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Corrosion evaluation of patch repair material using seawater mixed mortar

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Abstract

The rapid infrastructure development in the world highlights the significance of mortar, especially in mitigating corrosion damage by using patching material. This experiment demonstrated the impact of corrosion prevention method by coating techniques, binder type, cover thickness, and several exposure conditions on the corrosion resistance. Cube-shaped specimens were fabricated with two round steel bars and cover depth of 3 cm and 5 cm, using Portland Pozzolan Cement (PPC) and Portland Composite Cement (PCC) as the binders. Corrosion protection methods including steel coating and surface concrete coating were used. Half-cell potential test was used to periodically measure the corrosion probability. The result showed that PCC demonstrated superior corrosion resistance relative to PPC, principally because to its increased CaO content, which improves strength and reduces permeability. A cover depth of 5 cm demonstrated more efficacy than 3 cm in reducing corrosion risk by restricting the ingress of chloride ions. Corrosion was shown to increase when saltwater was utilized as a mixing water, especially during wet and dry-wet cycles. Surface concrete coating was shown to be the most efficient of the corrosion protection approaches, drastically decreasing damaged areas by closing pores and limiting air and water infiltration. While steel coatings were applied and provide some protection, their efficacy was seen to be less reliable. Dry exposure conditions were identified as optimum, since less contact with water decreased the likelihood of rusting. These results underscore the significance of material selection, cover depth, and protective coatings in reducing corrosion in reinforced concrete buildings.

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Keywords

Corrosion, Mortar, Patch repair, Seawater

Introduction

Chloride-induced corrosion is acknowledged as a significant problem impacting the structural integrity and durability of reinforced concrete (RC) [1][2]. This corrosion results in material degradation that compromises structural integrity and incurs substantial financial expenses for repairs and maintenance. The patch repair technique by removal of damaged material, which is then replaced with a chloride-free alternative, therefore restoring durability and structural integrity is regarded as a successful strategy among the numerous repair options [3][4].

On the other hand, researchers recognize seawater as a mixing water option that might enhance the compressive strength of concrete under specific conditions [5][6]. This method introduces chlorides, which raise concerns about possible long-term durability effects. Engineers and scientists require further investigation to better understand the impact of seawater on the long-term performance of concrete and to evaluate its advantages against the risks of chloride-induced deterioration [7][8].

Several trials on the patch repair material have been introduce by using organic and non-organic material [9][10]. The polymer material such as geopolymer concrete become one the innovation on patching material due to its relatively high porosity and low electrical resistivity, but the characteristic is unfavorable if it is combined by using another electrochemical repair method due to incompatibility [11][12]. Previous researchers informed the innovative and eco-friendly materials that use by-product or agricultural waste as the patch repair options, focusing only on mechanical properties but lacking information on electrochemical characteristic [13][14]. The objective of this research is to find the electrochemical characteristic specially of half-cell potential of steel bar embedded on patching material by using seawater as the mixing water.

Method

The laboratory experimental method was employed to conduct the research following the literature review, and the research procedure is illustrated in Figure 1. The cubical specimens with the dimension of 15cmx15cmx15cm were fabricated following the mortar mix design. Figure 2 illustrated the specimen's specifics. The mortar production utilized seawater as the blending water and potable water as a substitute. The binder material was comprised of Portland Pozzolan Cement (PPC) and Portland Composite Cement (PCC). A cover depth of 3 cm and 5 cm was used to embed two round steel rods in the specimen. By employing a bituminous-based corrosion inhibitor, the corrosion prevention strategies were implemented for the two conditions: steel bar coating and surface concrete coating [15][16]. The workability was assessed by conducting a flow table after the mortar material was mixed. The casting on the cubical timber mold was subsequently completed. The specimens were demolded and cured in the damp cloth condition for 28 days after one day. The exposure conditions were initiated after the curing period, and they were maintained for a total of 400 days since January, 2022 until February, 2024 in Universitas Muhammadiyah Yogyakarta with three distinct conditions: wet, dry, and dry-wet. The moist condition was maintained for two days, followed by five days of dryness. Table 1 contained a comprehensive inventory of the 18 specimens, including all of their variations.

