significant degree and increase impermeability. They help the construction member to behave more ductile, though not as much as steel fibers do. They have an important role in preventing the strength loss of constructional members against environmental factors such as freezing–thawing or high temperature. Therefore, PPs are used more intensely in applications to improve the mechanical properties of concrete under low or high temperature effects.

In ASTM C1116/C1116M standard [6], it is stated that 0.1% volume ratio of PP fibers is enough for 1 m^3 concrete. In literature, this ratio ranges from 0.05% to 0.2% in different applications. The fibers added to a slurry mixture may lead to agglomeration by sticking to each other, thus not having a homogeneous distribution.

1.3. High temperature effect

Concrete is a material resistant to temperature effects. However, different volumetric changes happen within concrete since its components have different thermal expanding features. Thermal non-compatibility in the components causes the concrete to reduce strength and to lose stability [7,8].

PP and steel fiber addition is one of the subjects worked onto reduce or prevent the loss of mechanical properties that occur when concrete is exposed to high temperature effect. Steel fibers have an important role in decreasing the loss of flexural strength and in giving more ductility to the concrete which has become more brittle under high temperature effect. Moreover, preventing fractures, they also help to avoid the loss of stability resulting from the changes in sectional aspects. In addition, they are also effective in providing ductility for the concrete which displays brittle behavior under high temperature effect. PP fibers decrease the pore space by filling in the pores within resulting from high temperature since they melt in lower temperatures (160 °C). In this way, not only they prevent breakage, but also the capillary pores resulting from melting aid in removing the high pressure inside the concrete [9–11].

2. Experimental study procedure

A concrete type which has characteristic stress strength of 40 MPa was used in the experimental study. Mixed (hybrid) fibered specimens were produced by adding steel and PP fibers in varying ratios into the concrete mixture. The produced specimens consisted of cylindrical samples and prismatic beam members, 150 × 300 mm and 150 × 150 × 750 mm respectively. Cure maintenance were done on the specimens in three distinct periods of 7, 28 and 90 days. The compressive strength and flexural strength experiments were conducted on the specimens that completed their curing period and then properties provided by hybrid fiber addition for strength was researched [12].

In the experimental studies, CEM I 42,5 R type of Portland cement was used. CS-I (Crushed stone) (7–16 mm), CS-II (Crushed stone II) (16–26 mm) were used as coarse and medium sized aggregate and CSD (Crushed sand) (0–7 mm) as thin aggregate. Plasticizer was added about 0.8 kg into every 100 kg cement. The cement and aggregate were mixed until a homogeneous mixture was obtained. After 70% of the water added to the mixture, plasticizer was added into the mixture together with the rest of water. In the experiments, Dramix RC-80/60-BN was used as hooked steel fibers that are used in concrete supplementation in accordance with TS 10513 standards [13]. The characteristic properties of steel fibers and PP fibers used are given in Tables 1 and 2 respectively.

Cylindrical and prismatic beam specimens were produced by adding steel fibers of 0.0%, 0.50%, 1.0%, 1.5%, 2.0% volume ratios and besides, adding PP fibers of 0.0%, 0.05%, 0.10%,0.15%, 0.20% in respectively the same order. In other words, while 0.05% PPs and 0.50% SFs were used together in the specimen, 0.10% PPs and 1.0% SFs were used together in the other specimen. The specimens referred as 0.0% were specimens without any fibers that were produced as reference specimens. In the study, the hybrid fibered concretes with this mixture are mentioned with codes S0.00/P0.00, S0.50/P0.05, S1.0/P0.10, S1.50/P0.15 and S2.00/P0.20.

180 Cylindrical specimens and 90 prismatic specimens with the same fiber ratio were produced to usage in the experimental study. It was paid special attention to obtain specimens from the same mixture, taking the specimens with the same fiber ratio and to be exposed to the same temperature effect in the same group. Tables 3a and 3b give the distribution of the produced specimens.

Table 1
Technical properties of steel fibers.

Fiber type	RC-80/60-BN
Length (mm)	60
Diameter (mm)	0.75
Fragility (l/d)	80
Performance class	80
Density (g/cm^3)	7.85
Min. tensile strength (N/mm^2)	1050
Pieces of unit (fiber/kg)	4600