Protecting Concrete Power Poles from Stray Alternating Current

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The purpose of this work was to investigate how the impedance of concrete subjected to alternating current (AC) is affected by adding silica fume, reducing water-to-cement ratio, and adding polypropylene fibers. Based on the test results, it is possible to increase concrete impedance and decrease its susceptibility to degradation by AC voltage.

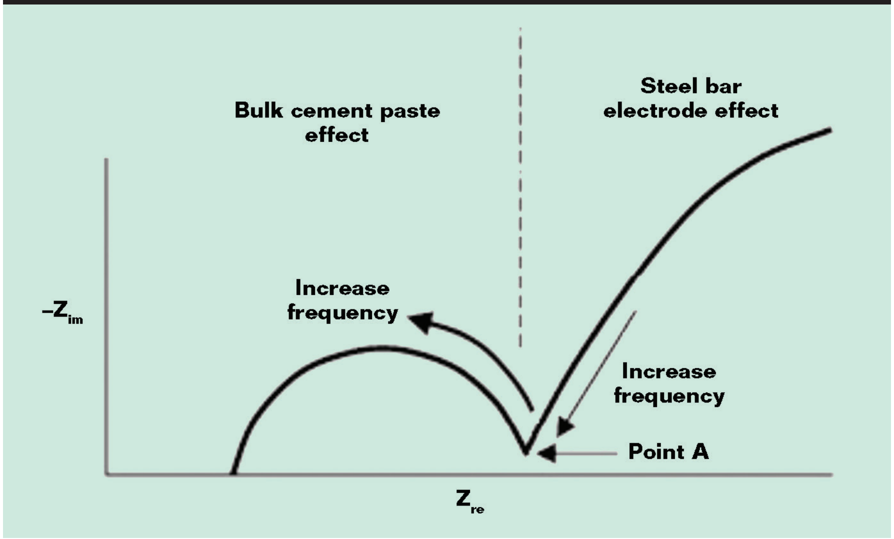
Concrete pores can act as capacitors and alternating current (AC) can pass through a capacitor. Thus, AC passes in concrete in two parallel ways—by capacitor and resistor paths. The capacitor paths consist of the pore network and resistor paths consist of the solid phase. If steel bars are embedded in the concrete, then the bars can also act as capacitors for passing AC.[1-3] As shown in Figure 1, there are two kinds of capacitors in concrete's equivalent of an electrical circuit. Therefore, three steel bars embedded in concrete can be used as working, counter, and reference electrodes during an electrochemical impedance spectroscopy (EIS) test. According to Figure 1, the EIS spectrum of concrete consists of two arcs, one that is related to the capacitance of the steel bars and appears in the low-frequency range, and another that is related to the capacitance of the bulk concrete and appears in the high-frequency range.[1-3]

At Point A in Figure 1, the imaginary part of impedance is very low compared to the real part, so that a higher amount of current can pass through the concrete and a high percentage of it will pass through the capacitance path (pores).[1,3-4] So if the AC voltage is high enough and the concrete is saturated with water, then serious nonuniform current distribution forms in concrete. This will lead to thermal and shrinkage stress in concrete and cause the formation of cracks and an increase in the concrete's permeability.[1,3-4] According to our results, the frequency of urban AC power (i.e., 50 Hz) is approximately equal to the frequency of Point A.

Under special conditions, including polluted air, rain, and low-quality concrete poles, high-voltage AC can leak from power lines to water-saturated concrete power poles.[4-5] Figure 2 shows concrete power poles after experiencing stray AC attack. The concrete surface has many cracks and in some areas the concrete cover has started to fall off. In dry concrete, AC stray current cannot pass through the capacitor path because there is insufficient liquid in the concrete's pores. Therefore, impedance of Point A is important only for water-saturated concrete.

In this work, the effects of silica fume, polypropylene (PP) fibers, and water-to-cement (w/c) ratio on the imaginary impedance of Point A in water-saturated concrete samples were studied by an EIS test. This research is a new investigation and we know of no reports in this field. Results of this research are very important in improving the resistance of concrete power poles against high-voltage AC leakage.

FIGURE 1



Schematic of EIS spectra of concrete, and the equivalent circuit of the EIS spectra of concrete (adopted from Reference 6).

