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Investigating the compressive and tensile strength of concrete containing recycled aggregate with polypropylene fibers

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Abstract

In this research, recycled concrete aggregates were used instead of natural aggregates in concrete, and then the recycled concrete was reinforced with polypropylene fibers.The purpose of this study is to first investigate the effect of replacing recycled aggregates with natural aggregates on the mechanical resistance of concrete and then to investigate the effect of adding polypropylene and micro silica fibers on concrete containing natural and recycled aggregates in two water-to-cement ratios of 0.4 and 0.55. The results of this research show that by replacing recycled aggregates with natural aggregates, the compressive and tensile strengths of concrete have decreased significantly. Also, the results show that the addition of polypropylene fibers with a weight ratio of 1.5% had a significant effect in compensating the reduction of compressive and tensile strengths in recycled concrete. It should be mentioned that the samples containing microsilica and polypropylene fibers in all mixing designs (natural and recycled aggregates) had higher resistance values (tension and pressure) than the samples without microsilica. Also, concrete samples with a water-cement ratio of 0.4 had higher compressive strengths than concrete samples with a water-cement ratio of 0.55. (DOI:https//**doi.org/10.52547/JCER.4.4.20**)

Key words: concrete; recycled aggregates; polypropylene fibers; microsilica; compressive strength.

1. Introduction

In recent years, the use of concrete has grown significantly around the world, and the use of concrete in the construction industry is increasing day by day.With this increasing trend, in the not-so-distant future, we will definitely face a shortage of mineral resources used to prepare natural aggregates, and we must inevitably seek to find a suitable alternative for natural aggregates [1, 2]. Due to the limitation of the life of concrete structures and the destruction of concrete structures due to natural factors such as earthquakes, floods, storms, etc., we are always faced with a large amount of waste and damaged concrete, whose accumulation in landfills causes many problems for the environment. Life has created [3, 4]. Protecting the environment and preventing the speed of reducing the destruction of natural resources is one of the basic measures in the direction of sustainable

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development. Continuous industrial development will bring serious problems due to the burial of construction waste and destructive concrete. A solution to solve this problem is to use these destructive concretes as recycled concrete aggregates, as a substitute for natural aggregates, to try to preserve the environment in addition to reducing the use of natural resources [5]. Research into the reuse of destroyed concrete and building materials as aggregates for new concrete dates back to the end of World War II. For the first time, the recycling of waste concrete caused by destruction and construction after World War II in Germany was done by Mr. Khalaf and his colleagues. Since then, extensive research work has been done in developed countries on the possibility of reusing recycled concrete in new concrete [6]. According to some studies, the use of recycled aggregates with a replacement percentage of 20-30% does not have a negative effect on the physical and mechanical properties of concrete made from these aggregates [7-11]. On the other hand, if the replacement percentage is 100%, the compressive, tensile and bending strengths of concrete will decrease by 20%, which can be attributed to the heterogeneity of recycled materials [12].

Also, research has shown that by increasing the use of recycled concrete materials (sand) instead of natural materials, the amount of water absorption of samples increases [13]. According to the research done, by increasing the amount of waste concrete aggregates (recycled sand) instead of natural aggregates in new concrete, a decrease in compressive, tensile and bending strength as well as an increase in 24-hour water absorption of concrete is observed [14].

According to the research done by Gomez and his colleagues, concrete that is composed of 100% recycled concrete sand will have more porosity than normal concrete, and from the age of 28 days to 90 days, the porosity of the samples will decrease in both types of concrete, and the amount of this reduction will be higher in recycled concrete [15].

Although the use of recycled concrete aggregates in the production of fresh concrete has an unfavorable effect on the physical and mechanical properties of concrete. The use of fibers in concrete and the production of fiber concrete has made it possible to create concrete with ductility and higher energy absorption ability and with low cracking development under the load and stresses resulting from shrinkage and heat [16].

Fiber concrete is a cement concrete reinforced with distributed fibers. In fiber concrete, thousands of small fibers are dispersed and randomly mixed in concrete during mixing, and therefore we have improvement of concrete properties in all directions. Fibers help to improve concrete ductility, concrete tensile strength, fatigue resistance, impact resistance and shrinkage cracks [17]. Fiber-reinforced concretes have been expanded because they can increase hardness, bending strength,and tensile strength depending on their type [18].

