Research Article

The Effect of Micro-Silica on Compressive Strength in Concrete Structures in Shiraz

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Abstract: In recent decades, extensive studies have been conducted on concrete admixtures using materials science in high-tech countries. Besides, over the past few years, almost comprehensive studies have been carried out by specialists to introduce a type of high strength concrete in Iran however, there is still a great need for more extensive studies in this field. Today, in addition to the basic ingredients of concrete, aggregate, cement, and water, other materials are often used in concrete, and are commonly called concrete admixtures. One of the admissible admixtures for high strength concrete is micro-silica gel admixture with a combination of polycarboxylate ether (PCE)-based super-plasticizer. This study aimed to determine the effect of these materials on concrete and its mechanical properties such as concrete compressive strengths and find suitable percentages of cement, water, and aggregate, both technically and economically, using Shiraz native materials in workshops. To do so, a series of tests were performed on samples made of concrete and the effect of admixtures, before and after being added to 7-, 28-, 42-, 90-, and 120-day cube samples as well as the weight percentages of cement, water and aggregates were examined in the mix design. Notable that through this study it was necessary to also evaluate concrete compressive strength made of Shiraz native materials.

Keywords: Concrete Strength, Concrete Structures, Micro-Silica, Admixtures

1. Introduction

Concrete has long been used as one of the most important buildings' materials. In recent decades, the study of the science of materials and concrete admixtures in high technology countries has also received much attention. Today, in addition to the main concrete components, namely aggregate, cement, and water, other materials are also used in concrete, commonly called concrete admixtures [1,2]. It is the latest generation of polymer-based admixtures with polycarboxylate-based admixture concrete paste. PCE molecules are produced in different shapes and structures, each of which produces different effects on concrete. A new compound has been used in the structure of this material, which substantially avoids slippage without decreasing the effect on the strengths of earlier ages. It is used as a good admixture in the production of Self-compacting concrete (SCC) [3]. The polymer molecules adhere to the surface of the cement particles and repel the particles and neutralize the agglomeration effect on the cement particles. As a result, the water is released, and a mixture is formed, and mortar plasticity is increased. Furthermore, due to the homogenization of the mixture and the uniform contact of water with the cement particles, hydration performs uniformity [4].

The purpose of this study is to investigate the concrete strength after adding admixtures, including micro-silica with a combination of a polycarboxylate water reducer and to compare the strength of concrete with Shiraz native materials and to achieve higher strength concrete.

Concrete is a very hard rock-like object that is obtained by mixing a certain amount of cement, sand, and water. After the water is added to the mixture of rock and cement materials, the cement and water enter into thermo-chemical interactions. As a result of these interactions, a jelly-like, adherent material is formed that binds different materials into the mixture and renders it a hard object [5]. It is possible to fabricate high and unexpected compressive strengths that can be used for the design of complex structures. One of the important factors in achieving these strengths is the use of high strength aggregates and the reduction of the maximum aggregate size in the concrete mixture to create a homogeneous structure. In high strength concrete, the water-cement ratio should be reduced as much as possible. It is obvious that admixtures, including plasticizers, super-plasticizers, and fine particle dispersers in concrete, must be employed to provide the performance of such mixtures with very low water.

Aggregates make up about three-quarters of the volume of concrete, so their quality is of particular importance. Their physical, thermal, and sometimes chemical properties affect the performance of concrete [6]. The grading of aggregates and the maximum aggregate size significantly affect both the ratio of aggregates to each other and the amount of cement and water used to make the concrete as well as the efficiency of the fabricated concrete, pumping ability, shrinkage, durability and economic cost [7].

Since in most parts of Fars province, the fineness modulus (FM) of the sand produced is greater than 3.2 (in most cases it is more than 3.6), and the sand filler is low, the amount of sand used to achieve a concrete with good pumping efficiency and capability. Each cubic meter of concrete is greater than the amount of coarse aggregate (sand). Concrete aggregates should be graded so that their bones are full, with the least vacancy and maximum spatial weight (spatial weight over 1.5 ton/m^3). These grains should be mixed in such a way as to minimize the amount of vacuum to a minimum so that the least amount of cement is used. For this purpose, grading must be good and continuous. In general, grading should be such that 95% of it passes through a sieve of 4.76 mm, and all its grains pass through a sieve with holes 9.5 mm in diameter. In the case of sand, the opposite is sand; that is, 90% of it should remain on a sieve of 4.76 mm, and its grains diameter should not exceed 70 mm for ordinary concrete.

Water with a pH of between 6 and 8 and not saline can be used for concrete. Dark colors do not necessarily indicate the presence of harmful substances in water [8].

2. Materials and Methods

Concrete compressive strength is one of the important mechanical properties influenced by concrete mix design. Concrete ingredients include cement, water, coarse-grained, and fine-grained materials, the amount of which in mix design affects concrete compressive strength [9].

According to the expected results of this study, the statistical population of Shiraz and the Kaftarak and Fars cement rock materials were selected. Then, using a selected mix design, different samples of concrete were made and tested, and the results were analyzed.

2.1. Lab program

Concrete jack (Matest 2000KN) was used to measure the compressive strength of 7-, 28-, 42-, and 90-day samples. For this purpose, 100 samples of water, cement, aggregate, and micro-silica gel were prepared for mix design. The amount of component composition in each concrete sample varied with the other sample (Table 1) [10].

Table 1. Variations of ingredients of mix designs.

