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Experimental evaluation of effect of Polypropylene fibers on the mechanical properties of fiber concrete

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Abstract: By improving the properties of concrete, structural elements[1] against the applied loads can be improved. In this study, to investigate the effect of fibers on the properties of structural concrete, polypropylene fibers between 20 and 40% by volume of concrete, Nominal cross section of 22 micron, and lengths of 6 and 12 mm, in a concrete mix design, and 45 cubic samples (15 cm × 15 cm ×15 cm) for compressive strength test, and 15 cylindrical specimens (15 cm × 30 cm) for the indirect tensile strength test, known as the Brazilian test were used. The results show that the effect of fiber on properties of concrete appears through the fiber performance (% by volume or weight of fibers). Fiber performance on properties of concrete depends on the cross-section[2] and length of the fiber. Also, it was observed that compressive strength of concrete with an increase of fibers, not much has changed, or has been dropped. This decrease can show the negative impact of the empty space created by the fibers in concrete. The results of the indirect tensile test, known as the Brazilian test, indicate that, in all cases, the tensile strength of concrete with increase of the percentage of fiber volume used has increased. Fibers increase the ductility and tensile strength of concrete. However, the use of large amounts of fiber on concrete properties have the opposite effect, in other words we can say that, to a certain extent the fiber, the role of fiber reinforcement in the concrete is well known. However, at higher amounts, reducing the density and increasing porosity, is followed by a decrease in tensile strength. The failure of concrete examples Fiber,

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[1] **Structural elements** are used in structural analysis to split a complex structure into simple elements. Within a structure, an element cannot be broken down (decomposed) into parts of different kinds (e.g., beam or column). Structural elements can be linear, surfaces or volumes. Linear elements:

- Rod - axial loads
- Beam - axial and bending loads
- Struts or Compression members- compressive loads
- Ties, Tie rods, eye bars, guy-wires, suspension cables, or wire ropes - tension loads

Surface elements:

- membrane - in-plane loads only
- shell - in plane and bending moments
  - Concrete slab
  - deck
- shear panel - shear loads only

Volumes:

- Axial, shear and bending loads for all three dimensions

[2] In geometry and science, a **cross section** is the intersection of a body in three-dimensional space with a plane, or the analog in higher-dimensional space. Cutting an object into slices, creates many parallel cross sections. A cross section of three-dimensional space that is parallel to two of the axes is a contour line; for example, if a plane cuts through mountains of a raised-relief map parallel to the ground, the result is a contour line in two-dimensional space showing points of equal altitude.

fibers after cracking can play role of the bridge in concrete structures, and with the passing tensile stress of its width, ultimate tensile strength increases.

In this paper, polypropylene fibers usage in concrete was studied on such as; splitting tensile strength according to (ASTM C496) and compressive strength according to (ASTMC39) and also slump test according to (ASTM C143).

Key words: Polypropylene fibers, Fiber reinforced concrete, Mechanical properties, Concrete mix design.

Introduction and background

Concrete is an inherently brittle material and its tensile strength[3] is much less than compressive strength. Concrete reinforced with short fibers, which are randomly distributed in its volume, is an effective method to reduce cracking, increased ductility and better energy absorption, and also increased tensile strength of concrete. Many chemical and physical changes in the concrete begin with creating surface cracks, and have significant impacts on the ultimate durability and longevity of concrete, so the use of fiber reinforced cement in concrete is an economic idea. Fiber length plays an important role in its performance. Excessive length of the fibers causes creating bullets at the mixing time, and when the bullets are open to the tensile stress, ability to cope with stress is lost. On the other hand, if the fibers are shorter than necessary, proper adhesion between the concrete and the fibers can not be made, and as a result, the fibers come out of concrete due to stretching. Thus, the fibers must have a certain length to diameter ratio. The optimum ratio of fiber length to diameter ratio is called the apparent ratio, which for some fibers is 50-210. To increase the adhesion of fiber to cement, procedures such as twist fibers, making loops by the ends of them, are considered. In recent studies, many matrix designs are engineered for cement composites, and high performance cement composites have been developed. The effect of woven fabric on mechanical properties of Fiber reinforced concrete is an example for the studied done [1]. Another research on Fiber reinforced concrete is investigation of effects of different fibers, such as polypropylene fibers on control cracking in concrete. The results show that, after using this type of fiber, breaking and cracking has fallen to 1.0 percent [2]. In another study, Yao noted that, in a cube sample of concrete with polypropylene until the age of 28 days, the tensile strength decreases nicely, but since then, tensile strength in increased. According to the Electron imaging in the aforementioned study, it was

[3] **Ultimate tensile strength** (**UTS**), often shortened to **tensile strength** (**TS**) or **ultimate strength**, is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength and the values can be quite different.

