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Review Article

IN SITU EVALUATION OF THE MECHANICAL PROPERTIES OF POZZOLANIC CONCRETE CONTAINING FIBERS

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Abstract

Several non-destructive and semi-destructive tests have been developed so far to evaluate the strength of concrete in the structure. Different parameters can be involved in selecting the appropriate method for estimating in situ concrete strength, such as cost, accuracy, time of testing. In this paper, in situ friction-transfer test was used to evaluate the rupture module and compressive strength of fiber-containing Pozzolanic concretes. For this purpose, 8 different mix designs with cubic compressive strength in the range of 15 to 50 MPa were used. Then, 0.3% glass fiber and polypropylene were added to each mix design separately. The relationship between the results of the friction-transfer test readings and standard laboratory tests was presented as calibration curves. The results showed a high correlation between the experimental results and the "friction-transfer" test, which allows this test to be used as an in situ method with high confidence to determine the mechanical properties of the concrete in the structure. The effect of fiber type and cement type on "friction-transfer" test results and standard laboratory tests were also discussed.

Keywords: "friction-transfer", in situ methods, rupture module, compressive strength, fibers

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INTRODUCTION

The concrete made of sand, cement, water, and fibers is called fiber concrete. Fibers are used in different shapes and sizes. They can be made of steel, paste, glass, and natural materials. The fibers bear the loads and the cement matrix protects the site where fibers where they are located. It also protects the fibers from damage to the surrounding environment [1-4]. Glass fiber is one of the most diverse building materials available to architects and engineers [5]. In the glass fibers, the spread of fiber as a mesh has a greater effect on the flexural strength of the sample compared to the mixed state [6]. Another widely-used fiber in concrete is polypropylene fibers. Polypropylene fibers are low-density synthetic fibers with a thin diameter and low module of elasticity and have specific characteristics such as high strength, flexibility and durability, abundant resources and low cost, so they can be widely used in concrete products [7]. In the studies conducted in this regard, an increase of over 15% in the strength of uniaxial tensile impact loads [8] and over 50% in flexural impact loads [9] has been reported for polypropylene fibers-containing concretes. Polypropylene fibers are also highly effective in improving impact loads after the first crack until complete rupture [10].

Although polypropylene fibers with low modules reduce concrete cracking due to shrinkage, steel fibers with the high module are used to improve the mechanical properties of concrete [11]. One of the most important cases in steel fibers is the appearance ratio. If the appearance ratio is larger than the critical appearance ratio, the fibers are ruptured [12]. In general, fibers are very useful for improving mechanical properties, especially energy absorption capacity, flexibility and strength against the impact, durability, etc. [13-18]. Examples of using fiber concretes in airport runways, sewage treatment plants and concrete without shrinkage and resistant to explosion and impact are abundantly found in the construction of reactor stations and pumping stations. Several methods have been developed for in situ concrete testing, which are generally divided into three groups: destructive, semi-destructive and non-destructive.

Laboratory tests show concrete strength under specific conditions and factors such as the way of sample selection, real conditions of the structure, lack of paying attention to treatment practice, differences in the temperature of concrete storage and moisture content may not represent the properties of concrete used in different parts of the desired structure.

Nowadays, different methods are used for evaluating the strength of concrete in a structure, which are divided into three categories: non-destructive, semi-destructive and destructive. Non-destructive tests include core obtaining and pullout methods that have limitations and disadvantages, including limited repeatability and damage to structures. and so on. Also, the results obtained from the core obtaining method show that the compressive strength of the cores is lower than the real compressive strength [21].

