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Experimental Study on the Effect of Aggregates Matrix, Admixture and Water-Cement Ratio on Mechanical and Physical Properties of High Performance Concrete

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Abstract

In this study, the combined effects of microsilica weighted ratio content, fineness modulus and water-cement ratio on physical and mechanical properties of concrete were investigated. For determination the effects of microsilica weighted ratio content on concrete parameters in different water-cement ratios and particle size distributions, 5 different microsilica weighted ratio contents, 3 water-cement ratios and 3 particle size distributions, were selected and totally 45 mix designs were prepared and subjected to slump test and compressive strength, tensile strength and modulus of elasticity tests. Obtained results show a direct relationship between microsilica weighted ratio content and physical and mechanical properties of concrete. Increase in microsilica content from 0% to 10 % in all water-cement ratios and fineness modulus, leads to slump decrease and mechanical parameters increase, while from 10 % to 20 % of microsilica content, mechanical properties fall down, but the reduction trend of slump continues. Also it can be seen that the effect of different weighted of microsilica, on physical and mechanical properties of concrete, reduces by increasing in water-cement ratio and intensifies with increment of fineness modulus of fine aggregates.

Keywords: Microsilica, fineness modulus, water-cement ratio, concrete mechanical and physical properties.

Introduction

Nowadays concrete is believed to be one of the most important materials in construction industry. There is no comprehensive definition of concrete behavior and properties available, many studies were carried out nonetheless. Concrete properties are dependent on many parameters such as ingredients, production and technology, construction methods and curing conditions that have made concrete as a complex and unpredictable material. But these are virtually ignorable against its precious advantageous and precise studies on above parameters may help us to produce concretes with our desirable properties. Ingredients are of those important parameters that play an essential role. Therefore it is seriously important to have enough knowledge about ingredients, their combined effects and interactions and also effects of their properties on concrete properties.

Pozzolan materials can help us to achieve desirable characteristics of concrete and develop its mechanical and physical parameters, hence they are used widely. Improvement of mechanical parameters, permeability reduction, and durability increase are among their fabulous benefits of application. They are deemed as essential ingredients of high durable and strength concretes[1]. Pozzolan type (including dimensions, surface characteristics, and minerals) and applied weighted ratio are major parameters which develop a homogenous and united medium and improve the physical and mechanical parameters of concrete[2,3]. The effects of pozzolan on physical and mechanical properties of concrete, moreover it's specifications, depend on the parameters of other ingredients, such as type of aggregates, particle size distribution of aggregates, fineness modulus of fine aggregates, water-cement ratio, cement type and ect. Then study of combined effects of pozzolan specifications and parameters of other ingredients is inevitable for achieving to a concrete with ideal parameters[4,5,6].

As we know, microsilica is the most popular pozzolan material which is used widely and it's parameters (such as weighted ratio, physical and chemical parameters,…) and other ingredients parameters (such as type of aggregates, particle size distribution of aggregates, fineness modulus of fine aggregates, water-cement ratio, cement type and ect) have combined effects on the variation of concrete physical and mechanical parameters[7,8]. So, in this study we selected microsilica as a pozzolan to determine the combined effects of its weighted ratio content, fineness modulus of fine aggregates and water-cement ratio on physical and mechanical properties of concrete[9].

Several researchers have also examined the influence of microsilica, fineness modulus and water-cement ratio on some parameters of concrete, separately. Some researchers investigated the effect of microsilica on different parameters of concrete. It is common in all these research that presence of microsilica has beneficial effects on concrete parameters[1-3,10]. Other researchers studied the effect of type, shape and size of aggregate particles on concrete parameters and compared various particle size distributions[2,6-8,11-13]. Also many researchers showed the effect of fineness modulus of fine aggregates on different parameters of concrete. However, combined effect of concrete ingredients on concrete parameters has received less attention[4,9,14,15].

The basic objective of this study was to investigate the combined effects of microsilica weighted ratio content, fineness modulus of aggregates and water-cement ratio on mechanical and physical properties of concrete. For this purpose, 5 weighted ratio contents of microsilica, 3 water-cement ratios, and 3 particle size distributions with different fineness modulus were used and prepared 45 mix designs and subjected to slump test, compressive strength, tensile strength and modulus of elasticity tests[16].

