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Research Article

Investigation of the effect of polyvinyle alcohol fibers on mechanical properties of the high-strength concrete containing microsilica

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ABSTRACT

Today, the use of fibers in concrete is one of the best methods to improve weaknesses such as low tensile strength and brittleness. Polyvinyl alcohol fibers are one of the best fibers to improve the mechanical properties of fiber concrete. These fibers improve the mechanical strength and performance of concrete by the connection between the micro-cracks, which is due to its excellent adhesion, tensile strength and high modulus of elasticity. The main purpose of this research is to analyze and evaluate the effect of polyvinyl alcohol fibers with a diameter of 0.014 mm and lengths of 6 and 12 mm in combination in high strength concrete containing microsilica. Accordingly, four mixtures with different amounts of polyvinyl alcohol fibers (0, 0.15, 0.3 and 0.6% of the total volume of concrete) were evaluated due to their effect on the fresh and hardened properties of high strength concrete. 10% microsilica was used as a substitute for Portland cement in all mixtures. A series of experiments (compressive strength, indirect tensile strength) showed that the low volume of polyvinyl alcohol fibers significantly increases the mechanical properties of concrete. The results of this research show that the use of volume ratio of 0.15% of polyvinyl alcohol fibers increases the compressive strength by 10.29% and tensile strength by 10.43%.

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INTRODUCTION

These days for achieving the design strength higher than 40 megapascal, using microsilica or other chemical additives is very common. Microsilica is the side product of ferosilisium production process that is the required rawmaterials in the production chain of steel and cast iron and using this material as the substitute of the part of used cement, decreases the demand for cement and helps the preservation and health of the environment. Because for producing cement, environmental damages from cement producing companies are inevitable. The use of microsilica in concrete, beside protecting the environment, has other advantages that among which we can increase mechanical strength, reduce permeability, reduce the mobility of chlorine ions and prevent

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corrosion of reinforcement in the reinforced concrete [1]. Fallah and Nematzadeh in 2017 [2], indicated that using 2% nanosilica and 12% microsilica have the highest effect on the compressive strength of high strength concrete with an increase of 0.14 and 41.1%, respectively. Also, they showed that the cement containing 0.2% polypropylene with 0 percent microsilica has the lowest amount of water absorption and porosity. Also the results of experiments showed Ali et al. Silica fume improves the performance of fibers in resistance to tensile and flexural loads, and the combined effect of fiber and silica fume is more useful than the sum of the effects of their individual composition. Silica fume helps reduce water absorption and chloride permeability of FRCs and improves their resistance to acid attack [3]. Ali et al. Showed in another article. The addition of micro-silica with steel fiber is not only beneficial to boost the strength properties, but it also improves the interaction between fibers and binder matrix. MS minimizes the negative effects of high fiber doses on the properties of concrete [4]. Li et al. in 2004 [5], studied the microstructure of simple cement mixture with nanoparticles by using electronic microscope. They showed that the nanoparticles react with calcium hydroxide of cement and hydrated calcium silicate gel is produced to fill the pores of the cement mortar. Despite the proper performance of this type of concrete, two major weaknesses: (1) low tensile strength (2) brittleness and fragility have faced its widespread use with many problems. Crack formation in concrete occurs during hydration, even before applying any external load. This is especially common in the contact area between the cement pastes and the aggregates because of the unilateral growth of the joint and the different hardness of the materials [6]. From an energy point of view, growing the existing cracks happens more easily than new cracks, resulting in low mechanical strength and brittleness. Although, these cracks generally increase over time, therefore the waterproof properties of concrete are disappeared and the concrete is exposed to destructive substances, that result in the reduction of the useful life of concrete [7,8].