Ultrasonic tests [22] and Schmidt's hammer tests [23] are among the non-destructive tests. Crack, the level of reinforcement and the cavity can affect the solutions. Some of the semi-destructive tests include "twist-off" [24], "pull-off" [25] and "friction-transfer" [26]. In the "friction transfer" method, a partial core is first created by the core obtaining device. Then, the metal device is placed on a partial core and with a conventional torque-meter, a bending moment is induced to be failed. Due to the high efficiency of the "friction-transfer" test, which makes this test usable for any environmental and laboratory conditions, this test can be used to determine the in situ and laboratory strength of materials and consumables in the road, building and construction industries to control the quality and conduct research studies. As failure occurs within the object itself in this method, its results are more valid than surface hardness determination test or the tests that indirectly determine the strength of the material. In this paper, by applying the "friction-transfer" test, the compressive strength and fracture module of fiber-containing pozzolanic concrete were evaluated. The present study was conducted to present the calibration curves of the "friction-transfer" method using laboratory tests to evaluate the strength of the fiber-containing pozzolanic concrete and the effect of fiber type on the results of the "friction-transfer" method.

LABORATORY WORKS

Used materials

To investigate the effect of fiber type on the obtained results, the "friction-transfer" method was used to determine the in situ strength of Pozzolanic concrete of five types of fiber-containing Pozzolanic cement at the strength range of 15 to 50 MPa.

Pozzolanic cement and two types of glass and polypropylene fibers were used and the results obtained from these fibers were compared with conventional concrete with pozzolanic cement. The sand used for fabrication of the samples in the experiments was broken and normal sand with sizes of 4.75 to 19 mm and its grading was performed according to ASTM C136-01 standard [27]. The sand used for fabrication of samples was washed twice in sand experiments and its grading was performed according to ASTM C136-01 standard. According to ASTM C128-15 standard [28], the sand density at saturation state with dry surface is 2510 kg / m3 and sand density at saturation state with dry surface is 2330 kg / m3. According to ASTM C128-15, ASTM C127-15 [29] standards, sand, and gravel water absorption rates were 2.6 and 3.2%, respectively.

The experiment procedure

To perform a compressive strength test, ninety and six 150-mm cubic samples were tested and for the rupture module test, ninety and six 350 × 100 × 100mm beams and forty 150-mm cubic samples were prepared to perform the "friction transfer" test. Table 1 shows the general process for selecting a specific number of samples. When the age of prepared samples reached to 28 days, the cubic samples were broken according to BS 1881-116: 1983 standard [30]. The device used to determine the compressive strength of the samples had the specifications specified in ASTM C39 / C39M-18 standard [31]. The flexural strength and rupture module of the beams were also calculated according to the ASTM C293 standard [32]. The "friction-transfer" test was performed simultaneously with the compressive and flexural tests. In the "friction- transfer" test, a partial core is created in the concrete by using a core obtaining device with a 25-mm height. Then, the "friction transfer" device is placed on it and a bending moment is induced to it so that the partial core to be failed (Figure 1).

a) Applying bending moment with torque-meter b)Final result of test

Figure 1- Friction-transfer test

According to the final bending moment (failure) and by using the relationship between shear stress and bending moment (relation 1), we have

$$\tau = \frac{Tc}{J}$$

Relation 1

Where, r is the radius of partial core and J is the second polar moment of the surface.

The ratios of mixtures of concrete samples with pozzolanic cement are presented in Table 1. Water absorption rates of aggregates were also calculated and added to mix design water. The table also shows the level of fluidity and percentage of fresh concrete air. Glass and polypropylene fibers were separately added to the mix at the value of 0.3% of concrete volume, as adding fibers to concrete reduces concrete efficiency

