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The effects of macro synthetic fiber reinforcement use on physical and mechanical properties of concrete

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ABSTRACT

Attempts to find a construction material having increased strength, ductility, toughness, and durability have led to interest in high performance fiber reinforced concrete. The use of such materials increases day by day. When the fibers are distributed in a homogeneous way and used in appropriate quantity inside the concrete, they reduce cracks, contribute to tensile strength, toughness, ductility and durability, and improve other mechanical properties. In this study, four types of concrete were produced: steel fiber (SFRC), polyester fiber (PYFRC), polypropylene fiber (PPFRC) reinforced concrete and a reference sample made of plain concrete (R1); these were then compared to one another. The ratio of fibers was used 4.25% of volume of concrete. The effects of the different types of fiber on hardened concrete were determined by conducting physical and mechanical experiments. Compressive strength, surface hardness, ultrasonic pulse velocity, carbonation, abrasion, capillarity and freeze–thaw resistance experiments were conducted on hardened concretes. SFRC had higher 12.4%, PYFRC 3.4% higher and PPFRC 4.3% lower compressive strength with respect to R1. PPFRC showed 8.04% higher compressive strength than R1 when it was determined by the surface hardness method. SFRC showed 5.4% higher compressive strength than R1 when we applied the ultrasonic pulse velocity method. In the abrasion experiment, the highest abrasion was found in SFRC with ~0.5%, while the lowest was found in PPFRC at ~0.18%. The highest and lowest amount of capillary water absorption was seen in R1 and PYFRC, respectively. In a carbonation experiment, SFRC was determined ~130.8% higher than R1. It was concluded that the types of fiber used for reinforcement influenced the physical and mechanical properties of the concrete.

1. Introduction

The enhancement properties of concrete in fresh and hardened states, its durability and its environmental impacts are interesting topics for research. One method for increasing some engineering properties of concrete is the use of fibers as an additional basic material in the concrete mixture. The fiber can be made from natural materials such as asbestos, sisal and cellulose, or of manufactured products such as glass, steel, carbon and polymer [1,2]. Fiber-reinforced concrete (FRC) is a structural material characterized by a significant residual tensile strength in the post-cracking regime and an enhanced capacity to absorb strain energy due to fiber bridging mechanisms across the crack surfaces [3]. The use of such materials is becoming more popular. When the fibers are distributed in a homogeneous way and used in an appropriate quantity inside the concrete, they reduce cracks, contribute to tensile strength, toughness, ductility and durability, and improve other mechanical properties [4]. It has been assumed that while undergoing tensile deformations in the concrete, the fibers with different mechanical and geometrical properties block the propagation and further development of cracking from the micro-to-macro scale [5].

Among the various types of fibers, steel fiber is the most commonly used for most structural and non-structural purposes. Research has shown that fibers have a significant effect on concrete performance; in particular, steel fibers increases flexural strength, some post-cracking or residual moment capacity and energy absorption [2,4,6–8]. Additionally, a complete replacement of steel bar reinforcement with steel fibers could lead to further cost reduction due to less manpower being required. Even if the material price of SFRC in high quantities is not necessarily competitive against conventional reinforced concrete, the necessary working

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time for the placement of reinforcing bars could be partially omitted [9]. The reasons for greater use of steel fibers include manufacturing facilities, economics, reinforcing effects and resistance to negative environmental conditions [10]. This is followed by polypropylene (PP), glass and other fibers; however, these are not commonly used for structural concrete applications [11,12].

Among all the types of fibers, steel fiber is most commonly used for improving the mechanical properties of concrete, [10–12]. Adding steel fiber to concrete increases its density. This is because this type of fiber has high specific gravity. The test results showed that a higher quantity of steel fiber usually yields heavier concrete. On the contrary, synthetic fiber produces lighter concrete [13–15].

The inclusion of fibers in concrete has a significant negative effect on the concrete's fresh properties [16,17]. The degree of reducing workability depends on the type and amount of fibers used and because of its high specific gravity, it can increase the dead load of a composite [16]. In addition, fiber reinforced concrete mixtures need more mixing and placing time than non-fiber plain concrete [1,10,14].