Methodology

Laboratorial Studies: Production of a concrete with ideal parameters like desirable mechanical parameters and durability, good workability, and economic efficiency is dependent on having enough knowledge about the combined effects of its ingredients on its parameters. In this study we investigated counteractive effects of weighted ratio content of microsilica, fineness modulus and water-cement ratio, on workability of fresh concrete and physical and mechanical properties of hardened concrete. Tests' procedures are as follow: i. Preparing 3 different aggregates size distributions using a constant coarse aggregate distribution and 3 various fines distributions, thus exhibiting 3 different fineness modulus[1]. ii. Designing 45 mix designs with 5 weighted ratio contents of microsilica, 3 water-cement ratios, and 3 particle size distributions. iii. Doing slump tests on our 45 mix designs. iv. Preparing 270 cubic specimens based on our mix designs for compressive strength and modulus of elasticity tests at 7 and 28-day ages. (For each mix design, tests were repeated for 3 times). iv. Preparing 270 cylindrical specimens based on our mix designs for tensile strength tests at 7 and 28-day ages. (For each mix design, tests were repeated for 3 times). v. Comparing results and prepare conclusions on effects of weighted ratio content of microsilica on workability and mechanical parameters of concrete.

Materials Specifications: In this section, material properties and specifications are introduced.

Aggregates: In this study granite with physical and mechanical parameters tabulated in table-1 was used. It was exploited from a mine and then shredded using a laboratorial machine and finally categorized using standard sieves. It should be also noted that all aggregates were initially washed and applied in SSD status.

Super plasticizer: Melamine Formaldehyde Sulfunate Shimi-Rezin Co. (ASTM C494-Type F) was used as a super plasticizer.

Table-1
Physical and mechanical properties of aggregates

Property	Value	Unit
Compressive Strength	228.3	MPa
Elasticity Modulus	64.9	GPa
Unit Weight	1650	Kg/m^3
Density	2.678	-
Water Absorption	0.4	%

Microsilica: microsilica used in this study is for Azna Co. (Gs: 2.11 and more than 99% pure), that it's chemical parameters are presented in table-2.

Table-2
Chemical properties of microsilica

Chemical Blends	Constitutive Percent	Chemical Blends	Constitutive Percent
MgO	0.97	H_2O	0.80
Na_2O	0.31	Sic	0.50
K_2O	1.01	C	0.30
P_2O_5	0.16	SiO_2	94.6-96.4
SO_3	0.10	Fe_2O_3	0.87
Cl	0.04	Al_2O_3	1.32
Color	66	CaO	0.49

Cement: Cement used in this study is type I (ASTM C150) , that it's mechanical, physical and chemical parameters are presented in table 3,4 and5.

Table-3
Mechanical properties of cement

Compressive Strength	Cement Type I
3 days (kg/cm^2)	224
7 days (kg/cm^2)	287
28 days (kg/cm^2)	403

Table-4
Physical properties of cement

Blain Specific Surface	**3100 cm^2/gr**
Setting Time Vicat	140 min
Auto Clave Expansion	0.03%
Water for Normal Consistency	25%

Table-5
Chemical properties of cement

Chemical Blends	Constitutive Percent	Chemical Blends	Constitutive Percent
SiO_2	20.96	Na_2O	0.45
Al_2O_3	5.78	K_2O	0.55
Fe_2O_3	3.12	Loss	1.60
CaO	62.72	Total	99.90
MgO	2.42	Insol Rez	0.44
SO_3	2.30	Free CaO	1.2
Composition clinker According To Bogue			
C_3S	46.11	2.79	$CaSo_4$
C_2S	25.38	-----	MgO
C_3A	9.91	93.67	Total
C_4AF	9.48		

Aggregates Size Distributions: In order to achieve 3 different aggregates size distributions, initially 3 different fines distributions were prepared and then mixed with a constant coarse aggregate distributions. To do so, first crashed materials were categorized using a vibrator in standard sieves (3/8, 1/4, 4, 8, 16, 30, 50, 100, and 200) and were mixed to each other by precise ratios, based on our desirable size distributions. The distributions were selected and prepared to obtain fines modules equal to 2.86, 3.06, and 3.26 and in range of ACI 211-4R guideline recommendations. Their Properties are presented in figure-1[12,17,18].

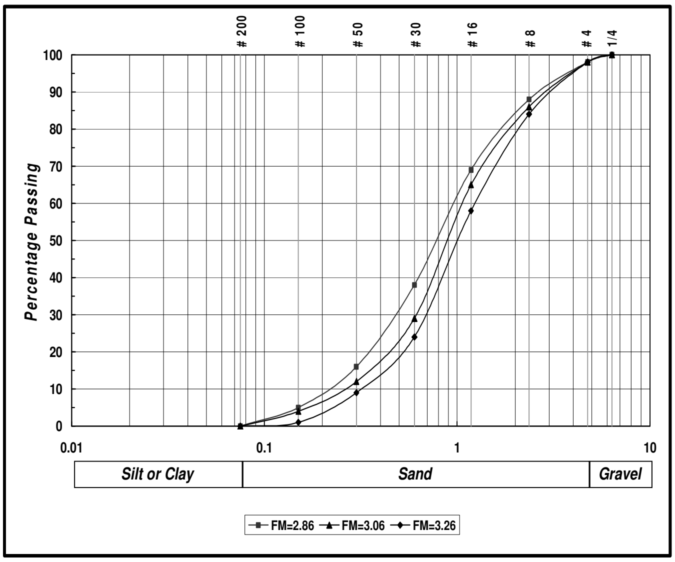


Figure-1
Particle size distributions diagrams of fines with different fineness modules

Furthermore, coarse material distribution was designed based on ASTM C33 (Table-3).

