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STUDY OF THE POLYOLEFIN FIBRES EFFECT ON THE PROPERTIES OF FRESH AND HARDENED CONCRETE

ISTRAŽIVANJE UTICAJA POLIOLEFINSKIH VLAKANA NA OSOBINE SVEŽEG I OČVRSLOG BETONA

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Keywords
- polyolefin fibres
- water absorption percentage
- modulus of concrete elasticity
- compressive and tensile strength of concrete
- fresh and hardened concrete

Abstract

To improve the brittleness of concrete, as well as reduce cracks due to load application, and to increase the strength of concrete, a variety of fibres are used in the concrete mixing design. The main purpose of this study is to investigate the effect of polyolefin fibres in different shapes on the properties of fresh and hardened concrete, including concrete performance, compressive and tensile strength, and modulus of elasticity of concrete in the laboratory (dry) and in the wet environment at ages of 3, 7, 28, and 56 days. Polyolefin fibres led to an increase in tensile and compressive strength, and finally an increase in modulus of elasticity of the tested concrete compared to fibre-free concrete sample. Increase in tensile strength of concrete is very significant. A maximal increase is observed in the Filamentary Polyolefin Fibres concrete (FPF) with tensile strength of 4.297 MPa and compressive strength of 57.1 MPa, and an increase in the modulus of elasticity by 14.9 % compared to the strength of control concrete in wet curing environment.

Ključne reči
- poliolefinska vlakna
- procentualna apsorpcija vode
- modul elastičnosti betona
- pritisna i zatezna čvrstoća betona
- svež i očvrsli beton

Izvod

Radi smanjenja krtosti betona, kao i smanjenja pojave prslina usled opterećenja i radi povećanja čvrstoće betona, primenjena su različita vlakna pri formiranju mešavina betona. Osnovni cilj istraživanja je iznalaženje uticaja poliolefinskih vlakana različitih oblika na osobine svežeg i očvrslog betona, uključujući i njegove performanse, pritisnu i zateznu čvrstoću, modul elastičnosti betona u laboratorijskim uslovima (suvi) i u mokrim uslovima posle perioda od 3, 7, 28 i 56 dana. Poliolefinska vlakna dovod do porasta zatezne i pritisne čvrstoće, a zatim i do porasta modula elastičnosti ispitivanog betona, u poređenju sa betonskim uzorkom bez vlakana. Značajan je porast zatezne čvrstoće betona. Najveći porast se primećuje kod betona sa filamentnim poliolefinskim vlaknima (FPF) sa zateznom čvrstoćom od 4,297 MPa i pritisnom čvrstoćom od 57,1 MPa, kao i sa porastom modula elastičnosti od 14,9 % u poređenju sa čvrstoćom kontrolnog uzorka betona u mokrim uslovima očvršćavanja.

INTRODUCTION

Today, with increase in world population, it is very important to progress in the field of construction, to maintain the existing structures and build earthquake-resistant structures more than ever. Among the new technologies effective in construction is the use of fibre reinforced concrete (Fibre Concrete). Concrete contains fibrous materials improve the desired properties such as its strength. The use of straw, especially horse- or goat hair in old buildings, especially domes, has a long history /1/. For many years, different types of fibres were used to increase the strength of concrete, but today the use of synthetic fibres and metal fibres is very common. Polypropylene fibres have many advantages over other synthetic fibres such as light weight, cost efficiency, low thermal conductivity and resistance to attack by acids and alkalis. One of the most important advantages of using polyolefins is the resistance to cracking and shrinkage of concrete in the early hours of concreting. Macro polyolefin fibres can effectively improve the flexural strength and post-cracking performance of concrete /2/. Fibre due to its filament and thinness will cause better adhesion to the concrete and this will increase the strength. The effect of fibres on the properties of fresh concrete depends on their nature, length, shape, and volume /3/. Reinforced concrete with polypropylene fibres requires more mixing time than ordinary concrete and less mixing time than reinforced concrete with steel fibres /4, 5/. Addition of polypropylene fibres due to low density, unlike other types of fibres such as steel fibres, has little effect on the density of concrete /6/. Shorter polypropylene fibres compared to longer ones have a relatively higher compressive strength and lower flexural strength /7/, also reduced cracking in the concrete with short polyolefin fibres is more evident than with the longer sample /8/.

