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Experimental investigating the properties of fiber reinforced concrete by combining different fibers

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Abstract. Adding fibers improves concrete performance in respect of strength and plasticity. There are numerous fibers for use in concrete that have different mechanical properties, and their combination in concrete changes its behavior. So, to investigate the behavior of the fiber reinforced concrete, an in vitro study was conducted on concrete with different fiber compositions including different ratios of steel, polypropylene and glass fibers with the volume of 1%. Two forms of fibers including single-stranded and aggregated fibers have been used for testing, and the specimens were tested for compressive strength and dividable tensile strength (splitting tensile) to determine the optimal ratio of the composition of fibers in the concrete reinforced by hybrid fibers. The results show that the concrete with a composition of steel fibers has a better performance than other compounds. In addition, by adding glass and propylene fibers to the composition of steel fibers, the strength of the samples is reduced. Also, if using the combination of fibers is required, the use of a combination of glass fibers with steel fibers will provide a better compressive strength and tensile strength than the combination of steel fibers with propylene.

Keywords: steel fibers; propylene fibers; glass fiber; compressive strength; dividable tensile strength

1. Introduction

The behavior of the reinforced concrete structures depends on the configuration of the structural elements as well as the mechanical properties of the concrete (Vetr 2016). The higher the structural plasticity, the more effective its seismic performance in severe earthquakes. Therefore, researchers are trying to increase the plasticity of the concrete structures. In spite of the many advantages of the reinforced concrete (RC) structures, their ductility is low and this is mainly due to the brittle behavior of the concrete. Since concrete is a brittle material with low strain capacity (Banthia 2014), many researchers have been trying to fix this problem by adding concrete fibers. The effect of adding (Dawood and Ramli *et al*. 2012, Hsie *et al*. 2008, Li *et al*. 2017) have investigated fibers on the mechanical properties of concrete in various conditions.

Based on the loads applied to the structural members such as pressure, tensile, shear, torsional moment, and flexural moment, the required strength for the members should be provided in order to achieve the required safety. The nature of the compressive, tensile, shear, torsional, and flexural strength of the structure members depends on the compressive strength and tensile strength of the concrete section. Therefore, the compressive strength and tensile strength of concrete are two important indicators for describing the mechanical properties of concrete which are of high sensitivity in designing the structures (Ramadoss 2013, Pan *et al*. 2014, Lee and Chang 2015, Haeri 2015, Sardemir 2016, Haeri *et al*. 2016, Sarfarazi *et al*. 2016, Shuraim 2016, Akbas 2016, Rajabi 2016, Mohammad 2016, Bagher Shemirani *et al*. 2016, Shaowei *et al*. 2016, Sarfarazi *et al*. 2017, Bagher Shemirani *et al*. 2017, 2018a, b). Yaylac *et al*. (2016) presented a comparative study of finite element method and analytical method for the plane problem of a layered composite containing an internal perpendicular crack. Main goal of the numerical simulation was to investigate the normal stress, stress intensity factors at the crack factor and the crack opening displacements. The layered composite consisted of two elastic layers having different elastic constants and heights. The dimensional analysis of the problem carried out by Yaylac and the results were verified by comparison with solutions reported. In addition to directly affecting the sectional capacity as well as the projection economy and geometric dimensions of the sections, concrete compressive strength also affects the mechanical properties of the concrete including the elastic modulus, indirectly. Therefore, providing the compressive strength required for concrete is a prerequisite for designing the reinforced concrete structures. Concrete tensile strength is also very important: tensile strength is a major and influential parameter for controlling the operating conditions and changes of the behavioral state of the reinforced concrete section. In addition, tensile strength is very important in designing some structures having a certain application, such as the structures of particular importance in areas with high

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seismic hazard, runways, stone pavements, etc. (Xu 2009). Hence, achieving concrete with high tensile and compressive strength with an approach of plasticity increase is an important achievement for structural engineers. One of these achievements for increasing the compressive and tensile strength of concrete is the use of fiber concrete, which has been discussed and investigated by Khooshechin *et al*. (2018), Sivakumar *et al*. (2007), Yao *et al*. (2003).