Experimental Procedures

Concrete blocks were prepared according to the mix design shown in Table 1 and cured in water at room temperature for 60 days (Figure 3[a]). Steel bars were embedded for EIS tests (Figure 3[b]) and the application AC voltage (Figure 3[c]).

After the samples were cured and water saturated, 220 and 380 V AC were applied through two of the steel bars for 40 min. To create a water-saturated condition, the concrete samples were soaked in distilled water at room temperature for five days.

Before and after application of AC, EIS tests were done on the concrete samples in a water-saturated condition. The test was done with a Parstat 2273† potentiostat/galvanostat/FRA instrument in a frequency range of 100 mHz to 2 MHz.

Results

The imaginary part of Point A in the water-saturated samples and its frequency before and after the application of 220 and 380 V AC was determined by EIS spectra (Table 2). The frequencies are near 50 Hz and they are close to the frequency of AC urban power. Based on the results in Table 2 and Figure 4, before and after application of AC voltage, the imaginary impedance of Point A had the lowest value in Sample 1. The impedance increased when increasing silica fume content (Samples 2 to 5), decreasing w/c ratio (Samples 5, 6, 10, and 11), and adding PP fibers to the concrete mix design (Samples 7 to 11). During application of AC voltage, the temperature of the samples was measured and a maximum temperature of 68 °C occurred in Sample 1.

†Trade name.

Discussion

Decreasing the w/c ratio and adding silica fume to the concrete mix design were the reasons why the volume of concrete pores reduced,[7] the water absorption of the concrete decreased, and the number of the capacitor paths decreased and their impedance increased. According to Table 2, this led to higher impedance for Point A of the EIS spectra of concrete. With increasing impedance of Point A, current through the samples decreased, which reduced the thermal and shrinkage effects of AC current. After the application of AC voltage, the percentage of decrease in the impedance of Point A was reduced because the development of pores by cracks decreased (Table 2 and Figure 4). PP fibers are a type of insulating material and so they increased the impedance in Point A of EIS spectra in samples. In addition, they increased the concrete's resistance to initiation and propagation of cracks.[8] For this reason, samples with PP fibers (Samples 7 to 11) had a lower percentage of decrease in their impedance of Point A after application of AC voltage (Table 2 and Figure 4).

FIGURE 2

The concrete cover on this power pole cracked and fell off as a result of high-voltage AC leakage.

Conclusions

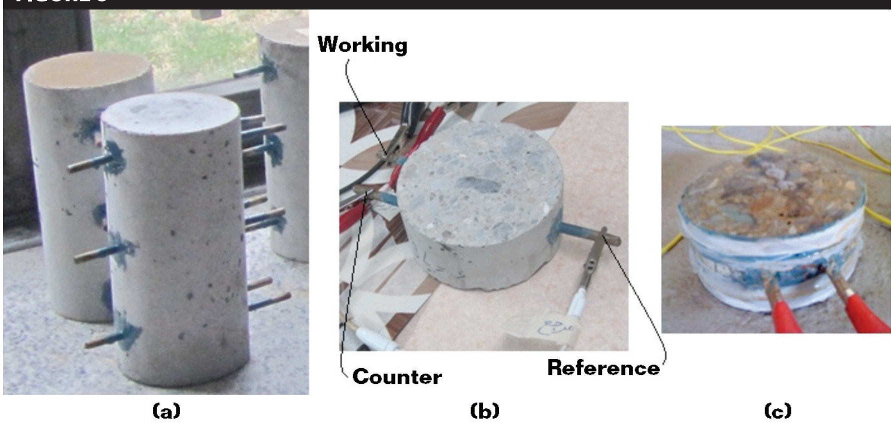
Decreasing w/c ratio and adding silica fume and PP fibers to the concrete mix

TABLE 1

Concrete mix design of concrete blocks

Mix	Portland Cement (kg/m³)	Aggregate <5 mm (kg/m³)	Aggregate 5-10 mm (kg/m³)	Aggregate 10-20 mm (kg/m³)	Water (kg/m³)	PP Fibers L=12 mm (kg/m³)	Super Plasticizer G110P (% Cement)	Silica Fume % Cement (kg/m³)	w/(c + SF) Ratio
1	350	1,145	199	558	147	—	2	—	0.42
2	329	1,145	199	558	140	—	2	6 (21)	0.40
3	322	1,145	199	558	140	—	2	8 (28)	0.40
4	315	1,145	199	558	140	—	2	10 (35)	0.40
5	301	1,145	199	558	140	—	2	14 (49)	0.40
6	301	1,145	199	558	129.5	—	2	14 (49)	0.37
7	329	1,145	199	558	140	2	2	6 (21)	0.40
8	322	1,145	199	558	140	2	2	8 (28)	0.40
9	315	1,145	199	558	140	2	2	10 (35)	0.40
10	301	1,145	199	558	140	2	2	14 (49)	0.40
11	301	1,145	199	558	129.5	2	2	14 (49)	0.37