Mix proportion parameters	Range of mass changes (Kg/M^3)	Description
Water (if the sand is sandy and dry)	191	
Fars cement	390	
Micro-silica (1.5-5%)	6-20	
Kaftarak almond and pea gravel	660	
sand clean Dokuhak	1100	
Cylindrical strength	-	250 (kg/cm^2)
Slump range	-	5-9 cm

2.2. Sample preparation

A hundred samples, including 20 series of samples, were considered for mix design that all differed in the amount of sand, and sand micro-silica, and water-cement ratio. The samples were lubricated in 15×15×15 cm plasticizers in three layers (stages) with 35 beats. To determine the plasticity of the concrete samples, the slip test was performed on each of the designs according to the standard (ISIRI3203-2). This study has attempted to assume factors affecting concrete strength, including slump, in all fixed designs, since slump can have a direct relationship with cement content, water mixing, and degree of concrete. Moreover, the Vicat test was used to determine the concrete retention rate.

Since the compressive strength evaluation was 28 days, 42 days, and 90 days for the concrete, samples were kept in cold water basin (21 to 25°C) for the mentioned periods. All 7, 28, 42, and 90-day cubic samples were subjected to compressive strength measurements after processing at a loading speed of 0.4 Mpa/Sec [11].

2.3. Data Analysis

As one of the most widely used building materials, concrete plays an important role in the strength of buildings. Since achieving a proper compressive strength of concrete has always been one of the most important concerns of experts, this study aimed to investigate the effect of micro-silica gel (polycarboxylate-based polymer admixture) on concrete compressive strength, especially 42 and 90-day concrete. So that one can eliminate the decline in strength at this age. For this reason, 100 samples of concrete with different mix designs were made in terms of water-cement ratio, admixture content, and aggregate and sand content. Besides, the effect of these factors on concrete compressive strength was investigated separately. The results show that increasing the amount of micro-silica increases concrete compressive strength. This experiment was performed for different water-cement ratios. In all cases, similar results were obtained. Furthermore, the results showed that increasing the water-cement ratio leads to a decrease in concrete compressive strength. Understanding the factors affecting concrete compressive strength is very effective in achieving its optimal mix design with the desired strength over time.

3. Discussion and Results

3.1. Results of compressive strength test on samples

To precisely analyze and achieve the desired results, considering the same conditions for the constituent parameters, 100 cubic samples of concrete, namely 25 samples of Group A, 25 samples of Group B, 25 samples of Group C and 25 samples of Concrete Designed for Group D. Factors affecting the growth of concrete compressive strength, especially in the 42- to 90-day interval, will be investigated along with the diagrams and will be presented further in this research.

In this study, five mix designs were made. In these designs, the amount of aggregate, including aggregate and sand, is constant. Besides, changes in the percentage of micro-silica gel and water-cement ratio caused some changes in the concrete compressive strength. In the first sample, no admixtures were used. In subsequent samples, the percentage of use of these materials increases for each, and the water-cement ratio decreases slightly. Overall, it has been attempted to ensure consistency across samples. The study used polycarboxylate-based polymer admixture at 1.5, 3, and 5 percent by weight of cement consumed.

3.2. Grading of rock materials

Rock materials make up about 1/4 of the volume of concrete, so their quality is of particular importance. Not only do rock materials affect concrete strength, but they also greatly affect the durability of concrete. The aggregates used in concrete, including coarse-grained, fine-grained aggregates, or a mixture thereof, must be of such a quality that a durable and durable concrete can be used.

The grading test of rock materials was performed according to the ASTM C136 standard and also by washing method for fine-grained rock materials, the results of which are illustrated in Figures 1 to 5. In the mentioned scheme, the consumption of FM sand was 3.42. The concrete design is based on the FM sand above.

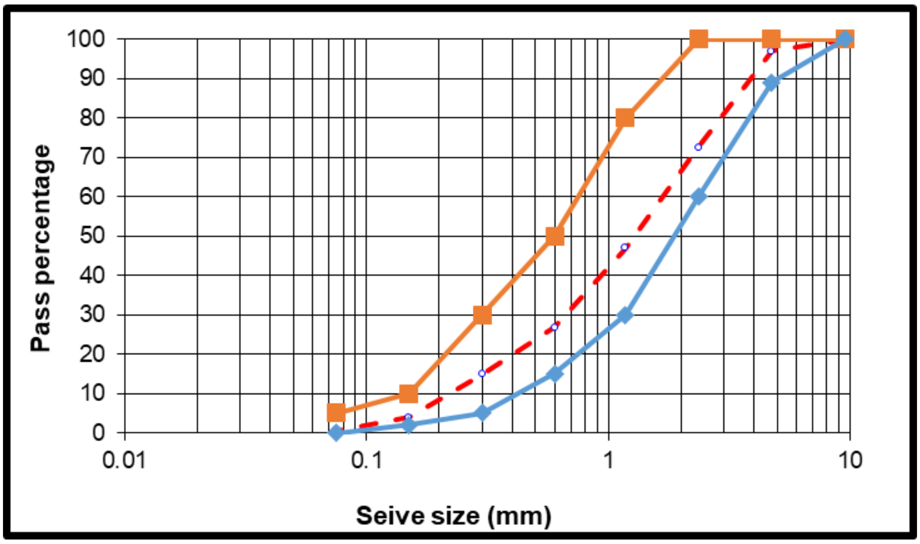

Figure 1. Dokuhak washed sand diagram grading according to 302 standard (Caption: Pass percentage/Sieve size (mm)).

The grading of washed sand materials complies with the mandatory grading range set out in Iranian National Standard 302. Besides, the FM sand, which indicates the roughness and softness of the sand, is 3.42.