2. Fiber concrete

Fiber-Reinforced Concrete (FRC) is a composite material based on concrete and is reinforced by fibers (Vetr 2016). The most important advantage of this type of concrete is the improvement of tensile strength at the threshold of crack formation and after forming it in the section. After a crack is created, the fibers participate in sewing the cracks and also increasing the tensile strength resulted from the slip of the fibers. This expected increase in resistance results in a rapture mode and can be plastic because the rapture is controlled by the fibers. In addition, this rapture mode increases the energy absorption due to the appearance of less wide cracks rather than wider cracks. The volume fraction of hybrid fibers and hybrid ratio are important factors that can be selected according to the different needs of various engineering projects, the various ratios of fibers in hybrid fiber concrete (HFRC). The volume fraction directly correlates with the ratio of the fibers dimensions, which can be optimized by selecting the appropriate geometry of the fibers. In general, the volume fraction of fibers harder than lower modulus fibers is higher (Pakravan 2017, Li 2017).

The main objective in the use of hybrid fibers is controlling crack with different sizes in different areas of concrete (cement dough or joint area between dough and seed), and at different ages of curing and in different stages of loading. The large and stiff fibers control the large cracks. The small and soft fibers control the opening and releasing the small cracks (Qian 2000).

Accordingly, the advantages of different methods of hybridization are as follows:

1. Hybrid based on the size of the fiber (length and diameter): since the size of the fibers is different, the small-sized fibers create micro tracks bridge and thus control their interconnection, while larger fibers are considered to prevent the release of large cracks. Controlling micro crack and macro crack, respectively, increases the strength and remarkable improvement in composite fracture toughness. As a result of this cooperation mechanism, the increase in plasticity depends mainly on long fibers. The dimensions of the fiber are often described using the specific surface (SSA), which can be defined as the surface of a mass unit.

2. Hybrid based on the fiber modulus: Since two fibers with different flexibility are used in cement composite, stronger and stiffer fibers provide the ultimate strength and tension for the first crack, while relatively more flexible fibers lead to improving the durability and capacity of the strain in the area after cracking (Pakravan 2017).