One of the best methods for improving these weaknesses of the cement is adding fibers. If fibers are distributed uniformly in all of the directions, they prevent creating plastic cracks in the cement and transformation of small cracks to big cracks. Also, by linking cracks, large cracks are placed close together and the premature concrete failure is prevented. Of course, the amount of improvement in concrete performance largely depends on the type and amount of connection between the fibers and the mortar. For example, polypropylene and polyethylene fibers have frictional bond due to their hydrophobic surface. In this study, hydrophilic polyvinyl alcohol (PVA) fibers were used to improve the performance of high-strength concrete containing microsilica. PVA fibers, due to having a free hydroxyl group in its structure, show a strong chemical bond with the cement hydrate and prevent the fibers from pulling out from the cement mortar. This situation indicates the adjustment and control of cracks, by a suitable surfactant, from the amount of special adhesive in the interfacial transition zone (ITZ), which improves the performance of concrete according to high strength and elastic modulus of this fibers. Kang et al. in 2016 [9], asserted that the use of PVA fibers in reinforced concrete withstands tensile stress up to 13 MPa and it has a significant energy absorption. Also, by comparing the performance of different micro fibers, including steel, basalt fibers and polyethylene fibers, it was found that after polyethylene, PVA fibers have the best effect on the tensile behavior of the sample.

Noushini et al. in 2014 [10], indicated that concrete with normal granulation containing fly ash and PVA fibers with a length of 6 mm have higher compressive strength than concrete with PVA fibers with a length of 12 mm. the reason of this issue is difficulty of compression in mixtures containing longer fibers while using fibers with 12 mm length show more deformation and strain than the concrete containing 6 mm length fibers. Other properties of these fibers are nontoxicity, degradability, environmentally friendly [11]. Also, these fibers maintain their tensile strength and durability in cement environment with high pH and severe alkaline conditions [12]. These unique properties of PVA fibers have led researchers to use it in the manufacture of engineered cement composites (ECC) in recent years. Engineered cement composites are a new generation of concrete and they are generally made of combination of cement, very fine stone materials, water and fibers and it is much more formable than conventional concretes, so that the ECC strain under a uniaxial stretch can reach up to 8% and this is 100 tomes more than ordinary concretes [13]. ECC with strength against opening cracks and preventing from the creation of cracks increases the tensile strength than ordinary concretes and also prevents the absorption of degrading materials such as solfate and chloride into the cement [14,15].

Şahmaran and Li [16,17] studied the durability of engineered cement composites containing polyvinyl alcohol fibers that was prior placed in mechanical load in the extremely alkaline environment and they confirmed the durability of this kind of composite. Hamoush et al. in 2010 [18], showed that the composites containing PVA fibers have more ductile failure than samples without fiber. They also showed that a strong bond between the polyvinyl alcohol fibers and the cement paste reduces the elastic cracks and this finding was achieved through microscopic analysis of the surface in the ruptured concrete sample. Liu et al. in 2020 [19], investigated the load-deformation performance of the reinforced beams with PVA fibers in their study. Their experimental results indicates that PVA-FRCC beams show obvious deflection stiffness and high ductile performance compared to conventional RC reinforced concrete beams and the final deformation is about 3.1-2.4 times more than RC beams. They also showed that in comparison with RC beams, the presence of PVA fibers for bearing load, excellent deformation capability and finally ductile failure is extremely useful.

Wang et al. in 2020 [20], for economizing and reducing environmental damages, through replacing the weight ratio of 10% silica fume, 10% GGBFS and/or 10% fly ash with cement improved the compressive strength of ECC. They also showed that the crack resistance, strain resistance and the final tensile strength of ECC made of PVA fibers without surface oil and with ECC made of PVA fibers with surface oil is approximately equal and 3.5 to 4 times more than the simple mortar. They believe that the new ECC product has a wider application in the field of civil engineering. Although, ECC does not have the problems of conventional concretes such as fragility and low tensile capacity, but because of using very fine aggregates (less than 200 mm), the amount of cement used in ECC is much higher than conventional concrete. The high cost for designing and manufacturing ECC, and also the environmental damages caused by increased demand and production, limit the widespread use of this type of concrete. In this situation, by adding PVA fibers to the conventional high-strength concrete containing microsilica, some of the desired conditions can be achieved. Also, in order to further reduce the cost, surface oil-free PVA fibers, i.e., oil-free cover on the surface of fibers, were used to improve the performance of high-strength concrete. For a typical 45 MPa PVA-ECC, the cost of oily PVA fibers includes 80% of the total ECC cost. Pan et al in 2015 [21], showed that ECC made of PVA fibers without surface oil has similar tensile strength and elastic modulus to ECC made of PVA fibers with surface oil. While, the price of these fibers is about one-eighth of PVA fibers with surface oil.

