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The Behavior of Self-Compacting Light Weight Concrete Produced by Magnetic Water

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Abstract**—**The aim of this article is to access the optimal mix design of self-compacting light weight concrete. The effects of magnetic water, superplasticizer based on polycarboxylic-ether, and silica fume on characteristics of this type of concrete are studied. The workability of fresh concrete and the compressive strength of hardened concrete are considered here. For this purpose, nine mix designs were studied. The percentages of superplasticizer were 0.5, 1, and 2% of the weight of cement, and the percentages of silica fume were 0, 6, and 10% of the weight of cement. The water to cementitious ratios were 0.28, 0.32, and 0.36. The workability of concrete samples was analyzed by the devices such as slump flow, V-funnel, L box, U box, and Urimet with J ring. Then, the compressive strengths of the mixes at the ages of 3, 7, 28, and 90 days were obtained. The results show that by using magnetic water, the compressive strengths are improved at all the ages. In the concrete samples with ordinary water, more superplasticizer dosages were needed. Moreover, the combination of superplasticizer and magnetic water had positive effects on the mixes containing silica fume and they could flow easily.

Keywords**—**Magnetic water, self-compacting light weight concrete, silica fume, superplasticizer.

I. INTRODUCTION

SELF-COMPACTING concrete (SCC) is a new innovation for concrete construction industry, and all innovations go through a process of recognition [1], [2]. The use of self-compacting light weight concrete (SCLC) is growing due to the certain physical and mechanical properties of this concrete. SCLC flows under its own weight without segregation, and it can fill in the narrow parts of the mould without any internal or external vibrations. Lightweight concrete is known with its advantage of reducing the self-weight of the structures, reducing the areas of sectional members as well as making the construction convenient [3], [4]. The concept of SCC was first proposed by Hajime Okamura in 1986 as a solution to concrete durability concerns, however the first SCC prototype was developed in 1988 [5], [6]. SCC was introduced in Japan in 1988 for the first time [7].

By using magnetic water in the concrete industry by researchers of the former Soviet Union and gaining positive results, American and European countries continued their studies in this field. Also in the last two decades, magnetic water is used in China to make concrete and to increase its performance [8]. When participating with magnetized water (distributed water) in hydration, the number of molecules participating in interaction increases [9]. Tiny particles of cement will be surrounded by the single molecular layer of water with lower density and the hydration process will be more complete and it also reduces the water consumption [10]-[12]. At the early ages, the growths of compressive strengths were observed in concrete samples. This was due to the rapid deformation of crystals and early hardening of the cement paste.

The nine mix designs of this laboratory research were designed based on proposed calculations of EFNARC institute. Empirical methods based on trial and error were done at the early tests for finding the best mixtures and achieving the slump flow in the SF2 class. In this study, three water to cement ratios of 0.28, 0.32, and 0.36 were utilized. Additionally, Light Expanded Clay Aggregates (LECA) is also studied.

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II. WORKSHOP AND LABORATORY PROGRAM

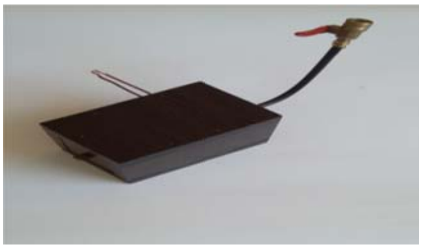
A. Magnetic Water

Magnetic field is a vector quantity and it is shown by the symbol B. Its magnitude can be obtained by:

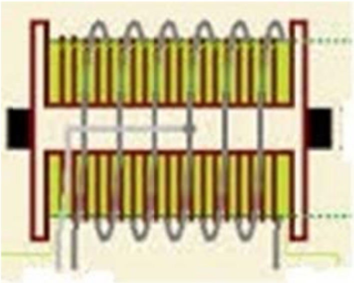
$$\vec{B} = \mu_0 \frac{I}{2r} \tag{1}$$

Tesla is the unit of magnetic field in SI unit and is shown by T. When the water passes through the magnetic field, the water becomes magnetized [13].

To conduct the experiments of this study, a magnetic device (Fig. 1) was made by the authors, and the physical characteristics of device and the results of its calculations are given in Table I. The principle of operation of the device is based on electromagnetism. In fact, the electrical current passes through the coil of wire, and the magnetic field is achieved. It is worth noting that the device power supply is Direct Current (DC). According to Fig. 2, by passing water through a magnetic field, its hardness reduced greatly.