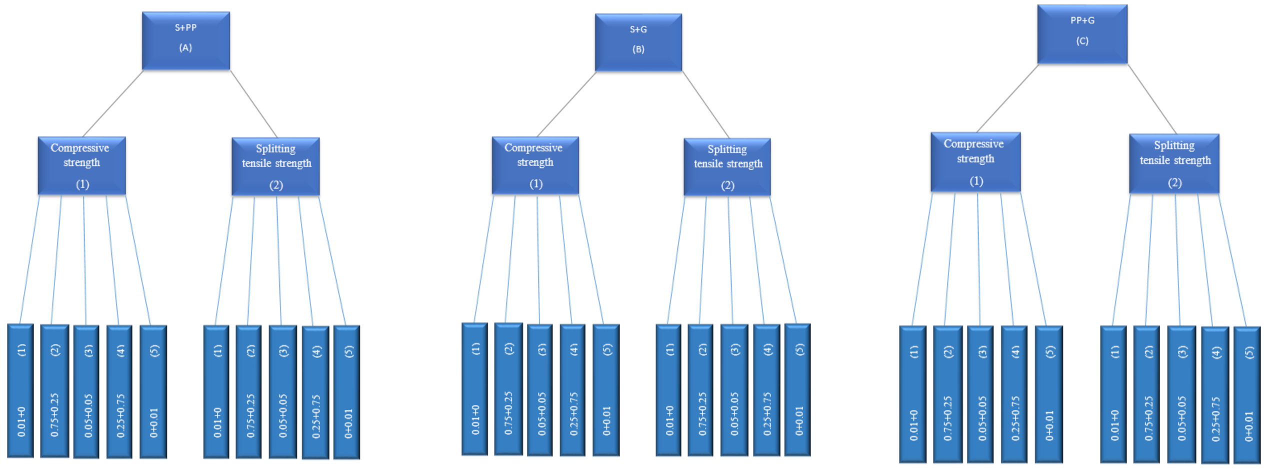
Due to the structure of the concrete that is brittle and fragile and some design requirements that inevitably make the concrete tension and in some cases cause its sudden fracture, so we require a highly plastic concrete, and this is achieved by using fibers in the concrete. By combining two types of fibers in concrete, we take advantage of each one, which by optimum mixing ratio, the maximum strength and plasticity of the concrete can be improved. So far, many studies have been conducted on fiber-reinforced concrete with different fibers. But the combination of steel fibers with propylene and glass fiber has not been comprehensively considered and will be discussed in this article. Therefore, the purpose of this paper is to determine the basic properties of hybrid fiber concretes with three different types of fibers, steel, polypropylene, and glass fibers in respect of compressive strength and splitting tensile strength. In fact, no concrete reinforced by single fiber has complete mechanical properties (Hsie, 2008). In hybrid fiber concretes, the fibers act complementarily to each other, which, in addition to covering the imperfections of each other, lead to the improvement of some mechanical properties of the concrete. But the important point is the reduction of compressive strength in this type of concrete by the increase of synthetic fibers. Since this is considered as a defect in hybrid fiber concrete, in the present study, it has been tried that by comparing the different composites, a composite be introduced, in which by adding more fibers, the compressive strength decreases less (Rashiddadash 2014, Ramezanianpour 2013, Richardson 2006)

3. Methodology

In this paper, in order to achieve the most suitable mechanical properties of concrete by finding the optimal fiber composition, the composite concrete will be investigated in vitro by a various combination of steel, propylene and glass fibers. In the studies, the effect of fiber composition on the concrete tensile and compression strength, which are all the most important parameters of concrete, are evaluated. As mentioned previously, the strength of concrete members (influenced by different loads) including compressive, tensile, shear, torsional and flexural strength, is directly correlated with the compressive and tensile strength of the concrete specimen. In addition, the deformations depend on EI (E is the elastic modulus, and I is the inertial moment). The inertial moment of the cross section, I, is related to the crack of the cross section, the cracking capacity is also dependent on the tensile and compressive strength. The elastic modulus also depends on the compressive strength.

It is clear that the deformations depend on the compressive and tensile strength of the concrete specimen. Therefore, the compressive strength and tensile strength are two important parameters and the cross-sectional strength is directly or indirectly dependent on these two parameters. So, in this paper, the effect of fiber on these two parameters will be evaluated. A series of laboratory studies have been conducted to achieve the best mechanical properties of concrete.

To achieve the optimal fiber condition, fiber concretes with different combinations of fibers have been tested and the results compared.



Group A Group B Group C

Fig. 1 Mixture and naming of specimens

Table 1 Mix proportions of concrete mixes

Mix ID	Specimen	Fiber volume fraction (%)		
		S	PP	G
A	S-1	1.00	0.00	–
	SP-0.75-0.25	0.75	0.25	–
	SP-0.50-0.50	0.50	0.50	–
	SP-0.25-0.75	0.25	0.75	–
B	SG-0.75-0.25	0.75	–	0.25
	SG-0.50-0.50	0.50	–	0.50
	SG-0.25-0.75	0.25	–	0.75
C	P-1	–	1.00	0.00
	PG-0.75-0.25	–	0.75	0.25
	PG-0.50-0.50	–	0.50	0.50
	PG-0.25-0.75	–	0.25	0.75
	G-1	–	0.00	1.00

