

Article



Research on the Mechanical Strengths and the Following Corrosion Resistance of Inner Steel Bars of RPC with Rice Husk Ash and Waste Fly Ash

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Abstract: In this paper, the slump flow and mechanical strengths (compressive and flexural strengths) of the reactive powder concrete (RPC) with rice husk ash (RHA) and waste fly ash (WFA) were investigated. The following corrosion resistance of steel bars-reinforced specimens was researched. The ultrasonic sound, the mass loss rate, the electrical resistance, and the electrical resistance time history curves were determined to reflect the corrosion resistance of steel bars. The influence of NaCl freeze-thaw cycles and dry-wet alternations was considered. Results showed that the addition of RHA and WFA demonstrated a negative effect on the fluidity of fresh RPC. The fluidity of fresh RPC with WFA was lower. Moreover, RHA and WFA could effectively improve the mechanical strengths of hardened RPC, and the enhancing effect of RHA was higher. The increasing dosage of RHA could improve the corrosion resistance of steel bars in RPC when the specimens were exposed to the environment of NaCl freeze-thaw cycles and dry-wet alternations. However, when WFA was added, the effect was the opposite. The steel bars in RPC corroded more seriously when the specimens were exposed to the environment of NaCl dry-wet alternations than the environment of NaCl freeze-thaw cycles.

Keywords: reactive powder concrete; rice husk ash; waste fly ash; corrosion resistance; electrical resistance

1. Introduction

Billions of tons of waste fly ash and rice husk ash are produced due to the generation of domestic refuse and agricultural production. Waste fly ash and rice husk ash are solid wastes that pollute the environment without reasonable treatment. The burned waste fly ash can pollute water source when buried in soil, while the rice husk ash easily causes haze. If the solid waste can be recycled, the pollution of solid dust will be alleviated. Moreover, the reuse of solid dust will provide more resources for human production and construction [1–4]. Cement concrete is the main construction building material, which has been used for many years. Massive pollution comes into being during the production and application of construction materials. Moreover, the production of construction materials leads to the cost of natural resources and energy. Therefore, the development of suitable raw materials is necessary [5–7].

Waste fly ash and rice husk ash possess a large number of active ingredients that may be advantageous to the cement hydration. Based on this reason, the addition of waste fly ash and rice husk ash can be used as active admixtures [8,9]. Hrvoje et al. reported that the rice husk ash with rich amorphous silica can promote the cement hydration and enhance the mechanical strengths of cement concrete [10]. Moreover, prior research pointed out that the addition of the rice husk ash was able to improve the corrosion resistance of steel bars in the cement concrete [11]. Moreover, Sharma et al. confirmed that the addition of rice husk ash could effectively prevent shrink and decrease the cracks of cement concrete [12].



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). The waste fly ash with a large amount of active substances was able to replace some cement. Furthermore, the waste fly ash could be applied in the preparation of 3D printable concrete [13]. However, the fluidity of cement concrete could be decreased by the addition of waste fly ash. Additionally, the cement concrete with waste fly ash may release some toxic substances and may pollute the environment [14,15]. Although the application of solid wastes (waste fly ash and rice husk ash in the cement concrete) have been reported, little attention has been paid to the research of the use of waste fly ash and rice husk ash in the durability of reactive powder concrete.

Researchers [16–21] found that the addition of rice husk ash with a pozzolanic effect could effectively increase the compactness of hydration products, thus improving the mechanical strength and the resistance of chloride ion permeability and carbonation. Moreover, as reported in some journals [22,23], the addition of rice husk ash could decrease the freeze–thaw damage. Furthermore, cement concrete with a low dosage (mass loss ratio by total binder materials lower than 10%) of rice husk ash could decrease the water permeability and freeze–thaw damage. Although some research about the durability of cement concrete with rice husk ash were reported, little attention was paid to the research on the external erosion of sodium chloride on the degradation of cement concrete with husk ash. Additionally, the waste fly ash possessing many metal elements may endanger the durability; little research about this topic is reported [24,25]. Cement concrete is generally prepared with steel bars during its operation. The steel bars corroded seriously when applied in a marine environment [26,27]. The research on the corrosion of steel bars' inner reactive powder concrete with waste fly ash and rice husk ash is a novel topic and is discussed in this study.