FIGURE 3



(a) Concrete blocks after curing, (b) one concrete sample sliced from the concrete block, and (c) application of AC stray current in the concrete sample. The steel rods were used in the EIS test.

design increased the critical impedance of concrete (Point A) in a water-saturated condition and also led to a lower reduction of the critical impedance after the application of AC voltage. Therefore, concrete power poles manufactured by the centrifugal method have higher resistance against AC because extra water is removed before curing and the w/c ratio is very low.

In concrete power poles manufactured by the molding method, resistance against AC can be increased by adding superplasticizer (for reducing w/c ratio) and pozzolanic materials such as silica fume to the concrete mix design.

Acknowledgment

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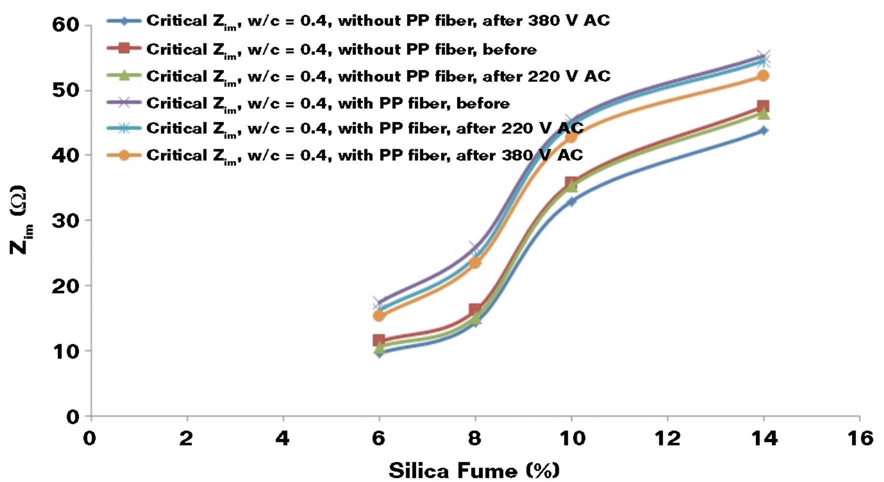
TABLE 2

Impedance of Point A and its frequency before and after application of 220 and 380 V AC stray current

Mix	Z_{im} (Frequency) of Point A before Applying AC Voltage Ω (Hz)	Z_{im} (Frequency) of Point A after Applying 220 V AC Ω (Hz)	Z_{im} (Frequency) of Point A after Applying 380 V AC Ω (Hz)	w/c	Silica Fume (% Cement)	Super Plasticizer G110P (% Cement)
1	7.1 (53)	6.37 (53)	5.9 (53)	0.42	—	2
2	11.5 (48)	10.7 (48)	9.7 (49)	0.40	6	2
3	16.2 (47)	15.2 (47)	14.4 (47)	0.40	8	2
4	35.8 (47)	35.3 (47)	33.0 (48)	0.40	10	2
5	47.5 (46)	46.6 (46)	43.8 (46)	0.40	14	2
6	78.7 (45)	77.7 (46)	73.3 (46)	0.37	14	2
7	17.5 (47)	16.3 (47)	15.3 (47)	0.40	6	2
8	25.9 (46)	24.4 (46)	23.4 (47)	0.40	8	2
9	45.3 (46)	44.7 (46)	42.8 (46)	0.40	10	2
10	55.3 (45)	54.5 (45)	52.2 (46)	0.40	14	2
11	99.4 (45)	98.1 (45)	94.7 (45)	0.37	14	2

FIGURE 4



The chart shows the effects of silica fume in increasing impedance of Point A in the concrete samples with and without PP fibers before and after the application of 220 and 380 V AC.

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