Effects of Mineral Admixture on Electrical Resistivity and Permeability of Chloride Contaminated Mortar

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ABSTRACT

The corrosion of reinforced concrete mainly was caused by chloride contaminated. Kinds of mineral admixtures such as Fly Ash Type B (FA), Silica Fume Type A (SF), Metakaolin (MKP) and Blast Furnace Slag Type B (BB) are necessary to increase the corrosion resistance. The electrical resistivity and permeability were used on evaluating the effects of mineral admixture. The electrical resistivity and permeability of mortar were measured by using four Wenner probes and Torrent. The parameters in this study were mineral admixtures and water-to-binder ratios. Electrical resistivity and permeability of dried mortar at 91 days were studied and compared with compressive strength. According to the results, lower water/binder ratio concrete had higher resistivity than those with higher water/binder ratios. When cement was replaced by BBMKP, electrical resistivity increased fifteen times when compared to that of OPC mortar. Based on experimental results, a good relationship was obtained between results of compressive strength with electrical resistivity of mortar. The results of this study can be applied further to predict electrical resistivity of concrete when some mineral admixture with different water-to-binder ratio are provided.

Keywords—mineral admixture, compressive strength, electrical resistivity, permeability

1. INTRODUCTION

Durability of concrete structures has a direct impact in the economy of civil construction industry. Chloride-induced corrosion is recognized as one of the major causes of degradation of reinforced concrete structures. Therefore, it is essential to understand the mechanisms that cause the degradation of concrete structures. Some of the main variables that control the degradation processes in the concretes are electrical resistivity, water absorption and concrete porosity. Here, in order to improve the concrete performance which is resistant to environmental conditions, mineral admixture is included in concrete [1, 2]. Mineral admixtures such as blast furnace slag, fly ash and silica fume are widely used in world. Mineral admixture can improve durability by reducing the pore volume of concrete.

In the past decades, seawater was used in concrete construction as an alternative material. Here, it should be understand that chloride contaminated concrete from the initial due to seawater used for mixing. Reference [3] was evaluate 6-years-old chloride contaminated mortar. Further, the utilization of mineral admixture on seawater mixed concrete has a positive effect on corrosion performance [4-6]. While as in [7] reported that compressive strength on seawater mixed concrete after 36-years-old were increased. The effect of mineral admixture on chloride-contaminated concrete is necessary to evaluate. Therefore, the aim of this study is to investigate the effectiveness of mineral admixtures such as fly ash, silica fume, metakaolin and blast furnace slag with water-to-binder (W/B) ratio of 40%, 50% and 60% on electrical resistivity and permeability of steel bar embedded in chloride-contaminated mortar. The data related to microstructure and compressive strength of mortar were reported in previous publication [8].

2. TEST PROGRAM

2.1. Materials

The cubic mortar specimens (135x135x120mm) were prepared. The specimens were made with cement Ordinary Portland Cement (OPC), and mineral admixtures such as Fly Ash Type B (FA), Silica Fume Type A (SF), Metakaolin (MKP) and Blast Furnace Slag Type B (BB). The washed sea sand was used as fine aggregate. The mortar was demolded one day after casting, then moisture curing by wrapping with wet towel and plastic sheet until 91days in a controlled room maintained at 20°C, R.H. 60% was conducted. The specimens were stored in laboratory with the temperature from 5°C in winter to 35°C in summer. The physical properties and chemical analysis of material are shown in Table 1.

Table I. Physical properties and chemical analysis of mineral admixtures used

Binder	OPC	FA	SF	MKP	BB
Chemical analysis					
SiO_2, %	-	60.60	95.50	52.37	34.10

Binder	OPC	FA	SF	MKP	BB
MgO, %	1.31	-	0.56	1.04	3.26
SO_3, %	2.14	-	0.18	7.56	2.04
Loss on ignition	1.97	2.40	1.22	-	1.46
Physical properties					
Blaine surfaces area,	340	397	18000	903	386
Specific gravity,	3.16	2.26	2.35	2.75	3.02