Arafa et al. in 2013 /9/, investigated the effect of Forta fibres on self-compacting concrete and its mechanical properties. They observed an increase in compressive strength of self-compacting concrete in the range of 1 to 7 % and tensile strength in the range of 20 to 30 %, compared to fibre-free concrete. Smirnova et al. in 2017 /10/, investigated the effect of polyolefin fibres on strength and ductility properties. They found that the increase in tensile strength for 28 days for concrete with macro fibres in the amount of 4.5 kg/m^3 was 23 and 29 %, and for macro fibres in the amount of 3 kg/m^3 was 19 and 26 %.

Poorsaheli et al. in 2021 /11/, studied the impact of using steel and polyolefin fibres at three volume ratios on the long-term performance of concrete when subjected to a high chloride medium. Concrete properties measured included compressive and flexural strength, water permeability under pressure, electrical resistivity, half-cell test, and water absorption. Results showed that fibres have no considerable impact on compressive strength while they can improve the flexural strength by up to 28 %. Electrical resistivity and half-cell test results showed that polyolefin fibres improve concrete performance against corrosion while steel fibres reduce the corrosion resistance of the concrete.

Picazo et al. in 2021 /12/, analysed the shear contributions of fibres in FRC by means of shear push-off tests. The influence of two of the most common structural fibres is examined: hooked-end steel and polyolefin fibres. They included the description of the experimental campaign and the push-off tests. In addition, the analysis of the cracking patterns by means of digital image correlation (DIC) is also included. The experimental results are compared with a shear crack opening behaviour model.

Rucka et al. in 2021 /13/, explored the monitoring of the fracture process in concrete beams and aims to characterize the evolution of damage in polyolefin fibre-reinforced concrete beams by utilizing the integrated application of two measurement techniques, digital image correlation and ultrasonic testing. The interpretation of registered wave time histories data is provided by the calculation of the magnitude-phase-composite metrics. An efficient procedure for the determination of the strain field and the identification of crack height was subsequently developed.

The main purpose of this study is to investigate the effect of polyolefin fibres in different shapes on the properties of fresh and hardened concrete, including concrete performance, compressive and tensile strength, and modulus of elasticity of concrete in laboratory environment (dry) and wet environment at the ages of 3, 7, 28, and 56 days.

LABORATORY PROGRAMME

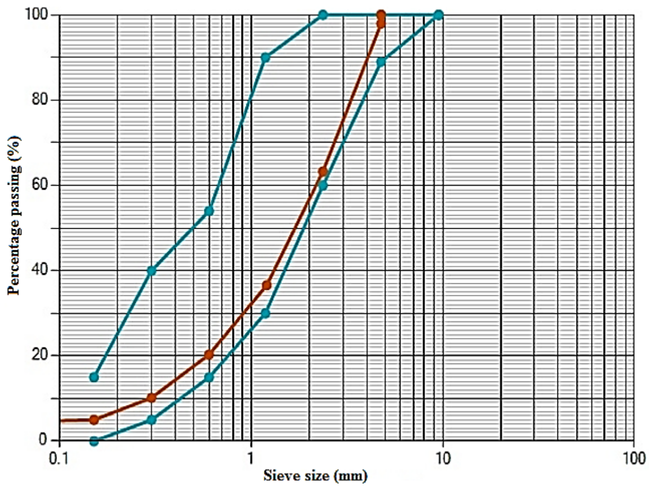
The aim of this study is to study the effect of polyolefin fibres on the mechanical properties of concrete in terms of pressure, tension, and modulus of elasticity with a characteristic strength of 30 MPa, as well as to calculate the water absorption of concrete. The total number of research samples is 196 including 96 cubic samples with a size of 15 cm for compressive strength test, 96 cylindrical samples of 10× 20 cm^2 for tensile strength test at the ages of 3, 7, 28, and 56 days in dry and wet processing conditions, and 4 samples are 10×10×10 cm^3 cubic samples to determine the water absorption percentage of concrete. Figures 1 and 2 show how concrete specimens are made and moulded.