Table 1- Ratios of mixes of concrete samples with pozzolanic cement

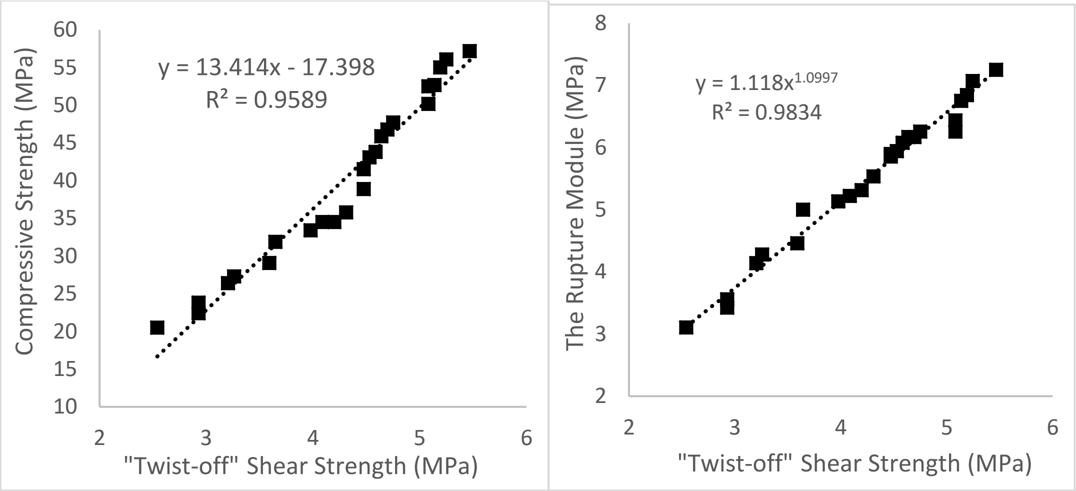
Design Number	Compressive Strength (MPa)	Water $(\frac{Kg}{m^3})$	Cement $(\frac{Kg}{m^3})$	Water to Cement Ratio	Sand $(\frac{Kg}{m^3})$	Gravel $(\frac{Kg}{m^3})$	Super plasticizer $(\frac{Kg}{m^3})$	Slump (mm)	Air Content (%)
1	15	221	328	0.67	901	716	0	4.7	**3/2**
2	20	215	356	0.6	888	707	0	4	**3/1**
3	25	211	381	0.55	879	699	0	3.1	**2.8**
4	30	206	416	0.49	864	687	0	2.5	**2.6**
5	35	198	440	0.45	862	686	1.17	6	**2.7**
6	40	195	476	0.41	851	677	1.61	5.7	**2.6**
7	45	191	516	0.37	838	667	2.12	5.5	**2.4**
8	50	187	534	0.35	835	664	2.61	5.3	**2.3**

Results and their analysis

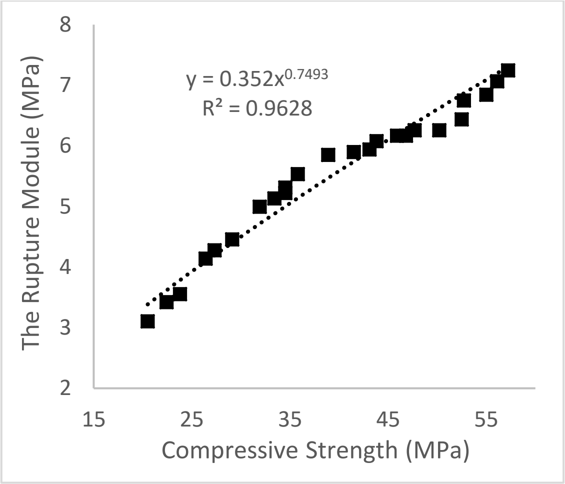
Then, regression analysis was used to investigate the relationship between the results of the "friction transfer" test with the compressive strength and the rupture module of concrete. First, coefficients of correlation and determination were obtained between the "friction-transfer" test and the compressive strength of concrete with linear regression. Then, since the relation between the rupture module and compressive strength of concrete is usually expressed as power regression [33], statistical regression analysis is used to obtain the intensity of correlation and determination between the "friction transfer" test and the rupture module of concrete.

Results for polypropylene fibers-containing concrete with pozzolanic cement

Figure 2 illustrates the correlation between the results of compressive strength, rupture module, and "friction-transfer" test for polypropylene fiber-containing concrete made of Pozzolanic cement.