This paper is devoted to the study of the mechanical strengths of reactive powder concrete with the addition of rice husk ash and waste fly ash. The following corrosion resistance of inner steel bars exposed to the environment of NaCl freeze–thaw cycles and dry–wet alternations was investigated. The concentration of sodium chloride solution in this study was 3%. The ultrasonic velocity, mass loss, and electrical parameters (electrical resistivity and electrical resistance time history curves) were determined to reflect the corrosion resistance of specimens. This thought of the thesis will provide a view of the application of rice husk ash and waste fly ash in the future.

2. Experimental

2.1. Raw Materials

Ordinary Portland cement (OPC) provided by Anhui Conch Cement Co., Hefei, China, was applied to manufacture the reinforced reactive powder concrete (RPC) with rice husk ash and waste fly ash. Mineral admixtures including silica fume and Ground Granulated Blast Furnace Slag (GGBS), offered by Lingshou Aihong mineral products Co., Ltd., Lingshou, China, were applied to manufacture RPC. The specific surface areas of silica fume and GGBS were 15 m^2/g and 436 m^2/kg . Meanwhile, their corresponding densities were 2.2 g/cm³ and 2.9 g/cm³. Quartz sand composed of 99.6% SiO₂, 0.02% Fe₂O₃, and other ingredients was used as aggregate. Quartz sand shows the particle sizes of 1~0.71 mm, 0.59~0.35 mm, and 0.15~0.297 mm. The mass ratios of quartz sand with particle sizes of 1~0.71 mm, 0.59~0.35 mm, and 0.15~0.297 mm were 1:1.5:0.8. Rice husk was provided by Jiangsu Province. The rice husk was burned at the temperature of 500 °C for 2 h. The residue was calcined and ground in a vibrating mill for 15 min. After all these steps were finished, the rice husk ash (RHA) formed. The specific surface area of rice husk ash was 54 m^2/g . The waste fly ash (WFA) with the specific surface area of 18 m²/g, produced by Shanghai Pudong New Area Yuqiao domestic waste incineration plant, Shanghai, China, was used in this experiment. The WFA was treated by wet grinding with a ball mill before use. The RHA and WFA were dried in a vacuum oven at 105 $^\circ$ C to a constant weight. The chemical compositions of WFA and RHA were determined by X-ray fluorescence spectrometer. Tables 1 and 2 show the composition and the particle size distribution, respectively.

Types	SiO ₂	Al_2O_3	Fe ₂ O ₃	MgO	CaO	SO ₃	T _{i2} O	CdO	Cr ₂ O ₃	PbO	CuO	ZnO
WFA	22.47	4.46	0.94	/	20.31	9.25	10.24	0.07	0.09	0.09	0.09	0.52
RHA	91.56	0.19	0.17	0.65	1.07	0.47	/	/	/	/	/	/
OPC	20.86	5.47	3.94	1.73	62.23	2.66	/	/	/	/	/	/
GGBS	34.06	14.74	0.23	9.73	35.93	0.23	3.51	/	/	/	/	/
SF	90	0.2	0.6	0.2	0.4	0	7.4	/	/	/	/	/

 Table 1. Chemical composition of the cementitious materials/%.

Table 2. Particle passing percentage of the cementitious materials/%.