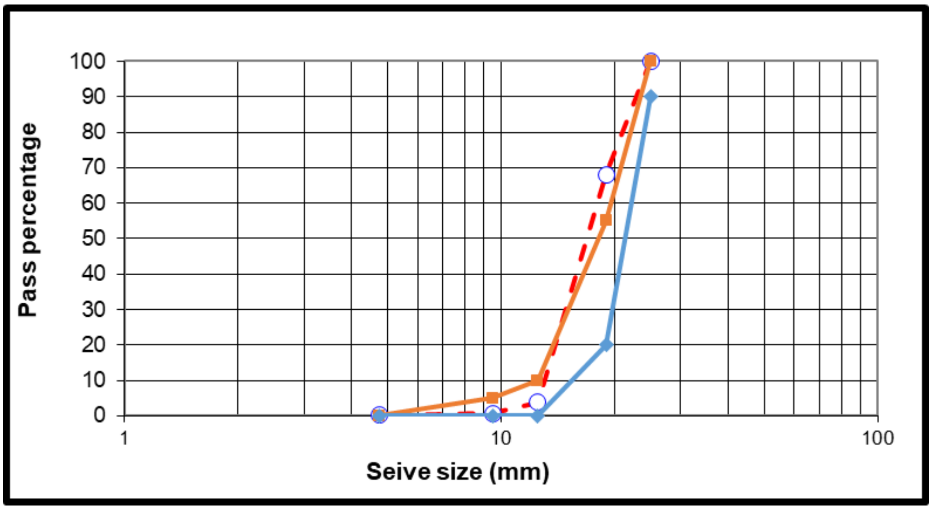

Figure 2. Dokuhak almond grading according to 302 standard.

The grading test for coarse-grained rock material was performed according to ASTM C136. According to the definitions in ASTM C125, the maximum nominal size of coarse-grained rock material for this design is 19 mm and without discrete grading.

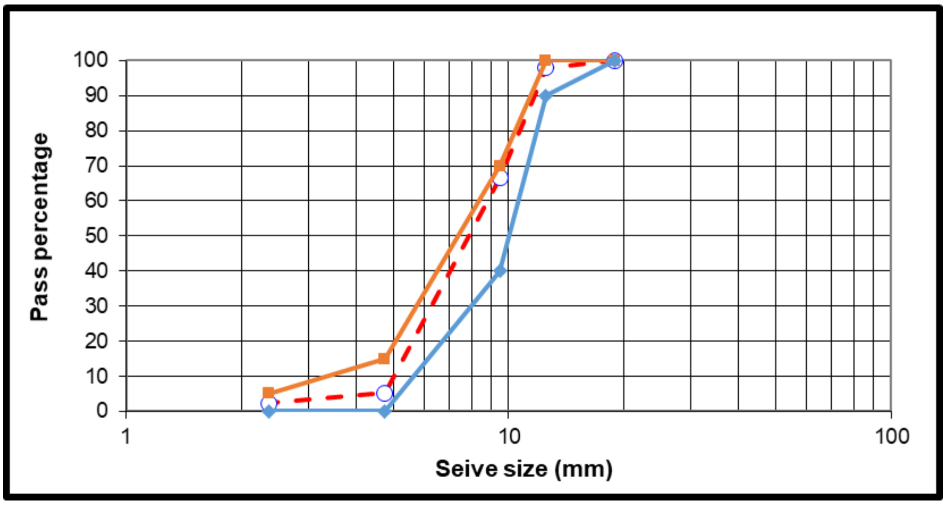

Figure 3. Dokuhak pea grading diagram based on standard 302.

It should be noted that this grading test was performed using the ASTM C136 standard for fine-grained rock materials. According to the diagram, this fact complies with the mandatory grading range outlined in National Standard 302 of Iran.

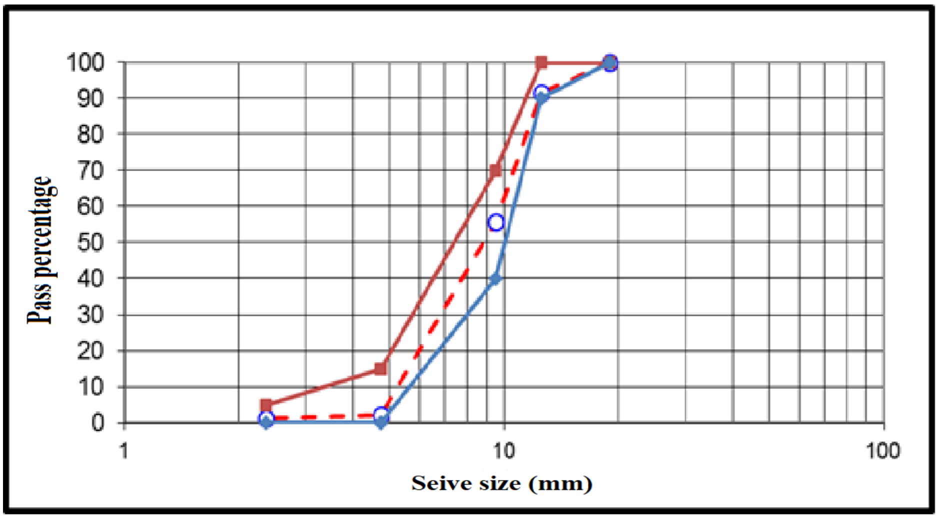

Figure 4. Kaftarak pea grading diagram based on standard 302.

It should be noted that this grading test was performed using the ASTM C136 standard for fine-grained rock materials. According to the diagram, this complies with the mandatory grading range outlined in National Standard 302 of Iran.