(a)



(b)

Fig. 1 (a), (b) Magnetic field and water generating device

TABLE I
PHYSICAL AND COMPUTING CHARACTERISTICS OF MAGNETIC FIELD GENERATING DEVICE

characteristic	*Value or unit*	*denomination or description*
Number of Coil rounds	1000	
Wire diameter	1 mm	
Wire resistance	1.66 Ohm	Copper
Central Core length	100 mm	
Core diameter	40 mm	
Entrance Voltage	9.2 Volt optimized	Flexible
current	5.54 Ampere optimized	

B. Primary Hardness Testing of Magnetic Water

After the passage of ordinary drinking water through the machine, the water hardness test was conducted in the laboratory. In fact, the condition of water molecules changes from disarray and cumulative to arranged and distributed, and oxygen - hydrogen bond would change from a triangular shape to a linear shape. It means that the magnetic water molecules become small, and by reducing the hardness, the solubility increases [14], [15].

The hardness of produced magnetic water samples was tested a few minutes after magnetizing the water. The changes in the hardness of water are shown in Table II.

TABLE II
CHANGES IN PRODUCED MAGNETIC WATER HARDNESS

Name	*Entrance unit (lit/h)*	*hardness changes over time (hours)*				
		0.5	24	48	72	96
MW1	50	0.39	0.25	0.19	0.11	0.08
MW2	40	0.32	0.19	0.16	0.08	0.0006
MW3	30	0.18	0.07	0.03	0.021	0.0001

C. Mix Designs

The consuming materials in making samples include sand, clay (expanded clay baked beans), powdered stone, limestone, cement, silica fume, superplasticizer based on polycarboxylic-ether, and magnetic water. For the comparability of test results, the constant weight of sand and LECA (aggregates) and limestone powder (neutral filler) was used. So, the specific weight of samples showed no significant difference in comparison with computing the specific weight. It is worth mentioning that in some mixtures, the magnetic water was not able to increase the compressive strength compared to the ordinary water. This means that the magnetic device failed to be effective on the ruling force (this force follows the Lorenz law) of positive and negative ions presented in the water and molecular make up of water. The mix designs can be seen in Table III.

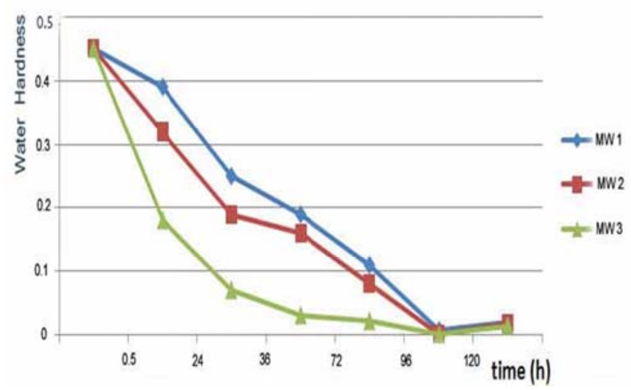


Fig. 2 Hardness of the magnetized water samples

TABLE III
MIX DESIGNS OF SCLC

W/C	*Sample name*	*silica fume (% by weight of cement)*	*Superplasticizer (% by weight of cement)*	*cement (kg/m^3)*
	S1	0	0.5	425
0.28	S2	6	1	399.5
	S3	10	2	382.5
	S4	0	0.5	380
0.32	S5	6	1	358
	S6	10	2	342
	S7	0	0.5	350
0.36	S8	6	1	329
	S9	10	2	315

Attention: Sand fix750 (kg/m^3), LECA fix320 (kg/m^3) and stone powder110(kg/m^3)

D. Consuming Materials

The ingredients of the mix designs, generally comply with the EN206 standard terms and specific conditions of each one are evaluated by the relevant standard.

1. Cement

Cement quality is the most important determinants of quality of concrete. Consuming cement in the mix designs is the type 1-425 of Tehran cement factory and has met the EN1197 condition.

The normal concentration of cement is according to ASTM C 204, and the initial setting time is 115 minutes and the final set is 235 minutes according to the ASTM C187-98. The specific surface area of cement was 3100 cm^2/gr according to ASTM C191-04.

2. Sand

Aggregate should be stored in such a way as to prevent segregation and to ensure consistent moisture content. Consuming sand was natural sand and its maximum grain size was 5 mm. Its specific weight was 2.53 tons per cubic meter, and the water absorption was 2.5% with 3.16 fineness modulus and had the other conditions of EN12620.

3. Superplasticizer

In Table IV, the properties of the utilized superplasticizer have been shown.

TABLE IV
CHARACTERISTICS OF CONSUMING SUPERPLASTICIZER

title	*Value or characteristic*
chemical base	Polycarboxylic-ether
Type (class)	Normal
Brand	NE 320
color	Brown
Specific weight	1.1 tones per cubic meter
Available color	less than 0.1%
Offer of consumption by manufacturer	0.2 to 1.5% by weight of cement

4. Filler

Limestone powder is used as filler in this research.

5. Silica Fume

Silica fume with the specific weight of 2.2 tons per cubic meter and a specific surface area of 230,000 cm^2 per gram is used.