T	Particle Size/µm									
Types	0.3	0.6	1	4	8	64	360			
WFA	0.13	0.46	2.15	17.21	31.34	97.52	100			
RHA	0	0.58	6.84	18.32	32.14	96.32	100			
OPC	0	0.33	2.66	15.01	28.77	93.59	100			
GGBS	0.025	0.1	3.51	19.63	35.01	97.9	100			
SF	31.2	58.3	82.3	100	100	100	100			

2.2. Specimen Preparation and Measurement Methods

The samples of RPC with WFA and RHA were prepared according to the mixing proportions. The solid raw materials were added to the UJZ-15 mortar mixer provided by Cangzhou Shengkai Instrument Equipment Co., Ltd., Cangzhou, China, and mixed for 1 min. After the mixing, the uniformly mixed mixture of water reducer and water was added to the raw materials and mixed for another 5 min. After the mixing was finished, all fresh paste was poured to form the specimens with sizes of 50 mm × 50 mm × 50 mm and 40 mm × 40 mm × 160 mm. Specimens with a size of 50 mm × 50 mm × 50 mm were used for the determination of electrical parameters and ultrasonic velocity. Meanwhile, the specimens with a size of 40 mm × 40 mm × 160 mm were used for the measurement of mechanical strengths. Table 3 shows the mixing proportions of RPC per 1 cubic meter. All specimens were manufactured according to Table 3. The dosages of WFA and RHA ranged from 0% to 25% by the mass ratio of the total binder materials.

Table 3. The mixing proportions of RPC per 1 cubic meter (kg).

Water	OPC	WFA	RHA	SF	GGBS	Quartz Sand	Water-Reducer
244.4	740.7	0	0	370.3	111.1	977.9	16.3
244.4	679.6	61.1	0	370.3	111.1	977.9	16.3
244.4	618.5	122.2	0	370.3	111.1	977.9	16.3
244.4	557.4	183.3	0	370.3	111.1	977.9	16.3
244.4	496.3	244.4	0	370.3	111.1	977.9	16.3
244.4	435.2	305.5	0	370.3	111.1	977.9	16.3
244.4	740.7	0	61.1	370.3	111.1	977.9	16.3
244.4	679.6	0	122.2	370.3	111.1	977.9	16.3
244.4	618.5	0	183.3	370.3	111.1	977.9	16.3
244.4	557.4	0	244.4	370.3	111.1	977.9	16.3
244.4	496.3	0	305.5	370.3	111.1	977.9	16.3

The slump flow of fresh RPC paste was determined by GB/T2419-1994 Chinese standard [28]. The compressive and flexural strengths of specimens were tested by the YAW-300 microcomputer full-automatic universal with the loading speed of 0.05 KN for the determination of flexural strength and the loading speed of 2.4 KN for the measurement of compressive strength. The measurement of mechanical strengths was carried out according to GB/T17671-1999 Chinese standard [29]. All specimens were cured in the standard curing environment (temperature of 20 ± 2 °C and relative humidity of above 95%) for 28 days.

A plain, round reinforcement with the diameter of 8 mm was fixed to the axis position of the mold for researching the corrosion resistance of steel bars. A 304 stainless steel

mesh was imbedded in each specimen and the space between the steel mesh and the axis position of the round reinforcement of the specimen was 4 cm. Before freeze–thaw cycles or dry–wet alternate conditioning, the specimens were cured in the standard environment for 24 days. After curing, all specimens were immersed in 3.0% NaCl solution for 4 days for the treatment of the experiment of freeze–thaw cycles or dry–wet alternation with 3% NaCl solution. During the NaCl freeze–thaw experiment, all specimens were immersed in 3.0% NaCl solution in stainless steel containers and conditioned at temperature from -18 °C to 8 °C, in accordance with Chinese Standard GB/T500820-2009 [30]. Additionally, before each dry–wet alternate cycle, the water on the surface of specimens was wiped and then they were dried in a vacuum drying oven at 60 °C for 36 h. After drying, specimens were cooled at a temperature of 20 °C for 2 h and finally were immersed in NaCl solution for 10 h. All parameters were measured after 0, 100, and 200 NaCl freeze–thaw cycles and 10 and 20 NaCl dry–wet alternations. All specimens were wiped and cleaned with a wrung-dry wet rag before testing.