a) “friction-transfer”- compressive strength b)“friction-transfer-rupture module



C) rupture module- compressive strength

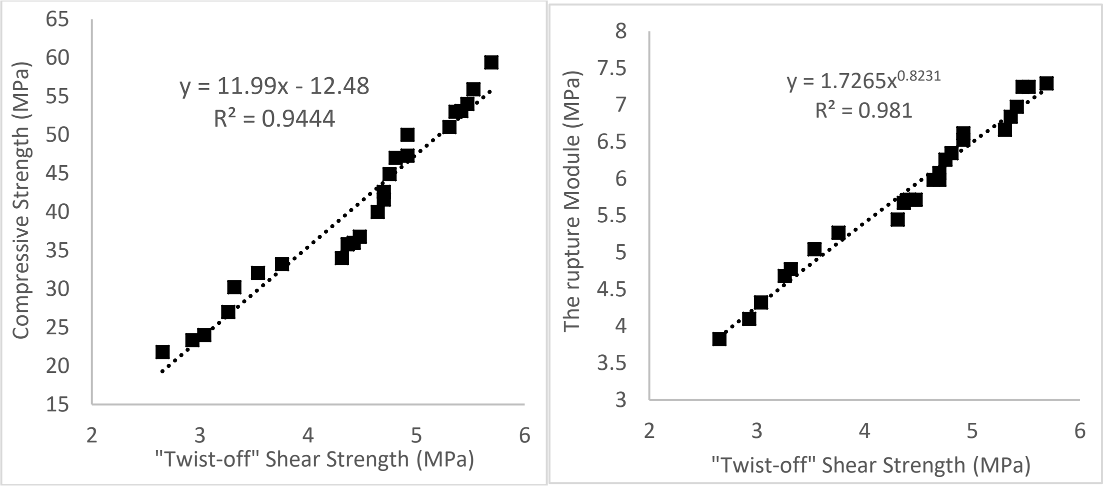
Figure 2: Results for polypropylene fiber-containing concrete

As shown in Figure 2, there is a high correlation between the results of the "friction-transfer" test and compressive strength and rupture module of the pozzolanic concrete containing polypropylene fibers. Figure 2a shows that there is a linear correlation between the compressive strength and the readings obtained from the "friction-transfer" test with the intensity of 98% and the coefficient of determination of 95%. Therefore, the compressive strength of pozzolanic concrete containing polypropylene fibers can be obtained with high confidence by this in situ test.

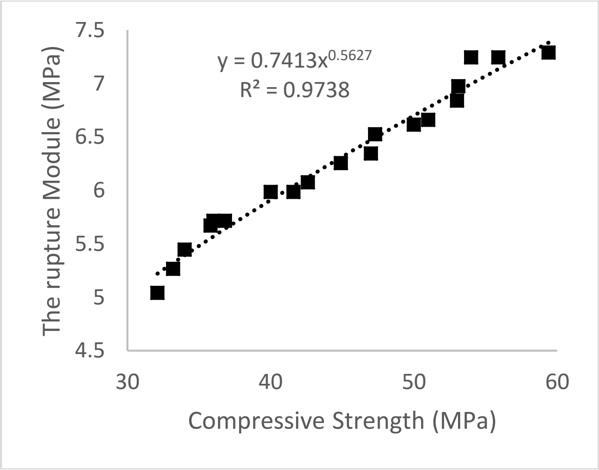
As shown in Figure 2b, the correlation coefficient between the rupture module of pozzolanic concrete containing polypropylene fibers and friction-transfer test results is 99% and the coefficient of determination is 98%. Therefore, the rupture module of Pozzolanic concrete containing polypropylene fibers can be obtained with high confidence by the "friction-transfer" test. Figure 2c also shows that the correlation coefficient and the coefficient of determination between the compressive strength and the rupture module of these types of concrete are 98% and 96%, respectively.

Results for concrete containing glass fiber with pozzolanic cement

Figure 3 shows the correlation between the results of compressive strength, rupture module and "friction-transfer" test for glass fiber-containing concrete made with Pozzolanic cement.



a) “friction-transfer”- compressive strength b)“friction-transfer”-rupture module