Table 2 Fibers properties

Fiber	Type	Length (mm)	Tensile strength (MPa)	Diameter (mm)	*E* (GPa)	Density (kg/m^3)
S	Hooked-End	30	1100	0.6	200	7800
PP	Straight	12	170	-	2.7	910
G	E-Glass	12	1600	-	77	2700

4. Experimental study

4.1 Experimental models

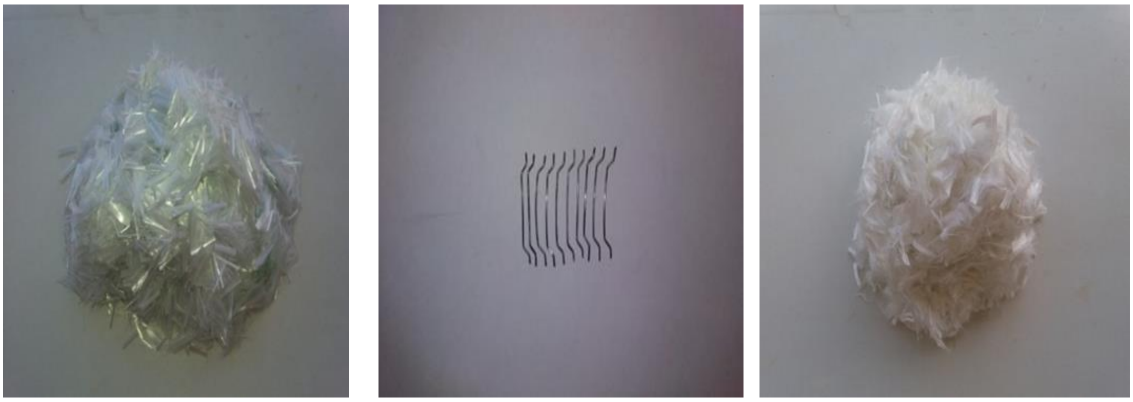
For experimental tests, a total of 117 fiber concrete samples have been tested in vitro, including 9 control concrete samples. Table 1 lists the characteristics of and naming the laboratory models. The manner of composition and naming HFRC samples has been shown in Fig. 1. The name of each specimen is composed of letter and number. The letter *S* represents concrete with steel fibers, *G* represents concrete with glass fibers and *P* stands for the concrete with polypropylene fibers, and using two letters in the name of each model indicates that both fibers are used in the concrete. The first number used represents the percentage of the fibers associated with the first letter and the second number relates to the percentage of the fibers associated with the second letter. For example, concrete specimen SG-0.75-0.25 is the concrete with glass and steel fibers containing with 0.75% steel and 0.25% glass fibers.

4.2 Materials

The materials used in the laboratory plan for making and testing the laboratory specimens include fibers, cement dough, and stone materials. Three types of steel (S) and polypropylene (PP) and glass (G) fibers will be used, the specifications of which are given in Table 2. Also in Fig. 2, the fibers used in this paper are shown. Portland cement of type 2 has been used for all concrete mixtures in accordance with ASTM C150, the characteristics of which are given in Table 3. The maximum gravel size is 19 mm and the minimum river sand size is 150 microns. The mixing ratios for cement, water, gravel, and sand are 388: 194: 932: 936 Kg/m^3. A superplasticizer based on polycarboxylate named Carboxal HF5000 with a density of 1.1 g/cm^3 was used. To maintain the efficiency and uniformity of the mixtures, 1% of the weight of the superplasticizer cement was required. All of these mixtures had the same amount of gravel, sand, water, superplasticizer, and cement.