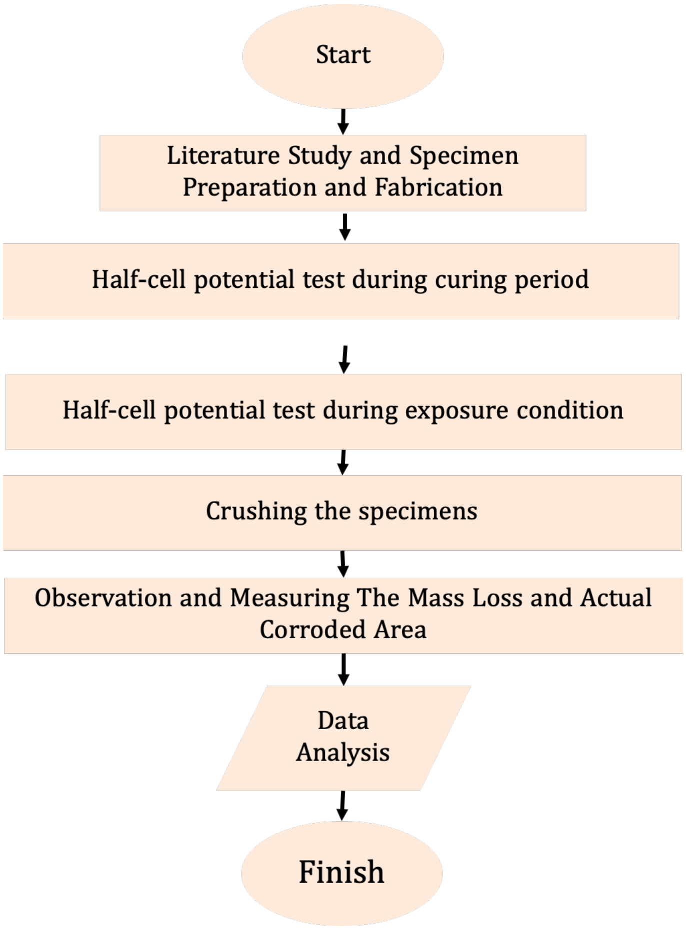

Figure 1. Research programs flow chart

Table 1. Detail of specimens that contain two round steel bars in 3cm and 5cm cover depth

Exposure Condition	**Number of Sample**	**Sample ID**	**Cement Type**	**Corrosion Prevention Method**
Wet Condition	6	Z1	PPC	Non-Coating
		AK1	PCC	
		Z4	PPC	Surface Coating
		AK4	PCC	
		Z7	PPC	Steel Coating
		AK7	PCC	
Dry Condition	6	Z2	PPC	Non-Coating
		AK2	PCC	
		Z5	PPC	Surface Coating
		AK5	PCC	
		Z8	PPC	Steel Coating
		AK8	PCC	
Dry-wet Cycle	6	Z3	PPC	Non-Coating
		AK3	PCC	
		Z6	PPC	Surface Coating
		AK6	PCC	
		Z9	PPC	Steel Coating
		AK9	PCC	

During the curing and exposure period, the half-cell potential of steel bars were measured periodically [17][18]. The ASTM C768 was used as the testing standard and interpretation data guide. If the potential value is more than -200 mV in comparison to the Calomel Saturated Electrode (CSE), it implies that there is a 90% possibility that there is no corrosion hazard, which shows that the steel bar is in a quiet state. When compared to CSE, values that fall within the range of -200 mV to -350 mV are considered to be unclear in terms of corrosion activity, which calls for more investigation. In the event that the potential is measured as being greater than -350 mV vs CSE, active corrosion is indicated with a probability of 90%, hence posing substantial risks to the RC structure.