Figure 1. Adding wave fibres to the dry mix.

Figure 2. Standard cubic and cylindrical forms in the research.

Materials used

Aggregates used in the research are from Cheshmeh-Kileh river in Tonekabon, Iran. Large-size aggregate is of specific weight 2640 kg/m^3 and its maximal nominal size is 25 mm. Small-size aggregate is of specific weight 2600 kg/m^3 and its type is round corner. The granulation curve according to ASTM C33 /11/ is shown in Fig. 3. The used cement is Portland type 2 and its specification is given in Tables 1 and 2. Due to the use of fibres in concrete, associated with a decrease in slump and efficiency, the additive used is a neutral polycarboxylate superconducting solution of 0.3 % by weight of cement in the concrete mix. Their specifications are given in Table 3. Three forms of polyolefin fibres with equal length (52-54 mm) including microgrid fibres, wave, and twisted macro-synthetic fibres are used in the research. Specifications of polyolefin fibres are given in Table 4 and in Fig. 4.



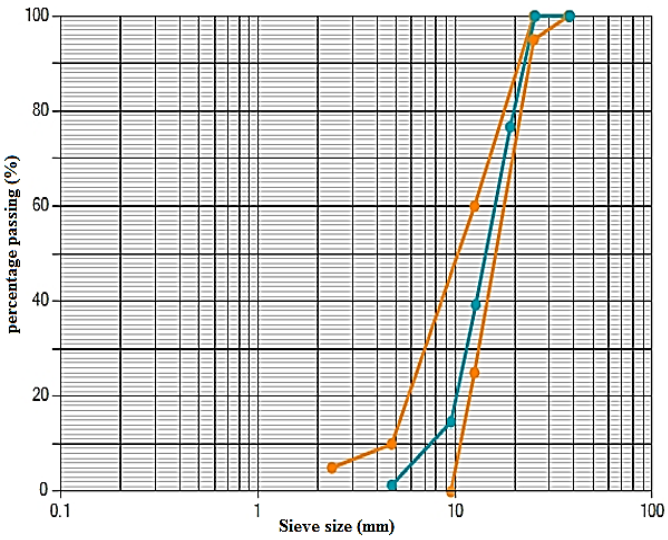


Figure 3. Graph of used aggregates and the allowable range of ASTM-C33.

Table 1. Physical properties of cement.

Special surface	Autoclave volume expansion	Secondary catching time	Initial catching time
2900 cm^2/g	0-5.15 %	180-240 min.	100-160 min.

Table 2. Chemical properties of cement (mass %).

Na_2O	K_2O	SO_3	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
0.45-0.65	0.45-0.65	1.5-5.5	1.2-5.2	63-65	3.4-8.2	4.5-7.5	1.5-22

Table 3. Specifications of superplasticizers.

Allowed consump.	pH	Spec. weight kg/m^3	Colour	Physical state	Ionic state	No.
0-2.8 %	~ 7	1.13	honey brown	liquid	anionic	PC11-A

Table 4. Specifications of polyolefin fibres.

Fibre specs.	Twisted	Wave	Mesh
Thickness (mm)	0.0-1.5	0.05	0.0-2.12
Density (g/cm^3)	91.94	0.91	0.91
Tensile strength (MPa)	450-800	450-700	400-500
Modulus of elasticity (MPa)	5500-6500	3500-7000	3500-4500
Increase failure length (%)	≥ 15	≥ 15	≤ 10

Figure 4. Shapes of mesh, wave and twisted polyolefin fibres.