As mentioned, PVA fibers are more economical to use instead of other fibers for several reasons. PVC fibers have better adhesion to cementitious materials than steel fibers, which prevents the fibers from being pulled out of the concrete easily. Also, due to the lower dose of PVC fibers used in concrete, these fibers are more economical than steel fibers. Also, due to the environmental effects of steel extraction, production of steel fibers and non-degradability, PVA fibers do not harm the environment.

In this study, in order to decrease the use of cement (to decrease environmental pollutions and decreasing the cost of cement usage) 10% microsilica is used as a substitute for a section of the used cement in all tests and to further decrease the costs PVA fibers with smaller diameter abd without surface oil is used in different ratios. For this purpose, four mixing designs including a fiber-free sample and three samples with different percentages of PVA fibers are fabricated and their mechanical properties such as compressive strength, tensile strength and stress-strain curve are compared.

To conduct this research, first, the study of valid sources and collection of necessary information has been done. In the second step, the necessity of conducting research is evaluated. In the third step, scenario building has been considered to start working. Finally, the required analyzes has been performed and conclusions has been obtained from the outputs.

PROGRAMME OF THE EPERIMENTS

Materials

The aggregates in this study were selected according to Iranian National Standard 302 [22]. The sand in this study is a broken type and has a volume density between 1520 to 1680 kg/m^3. Granulation properties of the used aggregates are reported in Table 1.

In this research, Portland cement type 2 is used, its properties can be seen in Table 2. Also, in all of the mixing designs, 10% microsilica has been replaced by cement and its specifications can be seen in Table 3. Also, surface oil-free PVA fibers with two lengths of 6 and 12 were used to improve the mechanical properties, its properties can be seen in Table 4. Consumed water in fabricating concrete is drinking water. In order to increase efficiency and reduce water consumption, a carboxylate-based superlubricant has been used and it has a specific gravity of 1.05 gr/cm^3.

Table 1. Comparing the granulation in Iranian National Standard 302 and the used granulation in aggregates

the maximum size of aggregates (mm)	119	112.5	99.5	44.75	22.36	11.18	00.6	00.3	00.15
Range of permitted passage percentage of coarse grain	990-100	445-90	220-55	00-10	00-5	--	--	--	--
Passage percentage of the consumed coarse grain	1100	448.42	220.73	00	00	--	--	--	--
Range of permitted passage percentage of fine grains	--	--	--	889-100	660-100	330-80	115-50	55-30	22-10
Passage percentage of fine-grained consumption	--	--	--	-0	668.40	448.80	333.91	220.55	77.51

Table 2. The chemical compounds and physical properties of cement

Chemical compounds	%
SiO_2	20.67
AL_2O_3	4.23
Fe_2O_3	4.23
CaO	62.75
MgO	1.76
SO_3	2.26
Na_2O	0.51
K_2O	0.65
Others	2.85
Physical properties	
Specific area (gr/cm^2)	2930
Density (gr/cm^3)	3.15

Table 3. Chemical compounds of microsilica

Chemical compounds	%
SiO_2	93.6
SiC	0.5
C	0.3
Fe_2O_3	0.37
AL_2O_3	1.32
CaO	0.49
MgO	0.97
Na_2O	0.31
Na_2O	1.01
P_2O_5	0.16
SO_3	0.1
Cl	0.04

Table 4. The properties of polyvinyl alcohol fibers

Length (mm)	Diameter (mm)	Density (gr/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Final strain (%)
6 and 12	0.014	1.29	1600	38.7	6.5±0.5