Steel, polymer, glass and carbon fibers are among the artificial fibers that are used today. Polypropylene is a thermoplastic polymer that is one of the cheapest and most widely used fibers in the concrete industry. These fibers have a high resistance to most corrosive environments, including alkaline, acidic and salty, and this feature, along with low density and moisture absorption, has made it the most widely used polymer fiber used in concrete. Propylene is a derivative of petroleum and is cheaper than other raw materials used for polymerization and formation of synthetic Introduction

fibers. Polypropylene fibers are prepared in the form of a linear polymer through the polymerization of propylene, and it is called PP for short [19].

Protection of the environment and primary resources, lack of depot and disposal of construction waste and the high cost of maintenance of construction waste are important factors to increase the attention of countries in the world in using concrete waste as materials used in concrete production [20].

Therefore, the issue of concrete waste recycling is considered important and necessary from an environmental point of view and according to the mentioned problems and the necessity of using recycled concrete, it will also be necessary to study the changes in the properties of this consumable by using fibers and replacing recycled aggregates. Therefore, the purpose of this study is to investigate the usability of polypropylene fibers in concrete made from recycled aggregates, which are mainly used in concrete.

2- Research method

In this research, recycled concrete aggregates as fine and coarse aggregates have replaced natural aggregates 100%. Also, polypropylene fibers with volume percentages of 0 and 1.5 have been used in the designs. The concrete mixing plan was made by considering the maximum nominal amount of aggregate of 19 mm for water-cement ratios of 40% and 55%. Table 1 shows the amount of materials used in one cubic meter of concrete for different mixing plans.
Considering that the use of waste materials in concrete will reduce the characteristics of hardened concrete [21] and the use of pozzolanic minerals such as micro silica can improve some of this reduction [22], In this research, in order to improve the properties of concrete with recycled aggregates, micro silica was used at the rate of 9 percent by weight of cement. Also, super-lubricant has been used to reduce water consumption and ensure the required efficiency of concrete. After making concrete, in order to determine the rheological properties of fresh concrete, slump flow test, to check the mechanical properties of concrete, tests of hardened concrete including compressive and tensile strength were performed on the samples. The complete specifications of the concrete plans made are stated in Table No. 1.

Table 1- Specifications of mixing plans

Water to cement ratio	Design name	Polypropylene	recycled concrete	Sand (4.75 to 19 mm) kg/m3	sand (0 to 4.75 mm) kg/m^3	Cement kg/m^3	Water kg/m^3	silica fume	super lubricant
40٪	Pp0-rc0	0٪	0٪	1024.6	743.3	360	160	40	1٪
	Pp1.5-rc0	1.5٪	0٪	1024.6	743.3	360	160	40	1٪
	Pp0-rc100	0٪	100٪	925.934	743.3	360	160	40	1٪
	Pp1.5-rc100	1.5٪	100٪	925.934	743.3	360	160	40	1٪
55٪	Pp0-rc0	0٪	0٪	1009.125	732.062	350	192.5	0	0.8٪
	Pp1.5-rc0	1.5٪	0٪	1009.125	732.062	350	192.5	0	0.8٪
	Pp0-rc100	0٪	100٪	911.950	732.062	350	192.5	0	0.8٪
	Pp1.5-rc100	1.5٪	100٪	911.950	732.062	350	192.5	0	0.8٪

2-1- Consumable materials:

In this research, the materials used in the concrete mixing plan include water, cement, natural and recycled crushed aggregates, polypropylene fibers, super-lubricant and micro-silica, whose general characteristics are as follows:

2-1-1- Cement:

The cement used in this research to make all mixing designs is type 2 portland cement from Neka company. The physical and chemical characteristics of this cement are according to Table 2 and 3:

Table 2- Chemical characteristics of used cement

Cl^-	SO_3	Na_2O	K_2O	MgO	Al_2O_3	CaO	Fe_2O_3	SiO_2	chemical mixture
0.008	2.49	0.35	0.64	1.27	4.7	64.35	3.18	19.8	Percentage

Table 3- Physical characteristics of used cement

Density (kg/m^3)	Specific surface (cm^2/gr)	Compressive strength (MPa)
3150	3020	435

2-1-2- Aggregate

Considering that approximately 75% of the volume of concrete is made up of aggregates, to prepare the concrete mixing plan, it is necessary to check the specifications of these materials. In this research, two types of aggregates in the size of sand (0 to 4.75 mm) and sand has been used in two categories: pea (4.75 to 9.5 mm) and almond (9.5 to 19 mm).