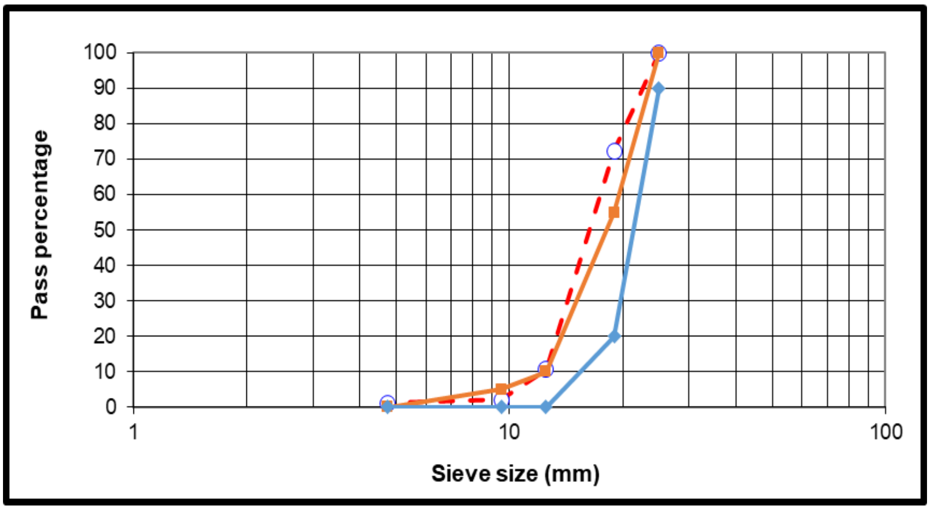

Figure 5. Kaftarak almond grading according to standard 302.

The grading test for coarse-grained rock material was performed according to ASTM C136. According to the definitions in ASTM C125, the maximum nominal size of coarse-grained rock material for this design is 19 mm and has continuous grading.

3.3. Cement

In the concrete design, the cement used is the Fars Type 2 Cement. It should be noted that the cement used should be completely healthy. In addition, its physical and chemical properties comply with the specifications outlined in ASTM C150 (Common Portland Cement) and ASTM C595 (Poznan Portland Cement).

3.4. Water

According to the Iranian Concrete Code, the pH of water consumed in concrete should not be less than 5 and not exceed 8.5.

3.5. Admixtures

In this study, polycarboxylate-based polymer admixture was used for 1.5, 3, and 5% by weight of cement consumed.

3.6. Mixing rock materials

In this study, the mix design used to produce concrete with a cement content of 390 for each cubic meter and a strength of 250 kg/cm 2 is considered. Based on the results of the grading of rock materials, the mix design of the present study is presented in the following table. The table below shows the weight value needed to make five cubic samples with a ratio of 0.05.

Table 2. Weight of materials needed to make five cubic samples per batch

Material name	Value	Unit
Gravel (coarse-grained)	33	kg
Gravel (fine-grained)	55	kg
Cement	20	kg
Water	10	l
For 1.5% admixture	300	g
For 3% admixture	600	g
For 5% admixture	1000	g

3.7. Mix design verification

For each series, the aggregate ratio is assumed to be constant, and the cement-to-water ratio is varied to provide a clearer effect of the admixture on compressive strength.

Table 3. Range of variations of basic ingredients of mix designs

Sample Group No.	mix design				w/c	Slump (cm)
	Gravel (kg)	Sand (kg)	Cement (kg)	Water (l)		
A1,B1,C1,D1	33	55	17	6.97	0.41	8
A2,B2,C2,D2	33	55	17.6	7.4	0.42	7
A3,B3,C3,D3	33	55	18.2	7.83	0.43	7
A4,B4,C4,D4	33	55	18.8	9.02	0.48	7
A5,B5,C5,D5	33	55	20	10	0.50	8

3.8. Results of compressive strength test on samples

In this study, 100 cubic samples were produced and tested in 4 groups of 25. Each batch contains five samples defined for ages 7, 28, 42, 90 days. For 28 days of age, two samples were tested, and the mean is listed in Table 4. The compressive strength test was performed on all four groups, and the results are presented in Figures 6 to 9. According to the analysis of the results, in each sample group and with each water-cement ratio, an increase in concrete strength growth in the 7-28-day period and a decrease in concrete strength growth in the 42-90-day period compared to the 28-day period is evident. As stated in section 4-3, the decrease in strength growth is due to the excess lime content in the cement. In addition, the amplitude of changes in compressive strength increases with decreasing water-cement ratio in each sample number, with the highest water-cement ratio being 0.41 and the lowest being 0.50.

Table 4. Compressive strength obtained for group A (without admixtures).

Group	Sample Group No.	Slump	7-day compressive strength (kg/cm2)	28-day compressive strength (kg/cm2)	42-day compressive strength (kg/cm2)	90-day compressive strength (kg/cm2)	42-28 growth percentage	90-28 growth percentage
A	A1	7	253	354	339	344	-4	-3
	A2	7	240	346	335	340	-3	-2
	A3	8	236	341	333	338	-2	-1
	A4	8	224	332	320	323	-4	-3
	A5	7	212	328	316	317	-4	-3