Mixing design

The scheme of mixing concrete tests with and without fibres is given in Table 5. In order for the samples to be tested under exactly the same conditions. Water to cement ratio is constant and equal to 0.38, also in the manufacture of fibre-free concrete, a superplasticizer additive was used. The volume percentages of the three forms of polyolefin fibres are 0.1, 0.4 and 0.5%, respectively, according to the cross-sectional area of the fibres and in their optimal consumption range for mesh, wave, and twisted form. The order of mixing the materials is such that first completely dry materials (coarse and fine aggregates and then cement) were poured into the mixer. The fibres were untied by hand in the outside of the mixer to prevent clogging in the concrete. In the next step, 70% of the water required for mixing was added and the superplasticizer used was mixed with the final part of the water and the mixing operation was continued until the ingredients were properly mixed. To process the concrete samples, after 24 hours, some of them were kept in a pool of water with a pH close to 7 and a water temperature of 20 ± 2, and others were subjected to dry processing (exposure to the open air).

RESULTS ANALYSIS

Fresh concrete slump

The presence of polyolefin fibres in concrete reduces the slump of fresh concrete. Based on the results in Fig. 5, the lowest and highest slump loss in fibrous concrete is observed in concrete containing polyolefin mesh fibres and containing polyolefin wave fibres, compared to fibreless concrete, respectively.

Table 5. Fibreless concrete mixing plan and fibre-containing concretes.

Fibre (kg/m^3)			Superplasticizer (kg/m^3)	Small-size aggregate (kg/m^3)	Large-size aggregate (kg/m^3)	Water (kg/m^3)	Cement grade (kg/m^3)	Mixing plan code
Twisted	Wave	Mesh						
0	0	0	1.43	716.5	1136	181	476.5	CONTROL
0	0	0.91	1.43	716.5	1136	181	476.5	MESH 0.1
0	3.64	0	1.43	716.5	1136	181	476.5	WAVE 0.4
4.55	0	0	1.43	716.5	1136	181	476.5	TWIST 0.5

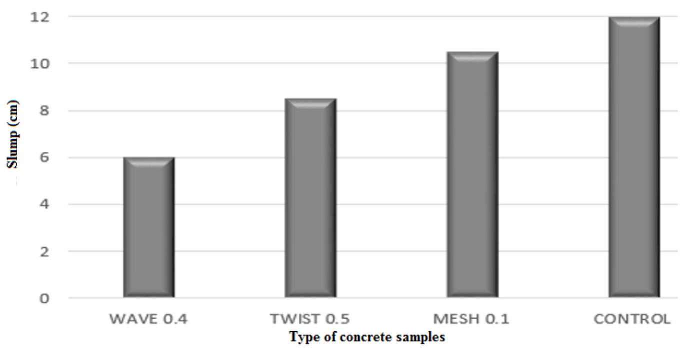


Figure 5. Results of concrete slump test, with and without fibres.

Compressive strength

The compressive strength results of wet and dry samples are shown in Fig. 6. At 3 and 7 days of wet concrete, the highest compressive strength is in concrete with twisted fibres, and at 28 and 56 days, concrete with wave fibres. In general, fibre-containing concretes show higher strength than control concrete. The compressive strength of wet samples at 56 days increased 6.7 % in concrete mesh, 23.6 % in concrete with wave fibres, and 17.2 % in concrete with twisted fibres compared to the control concrete. Also, the compressive strength of dry samples at 56 days increased 10.9 % in concrete with mesh fibres, 25.1 % in concrete with wave fibres, and 14.6 % in concrete with twisted fibres compared to the control concrete. Compressive strength of dry samples in control concrete is 96.8 %, in concrete with mesh fibres 99.4 %, in concrete with wave fibres 98.4 % and in concrete with twisted fibres it is 94.6 % of the compressive strength of wet samples, and generally the strength of wet samples is higher than in dry samples.