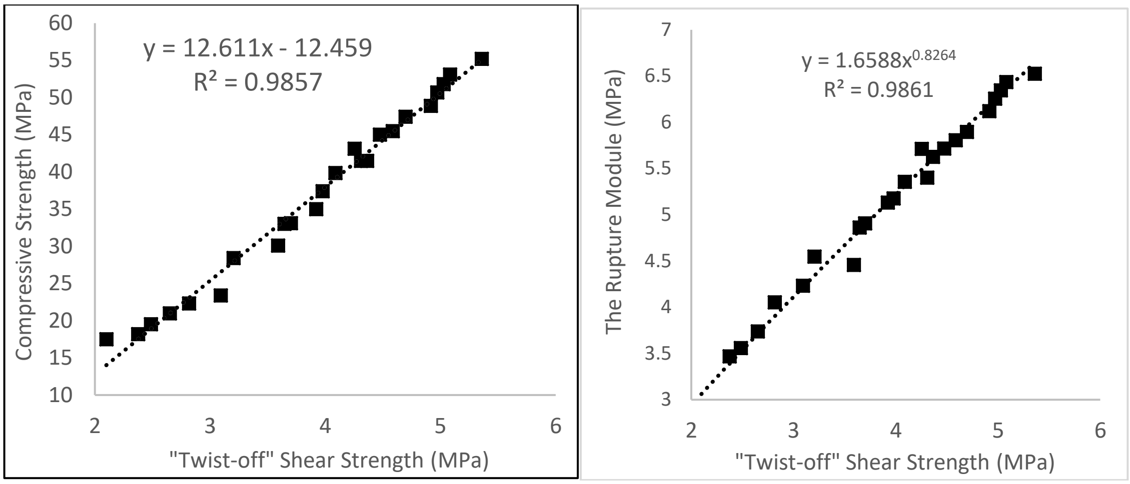


C) rupture module- compressive strength

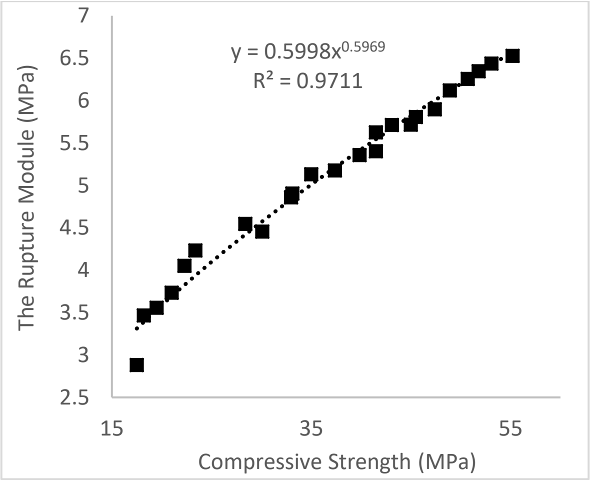
Figure 3: Results for glass fiber-containing concrete

As shown in Figure 3, there is a high correlation between the results of the "friction-transfer" test and the compressive strength and rupture module of the pozzolanic concrete containing glass fibers. Figure 3a shows that there is a linear correlation between the compressive strength and the readings obtained from the "friction-transfer" test with the intensity of 97% and the coefficient of determination of 94%. Therefore, the compressive strength of pozzolanic concrete containing glass fiber can be obtained with high confidence by this in situ test.
As shown in Figure 3b, the correlation coefficient between the rupture module of pozzolanic concrete containing glass fibers and friction-transfer test results is 99% and the coefficient of determination is 98%. Therefore, the rupture module of Pozzolanic concrete containing glass fiber can be obtained with high confidence by using the "friction-transfer" test. Figure 3c also shows that the correlation coefficient and the coefficient of determination between the compressive strength and the rupture module of these types of concrete are 98% and 97%, respectively.

Results for non-fiber concrete with pozzolanic cement
Figure 4 shows the correlation between the results of compressive strength, rupture module and "friction- transfer" test for concretes made with pozzolanic cement.



a) “friction-transfer”- compressive strength b)“friction-transfer”-rupture module



C) rupture module- compressive strength

Figure 4: Results for non-fiber pozzolanic concrete

As shown in Figure 4, there is a high correlation between the results of the "friction-transfer" test and the compressive strength and rupture module of the pozzolanic concrete. Figure 4a shows that there is a linear correlation between the compressive strength and the readings obtained from the "friction-transfer" test with the intensity of 99% and the coefficient of determination of 98%. Therefore, the compressive strength of pozzolanic concrete can be obtained with high confidence by this in situ test.