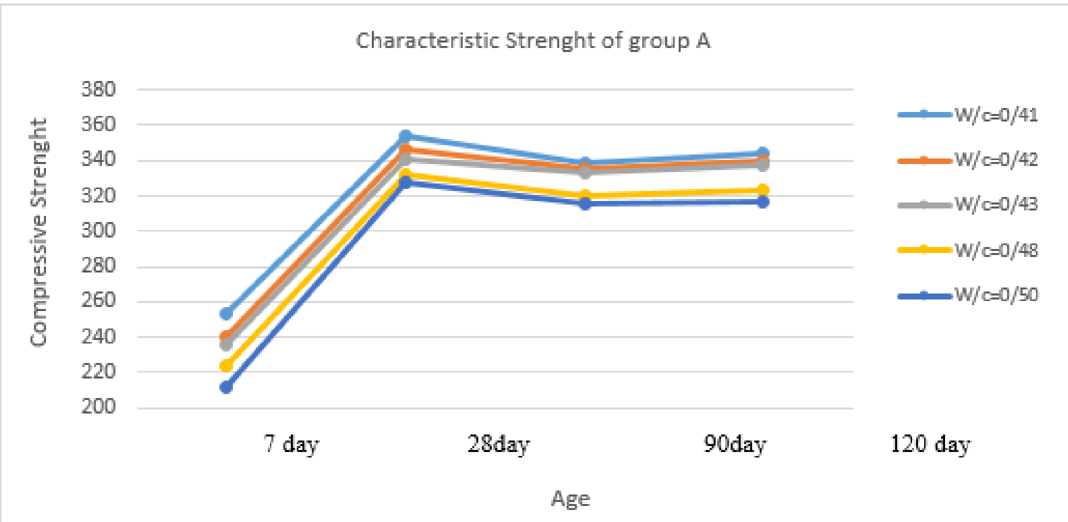

Figure 6. The trend of changes in compressive strength of Group A (Caption: Characteristic Strength/Compressive Strength/Age).

Table 5. Compressive strength obtained for group B (1.5% admixtures).

Group	Sample Group No.	Slump	7-day compressive strength (kg/cm2)	28-day compressive strength (kg/cm2)	42-day compressive strength (kg/cm2)	90-day compressive strength (kg/cm2)	42-28 growth percentage	90-28 growth percentage
B	B1	18	263	379	384	389	1	3
	B2	14	248	365	374	379	2	4
	B3	16	242	350	352	369	1	5
	B4	18	232	345	347	362	1	5
	B5	18	225	333	339	356	2	6

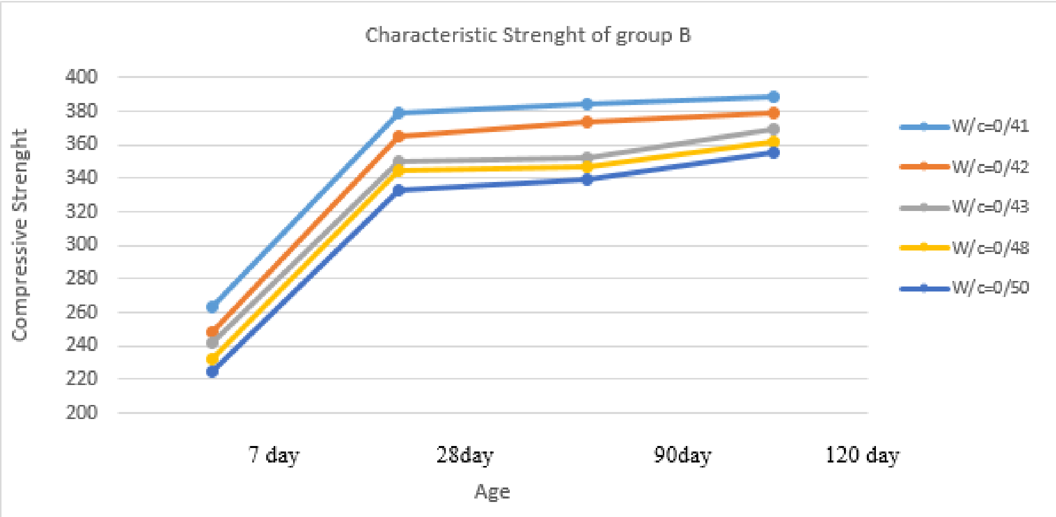

Figure 7. The trend of changes in compressive strength of group B.

Table 6. Compressive strength obtained for group C (3% admixtures)

Group	Sample Group No.	Slump	7-day compressive strength (kg/cm2)	28-day compressive strength (kg/cm2)	42-day compressive strength (kg/cm2)	90-day compressive strength (kg/cm2)	42-28 growth percentage	90-28 growth percentage
C	C1	15	269	386	398	405	3	5
	C2	18	253	370	386	393	4	6
	C3	16	248	362	368	386	2	6
	C4	16	238	358	360	373	1	4
	C5	16	230	342	348	369	2	7

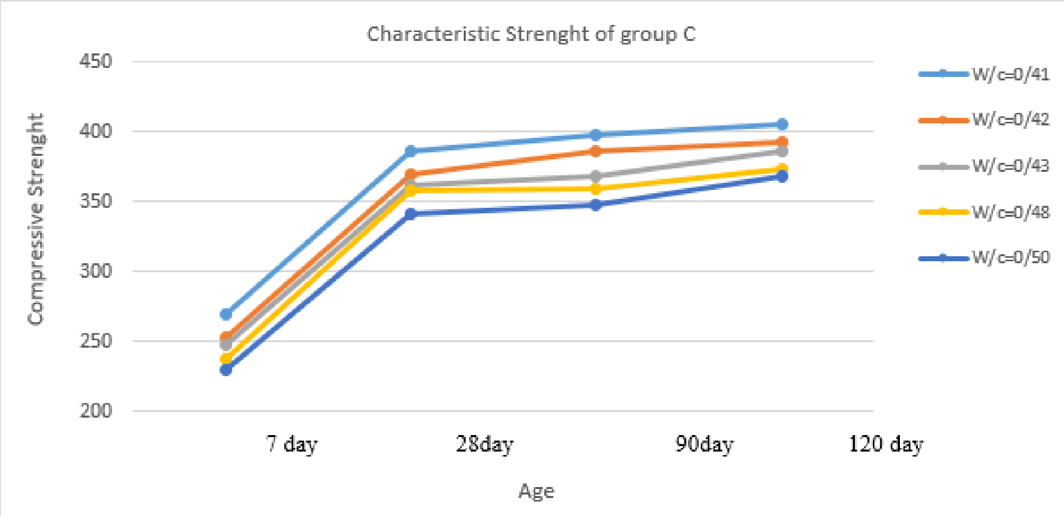

Figure 8. The trend of changes in compressive strength of group C.

