

# An Investigation of the Effect of the Different Mix Constituents on Concrete Electric Resistivity

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**Abstract**—Steel corrosion in concrete is considered as a main engineering problems for many countries and lots of expenses has been paid for their repair and maintenance annually. This problem may occur in all engineering structures whether in coastal and offshore or other areas. Hence, concrete structures should be able to withstand corrosion factors existing in water or soil. Reinforcing steel corrosion enhancement can be measured by use of concrete electrical resistance; and maintaining high electric resistivity in concrete is necessary for steel corrosion prevention. Lots of studies devoted to different aspects of the subjects worldwide. In this paper, an evaluation of the effects of W/C ratio, cementitious materials, and percent increase in silica fume were investigated on electric resistivity of high strength concrete. To do that, sixteen mix design with one aggregate grading was planned. Five of them had varying amount of W/C ratio and other eleven mixes was prepared with constant W/C ratio but different amount of cementitious materials. Silica fume and super plasticizer were used with different proportions in all specimens. Specimens were tested after moist curing for 28 days. A total of 80 cube specimens (50 mm) were tested for concrete electrical resistance. Results show that concrete electric resistivity can be increased with increasing amount of cementitious materials and silica fume.

**Keywords**—Corrosion, Electric resistivity, Mix design, Silica fume

## I. INTRODUCTION

STEEL corrosion is of most important problem in durability of reinforced concrete structures. Cementitious admixtures in concrete are applied for this purpose. Impermeability is considered as a main factor in durability determination. Concrete durability depends to a large extent upon the rate which liquid or gas can penetrate into the hardened cement paste. Low porosity and permeability is a key strength factor against damages due to freezing, acid and sulfate attacks, steel corrosion, carbonation and alkaline aggregate reaction [1]. Strength and permeability of hydrated cement paste have a close relationship to capillary porosity

[2]. Concrete electric resistivity for a specific amount of cement increases almost linearly with a decrease in w/c ratios and hence, concrete electric resistivity can be considered as a measure of determining compressive strength of concrete [3]. Dotto and et. al. investigated the improvement in physical property and steel corrosion behavior due to the addition of silica fume in concrete [4]. Turkman and Gavgali studied the steel corrosion in concretes containing silica fume and slag by use of a linear de-pole method. In this paper, a different proportion of water with super plasticizer to cementitious materials were studied so that its results is of importance not only for concrete durability but also economically for making concrete with low permeability [5].

## II. MATERIALS

Aggregate grading and chemical compositions of cement with silica fume were presented in tables 1 through 3, respectively. Aggregates used for this study were of broken silica sand with a maximum size of 4 mm. The aggregates used for the mix designs were first washed out of dust and air-dried before grading.

TABLE I  
GRADING A

Sieve No.	Passing %	Remaining %	Cum. Remaining %
4	100	0	0
8	80	10	10
16	70	20	30
30	35	35	45
50	25	10	75
100	5	20	95
Pan		5	
F.M. = 2.75			

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TABLE II  
GRADING A

Sieve No.	Passing %	Remaining. %
3/8"	100	0
4	25	75
8	7	18
16	0	7
30	0	0
F.M. = 3.33		

## III. MIX DESIGN

The purpose of preparing on impermeable concrete to increase its durability, different proportion of water plus super plasticizer and cementitious materials were used (table 4) so that the amounts of silica fume and super plasticizer were remained constant to a certain amount in table 5 the ration of water with super plasticizer to cementitious materials were proportioned to be constant with varying amounts of silica fume and super plasticizer. The ratio in table 6 were similar to table 5 varying amounts of cement and silica fume such that their total sum were constant for 3<sup>rd</sup> series of the mix design.

TABLE III  
COMPOSITION OF CEMENT  
AND SILICA FUME

Chem. composition	Cement type I	Silica fume(%)
SiO <sub>2</sub>	21.22	90
Al <sub>2</sub> O <sub>3</sub>	6.27	1.5
Fe <sub>2</sub> O <sub>3</sub>	3.08	1.5
CaO	63.41	2
MgO	1.85	0.8
SO <sub>3</sub>	1.73	-
K <sub>2</sub> O	0.57	-
Na <sub>2</sub> O	0.18	-
L.O.I	1.0	-
C <sub>3</sub> S	45	-
C <sub>2</sub> S	27	-
C <sub>3</sub> s	11	-
C <sub>4</sub> AF	9.4	-