Among the various types of fibers, the effect of steel and synthetic fibers has been researched with respect to the properties of concrete. In most cases, it was reported that although the steel fiber increases the compressive strength of concrete, the increase was not significant and that the synthetic fibers had no significant effect on the compressive strength of concrete [4,6,7].

However, the effects of corrosive environments on the steel fibers were negative. Examples: Fig. 1a shows concrete pavement rebars in Ankara-Turkey (over a period of 18 years); Fig. 1b shows the steel fibers after a year that were used in this study; Fig. 1c shows steel fibers used in a study by Granju et al. over a period of one year. Macro synthetic polyester and polypropylene fibers can therefore be shown as alternatives to steel fibers for preventing the negative effects of corrosion, alkaline reactions, acidic water, salt, chlorine, chemicals and micro-organisms. They also have water repellent properties and provide maximum adherence owing to their wavy curl formation and both ends being hooked [10,18].

In this study, three types of reinforced concrete were produced: steel fiber reinforced concrete (SFRC), polyester fiber reinforced concrete (PYFRC) and polypropylene fiber reinforced concrete (PPFRC); one type (R1) of made of plain concrete were produced. Compressive strength of the concretes was determined by uniaxial, surface hardness determination, ultrasonic pulse velocity and component methods. Furthermore, determination of depth of carbonation, capillary water absorption abrasion resistance and freeze–thaw resistance experiments were conducted on the concretes. The study aimed to determine the performances of macro synthetic fiber concretes with respect to steel fiber and (R1) made of plain concrete.

2. Materials and methods

2.1. Materials

2.1.1. Concrete

Four types of concrete were produced in C30 strength class. SFRC, PYFRC, PPFRC and R1 were produced in compliance with TS 802 [19] and EN 10515 [20] standards. In the formation of concretes, CEM I 42.5R cement, Ankara municipal water, crushed aggregates, air entraining admixtures (AEA) complying with EN 934-2 standard [21] and hardening retarding superplasticizers (SP) chemical additives were used. Mixture designs of concretes in 1 m^3 volume are shown in Table 1. A water/cement ratio of 0.45 was used.

2.1.2. Fibers

A volume of 4.25 dm^3/m^3 (0.425%) was used for each type of fiber. The polyester (PY), polypropylene (PP) and steel (S) fibers used are shown in Fig. 2 and their properties are shown in Table 2.

2.2. Method

Dry materials were mixed to form a homogeneous distribution of aggregates, cement and fibers in the production of concretes. Water with chemical additions, including 0.1% AEA and 1.5% SF of cement weight was added to the prepared dry mixture in a controlled manner. After approximately 10 min of mixing, fresh concrete was poured into molds and squeezed by using an external vibrator for 30 s. Duration of external vibration lasted longer because of a thin aggregate ratio of 0–4 mm, which is higher than in normal concrete. Production of fresh concretes was performed in compliance with TS 802, EN 10514 [22] and EN 10515 standards. Compressive strength, surface hardness, ultrasonic pulse velocity, carbonation, abrasion, capillarity and freeze–thaw resistance experiments were conducted on hardened concretes.

3. Results and discussion

3.1. Fresh concrete properties

Slump tests complying with ASTM C143 [23], air experiments complying with ASTM C138 and unit weight experiments complying with ASTM C138 [24] were conducted after the concretes had been prepared. Slump, the amount of air and unit weight were measured for each type of concrete six, three and six times, respectively, and averaged.

The average values of slump, amount of air and unit weight in concretes are shown in Table 3. According to TS 802, the planned slump was 12 cm. However, it was seen that R1 and PPFRC had 8% and 2% higher slump, respectively; SFRC and PYFRC had 11% and 42% lower slump, respectively. The reasons for PYFRC to have a lower slump was possibly because polyester fibers, as shown in Table 1, have a water retention capability of 0.4% of their weight.

More air (32%) was found in SFRC, 21% more in PPFRC and 29% more in PYFRC with respect to R1. In the SFRC study of Aruntas et al. [25], it was found that as the ratio of SF in concrete increased, the amount of squeezed air also increased. It was determined that the fluidizer, fibers and external vibration duration increased the amount of squeezed air in fiber concretes.

The unit weights of all concretes were found to be ~100 kg more than calculated according to TS 802. The reason for this can

Fig. 1. The expose to negative condition of steel fibers and rebars in concrete.