A ZBL-U51CO ultrasonic detector was applied for the determination of ultrasonic velocity. The testing method referred to Ref. [31]. Figure 1 shows the measurement of ultrasonic velocity. The TH2810D LCR digital electric bridge, produced by Changzhou Tonghui Co., Ltd., Changzhou, China, was chosen for the determination of AC electrical resistance. The determination of AC electrical resistance is shown in Figure 2.



Figure 1. The schematic diagram of ultrasonic measurement.



Figure 2. The schematic diagram of AC electrical resistance measurement.

The DC power with the maximum voltage of 1 V was provided for the measurement of electrical resistance time history curves. The DC voltage was collected by an ADAM

4117 acquisition instrument provided by Nanning Yanhua Electronic Technology Co., Ltd., Nanning, China. The electrical signals were collected per second. The electrical resistance time history curves were determined by reference resistance method. This method can be described as follows.

The reference resistor and specimen were a series in the circuit, and the electrical voltages at the ends of the reference resistor and specimen were collected by an ADAM 4117 acquisition instrument. The DC electrical resistance (R_d) of the specimen can be calculated by Equation (1).

$$R_d = \frac{V_d R_r}{V_r} \tag{1}$$

where R_r is the electrical resistance of the reference resistor and V_d and V_r are the electrical voltages of the specimen and the reference resistor, respectively. The determination of DC electrical resistance is shown in Figure 3. Six specimens for each group were prepared for the measurement of electrical performance and ultrasonic velocity, while three specimens were used for the test of mechanical strengths.



Figure 3. The schematic diagram of DC electrical resistance measurement.

3. Results and Discussion

3.1. Slump Flow of Fresh RPC Paste

Figure 4 shows the slump flow of fresh RPC paste with different dosages of rice husk ash and waste fly ash. As shown in Figure 4, the slump flow of fresh RPC paste decreased with the increasing dosages of rice husk ash and waste fly ash. This was attributed to the fact that the particle diameters of rice husk ash and waste fly ash were smaller than that of cement particles, thus resulting in increasing the surface area of cementitious material, leading eventually to adsorbing free water of fresh RPC and decreasing the slump flow. Moreover, the fresh RPC with rice husk ash showed a lower slump flow than that of fresh RPC with waste fly ash due to a higher superficial area [32,33].



Figure 4. The slump flow of fresh RPC.

3.2. The Mechanical Strengths

Figure 5 shows the flexural and compressive strengths of RPC specimens cured for 28 days. As depicted in Figure 5, the mechanical strengths of RPC increased with the increasing dosage of rice husk ash. Meanwhile, the mechanical strengths of RPC firstly increased and then decreased with the addition of waste fly ash. This was attributed to the fact that the rice husk ash and waste fly ash possessed higher activities than the Ordinary Portland cement, leading to increasing the hydration degree of cement [34,35]. Moreover, the fineness of RHA and WFA fall between that of SF and that of cement; it is likely that SF, RHA, WFA, cement, and quartz sand in the mixture with replacement ratio of 2/3 consistently formed the densest packing state. Apart from the filling effect, both pozzolanic reactivity and the internal curing effect of RHA and WFA contributed to the development of mechanical strengths [36,37]. However, many internal pores inside the waste fly ash can result in the defects inside the RPC, thus decreasing the mechanical strengths when the dosage of waste fly ash ranged from 20% to 25%.



Figure 5. The mechanical strengths of RPC specimens.

3.3. The Corrosion Resistance of Steel Bars in RPC

In this study, the ultrasonic velocity, mass loss, electrical resistance, and electrical resistance time curves were obtained to investigate the corrosion resistance of steel bars in RPC.