Table-6
Coarse material size distribution

Sieve Passing Percent	Sieve Extant Percent	Sieve size (mm)	Sieve No.
0.00	100.00	9.525	3/8"
60.00	40.00	6.35	1/4"
30.00	10.00	4.75	4
10.00	0.00	2.36	8

Mix Designs: Those mix designs that are mentioned here were designed based on volumetric method and recommendations by ACI 211. Since in ACI 211-4R superficial volume of coarse material is recommended to be up to 1.5 times of that recommended by ACI 211.1-85, we used a superficial volume equal to 1.4 times of ACI 211.1-85 recommendation. Also, in respect to fineness modules of 2.86, 3.06, and 3.26 for different mix designs, coarse volumes selected to be 0.63, 0.61, and 0.59, respectively. Furthermore, air volume was considered to be 0.02 of total concrete volume, and cement content equal to 550 kg/m3 was used constantly in all mix designs. Moreover, weighted ratio contents of microsilica equal to 0, 5, 10, 15, and 20 per cent were used instead of equal-weighted cement, and super plasticizer content used to be 2% of cement content. In the end, having known all ingredients volumetric ratios, fines volume was calculated and multiplied by unit weight to evaluate each ingredient's content for a cubic meter of concrete volume[17,19,22].

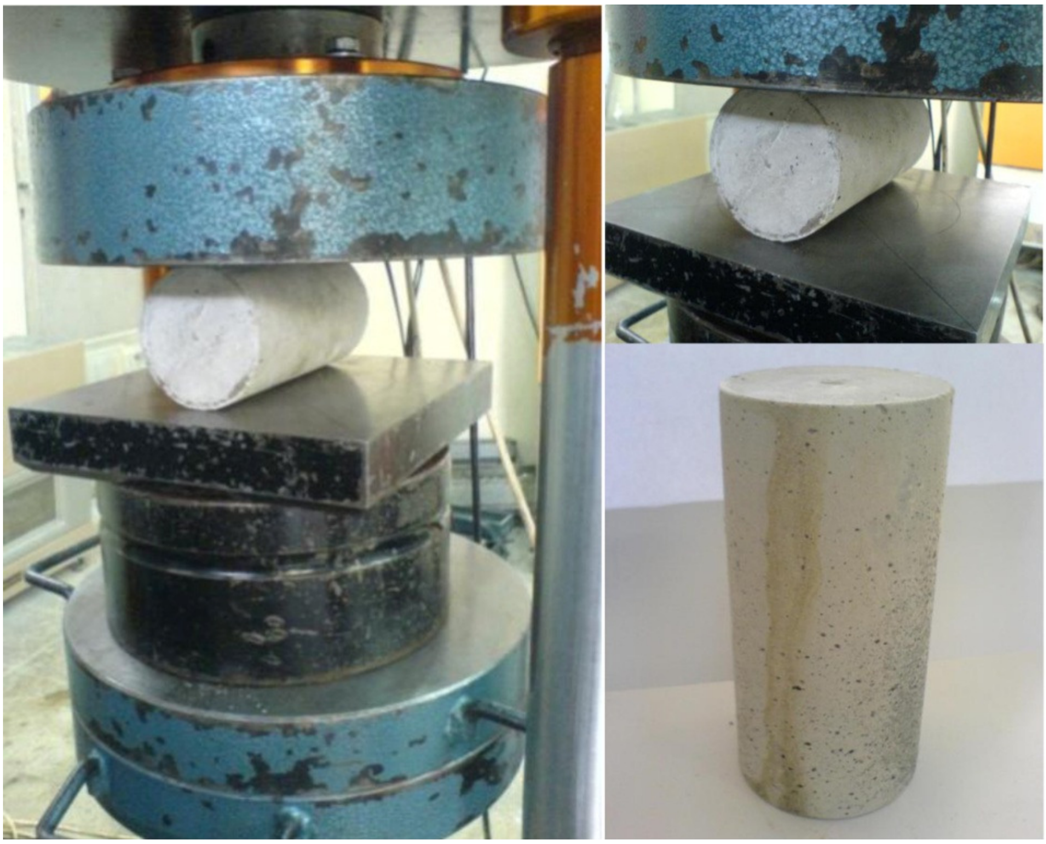
Test Procedures: In order to achieve specimens with similar characteristics, all ingredients were weighted by 0.1 gram precision and mixed using a laboratorial mixer then. They were applied in the following order: first water, second super plasticizer then cement were applied and aggregates were poured into cement paste at the final stage to obtain a homogenous combination.