Tensile strength

Tensile strength diagrams of wet and dry samples are given in Fig. 7. The growth trend of tensile strength is uniform and maximal strength at 56 days of wet concrete contains wave, twisted, and mesh fibres, respectively, and they have always been higher than the control sample of fibre concrete strength. The tensile strength of wet samples at the age of 56 days increases 38.06 % in concrete with mesh fibres, 62.08 % in concrete with wave fibres, and 42.85 % in concrete with twisted fibres, compared to the control concrete. Also, the tensile strength of dry samples at 56 days increases 20.47 % in concrete with mesh fibres, 54.8 % in concrete with wave fibres, and 32.7 % in concrete with twisted fibres, compared to the control concrete. Tensile strength of dry samples in control concrete is 97.7 %, and in concrete with mesh fibres 88.5 %, in concrete with wave fibres 94.8 %, and in concrete with twisted fibres 97.8 % of the tensile strength of wet samples, and always the strength of wet samples is higher than for dry samples.

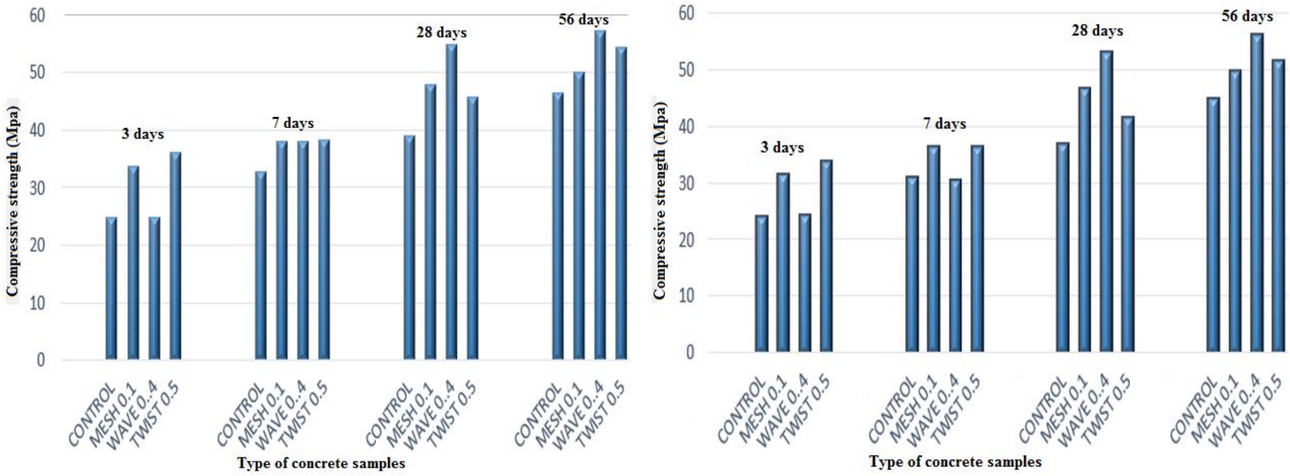


Figure 6. Compressive strength test results of wet and dry concrete samples, with and without fibres at 28, 7, 3, and 56 days.