Figure 6 shows the ultrasonic velocity of RPC and the following rate of ultrasonic velocity increments by NaCl freeze–thaw cycles. As depicted in Figure 6a, the ultrasonic velocity increased with the addition of rice husk ash and decreased with the increasing dosage of waste fly ash and NaCl freeze–thaw cycles. Moreover, it can be observed from Figure 6b that the decreasing rate of ultrasonic velocity by NaCl freeze–thaw cycles decreased with the addition of rice husk ash. This was attributed to the fact that the NaCl freeze–thaw cycles could induce the internal cracks of RPC, thus blocking the ultrasonic propagation [38,39]. Furthermore, the increasing dosage of waste fly ash led to increasing the decreasing rate of ultrasonic velocity due to the internal pores of the waste fly ash [40,41]. Besides, the waste fly ash possessed a higher content of metallic elements, thus aggravating the corrosion of steel bars and leading to increasing the decreasing rate of ultrasonic velocity by NaCl freeze–thaw cycles [42,43].



Figure 6. The ultrasonic velocity of RPC and the following increments during NaCl freeze–thaw cycles. (a) The ultrasonic velocity. (b) The increasing rate of ultrasonic velocity.

Figure 7 shows the ultrasonic velocity and the following increasing rate of RPC under the environment of NaCl dry–wet alternations. As illustrated in Figure 7, the ultrasonic velocity and the following increasing rate varied in the similar regulation as that of the NaCl freeze–thaw environment. It can be obtained from comparing Figures 6 and 7 that ultrasonic velocity decreased more obviously after 20 NaCl dry–wet alternations than after 200 NaCl freeze–thaw cycles. Therefore, the RPC with steel bars deteriorated more seriously after 20 NaCl dry–wet alternations than after 200 NaCl freeze–thaw cycles.



Figure 7. The ultrasonic velocity of RPC and the following increments during NaCl dry–wet alternations. (**a**) The ultrasonic velocity. (**b**) The increasing rate of ultrasonic velocity.

Figures 8 and 9 show the mass loss rate of RPC under the environment of NaCl freeze-thaw cycles and NaCl dry–wet alternations. As demonstrated in Figures 8 and 9, the mass loss rates of all RPC specimens increased with the increasing number of NaCl freeze-thaw cycles and NaCl dry–wet alternations. This was attributed to the frost heaving stress leading to the spalling on the surfaces of RPC. However, the corrosion of the imbedded steel bars caused by NaCl freeze–thaw cycles and NaCl dry–wet alternations could induce the cracking and spalling of RPC and reduce the mass of specimens [44,45]. The relationships between the mass loss rate and the number of NaCl freeze–thaw cycles or NaCl dry–wet alternations conformed to the quadratic function. It can be observed from Figures 8 and 9 that the addition of rice husk ash could lead to decreasing the mass loss rate of RPC specimens; meanwhile, the increasing dosages of waste fly ash could increase the mass loss rate. This was attributed to the fact that the pozzolanic effect of RHA could promote the hydration and compactness of RPC, thus increasing the corrosion resistance of the inner steel bars, leading to decreasing the mass loss rate. However, the metallic elements of WFA

could accelerate the corrosion of the inner steel bars; the increased rust resulted in the concrete expansion cracks and spalling. Therefore, the mass loss rate increased with the addition of WFA. Moreover, the mass of RPC specimens during NaCl freeze–thaw cycles decreased more slowly than that during the NaCl dry–wet alternations, indicating that the steel bar corroded more seriously in the environment of NaCl dry–wet alternations. Table 4 shows the fitting results of the relationship between the mass loss rate and the number of NaCl freeze–thaw cycles and the number of NaCl dry–wet alternations. It can be obtained from Table 4 that the relationship between mass loss rate of RPC and the numbers of freeze–thaw cycles and dry–wet alternations with the medium of NaCl solution conformed to the quadratic function, as expressed in Equation (2).

 $\frac{\Delta m}{m} = aN^2 + bN + c$

$$1.5$$

$$0\%$$
 Rice husk ash

$$1.0\%$$
 Rice husk ash

$$1.0\%$$
 Rice husk ash

$$1.0\%$$
 Rice husk ash

$$20\%$$
 Rice husk ash

$$20\%$$
 Rice husk ash

$$25\%$$
 Waste fly ash

$$225\%$$
 Waste fly ash

$$225\%$$
 Waste fly ash

$$25\%$$
 Waste fly ash

Figure 8. The mass loss rate of RPC during NaCl freeze–thaw cycles. (**a**) The mass loss of RPC with rice husk ash. (**b**) The mass loss of RPC with waste fly ash.