Slump test: Slump tests were conducted following ASTM C143-90 guidelines with 3-time repeats for each mix design. In this method, fresh concrete is poured into a trimmed cone with 102 mm diameter in top, 203 mm diameter in bottom, and 305 mm in height through 3 layers. Each layer is compacted using a bar (16 mm in diameter) by 25 hits. After compacting the last layer, extra-concrete is trimmed and the cone is removed slightly. Slump test value is the dropped height of fresh concrete after cone removal.

Compressive strength and modulus of elasticity test: Compressive strength and modulus of elasticity tests were conducted based on BS 1881: Part 108: 1983 guideline and 3-time repeats for each mix design. In this method, fresh concrete is poured into a cubic mould (100 x 100 x 100 mm) through 2 layers while each layer is compacted by a bar (25 mm2 section area) by 25 hits. After 16-28 hours, moulds are removed and cubic specimens are cured in a pond of water with 20±5 Celsius degrees temperature until the test time. Tests are conducted at 7 and 28-day ages using a 200 tons hydraulic jack with a loading rate equal to 0.2-0.4 MPa per second.

Tensile strength test: Tensile strength tests were conducted based on ASTM C496-90 guideline and 3-time repeats for each mix design. In this method, fresh concrete is poured into a cylinder mould (75 x 100 mm) through 3 layers while each layer is compacted by a bar (25 mm2 section area) by 25 hits. After 16-28 hours, moulds are removed and cylinder specimens are cured in a pond of water with 20±5 Celsius degrees temperature until the test time. Tests are conducted at 7 and 28-day ages using a 200 tons hydraulic jack with a loading rate equal to 0.02-0.04 MPa per second.

Figure-2
Compressive strength and modulus of elasticity test



Figue-3
Tensile strength test

Results and Discussion

Tests' results are categorized through two main groups as follow: i. Counteractive effects of microsilica weighted ratio content, fineness modulus and water-cement ratio on mechanical properties of concret. ii. Counteractive effects of microsilica weighted ratio content, fineness modulus and water-cement ratio on physical properties of concret.

Now, by knowing 3 underneath major points, the results are shown and justified: i. Since cement particles are larger in dimensions, the superficial surface value for cement is lower than microsilica. So, microsilica absorbs more water which in turn reduces slump value. ii. Because of the fact that, the specific gravity of microsilica particles is less than cemet specific gravity (specific gravity of microsilica is about 2/3 of cemet specific gravity), by substitution of definite weighted ratio of microsilica with same definite amount of cement, volume of cement paste increases which in turn the specific gravity of concrete reduces. iii. Generation of empty spaces among cement particles because of their arrangements, which leads to a weaker structure for cement paste. These empty spaces are used by extra water (more than amount used for hydration). Hence, as water-cement ratios increase, these empty spaces grow and cement particles get more dispersed. The final result is decrease of inter-particle forces and a weaker cement paste.

Mechanical parameters tests: For investigating the combined effects of microsilica weighted ratio content, fineness modulus and water-cement ratio on mechanical properties of concrete, 3 types of aggregate's particle size distributions with different fineness modulus were used. For each particle size distribution with specific fineness modulus, 5 different weighted % of microsilica and 3 water-cement ratios were considered. All of the specimens that were made in these conditions, subjected to compressive strength, tensile strength and modulus of elasticity tests at the age of 7 and 28 days.

The obtained results are shown in 3 major groups. Each group includes the results of tests on concrete specimens that composed of 1 fineness modulus, 5 weighted % of microsilica and 3 water-cement ratios.

Compressive strength: Figure-4 shows the results of compressive strength tests on specimens that made of different fineness modulus, weighted % of microsilica and water-cement ratio.