TABLE IV  
MIX DESIGN 1<sup>ST</sup> SERIES

ID	1	2	3	4	5
W (kg/m <sup>3</sup> )	129	147	165	183	201
Cement (kg/m <sup>3</sup> )	405	405	405	405	405
S.F (kg/m <sup>3</sup> )	45	45	45	45	45
(W+S.P) / (C+S.F)	0.3	0.34	0.38	0.42	0.46
F.A (kg/m <sup>3</sup> )	965	947	929	911	893
C.A (kg/m <sup>3</sup> )	850	850	850	850	850
S.P (kg/m <sup>3</sup> )	6	6	6	6	6
Grading	A+B	A+B	A+B	A+B	A+B
C+S.F (kg/m <sup>3</sup> )	450	450	450	450	450
S.F/ (C+S.F) (%)	10	10	10	10	10

TABLEV  
MIX DESIGN 2<sup>ND</sup> SERIES

ID	6	7	8	9	10
W (kg/m <sup>3</sup> )	142	162	182	203	223
Cement (kg/m <sup>3</sup> )	315	360	405	450	495
S.F (kg/m <sup>3</sup> )	35	40	45	50	55
(W+S.P) / (C+S.F)	0.42	0.42	0.42	0.42	0.42
F.A (kg/m <sup>3</sup> )	1053	982	911	840	769
C.A (kg/m <sup>3</sup> )	850	850	850	850	850
S.P (kg/m <sup>3</sup> )	5.3	6	6.8	7.5	8.3
Grading	A+B	A+B	A+B	A+B	A+B
C+S.F (kg/m <sup>3</sup> )	350	400	450	500	550
S.F/ (C+S.F) (%)	10	10	10	10	10

TABLE VI  
MIX DESIGN 3<sup>RD</sup> SERIES

ID	11	12	13	14	15	16
W (kg/m <sup>3</sup> )	162	162	162	162	162	162
Cement (kg/m <sup>3</sup> )	400	384	372	360	348	324
S.F (kg/m <sup>3</sup> )	0	16	28	40	52	76
(W+S.P)/ (C+S.F)	0.42	0.42	0.42	0.42	0.42	0.42
F.A (kg/m <sup>3</sup> )	982	982	982	982	982	982
C.A (kg/m <sup>3</sup> )	850	850	850	850	850	850
S.P (kg/m <sup>3</sup> )	6	6	6	6	6	6
Grading	A+B	A+B	A+B	A+B	A+B	A+B
C+S.F (kg/m <sup>3</sup> )	400	400	400	400	400	400
S.F/ (C+S.F) (%)	0	4	7	10	13	19

## IV. SAMPLE PREPARATION AND CURING

All ingredients including super plasticizer and silica fume admixtures that are added to water and cement respectively were mixed according to mix design tables and then placed into the 50mm cube moulds. Samples had a good slump and consolidated by vibrations table. They were taken out of moulds after 24 hours and then cured in a water tanks with an average temperature of 23°C. Samples were maintained outside of tanks in laboratory condition 24 hours before testing for compressive strength and electric resistivity. In this research, concrete electric resistivity was measured by an impedance spectrometer device.

## V. EXPERIMENTAL RESULTS

Results presented for compressive strength and electric resistivity of concrete in tables 7 through 9 are obtained from average test results of 3 and 2 samples for each mix design, respectively.

TABLE VII  
RESULTS OF 1<sup>ST</sup> SERIES

ID	Z (kohm)	E.R (kohm.cm)	Fc (N/mm <sup>2</sup> )
1	11.7	58.5	84.46
2	8.5	42.5	79.64
3	5	25	69.09
4	3.8	19	61.64
5	2.9	14.5	58.01

TABLE VIII  
RESULTS OF 2<sup>ND</sup> SERIES

ID	Z (kohm)	E.R (kohm.cm)	Fc (N/mm <sup>2</sup> )
6	4.4	22	59.26
7	3.7	18.5	61.55
8	3.4	17	66.55
9	2.9	14.5	63.53
10	2.3	11.5	60.91

TABLE IX  
RESULTS OF 3<sup>RD</sup> SERIES

ID	Z (kohm)	E.R (kohm.cm)	Fc (N/mm <sup>2</sup> )
11	1.1	5.5	35.96
12	1.5	7.5	48.46
13	2.7	13.5	57.85
14	3.7	18.5	61.55
15	5.7	28.5	64.99
16	9	45	71.64