4.3 mixing and curing

The mixing process started with a dry mix of grains for 1 minute. Next, about 1/3 water was added to the rotating mixer. The mixture was kept for 1 minute and then the cement was added and mixed for 2 minutes. After the previous process, a certain amount of fibers was added to the wet concrete. The fibers were spilled manually into the rotating mixer to ensure that the fibers have been distributed uniformly in the cement composites. Finally, the remained water is combined with the superplasticizer and added to the concrete. Table 4 shows the characteristics of concrete mixing. The concrete specimens were evaluated after 7 and 28 days of curing with 3 specimens for each age. The specimens were extracted from the mold after 24 hours and cured in water with 100% relative humidity at 20±2°C until



(a) (b) (c)

Fig. 2 Photos of fibers; (a) Glass fibers, (b) steel fibers, (c) Polypropylene fibers

Fig. 3 Placing the specimens under the 100% relative humidity

Table 3 Chemical analysis and physical properties of cementitious materials

Item	Chemical analysis (%)
	Cement
CaO	63.45
SiO_2	21.25
Al_2O_3	4.50
Fe_2O_3	3.60
MgO	1.35
SO_3	2.74
Na_2O	0.63
K_2O	0.61
C_3S	53.61
C_2S	20.50
C_3A	5.83
C4AF	10.95
	Physical properties
Specific gravity (kg/m^3)	3.15
Specific surface area (cm^2/g)	3140

the experiment day. Fig. 3 shows how to cure the laboratory specimens.

Fig. 5 Failure type in compression

Table 4 Mixture proportions

Unit weight (kg/m^3)					
W/B	*SP* (%)	Water	Cement	Coarse aggregate	Fine aggregate
0.5	1	194	388	932	936

4.4 Test methods

In the experimental program, for determining the compressive strength and tensile strength, the ASTM C39 test method and the ASTM C496 test method were used respectively. In all experiments on the stiffened concrete, the cylindrical specimens with a diameter of 100 mm and a height of 200 mm were used. The tests were controlled at a speed of 1mm / min. Fig. 4 shows launching the test.

5. Discussing and examining the results

5.1 Ultimate compressive strength

Table 5 lists the compressive strength of the specimens. Referring to the results of this table, as well as the specifications of the concretes, it can be seen that by increasing 1% steel fiber to the concrete, the 28-day compressive strength of the concrete increases 10%. As

(c) (b) (a)

Fig. 4 Test setup; (a) splitting tensile strength test, (b) compressive strength test, (c) capping

Table 5 Compressive strength test results (MPa)

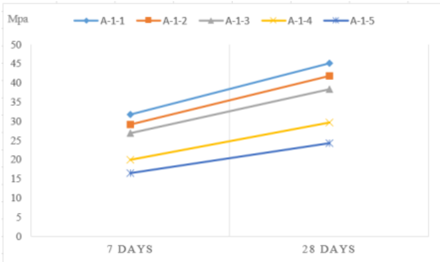
Mixture's ID	Age of test (days)			
	7	Strength effectiveness (%)	28	Strength effectiveness (%)
PC	28.5	-	40.8	-
S-1	31.7	+11	45.1	+10
SP-0.75-0.25	29.2	+2	41.7	+2
SP-0.50-0.50	26.8	-7	38.3	-7
SP-0.25-0.75	19.8	-31	29.6	-28
SG-0.75-0.25	30.2	+5	43.5	+6
SG-0.50-0.50	27.9	-3	42.9	+5
SG-0.25-0.75	21.1	-26	33.0	-20
P-1	16.4	-43	24.2	-41
PG-0.75-0.25	14.9	-48	21.3	-48
PG-0.50-0.50	16.0	-44	24.5	-40
PG-0.25-0.75	17.7	-39	26.0	-37
G-1	28.5	-41	24.3	-41

adding 1% fiber does not have economically much effect on the construction costs and results in 10% increase in compressive strength, so it will result in 10% lower costs. Therefore, the use of steel fibers is cost-effective. By contrast, using 1% glass fiber or 1% PP fiber reduces compressive strength by 41%. Replacing the steel fibers with PP or G makes the increasing trend of compressive strength increase reduce and continue decreasingly. for example, 0.25% of steel fibers and 0.75% of PP fibers reduce compressive strength by 28%.