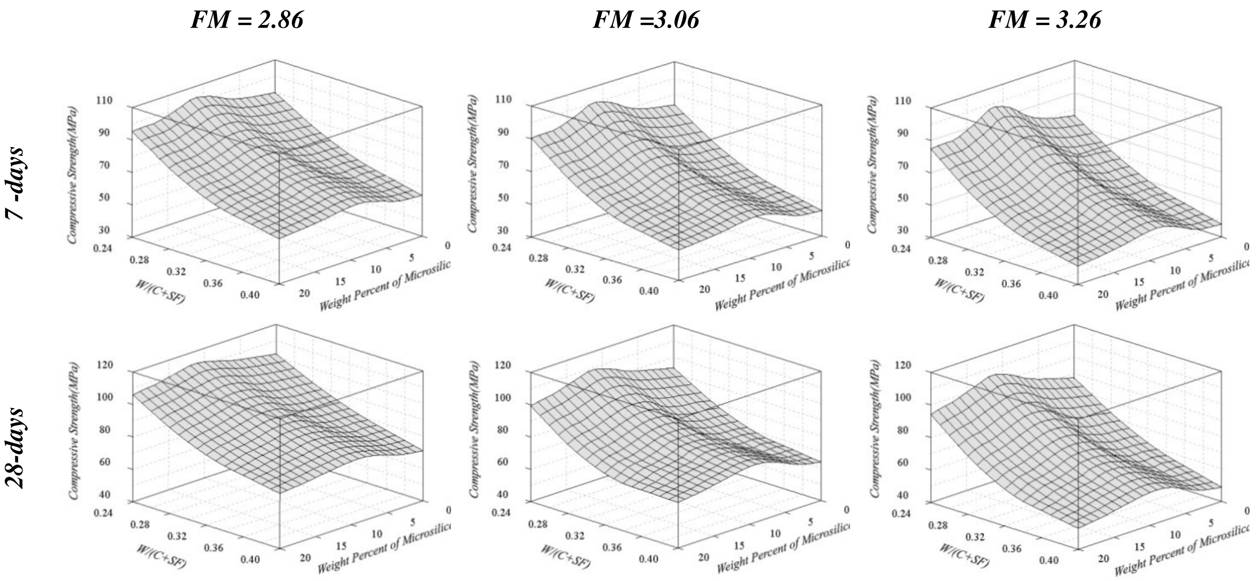


Figure-4
Compressive strength of 7 and 28-days age specimens with different weighted percent of microsilica, fineness modulus and water-cement ratios

The results show that increase in microsilica content from 0 to 10 per cent for all water-cement ratios and fineness modulus, leads to increment of compressive strength. While, microsilica content increasing from 10 to 20 % causes reduction in compressive strength. Increase in compressive strength in the range of 0 to 10 % of microsilica content may be justified by reduction of pores and their substitution with microsilica particles among cement particles, forming a much united structure. In other words, until 10 per cent, fine grains of microsilica fill empty spaces among cement particles and lead to stronger cement paste; eventually mechanical properties of concrete are increased.

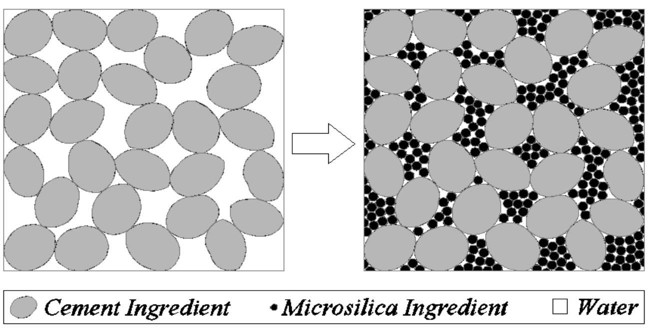


Figure-5
Filling of cement void ratios with microsilica aggregates

Compressive strength reduction in the range of 10 to 20 % of microsilica content is associated with development of distances between cement particles, substitution of microsilica particles in these spaces and reduction of inter-particle forces for cement particles. In other word, an increase in this range of microsilica content leads to presence of more microsilica particles among cement particles and development of empty spaces. This development makes cement particles much dispersed and reduces their inter-particle forces. This will lead to strength reduction of cement paste and eventually mechanical properties.

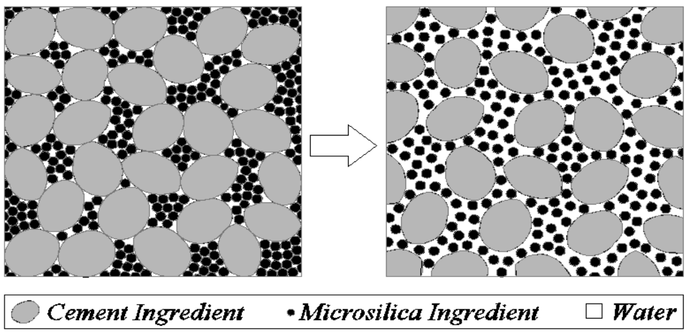


Figure -6
Dispersing of cement particles by increasing of microsilica content

Also we can see from the results, the effects of changes of microsilica weighted %, on compressive strength, reduce by increasing of water-cement ratios. In other word, by increasing of water-cement ratios, incremental trend of compressive strength in respect to increasing of microsilica weighted % reduces. This reduction might be related to presence of more water molecules (extra water than amount needed for hydration) among more dispersed cement particles. In fact, occupied spaces by water molecules will become air-filled after hydration process which increases cement paste structure's pores, in spite of cement paste void ratio reduction because of microsilica presence. This phenomenon fades microsilica good effects on unity and strength of cement paste. Hence, it might be concluded that for high water-cement ratios, the main reason for reduction in strength of cement paste is water content. This factor fades both negative and positive microsilica effects.