Some materials will break sharply, without plastic deformation, in what is called brittle failure. Others, which are more ductile, including most metals, will experience some plastic deformation and possibly necking before fracture.

The UTS is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress–strain curve (see point 1 on the engineering stress/strain diagrams below) is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it is dependent on other factors, such as the preparation of the specimen, the presence or otherwise of surface defects, and the temperature of the test environment and material.

determined that the cause of this issue as been associated with filling small cracks with polypropylene fibers, and this increases the cohesion of the concrete structure [3]. The main objective of this study was to evaluate the effects of fibers on the compressive strength, tensile strength and the workability of concrete, and reduction rate in the surface cracks growth.

Materials and Testing Polypropylene Fibers

Fibers used in this study are the Staple fibers of polypropylene. In this study, the fibers by cutting the fibers are used and have been cut in the manufacturing plants.

Table1. Characteristics of fibers used in the study

Fibers	Type	Length [Mm]	Nominal diameter [μm]	Percent elongation	Moisture absorption
Polypropylene(PP)	Staple	6 & 12	22	14	0
Fibers	Unit weight [$^{gr}/_{cm^3}$]	The modulus of elasticity [Mpa]	Tensile strength [Mpa]	Melting point (℃)	Ignition temperature (℃)
Polypropylene(PP)	0.91	3750	350-400	160-170	360

Fibers can increase strain capacity, resistance to impact, energy absorption, abrasion resistance and tensile strength of concrete. Fibers resist the creation and propagation of cracks, and increase the concrete resistance against fatigue, impact, shrinkage and thermal stresses, and in all modes of failure, affect the mechanical properties of concrete.

Matrix Properties

The first issue in the production of fiber-reinforced concrete is suitability and quality of aggregates used. Aggregates typically form 60% to 75% of the concrete and influence strongly on the properties of fresh and hardened concrete. In this study, concrete construction materials, include break-type coarse aggregate (gravel), as well as normal fine aggregate (sand). For conformance of aggregate grading with the standards of (ASTM C33 / C33M-13) [4], gradation correction was necessary. In the present study, the aggregate with maximum aggregate size of 19 mm is used for making samples. Abrasion resistance of aggregates used, based on D, according to the standard (ASTM C131) [5] was controlled, and ultimately was limited to 35%. On the other hand, sand used has sufficient in the lack of Chemical Method according to the standard (ASTM C289) [6]. Portland cement used in this study is type (II) cement. The cement used has been fulfilled conditions of (ASTM C150-4) [7]. Water used to make the sample in this study was the local drinking water.

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Table 2. The weight and volume proportions of materials used in the concrete mix design

Parameter	$\left[\frac{W}{C}\right]$	Cement [Kg]	Water [Kg]	Grave *[Kg]*	Sand *[Kg]*	Percent of air (%)
The amount	0.35	500	175	770	955	1.5

Super-plasticizer

Super-plasticizers reduce the surface tension, and increase consistency of concrete. In this research, the plasticizer of (GLENIUM 110P), a product of (O-BASF) Company was used. This super-plasticizer is water soluble of polycarboxylic ether. According to the manufacturer's recommendations, the proper amount of super-plasticizer mentioned above in the concrete mix is 0.5% to 1.5% of the cement materials weight. Also, in order to achieve maximum efficiency, it is recommended that the above-mentioned super-plasticizer, after adding 50% to 70% of water is added to the mix, and at least 60 seconds after adding, the mixture operations be continued.

Composites preparation

According to the guidelines (ASTM C192), to build a concrete example, first, the sand was poured into concrete mixer[4], and less than a fifth of mixing water, was added to it. Turning of the drum, grains of sand surface was evenly moist. At this time, the sand, the sand was added to the consumer and mixing continued. With mixing of sand along with the concrete mixer rotation, cement was added to sand, and the rest of the mixing water, which fibers are immersed in it, was poured into concrete mixer. To separate Polypropylene fibers from each other, we poured them in the remaining mixing water, and added to the concrete.