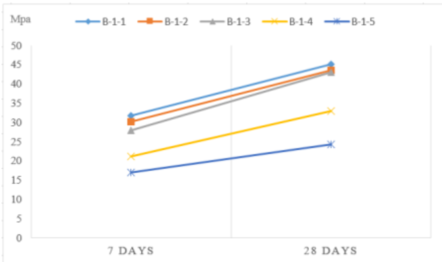
The reason for the increased compressive strength due to the addition of steel fibers is the effective role of fibers as a deterrent to crack expansion, which is also acknowledged by other researchers (ASTM C496). In addition, the loss of strength by adding PP is due to porosity and the confined air because of the presence of these fibers (Tabatabaeian 2017). In Fig. 5, a concrete specimen after the compression test is displayed.

5.2 Effect of concrete age on the increase rate of compressive strength

In Fig. 6, the compressive strength of concrete specimens with different fibers at the ages of 7 and 28 days



(a)



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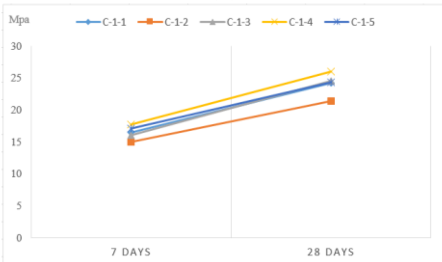


(c)

Fig. 6 The results of the compressive strength test; (a) Group A, (b) Group B, (c) Group C

is shown. As shown in this figure, all the specimens with any combination of fibers follow the same strength increase rate. So, it can be concluded that the fibers do not affect the increase rate of the concrete strength, thus having a 7-day strength, a 28-day strength can be achieved.

5.3 Splitting tensile strength

The results of the splitting tensile strength of the HFRC mixture are shown in Table 6. The results of this table

(a)

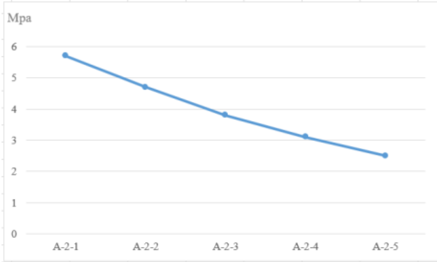
(b)

Fig. 7 The FRC specimen: (a) Tensile section without any fiber, (b) tensile section containing 1.0% of steel fibers

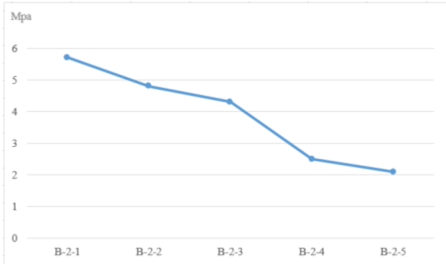
Table 6 Splitting tensile test results (MPa)

Mixture's id	Age of test (days)	
	28	Strength - effectiveness (%)
PC	2.28	-
S-1	5.7	250
SP-0.75-0.25	4.7	206
SP-0.50-0.50	3.8	166
SP-0.25-0.75	3.1	135
SG-0.75-0.25	4.8	210
SG-0.50-0.50	4.3	188
SG-0.25-0.75	2.5	109
P-1	2.5	109
PG-0.75-0.25	2.59	113
PG-0.50-0.50	2.6	114
PG-0.25-0.75	2.8	122
G-1	2.09	-9

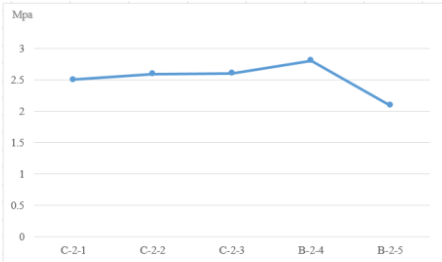
indicate that the steel fibers have a significant effect on the tensile strength of concrete. By adding 1% steel fibers, the tensile strength becomes 2.5 times. This situation for the concrete with glass and PP fibers will result in a 9% reduction in tensile strength. Therefore, the steel fibers show a better performance than other fibers. In Fig. 7, the two half specimens under splitting tensile are presented. If the steel fibers are used, synthetic fibers are also used. The use of the PP fibers shows better results than the glass fibers. In Fig. 8, the tensile strength of concrete samples with different fibers at the age of 28 days is shown.