2.1. Series of Mixture

Fifteen series of mortar mixtures with three types water-to-binder (W/B) ratio of 40%, 50% and 60% were set for mixing mortar-contaminated chloride were prepared. Two influencing parameters of chloride content in mortar were used. One is interpreted in %-cement (mass ratio of cement), another is interpreted in kg/m^3 (total chloride weight in mortar). Table II presents all cases of chloride content in each mix and the mortar mixture proportions of specimen are shown in Table III. In this reference, chloride content in mortar is 0.57 %-cement in accordance to 3.31 kg/m^3, 2.91 kg/m^3, 2.59 kg/m^3 at W/B=40%, 50%, and 60%, respectively. Series Normal is OPC-100% as control specimen. Series Normal-Cl is OPC-100% as mortar contaminated chloride content. And, Series binder is mortar contaminated chloride content and incorporated with FA-20%, SF-5%, and BFS-45%. However, BBMKP is blast furnace slag incorporated with metakaolin (BB-80% and MKP-20%).

Table II. Mixture series of specimen

Series	W/B (%)	Replacement (%)					Chloride content	
		OPC	*FA*	*SF*	*BBMKP*	*BFS*	*kg/m^3*	*%-cement*
Normal	40	o	-	-	-	-	-	-
	50	o	-	-	-	-	-	
	60	o	-	-	-	-	-	
Binder	40	-	o	o	o	o	3.31	0.57
	50	-	o	o	o	o	2.91	
	60	-	o	o	o	o	2.59	
Normal -Cl	40	o	-	-	-	-	3.31	0.57
	50	o	-	-	-	-	2.91	
	60	o	-	-	-	-	2.59	

Table III. Mix proportion of mortar

W/B (%)	Unit content (kg/m^3)							Remarks
	W	*OPC*	*FA*	*SF*	*MKP*	*BB*	*Sea sand*	
40	232	581	-	-	-	-	1490	Normal
	232	465	116	-	-	-	1452	FA
	232	552	-	29	-	-	1481	SF
	232	-	-	-	116	465	1458	BBMKP
	232	320	-	-	-	261	1480	BFS
50	255	510	-	-	-	-	1490	Normal
	255	408	102	-	-	-	1452	FA
	255	484	-	26	-	-	1481	SF
	255	-	-	-	102	408	1458	BBMKP
	255	281	-	-	-	230	1480	BFS
60	272	454	-	-	-	-	1490	Normal
	272	363	91	-	-	-	1452	FA
	272	431	-	23	-	-	1481	SF
	272	-	-	-	323	91	1458	BBMKP
	272	250	-	-	-	204	1480	BFS

2.2. Test methods

1) Compressive strength: Mortar cylinder specimens in size of ϕ100x200mm were demolded at 24-hours after casting then cured by wrapping with wet towel and plastic sheet in a room maintained at 20^{o}C, R.H. 60% controlled room. After 28 days and 91 days curing, compressive strength was measured in accordance with JIS A 1108 [9]. The average compressive strength of three specimens were determined for each mortar mixture in three curing conditions.

2) Electrical resistivity and permeability: Mortar prism specimens in size of 135x120x135mm were demolded at 24-hours after casting then cured by wrapping with wet towel and plastic sheet in a room maintained at 20^{o}C, R.H. 60% controlled room. After 91 days curing, electrical resistivity and permeability were measured by using Wenner probe and Torrent, respectively. For electrical resistivity, when measuring all the points, the probes were made in contact with the mortar surfaces and waited approximately for three to five seconds until the readings were stable. The four-point Wenner probe is commonly used to measure resistivity. It consists of four equally spaced probes, which contact the concrete surface. This method passes between the two outermost probes use a small alternating current, and determine the resistivity of the concrete by measuring the resulting potential difference between the inner two probes (shown in Fig. 1). Interpretation of resistivity measurements for depassivated steel is shown in Table IV. The resistivity of mortar specimen from the average of three times measurement were determined. For Torrent, the specimen should be in dry condition and it is suggested to carry out the measurement at the same place. Time interval measurements at the same place is required minimally 30 min. Then, the permeability of mortar specimen determined from the average of three times measurement. The effect of the degree of moisture saturation of concrete is taken into consideration by the subsequent measurement of the electrical resistivity ρ according to Wenner, in the same zone. The classification of concrete qualities is shown in Table V. Meanwhile the nomogram for determination of the qualitative category of concrete in relation to electrical resistivity is shown in Fig. 2.