Moreover, the effects of changes of microsilica weighted %, on compressive strength, reduce by decreasing of fineness modulus. In other word, by decreasing of fineness modulus, incremental trend of compressive strength in respect to increasing of microsilica weighted % reduces. This reduction can be justified by the fact that, in lower fineness modulus of fine aggregates, a much more united structure of aggregates is formed. By improving of solidarity of aggregates and interlocking of aggregate particles in low fineness modulus, the strength and bearing capacity of aggregates increase, therefore concrete needs less amount of adhesive material for increasing its strength. Thus cement has less proportion in strength of concrete and increase of cement strength by presence of microsilica in these conditions, doesn't have an important effect on concrete strength.

It is also noticeable that impression of concrete compressive strength from changes of weighted % of microsilica, is much obvious for 7-days age specimens than 28-days specimens.

Since the most effective factor on concrete strength in initial ages is strength of cement paste, less concrete strength in initial days is because of low cement paste strength. Therefore the amount of concrete strength variations in respect to variations of cement paste strength is more obvious in this range of time. So, by attention to this fact that changes of microsilica weighted % have direct effect on cement paste strength, we can say that the effect of microsilica weighted % on concrete strength in initial ages is more sensible.

Tensile strength and modulus of elasticity: The results of modulus of elasticity and tensile strength tests on the specimens with different fineness modulus, microsilica weighted ratio content and water-cement ratios at the age of 7 and 28 days, are shown in figures 8 and 9 respectively.

Physical parameters' tests: For investigating the combined effects of microsilica weighted ratio content, fineness modulus and water-cement ratio on physical properties of concrete, similar to mechanical properties, 3 types of particle size distributions with different fineness modulus were used. For each particle size distribution with specific fineness modulus, 5 different weighted % of microsilica and 3 water-cement ratios were considered. All of the specimens that were made in these conditions, subjected to determination of slump and unit weight tests.

The obtained results are shown in 3 major groups. Each group includes the results of determination of slump and unit weight tests on concrete specimens that composed of 1 fineness modulus, 5 weighted % of microsilica and 3 water-cement ratios.

Slump tests: The results of determination of slump tests on the specimens with different fineness modulus, microsilica weighted ratio contents and water-cement ratios, are shown in figure-13. The results show that, increment of weighted % of microsilica from 0 to 20, in all water-cement ratios and fineness modulus, leads to reduction in concrete slump. Also, the effect of various weighted % of microsilica on the slump of concrete, increases in respect to water-cement ratio and fineness modulus increment. Slump reductions may be justified by increase in microsilica content which in turn boosts specific surface value for cement paste. In other words, since microsilica particles have a very greater specific surface value rather than cement particles, the cement paste absorbs much water. This phenomenon accelerates by increase in microsilica content. Finally, as water is absorbed by cement materials, less water is available for aggregates to lubricate their movements and lower concrete workability takes place.

10 to 20% weighted percent of microsilica **0 to 10% weighted percent of microsilica**

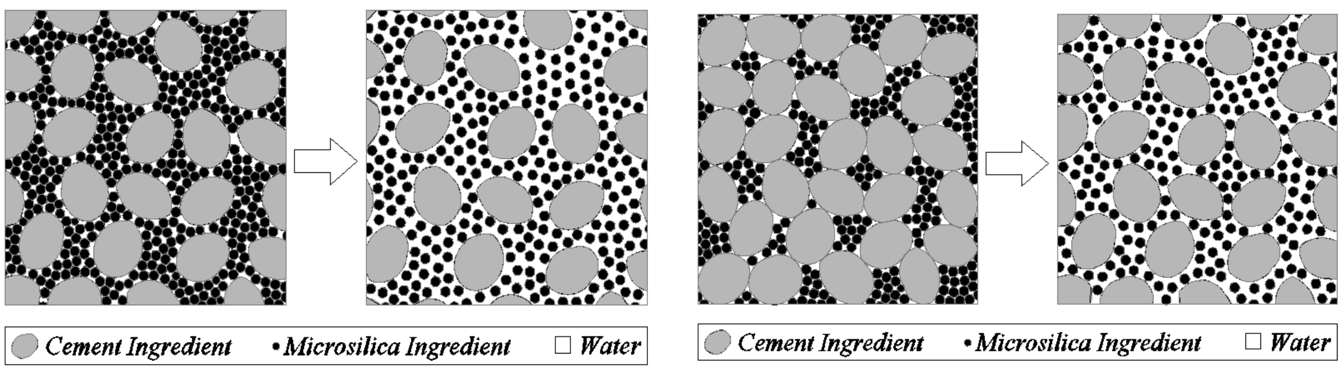


Figure-7
Dispersing of cement particles in respect to increase of extra water in different weighted percent of microsilica