Table 7. Compressive strength obtained for group D (5% admixtures).

Group	Sample Group No.	Slump	7-day compressive strength (kg/cm2)	28-day compressive strength (kg/cm2)	42-day compressive strength (kg/cm2)	90-day compressive strength (kg/cm2)	42-28 growth percentage	90-28 growth percentage
D	D1	15	280	410	425	435	4	6
	D2	16	262	389	404	420	4	7
	D3	14	255	379	382	410	1	8
	D4	16	246	369	372	401	1	8
	D5	18	234	350	355	388	1	10

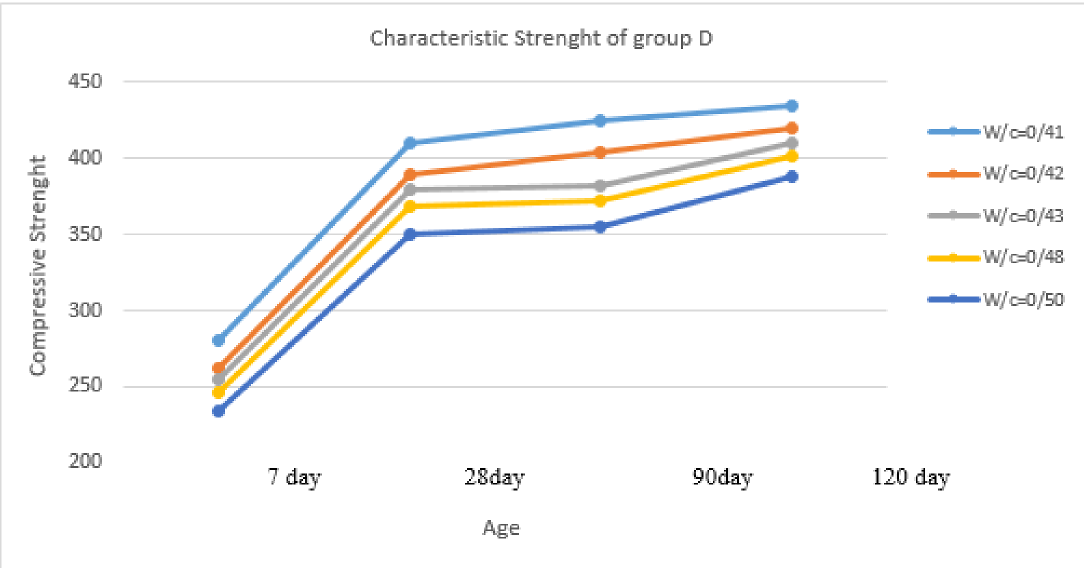

Figure 9. The trend of changes in compressive strength of group D.

According to the results, adding this admixture to concrete will increase strength at 42 and 90 days of age. Besides, it can be said that the addition of micro-silica gel compensates for the 42 and 90-day-old reverse growth vacuum before the aforementioned admixture.

Five water-cement ratios, namely 0.41, 0.42, 0.43, 0.48 and 0.50, are considered. For each of the aforementioned water-cement ratios, three admixture-to-cement ratios are considered. Due to the constant aggregate ratio, increasing admixture results in increased concrete compressive strength. Figures 4-14, 4-16, and 4-18 show that the higher the admixture and the lower the water-cement ratio, the greater the compressive strength for this domain. The reason for this may be that the low water-cement ratio and the high amount of polymer admixture result in the formation of a compact material, which improves the transition zone (aggregate surface and cement paste). As a result, the compressive strength of the system increases.

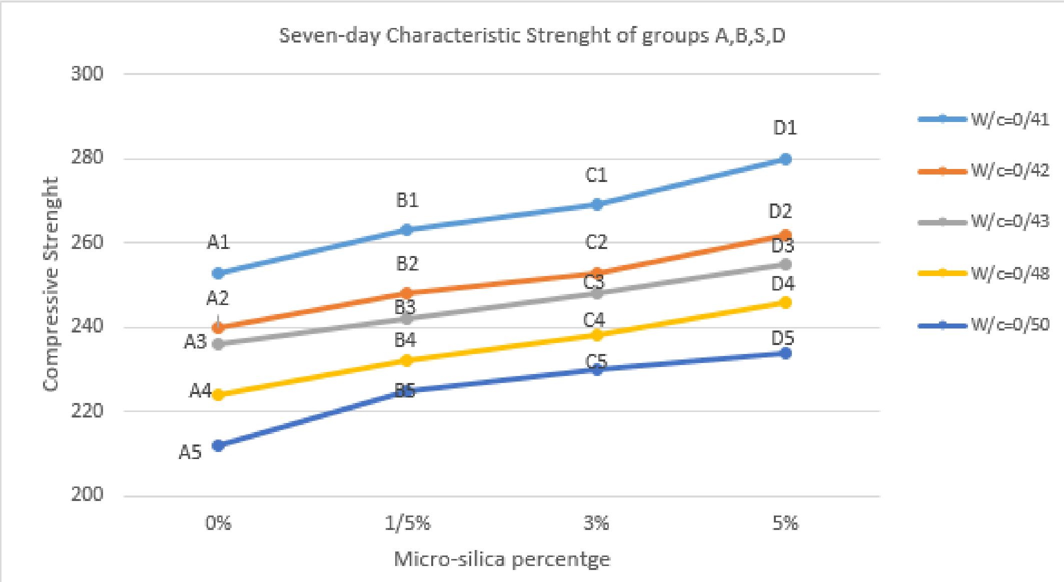

Figure 10. Changes in concrete compressive strength in micro-silica at different W/C ratios at 7 days of age (Caption: Micro-silica proportion or percentage).