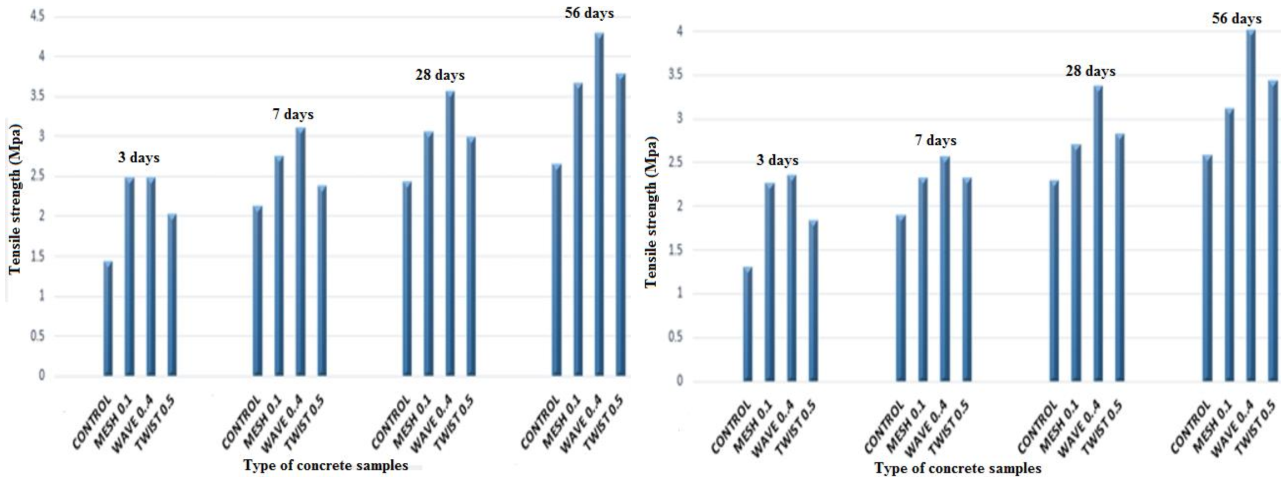


Figure 7. Tensile strength test results of wet and dry concrete samples, with and without fibres, at 28, 7, 3, and 56 days.

Relationship between concrete compressive and tensile strength

The correlation between the tensile and compressive strength of concrete can be shown by nonlinear equations, because tensile strength of concrete increases with increase in compressive strength and the ratio of tensile to compressive strength decreases with increasing compressive strength. The relationship between compressive and tensile strength of wet samples is shown in Fig. 8, and dry samples are shown in Fig. 9 at 28, 7, 3, and 56 days of concrete. In the results of nonlinear diagrams, the equation of the curve passing through the points, which includes the relation of tensile strength (f_t) in terms of compressive strength (f_c), and the correlation coefficient between the values of tension and pressure (R^2) is obtained. The closer the correlation coefficient is to 1, the more accurate are the results of this relationship. The equations obtained in the graphs show a good correlation coefficient and relatively low error. According to ACI 363R-92 /12/, the tensile strength is obtained from the relation $f_t = 0.59 f_c'^{\,0.5}$, where f_c' is compressive strength of concrete. Tensile strength results in the range of 10 % of this relationship are considered as the standard range. As shown in Fig. 10, the relationship between compressive and tensile strength of concrete, compared to the ACI relationship /12/, the strength of concrete samples is in the allowable range of 10 %.

For concrete containing mesh and wave fibres, the convexity of the curve is positive, indicating that the coefficient of conversion of compressive to tensile strength (diagram slope) increases with increasing compressive strength. In fibreless concrete and in concrete containing twisted fibres, the convexity of the curve is negative. In fact, tensile strength occurs at a much slower rate compared to increasing compressive strength which seems reasonable. The ACI equation overestimates tensile strength at an early age and is higher than for the research results.

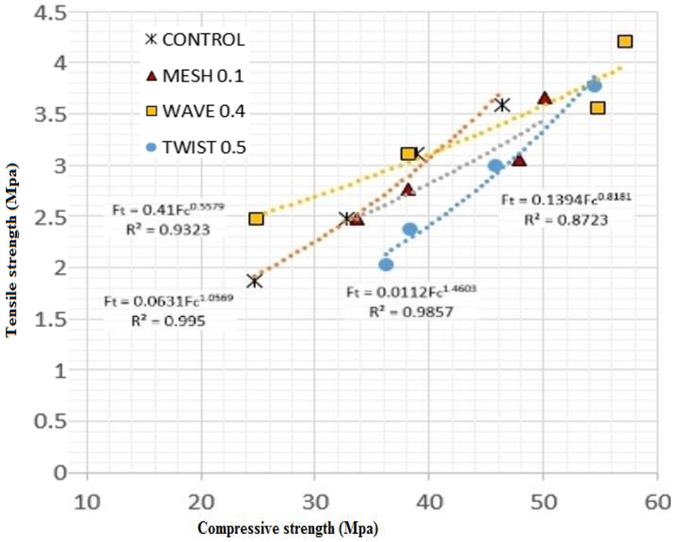


Figure 8. Relationship between compressive and tensile strength of wet concrete samples, with and without fibres.