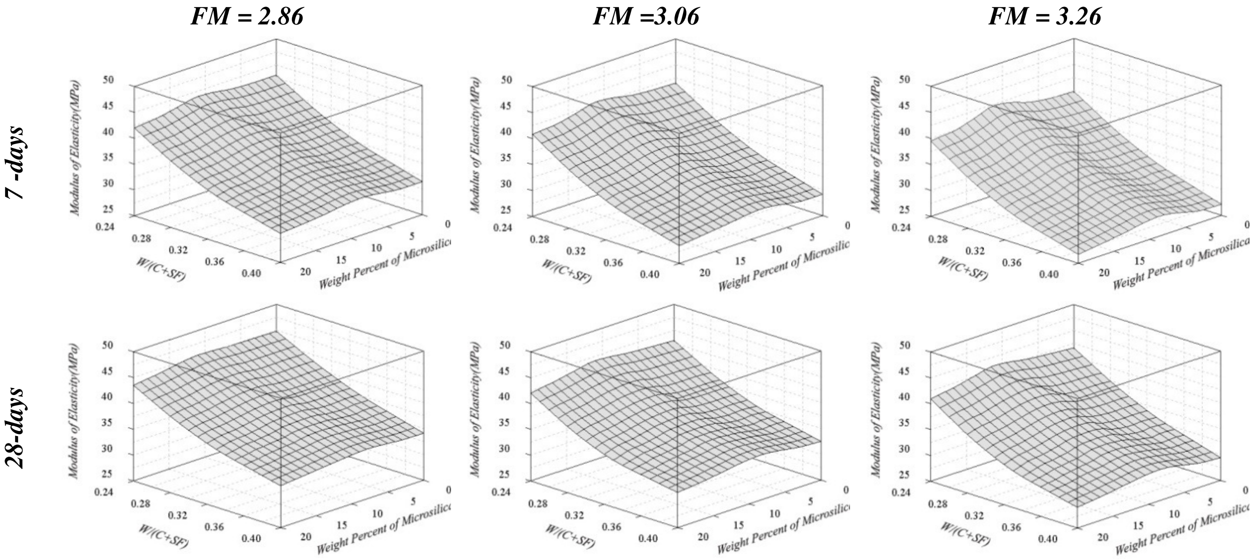


Figure-8

Modulus of elasticity of 7 and 28-days age specimens with different weighted percent of microsilica, fineness modulus and water-cement ratios

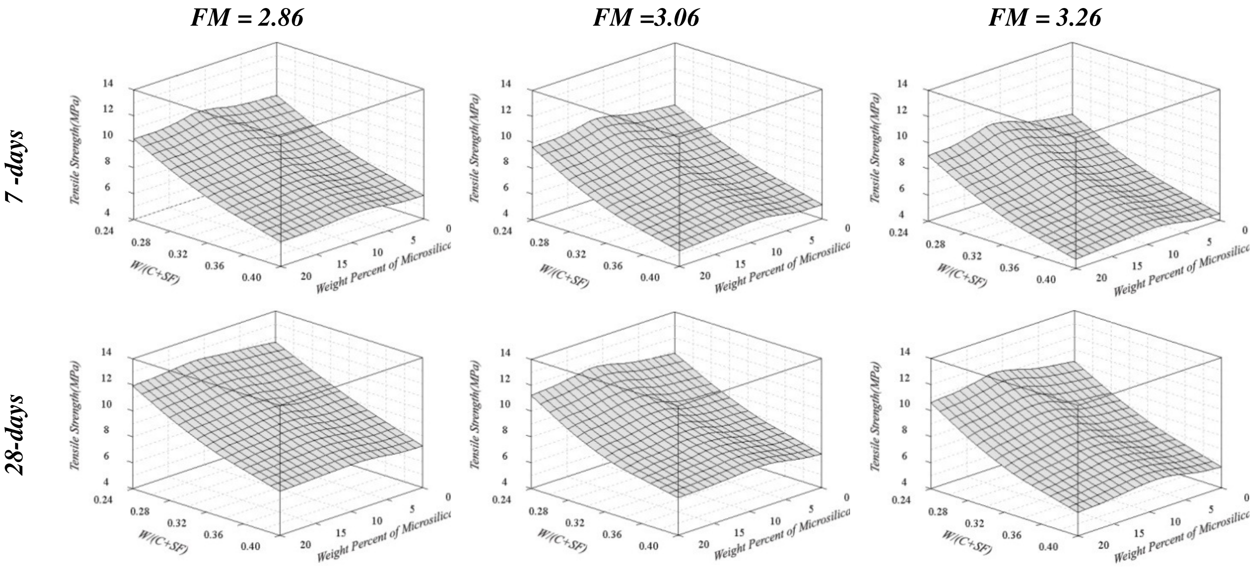


Figure-9

Tensile strength of 7 and 28-days age specimens with different weighted percent of microsilica, fineness modulus and water-cement ratios