The natural aggregates (NA) used in this project were obtained from a company in the Marzanabad. Recycled concrete aggregates (RCA) used in this research were prepared from broken materials from a stone crushing plant around the city of Chalous with a maximum grain size of 19 mm.

Preparation operation and Sieving of recycled aggregate it has been done in the stone crusher of this factory. After crushing recycled concrete by jack and stone crusher machines, the obtained aggregates were granulated after passing through the sieve and complying with the requirements of ASTM C33 regulations and it was used in the design of concrete mixes [23]. The granulation curve of natural and recycled aggregates is according to Figure 1. Figure 1 shows the range of coarse grain, fine grain and natural and recycled aggregate curve. The physical characteristics of natural and recycled aggregates used in this research are also presented in Table 4. According to Table 4, natural aggregates have lower specific gravity and water absorption percentage than recycled aggregates.

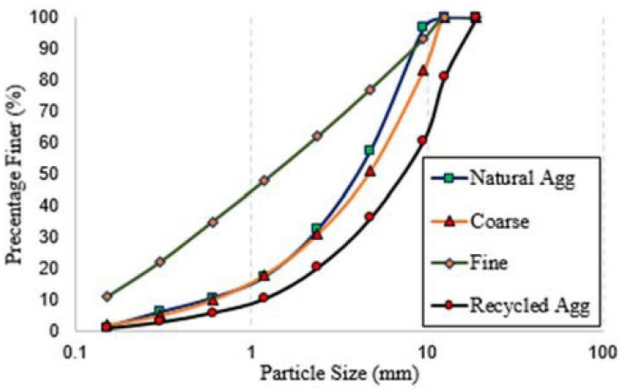


Figure 1- Granulation curve of consumed aggregates (natural and recycled)

2-1-3- Water:

water used to make concrete samples, the drinking water of Chalous city has a specific gravity of 1000 kg/m3, which is suitable for making concrete. The water used in the sample processing pond is non-hard water with 40 grams of lime dissolved per cubic meter.

2-1-4- Consumable fibers (polypropylene):

The fibers used in this research include polypropylene fibers, whose physical and mechanical characteristics are shown in Table 5.

Table 4- Physical characteristics of natural and recycled aggregates

(mm) Aggregate size	Water absorption percentage	(kg/m^3) Density	Materials
6-19	1.5	2720	Natural gravel
6-19	5.5	2620	Recycled gravel
0-6	2.5	2651	Natural sand
0-6	7.5	2230	Recycled sand

Figure 2- Polypropylene fibers used in this research

Table 5- Physical characteristics of polypropylene fibers

0.91	Density (g/cm^3)
18	Length (mm)
0.2	Diameter (mm)
90	Length to diameter ratio (L/D)

This fiber is simple. Figure 2 shows a view of the polypropylene fibers used in this research.

2-1-5- Super lubricant:

In this research, light brown polycarboxylate-based super-lubricant was used to ensure optimal concrete efficiency and reduce water consumption. According to the proposal of its manufacturer, the consumption of this material in concrete is 1 percent by weight of cement, which was used in this research in two ratios of 0.8 and 1 percent.

2-1-6- Micro silica:

Considering that the use of waste materials in concrete will reduce the properties of hardened concrete and the use of pozzolanic minerals such as micro silica can improve some of this reduction. In this research, in order to improve the properties of concrete with recycled aggregate, micro silica was used at the rate of 9 percent by weight of cement [22]. The chemical characteristics of micro silica used in the mixing plans of this research are according to Table No. 6 [37].

2-2- Steps of making and processing concrete samples:

The process of making fiber concrete was similar to concrete without fibers, with the difference that due to the fact that adding fibers requires spending some time, first, the aggregates were added to the mixer within 3 minutes, and the fibers were manually added to the mixture while the mixer was working, and by changing the angle of the mixer and monitoring the mixture, an attempt was made to distribute the fibers evenly in the concrete.

In all stages of concrete making, homogeneous and uniform concrete was made by changing the rotation angle of the mixer axis. After emptying the mixer, the concrete is first turned over with a shovel, and immediately after that, the slump test was performed. According to the measurements, the amount of fresh concrete slump is 10 cm. Also, the temperature of fresh concrete is 27 to 29 degrees Celsius and the temperature of processing water is 20 to 24 degrees Celsius.