Figure 9. The mass loss rate of RPC during NaCl dry–wet alternations. (a) The mass loss of RPC with rice husk ash. (b) The mass loss of RPC with waste fly ash.

(2)

Types	Content/%	а	b	с	R^2
	0	$-1.33 imes10^{-5}$	0.0077	0.032	0.96
	5	$-8.03 imes10^{-6}$	0.0063	0.030	0.97
RPC with RHA after NaCl	10	$-6.46 imes10^{-6}$	0.0057	0.038	0.95
freeze-thaw cycles	15	$-8.86 imes10^{-6}$	0.0057	0.033	0.95
	20	$-7.49 imes10^{-6}$	0.0052	0.029	0.96
	25	$-6.80 imes10^{-6}$	0.0046	0.037	0.91
	0	$-7.09 imes10^{-6}$	0.0049	0.038	0.92
	5	$-8.89 imes10^{-6}$	0.0056	0.032	0.95
RPC with WFA after NaCl	10	$-9.71 imes10^{-6}$	0.0060	0.033	0.95
freeze-thaw cycles	15	$-6.71 imes10^{-6}$	0.0059	0.037	0.95
	20	$-9.34 imes10^{-6}$	0.0067	0.029	0.97
	25	$-1.69 imes 10^{-5}$	0.0086	0.024	0.93
	0	$-1.33 imes10^{-3}$	0.077	0.032	0.96
	5	$-8.03 imes10^{-4}$	0.063	0.030	0.97
RPC with RHA after NaCl	10	$-6.46 imes10^{-4}$	0.057	0.038	0.95
dry-wet alternations	15	$-8.86 imes10^{-4}$	0.057	0.033	0.95
	20	$-7.49 imes10^{-4}$	0.052	0.029	0.96
	25	$-6.80 imes10^{-4}$	0.046	0.037	0.91
	0	$-7.14 imes10^{-4}$	0.070	0.056	0.93
	5	$-1.34 imes10^{-3}$	0.083	0.083	0.86
RPC with WFA after NaCl	10	$-1.77 imes 10^{-3}$	0.099	0.069	0.91
dry-wet alternations	15	$-2.49 imes10^{-3}$	0.12	0.056	0.95
	20	-2.77×10^{-3}	0.13	0.056	0.96
	25	$-3.0 imes10^{-3}$	0.14	0.066	0.95

Table 4. The fitting results of mass loss rate.

As concluded from prior research, higher electrical resistance before the external corrosion effect indicates better corrosion resistance of steel bars in the cement-based materials. Meanwhile, a higher increasing rate of electrical resistance means more severe corrosion [46,47]. Figures 10 and 11 show the electrical resistance of RPC under the environment of NaCl freeze-thaw cycles and NaCl dry-wet alternations. Moreover, the following variation rate of the electrical resistance due to the NaCl freeze-thaw cycles and NaCl dry-wet alternations was calculated. As illustrated in Figures 10 and 11, the electrical resistance increased with the increasing dosage of rice husk ash and decreased with the addition of waste fly ash. This was attributed to the fact that the addition of rice husk ash could improve the hydration degree of cement, thus decreasing the free water in the specimens and leading to the reduction of free ions of pore solution [48,49]. Therefore, the electrical resistance was increased by the addition of rice husk ash. However, the waste fly ash possessed more metallic elements, leading to improving the conduction of RPC, thus decreasing the electrical resistance [50]. It can be obtained from Figures 10 and 11 that the corrosion resistance of RPC with rice husk ash was better. Furthermore, the electrical resistance increased faster during NaCl dry-wet alternations than NaCl freeze-thaw cycles, indicating the steel bars corroded more seriously in the environment of NaCl dry-wet alternations.