6. Magnetic Water

Magnetic water samples with the specifications set in Table II were used.

7. LECA

LECA can be obtained from heating clay in rotary motion ovens at 1100 to 1200 °C. its shape is almost round with rough surfaces. Its roughness is on the outer surface and its inside is spongy and black which is produced by Iran LECA Company.

Fig. 3 Consumed LECA produced in Iran

Consuming LECA samples are shown in Fig. 3 and its grading can be seen in Table V. Since its seeds are produced at temperatures close to 1200 °C, they are able to tolerate the heat shock near 100 °C with no ignition. Its density, water absorption in 30 minutes, and passing through sieve No. 4 were 1.105 gr/cm^3, 11.2%, and 70 %, respectively.

Fig. 4 Fresh concrete testing devices

TABLE V
SIEVE ANALYSIS OF LECA

mm	*percentage*
9.5	99
4.75	73
2.36	2
1.18	0
0.6	0

III. FRESH CONCRETE

Concrete samples obtained from nine mix designs in fresh condition were tested. The workability tests of concrete samples were analyzed by devices such as slump flow, V-funnel, L box, U box, and J ring (Fig. 4). The results are shown in the following tables. It is worth noting that if the magnetic water was used instead of ordinary water, less superplasticizer was necessary due to the scattering of water molecules. In high volume industrial production of concrete, this reduction in consumption is economically considerable. Also, the combination of magnetic water and superplasticizer from polycarboxylic-ether type had very good effects on concrete mixes containing silica fume and they could flow quickly.

TABLE VI
RESULTS OF V-FUNEL AND SLUMP FLOW TESTS IN W/C=0.28

Name	$D_{(mean)}$*mm*	*Results Slump 0.28*	*Results v*
S1	69	SF2	VS2/VF2
S2	69.5	SF2	VS2/VF2
S3	69	SF2	VS2/VF2

TABLE VII
RESULTS OF V-FUNEL AND SLUMP FLOW TESTS IN W/C=0.32

Name	$D_{(mean)}$*mm*	*Results Slump 0.32*	*Results v*
S4	71.2	SF2	VS2/VF2
S5	72	SF2	VS1/VF1
S6	71.3	SF2	VS1/VF1

TABLE VIII
RESULTS OF V-FUNEL AND SLUMP FLOW TESTS IN W/C=0.36

Name	$D_{(mean)}$*mm*	*Results Slump 0.36*	*Results v*
S7	72.5	SF2	VS1/VF1
S8	72.6	SF2	VS1/VF1
S9	72.9	SF2	VS1/VF1

TABLE IX
THE RESULTS OF RHEOLOGY OF FRESH CONCRETE SAMPLES (U, L, U, J)

U-Test		*L-Test*	*Urimet and j*	
h_2-h_1	T(s)	Δh	T(s)	h_2/h_1
17	4.8	11	5	1.4
9	4.1	4	4.2	1.2
3	3.7	2	3.5	1.1
14	4.1	8	4.1	0.8
6	3.8	2	3.2	0.8
1	3	0	2.5	0.8
9	3	5	3.9	0.6
3	2.6	0	2.8	0.7
3	2.1	0	2.2	0.9

A. Rheology Interpretation of Produced Samples with the Water to Cement Ratio of 0.28

According to the proposed table of EFNARC Institute, S1, S2, and S3 concrete mixes are in the categories of SF_2, VS_2/VF_2, and PA_2 in terms of slump flow, V funnel, and L-box tests. Also, these concrete mixes are the mixtures with high viscosity in terms of U- box test, and they are mixtures with high viscosity and low efficiency in terms of urimet and J-ring test.

B. Rheology Interpretation of Produced Samples with Water to Cement Ratio of 0.32

According to the proposed table of EFNARC Institute, S4, S5 and S6 concrete mixes are in the categories of SF_2, VS_1/VF_1, and PA_1 in terms of slump flow, V funnel, and L-box tests. Also, these concrete mixes are the mixtures with desired viscosity in terms of U- box test, and they are mixtures with high viscosity in terms of urimet and J-ring test.

C. Rheology Interpretation of Produced Samples with Water to Cement Ratio of 0.36

According to the proposed table of EFNARC Institute, S7, S8, and S9 concrete mixes are in the categories of SF_2, VS_1/VF_1, and PA_1 in terms of slump flow, V funnel, and L-box tests. Also, these concrete mixes are the mixtures with high viscosity in terms of U- box test, and they are mixtures with high viscosity in terms of urimet and J-ring test.

IV. Compressive Strength

Sampling was conducted in accordance with the EN12350-1, and compressive strength tests were carried out on cube specimens with the size of 10 * 10 * 10 cm^3 at the periods of 3, 7, 28, and 90 days. The results are shown in Figs. 5-7. Actually, in the samples produced by magnetic water, the most growth in compressive strength was observed at the ages of 3 to 7 days. Also, the consumption of 6 to 10% silica fume was the proper range for cement replacement level.