Table 6- Chemical characteristics of micro silica

SO_3	Na_2O	MgO	Al_2O_3	CaO	Fe_2O_3	SiO_2	Chemical mixture
0.19	0.294	0.902	0.748	0.44	0.829	0.19	Percentage

After this stage, concrete was poured into lubricated cubic, cylindrical and prismatic molds and placed in laboratory conditions for 24 hours to harden.

After that, we removed the samples from the mold and placed them in the water basin and they were kept in the laboratory environment at a temperature of 20 to 24 degrees Celsius for processing and testing at the desired ages.

Compressive and tensile strength tests were performed on concrete made at the ages of 5, 7, 28 and 90 days. 3 samples from each mixing plan were tested. The complete specifications of the plans are presented in Table 1. The compressive strength test was performed with 100x100x100 mm cubic samples according to the standard [24]. Cylindrical samples (150 x 300 mm) were also used to determine the tensile strength [25, 26].

3- Results

3-1- Slump

The results obtained from the fresh concrete test are shown in Table 7. The materials are at the workshop humidity level during mixing and are not in the SSD state, on the other hand, the water absorption of recycled materials is much higher. Therefore, in order to unify the consideration of water in mixing plans, the initial water of recycled mixing plans should be considered higher according to the consumption of recycled materials. As a result, at the beginning of mixing, designs containing recycled materials that have a higher initial water content have higher efficiency. Therefore, according to this issue, smaller amounts of super-lubricant should be used for recycled designs in order to achieve almost the same efficiency of mixing designs and to prevent the concrete from dewatering and the separation of concrete particles [27].

In this research, the method presented in the ASTM-C143 standard [28] was used to determine the slump of fresh concrete.

According to the results, the replacement of recycled aggregates with natural aggregates has reduced the slump, which is due to the increase of voids in the recycled aggregates and, as a result, the reduction of the specific weight of recycled concrete [29].

Also, according to the results of Table 7, the use of polypropylene fibers has reduced the slump in samples containing natural and recycled aggregates and in equal conditions, the amount of slump in the samples containing polypropylene fibers and recycled aggregates has decreased to a greater extent than the samples containing natural aggregates and polypropylene fibers. In the conducted studies, it was determined that the reason for this could be the interference of the effect of fibers in creating voids and voids in recycled aggregates [30].

The addition of micro silica to the laboratory samples of this research has reduced the slump compared to the samples without micro silica. In general, micro silica in concrete samples causes an increase in slump. The reason for this could be that micro silica is basically a strong pozzolanic material that increases the adhesion of cement to aggregates and prevents the water absorption of aggregates and thus increases slump [31, 32]. It should be noted that in this research, different water-cement ratios in the mixing designs may have caused slump reduction in samples containing micro silica.

Table 7- Slump test results

Water to cement ratio	Design name	recycled concrete	Percentage of polypropylene fibers	super lubricant	silica fume	Slump(cm)
%40	Pp0-rc0	0	%0	%1	40	9
	Pp1.5-rc0	0	%1.5	%1	40	7.5
	Pp0-rc100	100	%0	%1	40	7
	Pp1.5-rc100	100	%1.5	%1	40	6.5
%55	Pp0-rc0	0	%0	%0.8	0	9.5
	Pp1.5-rc0	0	%1.5	%0.8	0	8.2
	Pp0-rc100	100	%0	%0.8	0	8
	Pp1.5-rc100	100	%1.5	%0.8	0	7

3-2- Compressive resistance

Compressive strength is one of the most important parameters for measuring the behavior of concrete. From the past until now, many researchers have improved the compressive strength of concrete by adding different additives and fibers. In this research, by combining polypropylene fibers in concrete containing natural and recycled aggregates, the compressive strength of concrete at the ages of 5, 7, 28 and 90 days has been investigated.

According to Table 8, by replacing recycled aggregates instead of natural aggregates, the compressive strength has decreased, the possible reason for this is that, firstly, waste concrete aggregates have high water absorption, secondly, recycled concrete aggregates have low density and thirdly, old mortar (mortar on recycled concrete aggregate) attached to recycled concrete aggregate has a weaker surface than the surface of natural aggregate. It should be noted that most of the studies conducted in the field of concrete with recycled concrete aggregate have a consensus opinion on the reduction of compressive strength [33-35]. Also, by using 1.5% of polypropylene fibers, the compressive strength has increased somewhat. As it is clear from the results, the highest amount of compressive strength was obtained in the sample containing natural aggregates and polypropylene fibers, and the lowest amount of compressive strength was obtained in the samples without fibers and containing recycled aggregates.