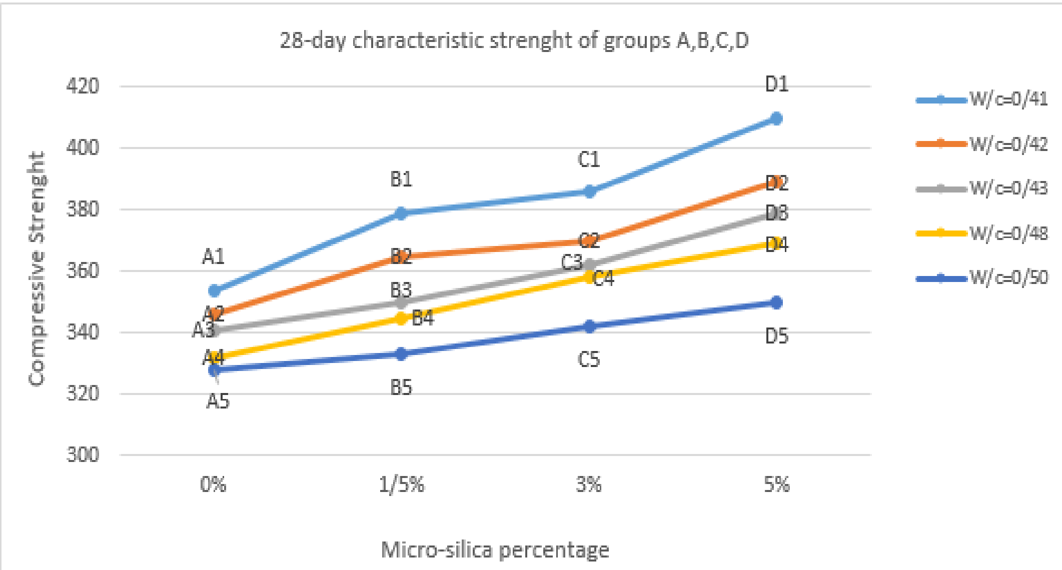

Figure 11. Changes in concrete compressive strength in micro-silica with different W/C ratios at 28 days of age.

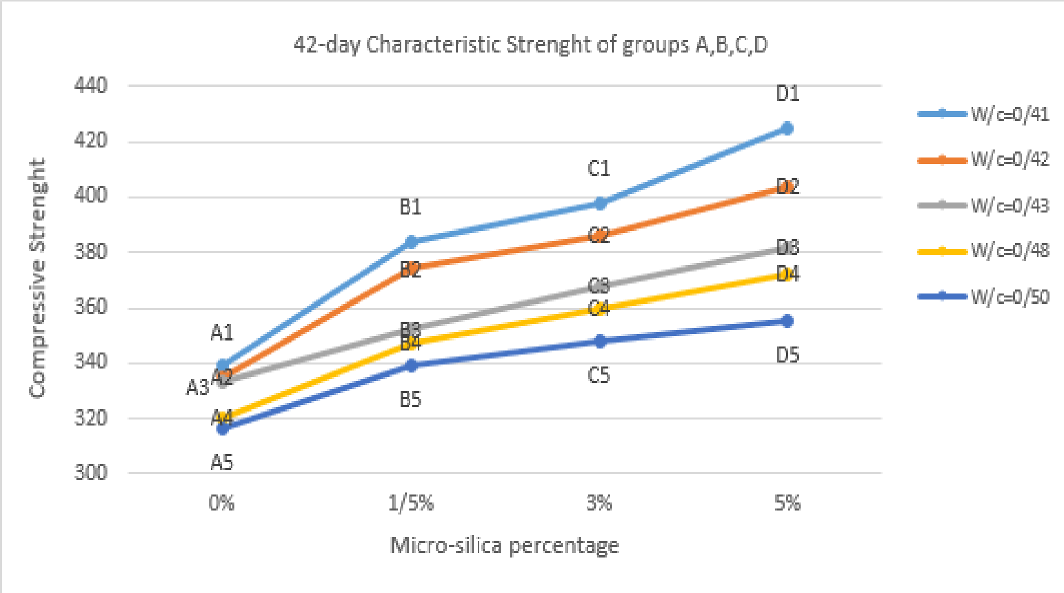

Figure 12. Changes in concrete compressive strength in micro-silica with different W/C ratios at 42 days of age.