It is clear that the growth trend of compressive strength has more slopes at the age of seven days. Also, samples with silica fume have more initial and final strength than samples without silica fume.

Most of the times, as the water, superplastcizer and silica fume increased, the compressive strength was improved. By increasing the use of magnetic water, its effect rises sharply in S3, S6, and S9. Table X shows the equations for predicting the long term compressive strength of samples S9, S6, and S3.

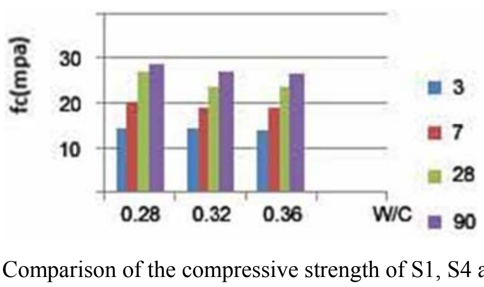


Fig. 5 Comparison of the compressive strength of S1, S4 and S7 specimens

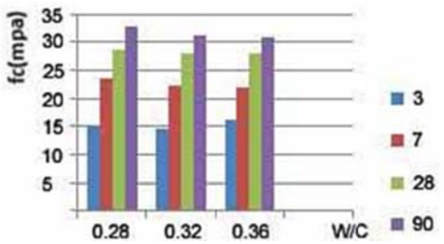


Fig. 6 Comparison of the compressive strength of S2, S5, and S8 specimens

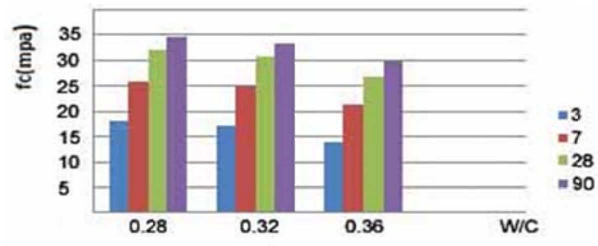


Fig. 7 Comparison of the compressive strength of S3, S6, and S9 specimens

TABLE X
Software Results of Compressive Strength for S3, S6, and S9

W/C	*Sample name*	*software output*
0.28	S3	$FC = 31.2 - 17.5\,w$
0.32	S6	$FC = 38.8 - 35\,w$
0.36	S9	$FC = 72 - 61.25\,w$

By FC means 90-day compressive strength and by W means consumed magnetic water

TABLE XI
The Ultrasonic Test Results of W/C=0.28

w/c	*silica fume (% by weight of cement)*	*Super Lubricants (% by weight of cement)*	*V(M/S)*
0.28	0	0.5	3784
		0.45	3775
	6	1	3780
		0.85	3790
	10	2	3721
		1.75	3832

The results are in acceptable range. The ratio 10- 1.75 of the highest density observed.

V. Ultrasonic Test

The ultrasonic test was done on hardened concrete samples. The results can be seen in Tables XI-XIII. These tables indicate that the compactness and the uniformity of samples with magnetic water and silica fume are more suitable than the other mixes. According to the ultrasonic test results, in low water to cement materials ratios, using magnetic water instead of ordinary water was more efficient for improving the hardened properties of concrete specimens.

TABLE XII
THE ULTRASONIC TEST RESULTS OF W/C=0.32

w/c	*silica fume (% by weight of cement)*	*Super Lubricants (% by weight of cement)*	*V(M/S)*
0.32	0	0.5	3759
		0.4	3771
	6	1	3780
		0.8	3792
	10	2	3801
		1.65	3819

TABLE XIII
THE ULTRASONIC TEST RESULTS OF W/C=0.28

w/c	*silica fume (% by weight of cement)*	*Super Lubricants (% by weight of cement)*	*V(M/S)*
0.36	0	0.5	3696
		0.35	3701
	6	1	3711
		0.7	3728
	10	2	3735
		1.5	3746

VI. CONCLUSIONS

1. By passing water through a magnetic field, its hardness reduces greatly.
2. In producing SCLC mixtures, if magnetic water is used instead of ordinary water, less superplasticizer is consumed due to the scattering of water molecules. In high volume industrial production of concrete, this reduction in consumption is economically considerable.
3. The combination of magnetic water and superplasticizer from polycarboxylic-ether type had very good effects on concrete mixes containing silica fume and they could flow quickly.
4. In the samples produced by magnetic water, the most growth in compressive strength can be seen at the periods of 3 to 7 days.
5. The consumption of 6 to 10% silica fume was the proper range for cement replacement level.
6. In low water to cement materials ratios, using magnetic water instead of ordinary water was more efficient for improving the hardened properties of the investigated specimens.

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