Also, the results of the compressive strength in this research show that with the passage of time, the compressive strength of all the examined samples is increasing and the maximum strength of the samples was achieved in 90 days. Also, the highest rate of growth of compressive strength has taken place from 28 to 90 days. Diagrams 1 and 2 respectively show the compressive strength of the samples investigated in this research in two water-to-cement ratios (0.4 and 0.55). Also, micro silica pozzolanic material has been used in concrete samples made with a water-cement ratio of 0.4. As it is clear from the results, by adding micro silica to concrete samples, due to the strong pozzolanic property of micro silica, which has increased the adhesion of cement to aggregates, the compressive strength has increased [36].

Table 8- Compressive strength of fiber concrete samples containing natural and recycled aggregates

Water to cement ratio	Design name	Percentage of polypropylene fibers	recycled concrete	5 days (Mpa)	7 days (Mpa)	28 days (Mpa)	90 days (Mpa)
٪40	Pp0-rc0	٪0	0	15.320	19.874	28.324	44.358
	Pp1.5-rc0	٪1.5	0	17.514	21.247	30.145	46.214
	Pp0-rc100	٪0	100	10.245	13.247	24.178	43.751
	Pp1.5-rc100	٪1.5	100	13.547	14.796	25.386	44.971
٪55	Pp0-rc0	٪0	0	13.850	18.357	27.014	43.744
	Pp1.5-rc0	٪1.5	0	15.347	20.001	29.746	44.974
	Pp0-rc100	٪0	100	9.745	11.389	22.159	42.775
	Pp1.5-rc100	٪1.5	100	12.478	13.763	23.1	43.952

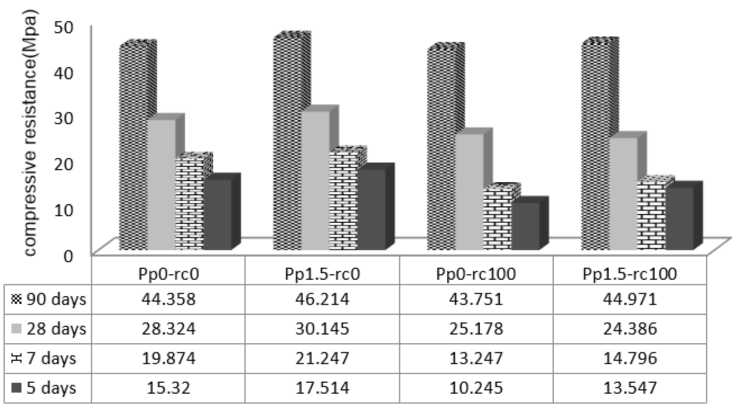


Chart 1- Compressive strength of concrete samples with 0.4 water-cement ratio and containing micro silica

The results of the tests show that the compressive strength only in the mixture of 1.5% fibers in all water-cement ratios, compared to the control sample, has resistance growth in all periods. But in other mixtures, compared to the control sample, the amount of compressive strength has decreased, and with the passage of time and increasing age of the samples, the difference has decreased. This issue can be explained according to the activity of pozzolan used in this research.

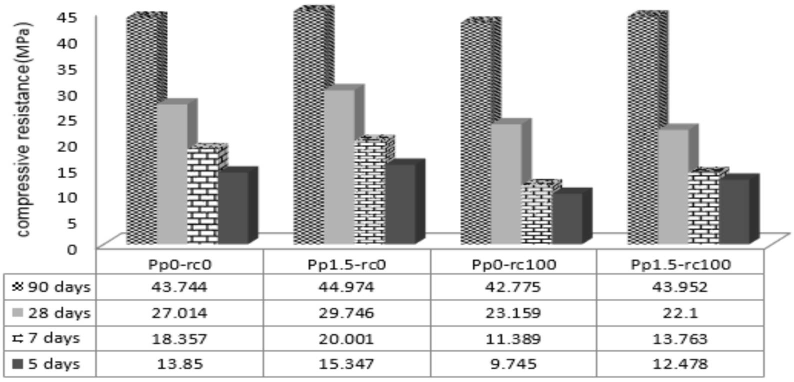


Chart 2- Compressive strength of concrete samples with a water-cement ratio of 0.55 and without micro silica

The strength loss factor in the mixtures compared to the control sample can be attributed to the excessive use of recycled concrete compared to the optimal amount. Of course, declaring a definite opinion is subject to more research and a more detailed examination of the microstructure of concrete.