Unit weight: The results of determination of unit weight tests on the specimens with different fineness modulus, microsilica weighted ratio contents and water-cement ratios, are shown in figure 14. By study the results of unit weight of concrete in different weighted ratio content of microsilica in all water-cement ratios and aggregate size distributions with various fineness modulus, it can be seen that increasing in microsilica content, leads to decrease in concrete unit weight and this reduction have a same trend in aggregate size distributions with various fineness modulus. So it can be stated that type of aggregate size distribution has no effect on variation rate of concrete unit weight in different microsilica content. Also, by increasing of water-cement ratio, rate of reduction in concrete unit weight due to increasing of microsilica content, reduces. It may be justified by increment of absorbed water by microsilica particles due to increasing of microsilica content among cement paste. This increment leads to reduction of extra water for hydration and followed by decreasing in aired-pore spaces in extra water in concrete. Hence, the unit weight of concrete reduces due to reduction in aired-pore spaces in extra water in concrete.

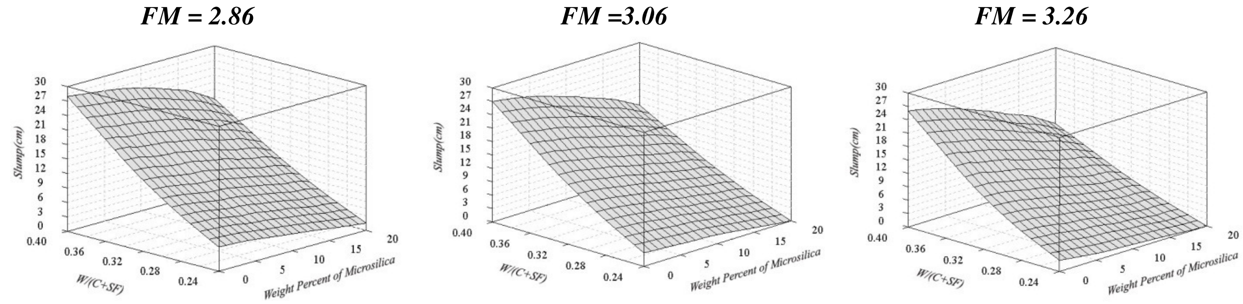


Figure-10
Slump of specimens with different weighted percent of microsilica, fineness modulus and water-cement ratios

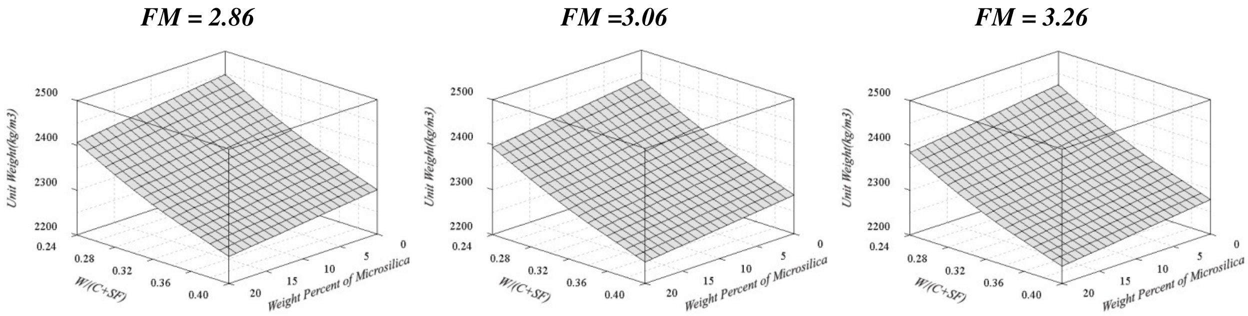


Figure-14
Unit weight of specimens with different weighted percent of microsilica, fineness modulus and water-cement ratios

Conclusion

The most important results of experimental study on the combined effects of microsilica weighted ratio content, fineness modulus of aggregates and water-cement ratio on mechanical and physical properties of concrete are as follow: i. Increase in microsilica content from 0 to 10 % for all water-cement ratios and fineness modulus, leads to increment of compressive strength. On the other hand, microsilica content increasing from 10 to 20 per cent causes reduction in compressive strength. ii. The effects of changes of microsilica weighted %, on compressive strength, reduce by increasing of water-cement ratios and increase by increment of fineness modulus. iii. The effect of microsilica content on modulus of elasticity and tensile strength of concrete is less than this effect on compressive strength in all the above conditions. iv. The impression of concrete mechanical parameters from changes of weighted % of microsilica, is much obvious for 7-days age specimens than 28-days specimens. v. Increment of weighted % of microsilica from 0 to 20, in all water-cement ratios and fineness modulus, leads to reduction in concrete slump. vi. The effect of various weighted % of microsilica on the slump of concrete, increase in respect to water-cement ratio and fineness modulus increment. vii. In different weighted ratio content of microsilica in all water-cement ratios and aggregate size distribution with various fineness modulus, it can be seen that increasing in microsilica content, leads to decrease in concrete unit weight.

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