Mixing Scheme

The control mixing scheme used in this research was made according to the ninth topic of the National Building Regulations (design and construction of reinforced concrete buildings). In this study, a total of four concrete samples including one without PVA fibers and three with different volume ratios (0.15, 0.30 and 0.60%) of PVA fibers were fabricated. According to studies by other researchers, using a volume ratio more than 0.5% of PVA fibers reduces the mechanical strength. Hence, the maximum fiber in this study was selected 0.6%. In order to analyze the effect of PVA fibers on the mechanical properties of concrete, the amount of used cement, microsilica and water to cement ratio in all mixtures were kept constant in mixing scheme. As it was expected, by adding PVA fibers, the performance of cement decreases. In the mixing scheme, the amount of superlubricant was increased as the fiber amount increased in the cement. The quantities and ratios of the components in the studied mixtures are reported in Table 5. Figure 1 shows an example of polyvinyl alcohol fibers and Figure 2 shows an example of the used microsilica.

In order to facilitate identification, each sample with PVA fibers is uniquely introduced by a name consisting of two parts. The first phrase contains PVA and the second phrase shows the volume percentage of fibers in the design (percentage). For example, PVA-0.3 mixture contains three tenths percentage of polyvinyl alcohol fibers volume in per cubic meter of concrete.

Table 5. The properties of mixing scheme

Sample code	Cement	Water	Ballast	Sand	MS	Sl	PVA
	Mixing ratio (Kg/m^3)						
Control	518.82	196	813.76	813.76	57.65	2.306	0
PVA-0.15	518.82	196	813.76	813.76	57.65	2.498	1.95
PVA-0.3	518.82	196	813.76	813.76	57.65	2.69	3.9
PVA-0.6	518.82	196	813.76	813.76	57.65	2.882	7.8

MS: Micro-Silica; SI: Super lubricants; PVA: polyvinyl alcohol fibers

Figure 1. PVA fibers used in the study.

Figure 2. The used microsilica.

Production of Cement

In order to fabricate the samples, first the used aggregates were dry mixed in a blender for 30 seconds. Then some of the required water in the scheme was added and mixed for another 30 seconds. In following, the required cement and microsilica along with the rest of the water and some superlubricant were added to the mixer in two steps and mixed thoroughly. Finally, PVA fibers, after separating by hand, were added slowly and gradually to the concrete mixture while mixing. After adding the fibers to the concrete, we continued mixing for about three minutes.

After mixing operation, the slump of the mixtures was measured. For compressive strength test, the standard cube mold of 15×15×15 mm and for tensile strength, the standard cylinder mold of 20×10 mm was used. To pour the concrete into the molds, the concrete was poured into the mold in three stages and in each stage, it was beated with a maul until it is well compacted. After compaction, the samples were kept in the mold for 24 hours and after opening the mold, the samples were kept in a pool of water until they reach to the desired age. In figure 3 the fabrication and molding of the samples are shown.

Performed Experiments

In this study, a slump test according to ASTM C143, was performed to measure the mixtures before pouring into the mold [22]. Compressive strength test according to BS EN 12390-3, was performed on the cubic specimens with a dimension of 15 cm and at the ages of 7 and 28 days [23]. The cubic samples were placed between the two plates of a device shown in figure 4 in a direction that the surface of the sample contact with the mold. And a vertical force with a constant speed was applied to the cubic sample until the

Figure 3. Fabrication and molding of the samples.

Figure 4. Compression strength test.

Figure 5. Tensile strength test.

sample breaks due to compressive force and the maximum applied load at the rupture time was recorded. The loading system was adjusted to have an ability to record the applied displacement force simultaneously, hence the stress-strain plot of the sample was achieved in compression. The tensile strength in the specimens was determined indirectly through the halving method (Brazilian test) in a way that the compressive force is applied uniformly from the lateral surface of the cylinder to the specimen placed horizontally between the two plates of the test apparatus until the rupture occurs in the length of the specimen and the maximum applied load at rupture time was converted to tensile rupture stress by using several equations. This experiment according to ASTM C496 standard, was performed at the age of 28 days on cylinder specimen 200×100 mm [24]. Figure 5 shows the indirect tensile strength test.