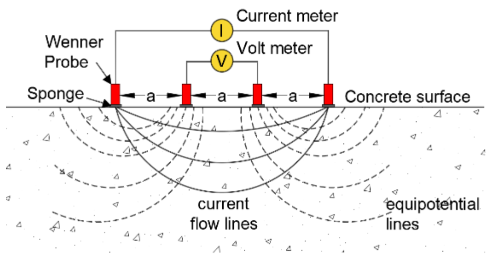

Fig. 1. Principle of Wenner probe measurement of concrete resistivity [10]

Table IV. Relationship between resistivity and corrosion risk [10]

Resistivity (k Ω-cm)	Risk level
> 100 – 200	Very low corrosion rate even if chloride contaminated
50 – 100	Low corrosion rate
10 – 50	Moderate to high corrosion rate
< 10	High corrosion rate; Resistivity is not the controlling parameter

Table V. The classification of concrete qualities [11,12]

Quality of the concrete cover	Index	k_T [$\times 10^{-4}$ m^2]
Very bad	5	>10
Bad	4	1.0-10
Medium	3	0.1-1.0
Good	2	0.01-0.1
Very good	1	<0.01

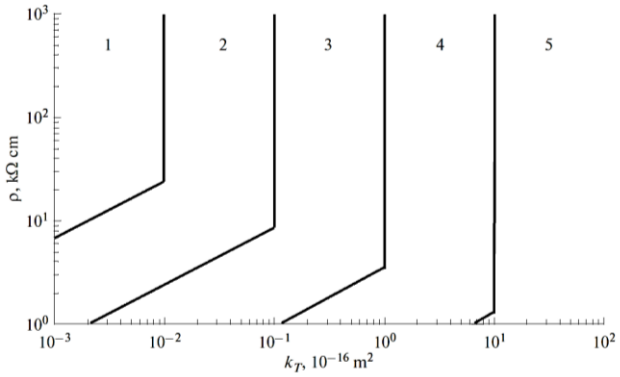

Fig. 2. The nomogram for determination of the qualitative category of concrete in relation to electrical resistivity [12]

3. RESULT AND DISCUSSION

3.1. Compressive strength

The compressive strength results of different mortar mixes at 91 days is shown in Table VI. The results show the general trend of increasing strength with age for all mixes. However, the effect of W/B ratio on strength performance is also found. At the age of 28 days and 91 days, the compressive strength on OPC and Mineral admixture decreasing with increase W/B ratio.

Table VI. Compressive strength

Specimen		Compressive strength, fc' (MPa)		
		W/B=40%	*W/B=50%*	*W/B=60%*
Normal		75.0	56.9	39.5
Binder	FA	62.0	56.0	36.5
	SF	78.9	65.4	45.2
	BBMKP	72.2	55.4	41.2
	BFS	71.2	54.8	38.9
Normal-Cl		64.5	49.5	39.0

The SF mortar showed higher strength values to that of another's mortar at all tested ages. Only the result of the FA was different, as it gave the lowest compressive strength. The compressive strength lowest is related to the properties of FA that declines the heat of hydration process. As a result, FA slows the rate of hardening and reduces the compressive strength [12]. In addition, perhaps this condition may be due to chloride contaminated.

3.2. Electrical resistivity and permeability

The electrical resistivity with various W/B ratio is shown in Fig. 3. According to the results, lower of W/B ratio mortar shows higher resistivity than those with higher to W/B ratios. This is because amount of interconnected pores decreases as the water-to-binder ratio decreases [13]. However, mineral admixture has substantial influence on the concrete resistivity. According to binder type, the electrical resistance tends to increase in the following order: BBMKP > FA > SF = BFS > OPC. Effect of FA and BBMKP on electrical resistivity is mainly related to the changes in the microstructure of concrete. The resistivity of Normal mortar and Normal-Cl mortar is categorized high corrosion level, at all cased W/B ratio. Further, the resistivity of SF and BFS is categorized low, low to moderate, and high corrosion level at W/B ratio 40%, 50% and 60%, respectively. Moreover, the electrical resistivity of FA and BBMKP is categorized low corrosion level at all cased W/B ratio. In addition, Normal-Cl is not significantly different in term of resistivity from normal OPC.