Figure 10. The electrical resistance of RPC during NaCl freeze–thaw cycles. (**a**) The electrical resistance. (**b**) The variation rate of electrical.





Figure 11. The electrical resistance of RPC during NaCl dry–wet alternations. (**a**) The electrical resistance. (**b**) The variation rate of electrical.

As pointed out from prior studies, the DC electrical resistance-time curves of steel bar-reinforced, cement-based materials can be applied to reflect the corrosion resistance of steel bars [51]. As depicted in Figure 12, a higher growth rate of the variation rate of DC electrical resistance during power on time before corrosive action indicates better corrosion resistance. However, the increasing rate of electrical resistance during NaCl freeze-thaw cycles and dry-wet alternations indicated more serious corrosion. It can be observed from Figure 12 that the variation rate of DC electrical resistance before corrosive action increased with the addition of rice husk ash and decreased with the increasing dosage of waste fly ash, which means rice husk ash demonstrated a positive effect on the corrosion resistance of steel bars in RPC and the waste fly ash played a negative role on the corrosion resistance. However, after the NaCl freeze-thaw cycles and dry-wet alternations, the variation rate of DC electrical resistance with waste fly ash was higher than that with rice husk ash. Moreover, NaCl dry-wet alternations induced a higher increment of the DC electrical resistance than NaCl freeze-thaw cycles. It can be concluded from this research that the addition of rice husk ash was advantageous to the corrosion resistance of steel bars in RPC. However, when waste fly ash was added in RPC, the effect was adverse. Furthermore, as obtained from this study, the NaCl dry-wet alternations contributed a more severe corrosion effect to the steel bars in RPC than the NaCl freeze-thaw cycles. Comparing with Refs [11,46,51], the initial electrical resistances of RPC with RHA and WFA were higher and the following increasing rate of electrical resistances was lower than those of steel bars-reinforced cement paste or cement mortar with sodium nitrite, which indicated that the RPC with RHA and WFA showed better corrosion resistance.



Figure 12. Cont.



Figure 12. DC electrical resistance–time curves of steel bar-reinforced RPC. (**a**) RPC with rice husk ash after standard curing for 28 days. (**b**) RPC with rice husk ash after standard curing for 28 days after 200 NaCl freeze–thaw cycles. (**c**) RPC with rice husk ash after 20 NaCl dry–wet alternations. (**d**) RPC with waste fly ash after standard curing for 28 days. (**e**) RPC with waste fly ash after 200 NaCl freeze–thaw cycles. (**f**) RPC with waste fly ash after 20 NaCl dry–wet alternations.

4. Conclusions

In this study, the fluidity, mechanical strengths of reactive powder concrete, and the following corrosion resistance of inner steel bars were investigated. The conclusions can be drawn as follows.

The addition of RHA and WFA led to decreasing the fluidity of fresh RPC; meanwhile, the slump flow of fresh RPC with RHA was lower than fresh RPC with WFA. Moreover, RHA and WFA could effectively improve the mechanical performances of RPC. The decreasing rates of mass and ultrasonic velocity were increased by RHA and decreased by WFA, showing that RHA demonstrated a positive effect on the resistances of NaCl freeze-thaw cycles and dry–wet alternations. However, when WFA was added, the effect was the opposite.

The AC electrical resistance and the variation rate of DC electrical resistance before the corrosive effect of NaCl freeze-thaw cycles or NaCl dry-wet alternations were increased by the addition of RHA and decreased by the increasing dosage of WFA. After the external erosion of NaCl freeze-thaw cycles or NaCl dry-wet alternations, the AC electrical resistance and the variation rate of DC electrical resistance of all specimens increased. The increasing rates of AC electrical resistance and DC electrical resistance increased with the addition of WFA and decreased by increasing the content of RHA.

Finally, as obtained from this research, RHA could effectively improve the corrosion resistance of steel bars in RPC. However, when WFA was added, the result was the opposite. Steel bars corroded more seriously when specimens were exposed to the environment of NaCl dry–wet alternations than the NaCl freeze–thaw cycles.

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