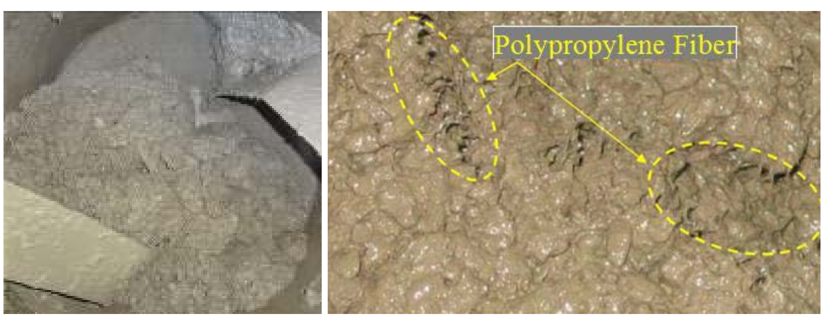

Figure 1- Fiber reinforced concrete produced in the laboratory

Environmental conditions

During this test, to achieve more accurate results about the samples made, it is tried that, environmental conditions are kept constant. Thus, materials used and laboratory works in the

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[4] A **concrete mixer** (also commonly called a **cement mixer**) is a device that homogeneously combines cement, aggregate such as sand or gravel, and water to form concrete. A typical concrete mixer uses a revolving drum to mix the components. For smaller volume works portable concrete mixers are often used so that the concrete can be made at the construction site, giving the workers ample time to use the concrete before it hardens. An alternative to a machine is mixing concrete by hand. This is usually done in a wheelbarrow; however, several companies have recently begun to sell modified tarps for this purpose.

room where its environmental conditions can be controlled, was done. So that, during the test, the temperature of the materials depot room air, construction and maintenance of the samples was 24 ° C, the temperature of the curing pond water was 22 ° C.

Figure 2- curing of concrete samples in the laboratory

Mechanical Testing

In total, 60 samples for 5 mix designs and for each mix design, 9 cube samples, and 3 cylindrical samples were built, and compressive test fro three samples from each mix, at 7 days, 14 days and 28 days, was done and indirect tensile test was performed for 3 cylindrical specimens from each mix, at the age of 28 days. Also, to check the results of tests conducted, the average measured of 3 samples, at any stage to reduce the amount of errors is used. Also, to analyze the results of tests conducted, the way ANOVA[5] was used at a 5% level of confidence. Naming designs, is presented as follows [*C*-*X*-*XX*], cubic or cylindrical concrete specimens made from the mix design, as shown in Table 2, with *X* % by volume to the total volume of concrete and fibers length used in the examples is *XX* in terms of mm. The results of compressive strength test at ages 7, 14 and 28 days and at 28 days and tensile test results for specimens at ages 28 days with different fiber are shown in Table 3. By analyzing the results, it is observed that compressive strength of concrete containing fibers of the same length by increasing the fibers percentage, has not changed much. This can indicate the negative effect of empty space created by the fibers in concrete. Yao research suggests that, in a concrete example with polypropylene, at the age of 28 days, the tensile strength decreases, but since then, the tensile strength increases. So, we just perform tensile test for specimens at 28 days of age [3]. The results of the indirect tensile test, known as the Brazilian test, indicate that in all cases containing fibers of the same length, the tensile strength of concrete has increased by the increase in the volume of used fibers. It should be noted that this is not true for high and unusual weight of fiber (fiber content of more than 2.5

[5] **Analysis of variance** (**ANOVA**) is a collection of statistical models used in order to analyze the differences between group means and their associated procedures (such as "variation" among and between groups), developed by R. A. Fisher. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the *t*-test to more than two groups. As doing multiple two-sample t-tests would result in an increased chance of committing a statistical type I error, ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance.

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kg / m3), and it has been reversed. For interpretation of this issue, we can say that, to a certain quantity of the fiber, the role of fiber reinforcement in the concrete is done well. However, in higher amounts, reduction in the density and the tensile strength and increase in porosity are seen. The failure of concrete examples Fiber, fibers after cracking can play role of the bridge in concrete structures, and with the passing tensile stress of its width, ultimate tensile strength increases.

Figure 3- Indirect Tensile strength and compressive strength tests for the sample C-20-12at 28 days after loading

Tensile and Compressive Strength

According to the bylaws ACI3 18-11, the samples were placed so that the load direction is perpendicular to the concreting direction in mold. A tension load with constant speed was applied. Tensile strength and compressive strength results obtained in this study are presented in tables and graphs below.