3-3- Tensile strength

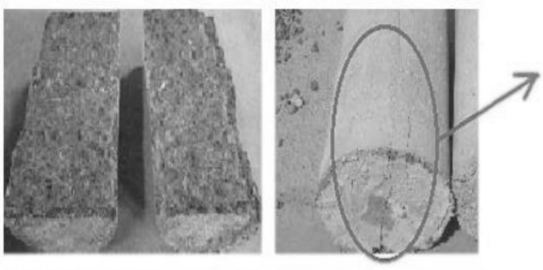
This test, which is also known as the Brazilian test, was carried out using standard cylindrical samples with a height of 30 cm and a diameter of 15 cm for 8 mixing designs at the ages of 5, 7, 28 and 90 days by dividing the concrete samples into two halves. Table 9 and graphs 3 and 4 show the tensile test results. As it is clear from the results, by replacing recycled aggregates instead of natural aggregates, the tensile strength of concrete has decreased, and the possible reason for this is that, firstly, waste concrete aggregates have lower resistance than natural aggregates, and also the presence of voids in recycled aggregates. It is another factor that can reduce the tensile strength in concrete samples made from these aggregates. It should be noted that most of the studies conducted in the field of concrete with recycled concrete aggregate have a consensus opinion on the reduction of tensile strength [33-35]. Also, the results show that by using 1.5% of polypropylene fibers, the tensile strength has increased to some extent. As it is clear from the results, the highest amount of tensile strength was obtained in the sample containing natural aggregates and polypropylene fibers, and the lowest amount of compressive strength was obtained in the samples without fibers and containing recycled aggregates.

Samples of concrete with fiber and without fiber after tensile strength test are shown in Figure 3. As it is clear from this figure, in concrete without fibers, after the test, the sample is completely separated and broken. But in fiber concrete, after testing on concrete samples, only small cracks can be seen and the concrete has maintained its cohesion and does not break apart. This article shows that fiber concrete does not crumble and break when broken and fibers play an important role in controlling concrete cracking. In fact, the fibers prevent their development and expansion by bridging the cracks. Therefore, the addition of fibers improves the brittle behavior of concrete.

Also, the results of tensile strength in this research show that with the passage of time, the amount of tensile strength is increasing in all the examined samples, and the maximum strength of the samples was achieved in 90 days. Also, the highest growth rate of tensile strength was observed from 28 to 90 days. Graphs 3 and 4 respectively show the tensile strength of the samples investigated in this research in two water-to-cement ratios (0.4 and 0.55). Also, micro silica pozzolanic material has been used in

Table 9- Tensile strength of fiber concrete samples containing natural and recycled aggregates

Water to cement ratio	Design name	Percentage of polypropylene fibers	recycled concrete	5 days (Mpa)	7 days (Mpa)	28 days (Mpa)	90 days (Mpa)
٪40	Pp0-rc0	٪0	0	1.40	1.70	2.53	3.43
	Pp1.5-rc0	٪1.5	0	2	2.11	2.88	3.64
	Pp0-rc100	٪0	100	1.41	1.59	2.01	2.77
	Pp1.5-rc100	٪1.5	100	1.54	1.73	2.28	2.89
٪55	Pp0-rc0	٪0	0	1.33	1.60	2.5	3.35
	Pp1.5-rc0	٪1.5	0	1.88	2	2.7	3.54
	Pp0-rc100	٪0	100	1.10	1.41	2	2.69
	Pp1.5-rc100	٪1.5	100	1.30	1.67	2.14	2.79