As shown in Figure 4b, the correlation coefficient between the rupture module of pozzolanic concrete and friction-transfer test results is 99% and the coefficient of determination is 98%. Therefore, the rupture module of Pozzolanic concrete can be obtained with high confidence by using the "friction-transfer" test. Figure 4c also shows that the correlation coefficient and the coefficient of determination between the compressive strength and rupture module of these types of concrete are 98% and 97%, respectively.

The impact of fiber on the results

In this section, the effect of glass fiber and polypropylene on the compressive strength, rupture module and results of the "friction-transfer" test for concrete made with pozzolanic cement is presented. Figure 5 shows the compressive strength values of concrete samples made with Pozzolanic cement in three states of containing polypropylene fiber, containing glass fiber, and without fiber.

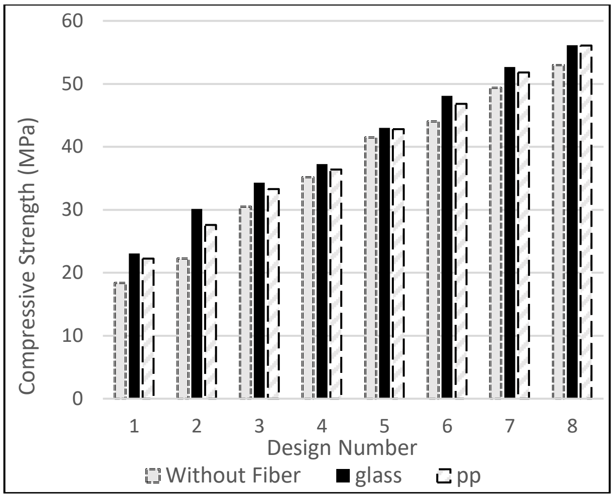


Figure 5. Compressive strength of concrete samples

As shown in Figure 5, the compressive strength of concrete for fiber-containing samples is higher than the compressive strengths of non-fiber samples. Its reason is the presence of fibers inside the concrete matrix and between the cracks, which act as a bridge and prevent opening of small cracks inside the concrete.

As shown in Figure 5, the effect of glass fibers on the compressive strength of concrete is slightly greater than that of polypropylene fibers. On average, glass and polypropylene fibers increased the compressive strength of cubic samples by 13.1% and 9.7%, respectively. As shown in Figure 6, the fiber-containing concrete retains its general consistency after failure and is not ruptured after failure, whereas the concrete-free fibers are ruptured after reaching the final load, and even at high strengths, concrete is failed explosively.

a) Failure of fiber-containing cubic concrete b) Failure of non-fiber cubic concrete

Figure 6: Comparison of failures of non-fiber concrete and fiber-containing cubic concretes

Figure 7 shows the rupture module of concrete beam samples made of pozzolanic cement in three states of containing polypropylene fibers, containing glass fibers, and without fibers.

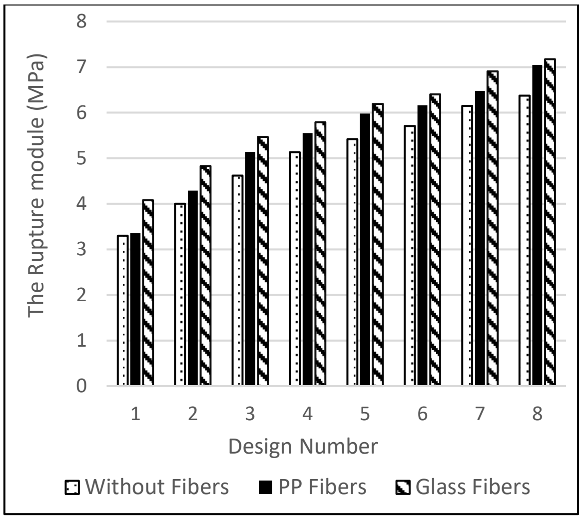


Figure 7-Rupture module of concrete beam samples

Figure 7 shows that adding fibers to concrete increases the rupture module of concrete beams and this increase is higher for samples containing glass fibers than samples containing polypropylene fibers. On average, glass fiber and polypropylene increased the rupture module of concrete beams by 15.9 and 7.8%, respectively. Also, Figure 8 shows the failure of two samples of non-fiber and fiber-containing concrete samples. Figure 8 shows that the fibers prevent the separation of concrete components and hold the beam halves together after failure.