Table3. Results of compressive and tensile strength tests

	Compressive Strength (*MPa*)			Tensile Strength (*MPa*)
Sample	7days	14days	28days	28days
C – 0 – 0	15.55	23.3	27.4	4.6
C – 20 – 12	16.69	24.23	30.21	14.2
C – 20 – 6	15.23	22.86	28.16	10.4
C – 40 - 12	17.4	24.58	31.16	15.3
C – 40 – 6	15.86	23.6	28.86	18.2

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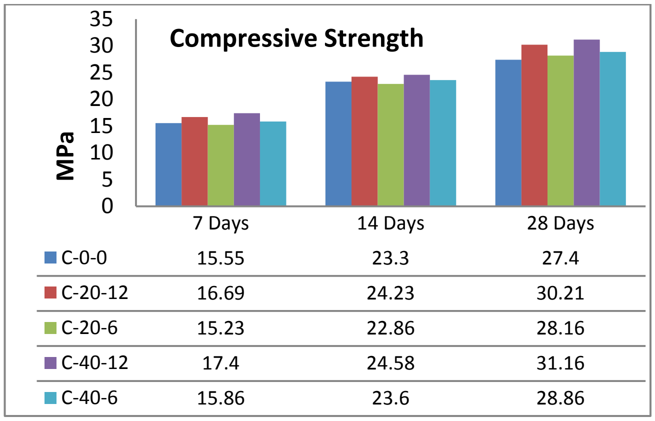

Figure 4- Graph of the results mean compressive test of 5 mix designs at different ages

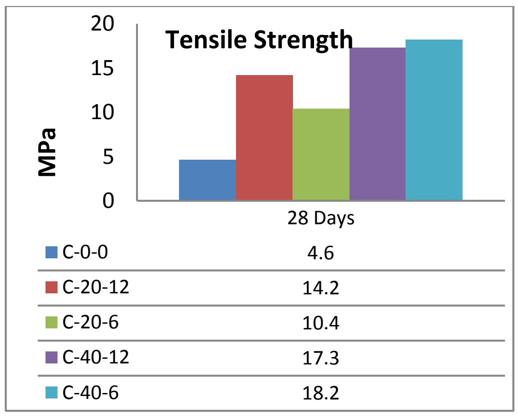

Figure 5- Graph of the results mean tensile test of 5 mix designs at different ages

Concrete specimen without fibers (C - 0 - 0), after applying force is destroyed, however, samples containing fibers after applying similar forces, retain their shape, and are not damaged. In concrete samples containing fibers, instead of collapsing structures, cracks along the axis of applying force are created, which in the entire specimen, almost uniformly are distributed, as shown in Figure 5.

Figure 6- The failure of the concrete samples without fibers and with fibers at 28 days after the compressive loading

Due to great tensile strength of fibers, they prevent cracks progress, and keeping the cement matrix, and forming a bridge between cracks, fibers prevent cracks propagation. As a result, the length and thickness of the crack does not increase.

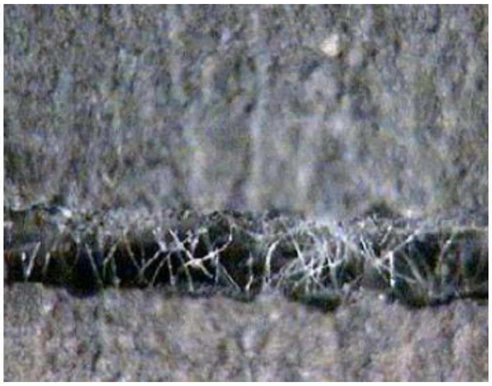

Figure 7- Way of bridging fibers on the crack

CONCLUSIONS

The main objective of this study was to evaluate the effects of fibers on the compressive strength, tensile strength and the performance of concrete, and reduction rate of surface cracks growth. According to the results, the 28-day compressive strength of concrete specimens C - 40 - 12 is more than C - 40 – 6 samples. It was observed that in all samples containing fibers of the same length, by the increase of the percentage of polypropylene fibers, the compressive strength has not gotten a lot of increase, but we cannot find a linear relationship between these two factors and it is caused due to the increase in porosity in proportion to the increase in the amount of polypropylene fibers. The results show that in the designs with the same percentage of fiber, by increasing the fiber length and in the designs containing fibers with same length, by the increase in fiber percentage, the slump is reduced. It was observed that, according to the results, whatever the ratio of water to cement is lower, concrete is more efficient. This ratio can be minimized by using a suitable plasticizer. Slump is an important parameter to estimate the effectiveness of fresh concrete. Using polypropylene fibers, the amounts of the slump can be reduced. Fibers such as poly prevent crack propagation and fracture of concrete. With increasing fiber length, it would be done better. Fibers have a high specific surface which it leads to mechanical reinforcement of the pulp, cement and hold concrete.

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