RESULTS AND DISCUSSION

Slump Test

The results of slump test in concrete mixtures along with the volume percentage of fibres, the amount of superlubricant and the weight of the cubic sample after 28 days are reported in table 6. In general, adding fibres and pozzolans to the concrete mixture reduces its slump [25,26]. The high percentage and large surface area of the fibres can absorb more cement paste, which leads to increase the viscosity of the concrete mixture and decrease slump [27]. Also, microsilica, as a substitute for cement, reduces the amount of slump and concrete performance by absorbing a lot of water due to higher specific surface area and much smaller dimensions than cement. As shown in table 6, the slump value for high-strength concrete containing fibre-free microsilica is 8 mm, and by increasing the volume of PVA fibres the slump value decreases. The highest amount of slump is allocated to the control sample and the lowest amount of slump is allocated to the PVA-0.6 sample.

By increasing the volume of fibbers, we increased the volume of lubricant, but this work did not have a significant effect on the performance of concrete. Decreased performance of fibres-reinforced concrete has also been reported in other researches [20]. According to table 6, it is clear that with increasing the volume of fibbers, the weight of the concrete sample decreases. The interaction of PVA fibbers with aggregates twists the fibbers around the aggregates, which reduces the performance of concrete. Also, air molecules get stuck in the distance between the fibbers and aggregates and increase the trapped air inside the concrete [20]. Of course, the low density of PVA fibbers (1.33 gr/cm3) and its hydrophilicity are not effectless in reducing the performance of concrete.

Table 6. The results of new cement experiment

Sample code	Volume percentage of fibers (%)	The ratio of lubricant to cement (%)	Superlubricants Kg/m^3	Slump mm	Weight of the cubic sample Kg
Control	0	0.4	2.306	8	8.40
PVA-0.15	0.15	0.43	2.498	4	8.25
PVA-0.3	0.3	0.46	2.69	1	8.06
PVA-0.6	0.6	0.5	2.882	0	7.83

Compression Strength Test

In all of the mixtures, the compression strength test was performed in the age of 7 and 28 days after keeping in the wet conditions. The results of the compressive test on the specimens are shown in table 7. Also, a comparison of the compression strength in the conventional high-strength concrete specimens and high-strength fiber concretes can be seen in figure 5. It should be noted that the resistance value in the plot of figure 5 is the average value of the compression strength in the two samples from every mixing scheme. Based on the results from the compressive strength test, the average 28 days compression strength in the PVA-0.15 specimen increased by 10.29% compared to the control sample. The average 28 days compression strength in PVA-0.3 and PVA-0.6 specimens showed a reduction in resistance of about 25 and 39% compared to the control sample, respectively. This unexpected decrease in compression strength can be due to the high soft modulus of the used fine-grained materials and using microsilica that decreases the performance of high strength concrete.

As mentioned in previous chapters, polyvinyl alcohol fibers are hydrophilic and adding them to concrete (as shown by the slump test in table 6) reduces the performance of the concrete and subsequently the fibers are distributed non-uniformly in the concrete mix. This phenomenon leads to conglobate, concentration tendency in the concrete and it creates porosity inside the concrete. Another significant point is that as the volume of PVA fibers becomes larger in the specimens, the difference between the two specimens increases. The sample PVA-0.6 shows 27% difference between two tested sample. This difference in a similar mixing scheme shows the tendency of the polyvinyl alcohol fibers to concentrate at one point and its non-uniform dispersion in the concrete mixture in the second sample. Ot means that if the volume of used fibers exceeds a certain amount, not only does not have an effect on increasing the compressive strength of concrete, but also reduces its strength due to its non-uniform distribution in concrete. The results of research by other researchers also confirm this result [28]. In figure 6 the CONTROL sample and the PVA-0.15 sample after the compression strength test was shown and also the porosity of the samples having fibers compared to the non-fibrous sample can be seen.