a) Failure of fiber-containing concrete beam sample b)Failure of non-fiber concrete beam sample

Figure 8: Comparison of failures of non-fiber and fiber-containing concrete beam samples

Figure 9 shows the results of the "friction-transfer" test on concrete cubic samples made with Pozzolanic cement in three states of containing polypropylene fibers, containing glass fibers and without fibers. As shown in Figure 9, adding fibers to concrete increases the strength resulting from friction-transfer test. Also, the effect of glass fibers is more than that of polypropylene fibers. The effect of fibers on the concrete samples with lower strength is higher compared to the concrete samples with high strength, so that at lower strengths, adding of glass fibers and polypropylene increased friction transfer test results by 20.3% and 17%, respectively, but for samples with high strength, this increase was 5 and 4%, respectively.

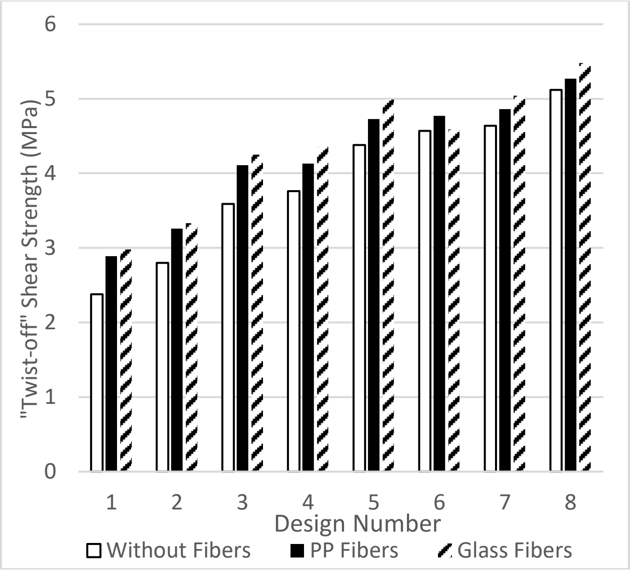


Figure 9. Results of the "friction-transfer" test on cubic concrete samples

The effect of cement type on the results of the rupture module, compressive strength, and friction- transfer test

To investigate the effect of cement type on the results of the rupture module, compressive strength, and "friction transfer" test, a set of samples with type II cement were made. The results are as follows. Figure 10 shows the results of the compressive strength of cubic concrete samples made with Pozzolanic cement and Type II cement. As shown in Figure 10, the compressive strength of cubic samples made with type II cement is higher by 6.2% on average than that of samples made with pozzolanic cement. It is due to the presence of pozzolan in the cement, as pozzolan reduces the hydration heat in concrete at early ages and it causes that the 28-day compressive strength of the concretes made with type II cements to be greater than the concretes made with pozzolanic cement.

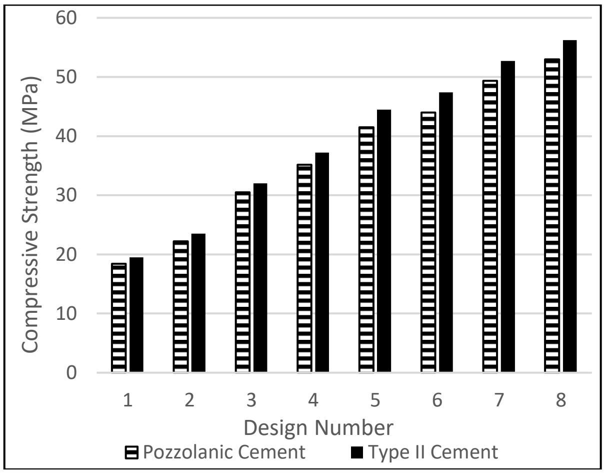


Figure 10- Compressive strength of samples made with pozzolanic cement and type II cement

Figure 11 shows the results of the rupture module of concrete beams made with pozzolanic cement and type II cement.