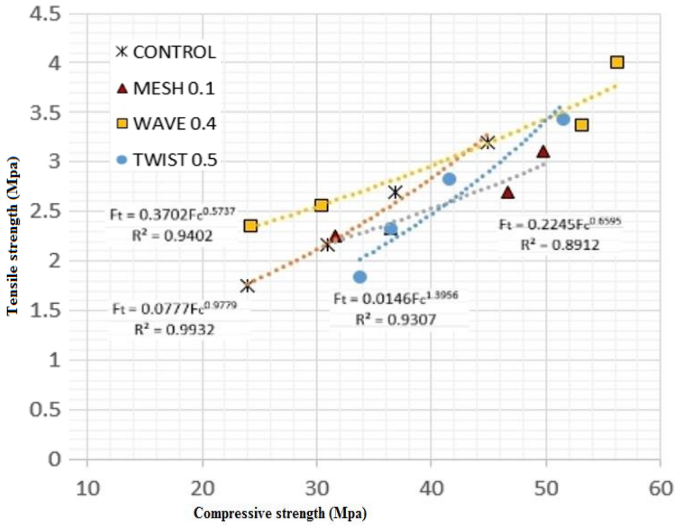


Figure 9. Relationship between compressive and tensile strength of dry concrete samples, with and without fibres.

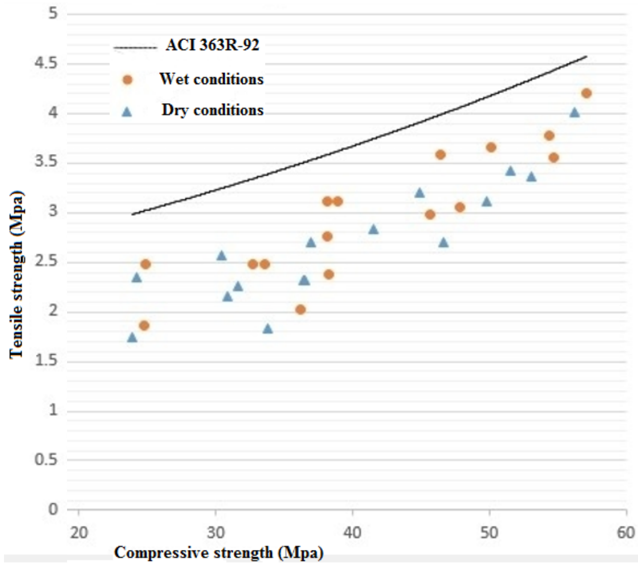


Figure 10. Comparison of compressive and tensile strength of concrete in dry and wet conditions with experimental relationship of ACI.

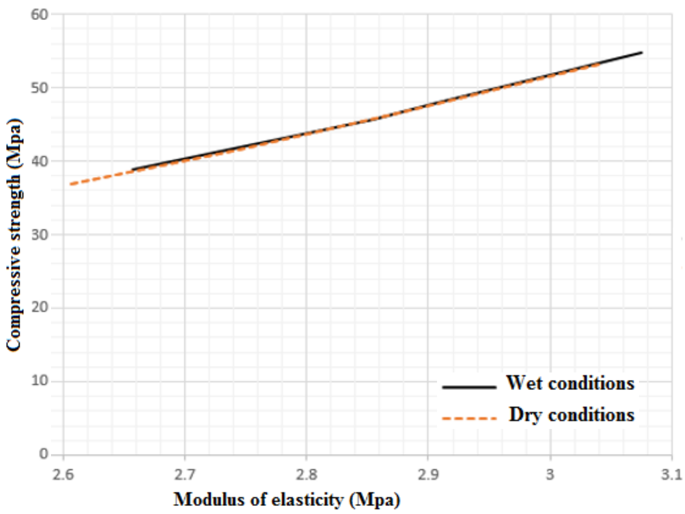


Figure 11. Modulus of elasticity and compressive strength at 28 days of concrete, with and without fibres.