Table 7. Results of compression strength tests

Sample code		7 days compression strength	28 days compression strength	28 days Modulus Elasticity	Strain equivalent to maximum compression stress
		Mpa	Mpa	Mpa	
Control	1	30.57	38.00	6364.78	0.0058
	2	27.91	36.86	-	0.00596
PVA-0.15	1	26.22	42.53	4933.33	0.00847
	2	28.82	40.00	5741.94	0.00687
PVA-0.3	1	16.18	29.87	4482.76	0.00653
	2	22.27	25.87	5460.32	0.00567
PVA-0.6	1	24.04	26.31	4011.49	0.00613
	2	16.13	19.29	4450.45	0.00827

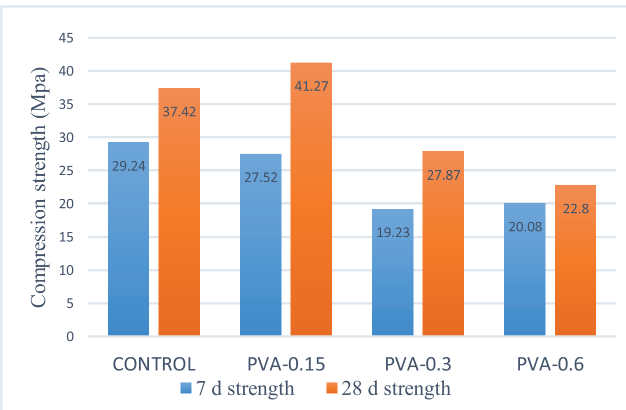

Figure 5. The plot of the compressive strength tests results.

Figure 6. Control sample and PVA-0.15 sample after loading.

Figure 7 shows the compression strength of samples having fiber to the compression strength of control sample in two ages of 7 and 28 days. According to figure 7, it can be seen that in the case of using PVA fibers the rate of strength in early ages is less than strength rate in 28 days. This is because connecting and complete bonding between polyvinyl alcohol fibers and cement paste is a time-consuming process and reaches an acceptable level around the age of 28 days [28]. Also, it is seen that using 0.15% PVA fibers increases the 28 days compression strength of concrete by about 10.3% and the compression strength of the specimens decreases by increasing the percentage of PVA fibers.

In figure 8 the compressive stress-strain plot is seen. The stress-strain plot of samples is provided in figure 8 that has higher compression strength than the average amount. Considering figure 8, it is seen that the rupture state of the control specimen is more brittle and occurs with less strain, but specimens with polyvinyl alcohol fibbers have a more ductile failure mode, so that the stress-strain curve of the PVA-0.15 specimen shows an increased stress even at a strain of 0.0085 and with increase in the volume of polyvinyl alcohol fibbers, the amount of strain decreases so that the maximum strain in the compression strength for PVA-0.3 and PVA-0.6 samples is 0.0065 and 0.0061, respectively. This can be due to the presence of polyvinyl alcohol fibbers in the interfacial transition zone (ITZ) and creating an integrated structure between the cement paste and the aggregates. The equivalent strain to the maximum compression stress has reported in table 7 in the age of 28 days. The reason of this phenomenon is linking between PVA fibbers on the small cracks because if the fibbers are dispersed well, they link more cracks and also better dispersion of these fibbers in concrete create lower porosity in concrete than ununiformed distribution and this makes better adhesion of these fibbers to the concrete matrix. Also, in the samples with polyvinyl alcohol fibbers, many small cracks are observed during degradation. The results of the conducted research by other researchers also confirm this subject. Meda et al. in 2012 [29], showed that the use of fibres prevents the brittle and sudden failure of concrete and increases the energy absorption and tolerance of concrete.

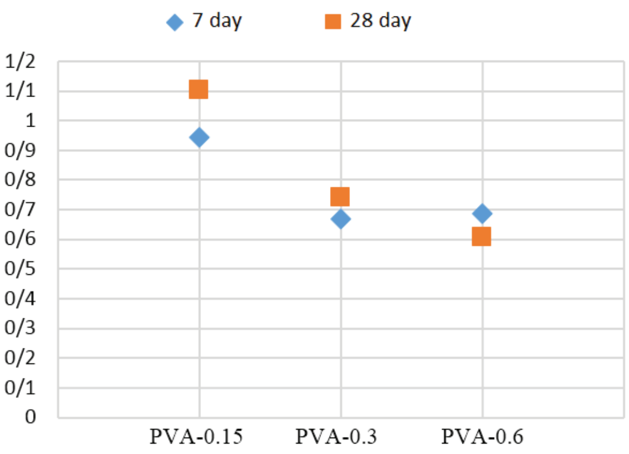

Figure 7. Compressive strength ratio of fiber samples to control sample.