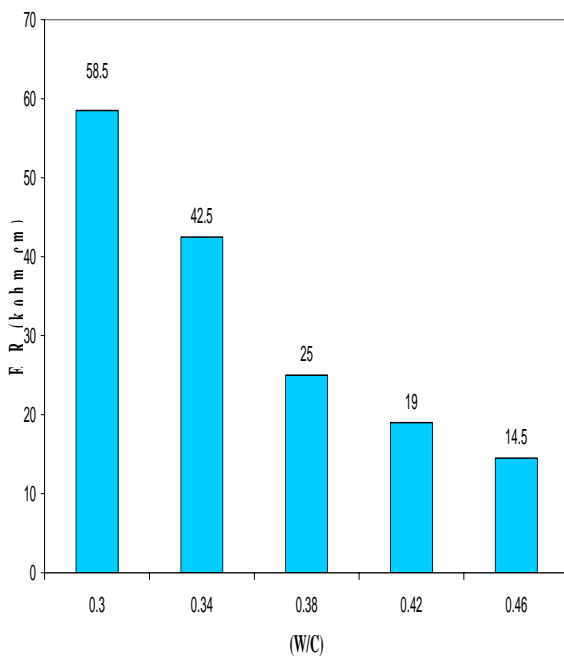


Fig. 1 Electric resistivity vs. w/c

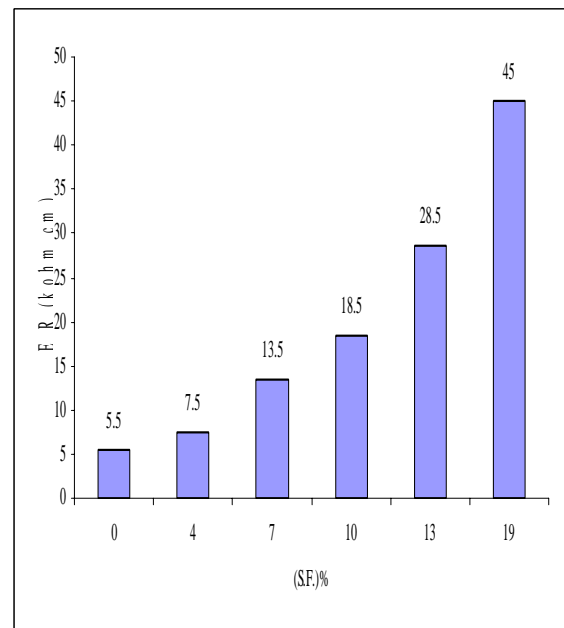


Fig. 3 Electric resistivity vs. % of silica fume

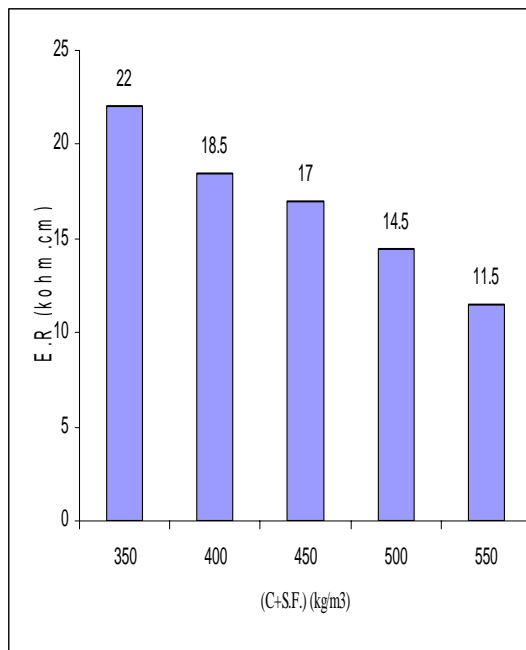


Fig. 2 Electric resistivity vs. cementitious materials

## VI. CONCLUSION

- Making a concrete resistant to corrosive environment should not have a w/c ratio greater than 0.5.
- An increase in cement did not increase concrete electric resistivity but also decreased that at equal condition.
- Use of silica fume as a partial cement replacement in concrete can considerably increase concrete electric resistivity
- Concrete electric resistivity similar to other concrete strengths has a direct relation to its compressive strength.
- Partial replacement of cement with silica fume along with reduction in w/c ratio by use of a good quality super plasticizer allow one to produce a concrete resistant to corrosion with cost much lower than that of the cost compared to its maintenance and repair.

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