Maintaining the cohesion of concrete and controlling cracking by means of fibers

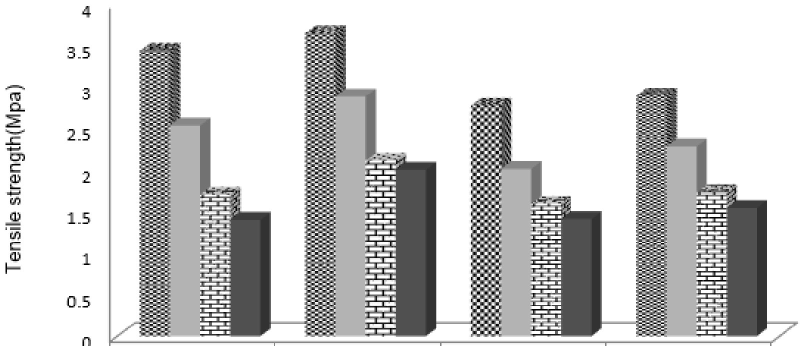
Figure 3- Comparison of recycled concrete with fibers (right side) and without fibers (left side) in terms of cracking and failure

concrete samples made with a water-cement ratio of 0.4. As it is clear from the results, by adding micro silica to concrete samples, the tensile strength has increased due to the strong pozzolanic property of micro silica which has increased the adhesion of cement to aggregates [36].

4 - Conclusion

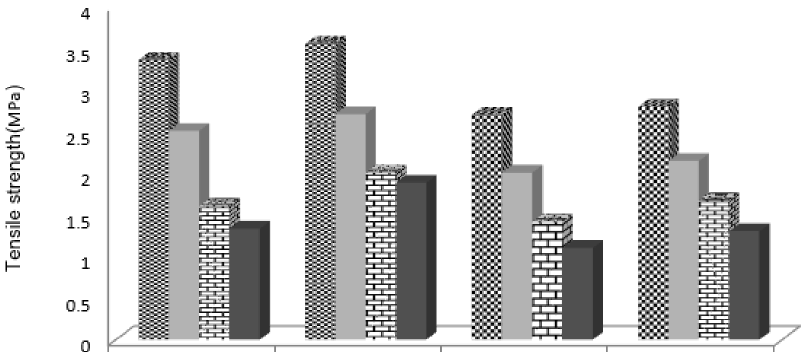
The main goal of this research is investigating the use of recycled aggregates obtained from the destruction of concrete in the construction of new concrete has been for the protection of natural resources and sustainable development, Therefore, in this regard, in this research, we investigated and compared the mechanical properties of concrete containing natural and recycled concrete aggregates and polypropylene fibers along with micro silica in two water-to-cement ratios of 0.4 and 0.55. According to the current investigation regarding the use of recycled aggregates and polypropylene fibers and micro silica, the following results have been obtained:

- Although the efficiency of concrete decreases due to higher water absorption by recycled aggregates and the use of polypropylene fibers, can be compensated by using materials such as super-lubricants. Considering that polypropylene fibers also improve the behavior of structural concrete.



	Pp0-rc0	Pp1.5-rc0	Pp0-rc100	Pp1.5-rc100
90 days	3.43	3.64	2.77	2.89
28 days	2.53	2.88	2.01	2.28
7 days	1.7	2.11	1.59	1.73
5 days	1.4	2	1.41	1.54

Diagram 3- Tensile strength of concrete samples with 0.4 water-cement ratio and containing micro silica



	Pp0-rc0	Pp1.5-rc0	Pp0-rc100	Pp1.5-rc100
90 days	3.35	3.54	2.69	2.79
28 days	2.5	2.7	2	2.14
7 days	1.6	2	1.41	1.67
5 days	1.33	1.88	1.1	1.3

Diagram 4- Tensile strength of concrete samples with a water-cement ratio of 0.55 and without micro silica

- If recycled aggregates are used, the compressive and tensile strength of the samples decreases, but the addition of fibers and micro silica improved the tensile and compressive strength performance to some extent.

- With the passage of time in all the mixing plans, the compressive and tensile strength of the samples increased, and the greatest increase in strength was from the age of 28 to 90 days.

- Observations related to the failure of concrete tensile samples showed that the presence of fibers in concrete delays the initial cracks and prevents the crushing of concrete, which is a brittle material by nature. In fact, the fibers in concrete bridge the cracks and prevent the crack from spreading.

- Considering the results of this research in the direction of protecting natural resources and sustainable development, fiber recycled concrete can be used in applications where tensile and compressive strength and concrete cracking control are important. Among these cases, we can mention the paving of roads, runways, industrial floors, construction of prefabricated building parts including canopy panels, concrete of curved surfaces such as tunnels.

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