(a)



(b)



(c)

Fig. 8 The results of Splitting tensile test; (a) Group SP, (b) Group SG, (c) Group PG

5.4 Effect of fibers on specimens' plasticity

The most important reason for using fibers is crack controlling. In fact, by controlling the cracks and preventing their expansion, the fibers improve the mechanical properties mentioned. Due to the role of the fibers in sewing the cracks, the rupture and crushing of the concrete specimens are prevented. In fact, the rupture of concrete fibers is accompanied by a high degree of plasticity and the concrete retains its cohesion when fracture. Figure 9 shows the deformation of fiber concrete specimens during the rupture.

5.5 Calculation of tensile strength using compressive strength results

The closer the rate of tensile strength to the compressive strength, the better performance the concrete has under the loads. Table 7 lists the characteristics of the tensile strength and compression strength of the concrete. As the results of this table show, the use of the concrete with the composite fibers reduces the rate of the tensile strength to the compressive strength of concrete with single fibers.

Therefore, the use of composite fibers is not recommended. In addition, using a 7-day-old concrete strength with any combination of fibers, the strength of the concrete specimen of 28 days can be obtained. On average,

(a) (b) (c)

Fig. 9 Fracture of fiber reinforced concretes; (a) & (b) Group A, (c) Group B

Table 7 characteristics of the tensile strength and compression strength

Model	Compression 28/Compression 7	Tension/ Compression (%)
PC	1.42	12,64
S-1	1.43	11,27
SP-0.75-0.25	1.43	9,92
SP-0.50-0.50	1.49	10,47
SP-0.25-0.75	1.44	11,03
SG-0.75-0.25	1.54	10,02
SG-0.50-0.50	1.56	7,58
SG-0.25-0.75	1.48	10,33
P-1	1.43	12,16
PG-0.75-0.25	1.53	10,61
PG-0.50-0.50	1.47	10,77
PG-0.25-0.75	1.43	8,60
G-1	1.42	12,64
PC	1.42	12,64

28-day concrete specimen strength is about 1.47 times the 7-day concrete strength.

6. Conclusions

In this paper, the behavior of fiber concrete strengthened by three types of fiber was investigated. Brief of results have indicated as follows:

- By controlling cracks and preventing their expansion, the fibers improve the mechanical properties of concrete. Due to the role of the fibers in sewing the cracks, the rupture and crushing of the concrete specimens are prevented. In fact, the rupture of concrete fibers is accompanied by a high degree of plasticity and the concrete retains its cohesion when rupture.
- By adding 1% steel fibers, the tensile strength is increased 2.5 times. This situation for the concrete with glass and PP fibers will result in a 9% reduction in tensile strength. Therefore, the steel fibers show a better performance than other fibers.
- by increasing 1% steel fiber to the concrete, the 28-day compressive strength of the concrete increases 10%. As adding 1% fiber does not have economically much effect on the construction costs and results in 10% increase in compressive strength, so it will result in 10% lower costs. Therefore, the use of steel fibers is cost-effective. By contrast, using 1% glass fiber or 1% PP fiber reduces compressive strength by 41%. Replacing the steel fibers with PP or G makes the increasing trend of compressive strength increase reduce and continue decreasingly.
- all the specimens with any combination of fibers follow the same strength increase rate. Therefore, it can be concluded that the fibers do not affect the increase rate of the concrete strength, thus having a 7-day strength, a 28-day strength can be achieved.

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