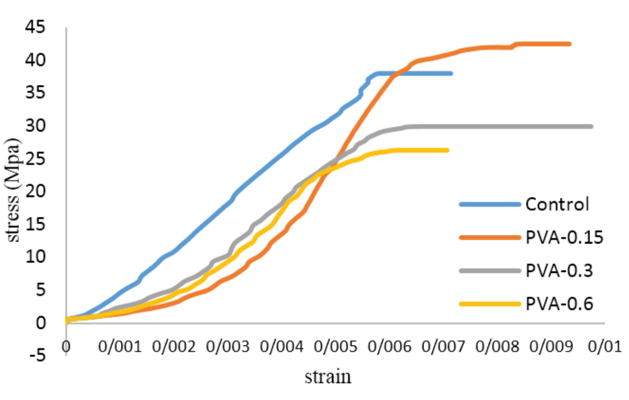

Figure 8. Compression stress-strain plot.

The Experiment of Tensile Strength

In this research, indirect tensile test (Brazilian) was used to measure the tensile strength of concrete at the age of 28 days. In table 8 and figure 9, the amount of tensile strength of concrete with different percentages of fibers can be seen. Based on the obtained results from the tensile strength test, the 28-day tensile strength of the control sample is 2.69 MPa. The tensile strength of PVA-0.15 sample is 2.97 MPa, which increases the tensile strength by 10.43% compared to the control sample. The reason for this subject is the feature of linking the fibers on the microcracks and increasing the energy absorption capacity of the concrete. The average of 28 days compression strength of PVA-0.3 and PVA-0.6 samples showed a decrease in strength of about 2.3 and 7% than the control test, respectively. This means, if the volume of the used PVA fibers exceeds a certain amount, it reduces the tensile strength of concrete. This decrease in strength is different from the research results conducted by other researchers [10]. Reduction in tensile strength in tests with a percentage of polyvinyl alcohol fibers more than 0.15% can be due to the high softness modulus of the used fine-grained materials and the use of microsilica, which reduces the performance of concrete. Adding hydrophilic polyvinyl alcohol fibers to concrete, as shown by slump test, reduces the performance of concrete and consequently the fibers are distributed uniformly in the concrete mix, which causes porosity inside the concrete. Also, the amount of linking in fibers with the cement paste is decreased. In this case, the decrease in tensile strength due to porosity is more than the tensile strength increase due to the linking properties of fibers. In general, the strength of concrete decreases [28].

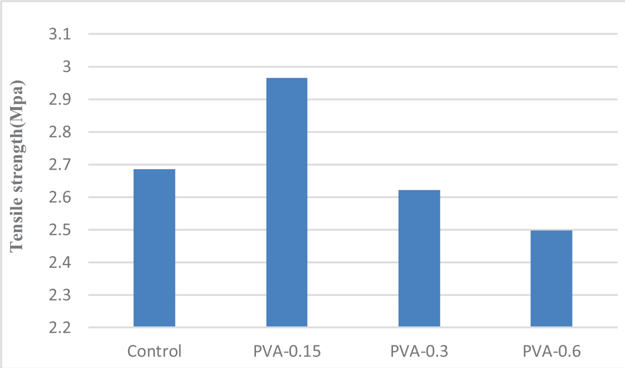

Figure 9. The results of tensile strength test in concrete having various percentage of fibers.