Modulus of elasticity

The modulus of elasticity of the samples is calculated and evaluated from the results of the compressive strength test. The relationship between compressive strength and modulus of elasticity (Fig. 11) indicates a direct relationship between them, and as compressive strength increases, the modulus of elasticity also increases. The maximal increase is observed in 28-days-wet sample containing wave fibres with a value of 3.075 MPa.

Water absorption

Results of water absorption test of 7 and 28 day samples (Fig. 12) show that at total age of 28 days, the percentage of water absorption of fibrous concrete is less than for the control sample. This may be due to the lack of water absorption by the fibres and the occupation of parts of the concrete volume, which prevents more water from penetrating into the concrete pores.

CEB-FIP regulation /13/, based on the percentage of water absorption of concrete, classifies the quality of concrete, which at the amount of water absorption is between 0 to 3 % of good quality, 3 to 5 % of average quality, and above 5 % of poor quality concrete. The quality of concrete in this research is good based on the CEB-FIP regulation /13/. The results show that polyolefin fibres can slightly improve the resistance to water, sulphates, alkali ions and other harmful substances that cause chemical attack by slightly reducing the permeability of concrete.

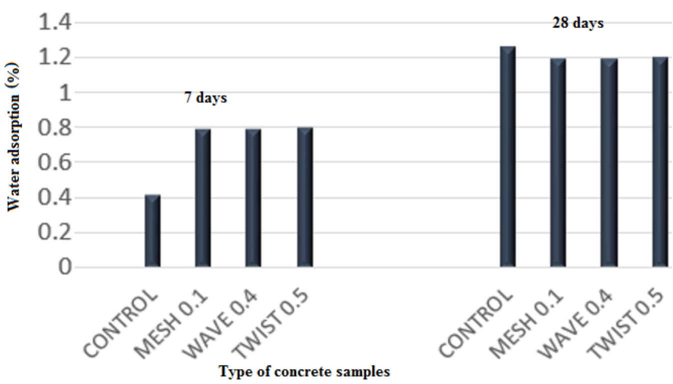


Figure 12. Concrete water adsorption with and without fibres.

CONCLUSIONS

Polyolefin fibres have a negative effect on the properties of concrete and reduce the performance of fresh concrete, which in the concrete samples with mesh fibres 12.5 %, concrete with wave fibres 50 %, and concrete with twisted fibres 29.1 %, decreases compared to the control concrete.

Polyolefin fibres have increased the compressive strength of concrete. The maximal increase at the age of 56 day is for concrete containing wave polyolefin fibres with an increase of 23.6 %, and the lowest is for concrete with mesh fibres with an increase of 7.97 % with wet processing conditions compared to the sample without fibres.

The maximal growth of tensile strength of concrete at the age of 56 day of concrete containing wave fibres has increased by 62.08 %. The lowest is related to concrete with mesh fibres with about 38.06 % increase with wet processing conditions compared to the sample without fibres, which shows the high impact of fibres on the tensile strength of concrete.

The strength of concrete samples with wet processing conditions has always been higher than for the samples with dry processing conditions. Maximal compressive strength of 56 day of concrete containing wave fibres is 98.4 % of the dry sample strength, and 94.8 % of wet tensile strength.

Increase in the modulus of elasticity of fibre-containing concretes compared to the sample of fibre-free concrete is about 9 % in concrete with mesh fibres, 14.9 % in concrete with wave fibres, and 6.3 % in concrete with twisted fibres.

The average of water absorption of samples containing mesh and wave polyolefin fibres decreases by 5.6 %, and with twisted fibres by 4.7 %, compared to the sample without fibres, and the lack of water absorption of polyolefin fibres is evident.

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