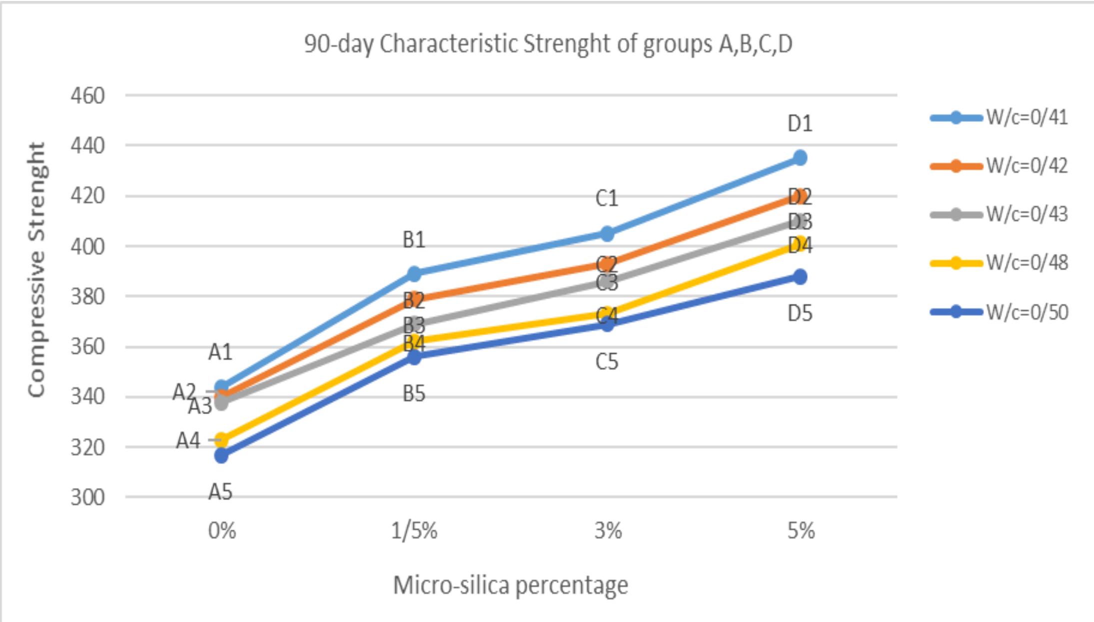

Figure 13. Changes in concrete compressive strength in micro-silica with different W/C ratios at 90 days of age.

With a little contemplation in Figures 10 to 13, it can be concluded that the use of polycarboxylate-based admixtures on concrete compressive strength has directly yielded the desired results. This increase in compressive strength results in higher numbers with increased participation in the mix design. Using maximum mix proportion, this by-law, or in other words mixing 5% of cement weight, will produce strength approximately 1.2 times that of a non-admixture sample at 90 days of age.

It is also inferred that strength growth at 7, 28, 42, and 90 days of age has a direct relationship with the percentage of polycarboxylate-based polymer admixture. For example, for the 7-day strength characteristic of groups A, B, C, D, increasing admixture percentage and concrete age increase the strength of samples in each group and with each water-cement ratio, such that the amplitude changes over the 42 and 90-time intervals. Fasting reaches its maximum level. Besides, the reverse growth of concrete during this period has been resolved with the participation of polycarboxylate-based micro-silica gel.

Moreover, the higher the admixture and the lower the water-cement ratio used, the greater the compressive strength for this domain. In Figures 19-19 and 4-22, with the lowest water-cement ratio (0.41 = W/C) and the highest admixture (5%), point D1 has the highest compressive strength equivalent to 435. Furthermore, with the highest water- The cement ratio (0.50 = W/C) and the lowest admixture value, point A5 has a minimum compressive strength of 212.

In addition, by considering diagrams of variations in strength in terms of different water-cement ratios, it can be concluded that the highest slope of the diagrams is in the 42- to the 90-day interval, with a maximum of 0.41 in the water-cement ratio. As the water-cement ratio increases from top to bottom, from 0.41 to 0.50, the slope of the diagrams decreases over this period, indicating a decrease in the amplitude of changes in strength growth as a result of increasing water-cement ratio. It can be concluded that the trend of increasing strength at older ages is directly related to the percentage of admixtures and is inversely related to the water-cement ratio.

4. Conclusion

After performing compressive strength tests on the samples produced and collecting the data obtained from this experiment, it becomes clear with some reflection that the use of polycarboxylate-based polymer admixtures directly on the compressive strength has the desired effect. Such increment of compressive strength results in higher numbers with increased participation in the mix design. Besides, using a maximum mix proportion, a by-law, or a mixing of 5 percent cement weight, will produce a strength greater than 1.2 times the sample without admixture.

On the other hand, it is worth considering the concrete strength numbers obtained. The higher the percentage of admixtures involved in concrete mix design, the sooner the concrete is manufactured to its ultimate strength.

In addition, according to Tables 4 and 7, it is inferred that the growth trend of increasing strength at older ages is directly related to the percentage of admixtures involved. Adding this admixture to concrete will increase strength at 42 and 90 days of age. It can be said that the addition of admixture compensates for this reversal of growth at 42 and 90 days of age compared to the pre-admixture state.

For any given water-cement ratio, increasing admixture increases concrete compressive strength. It should be noted that in this study, the cement reduction rate is considered to be up to 15%. Figures 12 and 13 show that the higher the amount of micro-silica gel, and the lower the water-cement ratio used, the greater the compressive strength for this domain. The reason for this may be that a low water-cement ratio and a high amount of polycarboxylate-based polymer admixture result in the formation of a compact material, which improves the transition zone (aggregate and cement paste surface). As a result, the compressive strength of the system increases.

The use of this admixture has a direct effect on concrete flexural strength. Experience and research have shown that increasing concrete compressive strength will have a positive effect on concrete flexural strength. The results indicate that the use of polycarboxylate-based polymer admixture can be scientifically and economically justified in several respects:

Using this admixture in concrete mix design results in higher strengths than consumable content without the need for increased cement content. This is economically justified by the high volume of concrete placement.

Given the 7-day increase in strength by applying the maximum by-laws and completing the growth process of concrete strength at the age of 7, we can achieve a faster pace in the execution of concrete projects that require stopping to achieve optimal strength.

As increasing cement content in the mix design makes the concrete more fragile and eventually less robust, the admixture used can increase concrete compressive strength without the need for high content consumption.

Finally, in light of the above results, the use of polycarboxylate-based admixtures is more economically and technically justifiable than increasing concrete content to achieve strength.

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