Table 8. The results of tensile strength test in specimens

Tensile strength MPa	Sample code
2.685	Control
2.965	PVA-0.15
2.622	PVA-0.3
2.497	PVA-0.6

The Relationship Between Compression and Tensile Strength

In figure 10 the linear relationship between changes in compression strength and changes in tensile strength for high-strength concrete containing microsilica and polyvinyl alcohol fibers compared to simple high-strength concrete is shown. In figure 10 the horizontal axis shows the change in the compression strength in high-strength concrete with fibers compared to conventional high-strength concrete and its vertical axis indicates the change in tensile strength in high-strength concrete with fibers compared to conventional high-strength concrete. In the figure, it can be seen that the trend of changes in the tensile and compression strength in high-strength concrete with fibers is similar to each other, hence, the relationship between tensile strength and compression strength is direct.

Based on the results of the Brazilian indirect tensile strength test, the 28-day tensile strength of the control test is 2.69 MPa. Also, the compressive strength of PVA-0.15 test is equal to 2.97 MPa, which increases the tensile strength of high-strength concrete containing microsilica (by adding a volume ratio of 0.15%) by about 10.43% compared to the control sample. The reason for this is the bonding properties of the fibers on the microcracks and increase the energy absorption capacity of the concrete. The average 28-day compressive strength of PVA-0.3 and PVA-0.6 test is 2.62 and 2.5, respectively. This shows a decrease in strength of control concrete by about 2.3% and 7% compared to the control test, respectively. These results mean that if the volume of used fibers exceeds a certain amount, PVA fibers not only have no effect on increasing the tensile strength of concrete, but also reduce its strength. This reduction in resistance is consistent with the results of research conducted by other researchers [30].

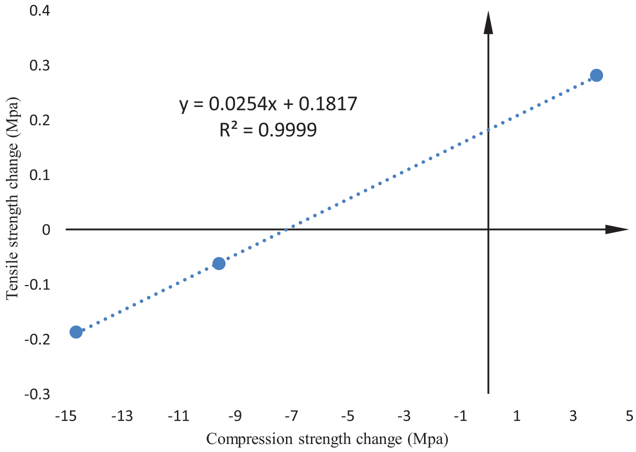

Figure 10. The plot of the changes in compression strength to the changes in tensile strength.

CONCLUSION

- The use of PVA fibers reduces the workability and slump of concrete, so that the higher the percentage of use of PVA fibers, the lower the slump of concrete and the greater the need for superplasticizer.
- According to the results of 7 and 28 day tests, linking and complete connection between PVA fibers and the cement paste is a time-consuming process and it reaches an acceptable range around 28 days age.
- In the case of using 0.15 percentage of PVA fibers, the tensile strength of the concrete increases to 10.43% percent and by increasing the volumetric ratio of PVA fibers in the concrete, tensile strength of sample decreases in comparison with the sample without fiber.
- If polyvinyl alcohol fibers are distributed decentrally and uniformly in the concrete matrix, not only it will increase the compression strength of the concrete, but they will also increase the equivalent strain to the maximum compression strength in the stress-strain curve and the concrete failure happens in a ductile manner. So, in PVA-0.15 sample, not only the compression strength has increased significantly but also the strain at the maximum stress reaches 0.0085.
- Brazilian tensile strength of high-strength fiber-containing concrete increases compared to conventional concrete. This increase in strength is such that as the volume of PVA fibers increases, the tensile strength of the mixture first increases and then decreases. The

highest tensile strength in PVA-0.15 test is increased by about 10% and with increasing percentage of PVA fibers, the tensile strength decreases.

- The ratio of increase in tensile and compressive strength of 28-day PVA-0.15 test is almost the same, but by increasing percentage of PVA fibers in high strength concrete containing microsilica, the compressive strength of concrete decreases more than tensile strength.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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