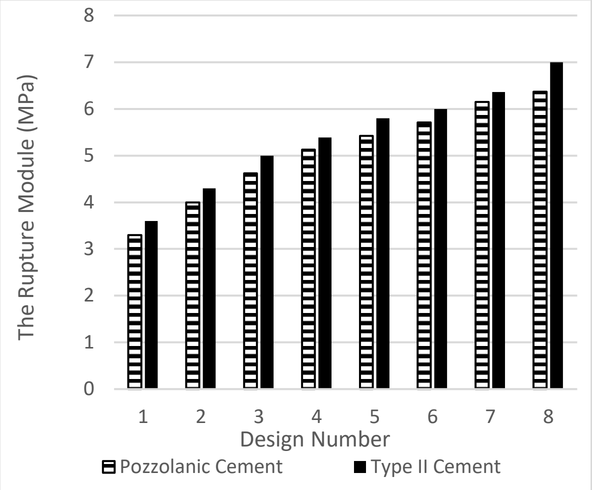


Figure 11- Rupture module of samples made with pozzolanic cement and type II cement

Figure 11 shows that the rupture module of concrete beams made with Type II cement is 6.9% more than that of the concrete beams made with Pozzolanic cement. This difference is due to the higher strength of the samples made with type II cement at the age of 28 days.

Figure 12 shows the results of the "friction-transfer" test.

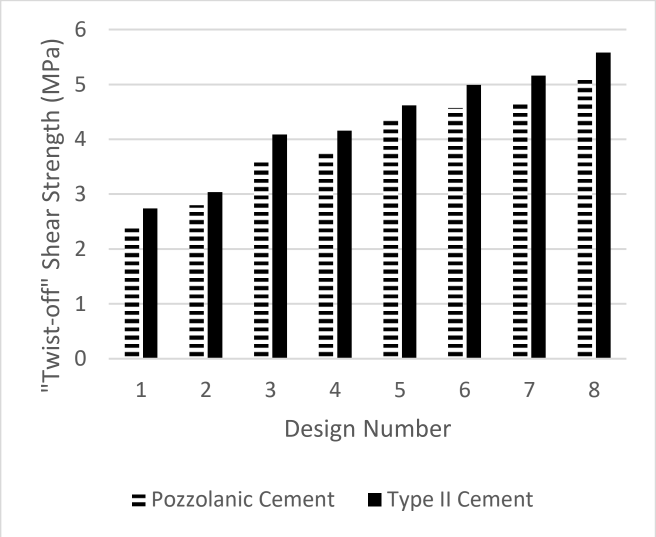


Figure 12. Results of the "friction-transfer" test on samples made with pozzolanic cement and type II cement

Figure 12 shows that the strength of the "friction transfer" test on cubic samples made with type II cement is on average 11% higher than the samples made with pozzolanic cement, which is due to the higher compressive strength of samples made with type II cement compared to the samples with Pozzolanic cement.

CONCLUSION

Based on the experiments performed and the analysis of the results, it can be concluded that:

1. The "friction transfer" test can be used as an accurate method with wide application to evaluate the strength of pozzolanic concrete. The failure of this test is very slight.

2. If the "friction-transfer" method is used, the calibration equation for each concrete can be used to determine the compressive strength and rupture module of the Pozzolanic concrete beam and the desired value can be obtained based on MPa and at the confidence range of 97% that is a significant value compared to other tests.

3. Adding 0.3 volumetric percentage of fiber to the pozzolanic concrete increased the rupture module, compressive strength and results of the "friction-transfer" test and this increase was greater for glass fibers than polypropylene fibers.

4. Fibers increase the bond strength of the constituents of pozzolanic concrete when it is failed and prevents the breakdown of concrete, but non-fiber concrete is broken down when it is failed.

5-Results of "friction-transfer" test, compressive strength and rupture module in type II cement concrete were 11%, 6.2% and 6.9% higher than those of the samples made with pozzolanic cement.

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