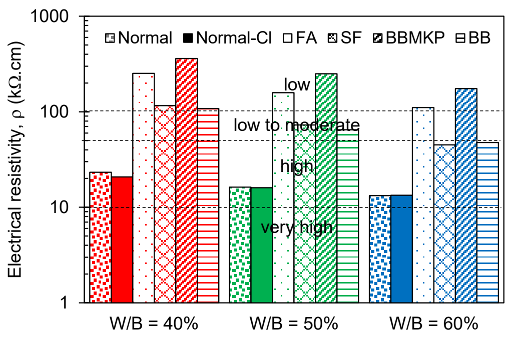

Fig. 3. Electrical resistivity with various water to binder ratio.

Table VII gives the electrical resistivity expressed as fractions of that of normal OPC. It is found that by using SF and BFS, electrical resistivity increased 4 times when compared to normal OPC. Further, by using FA, electrical resistivity increased about 10 times when compared to normal OPC. The FA causes finer pores and lowers ionic concentration in the pores, that leads to higher electrical resistivity than normal OPC [14]. This is because of the pozzolanic reactivity of fly ash which is still active in long term. Therefore, corrosion current flow, in FA mortar is expected to be retarded. In addition, by using BBMKP, electrical resistivity more increased about 15 times when compared to Normal OPC.

Table VII. Electrical resistivity of as fraction of Normal OPC

Series		W/B		
		40%	*50%*	*60%*
Normal OPC		1.00	1.00	1.00
Binder	FA	10.82	9.74	8.34
	SF	4.98	4.48	3.39
	BBMKP	15.49	15..42	13.19
	BFS	4.64	3.98	3.59
Normal OPC-Cl		0.89	0.99	1.01

Fig. 4 shows the relationship between permeability and electrical resistivity. As the result, normal OPC and Normal-Cl are categorized as good quality. Implies that addition of chloride to mortar less effects on the permeability. In the others hand, mineral admixture has substantial reduced the permeability. All mortar specimens with mineral admixture are categorized very good quality. However, only for SF at W/B=50% and 60%, the permeability changes to categorized good quality.

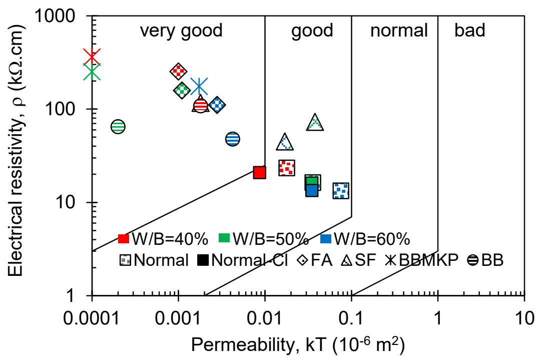

Fig. 4. Relationship between permeability and electrical resistivity.

Fig. 5 shows the relationship between compressive strength and electrical resistance. As the result, these figures indicate that compressive strength shows clear linear relationship with electrical resistivity. Electrical resistivity increased with increase compressive strength. In addition, a good correlation is acquired in which R^2 values are about 0.90 all mortar specimen with and without mineral admixture. Moreover, only FA mortar have low correlation, R^2 value is 0.7826. As the compressive strength increases, the electrical resistivity increase correspondingly for same mortar mixture design.

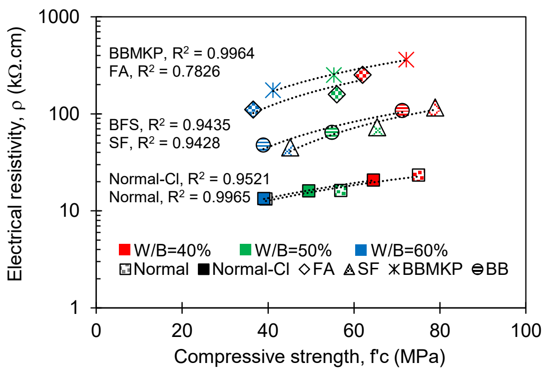

Fig. 5. Relationship between compressive strength and electrical resistance.

4. CONCLUSIONS

It is considered that mineral admixture has an effect in positive direction by increasing electrical resistivity. Further, utilization of BBMKP indicate the electrical resistivity quite increased about 15 times compared to Normal-Cl. Moreover, mineral admixture also showed more effective in reducing permeability.

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