Results and Discussion

Corrosion Potential of Steel Bars

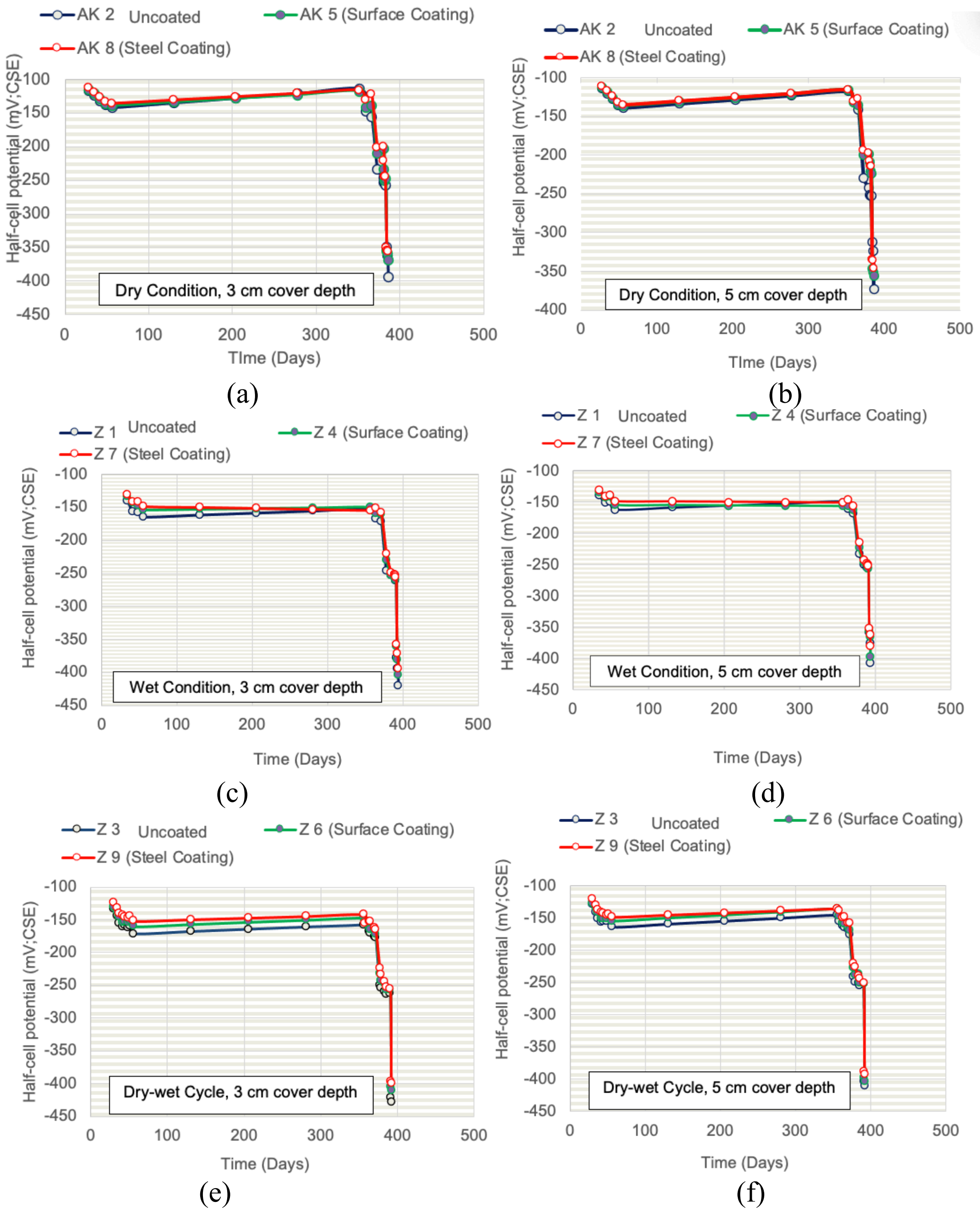

Figure 2. Half-cell potential value of steel bars in varied condition, (a) dry condition, 3 cm cover depth, (b) dry condition, 5 cm cover depth, (c) wet condition, 3 cm cover depth, (d) wet condition, 5 cm cover depth, (e) dry-wet cycle, 3 cm cover depth, and (f) dry-wet cycle, 5 cm cover depth

After 400 days of exposure, the potential value of all steel bars was below -350 mV vs CSE. A comparison of two binder types, Portland Pozzolan Cement (PPC) and Portland

Composite Cement (PCC), revealed that Portland Composite Cement (PCC) had a lower corrosion risk than Portland Pozzolan Cement (PPC). This behavior aligned well with prior study findings owing to the elevated CaO component level in PCC compared to PPC [19]. The CaO compound enhanced strength and reduced permeability. The cover depth of 5 cm was more effective than 3 cm, resulting in a reduced chance of corrosion. The entrance of chloride ions in cement paste is contingent upon the quality of the material and the depth of the cover [20][21]. However, the use of seawater as mixing water in this investigation exacerbates the conditions regarding the corrosion potential measurement results. The impact of corrosion control techniques using bituminous-based coatings on steel and surface concrete coatings was also discussed. The application of the steel coating emerged as the optimal approach, shown by the maximum corrosion potential value, despite indications of corrosion conditions persisting for 400 days of exposure owing to the presence of saltwater during the mixing process. The dry condition was the optimal exposure type for using seawater as mixing water, since it resulted in less contact with the water that may elevate the likelihood of corrosion, as shown by the specimens subjected to wet and dry-wet cycle conditions.

Actual Corroded Area

The average of actual corroded area of two steel bars (3 cm and 5 cm) was measured after the crushing specimens. The steel bars were taken out and the corroded area was re-drawn and measured by using automatic tools in CAD programs. The summarized actual corroded areas were described in Table 2.

Table 2. Average of actual Corroded Area

Type of Binder	Actual Corroded Area (%)
PPC	11.26
PCC	18.83
Prevention	**Actual Corroded Area (%)**
Non-Coating	14.69
Surface Concrete Coating	10.50
Steel Coating	14.28
Exposure	**Actual Corroded Area (%)**
Wet Condition	17.66
Dry Condition	9.56
Dry-Wet Cycle	17.91

The effect of corrosion prevention method by using surface concrete coating and steel coating was evaluate. Based on the actual corroded area test data, surface concrete coating is the most effective method to prevent corrosion process due to it was applied on the surface of specimen and filled the pore so it prevented the air and water intrusion. The actual corroded area of specimen with surface concrete coating is 10.50 cm, and there is almost similar result of actual corroded area in the steel coating (14.69%) and no coating method (14,28 %). The exposure condition was also affect on the corrosion condition, the dry condition presented the best condition due to less interaction to the water during exposure condition. The wet condition and dry-wet cycle presented the same similar result, 17.66 % and 17.91 %, respectively.

Conclusion

Portland Composite Cement (PCC) demonstrated superior corrosion resistance relative to Portland Pozzolan Cement (PPC), principally because to its increased CaO content, which improves strength and reduces permeability. A cover depth of 5 cm demonstrated more efficacy than 3 cm in reducing corrosion risk by restricting the ingress of chloride ions. Corrosion was shown to increase when saltwater was utilized as a mixing water in mortar manufacturing, especially during wet and dry-wet cycles. Surface concrete coating was shown to be the most efficient of the corrosion protection approaches, drastically decreasing damaged areas by closing pores and limiting air and water infiltration. While steel coatings were applied and provide some protection, their efficacy was seen to be less reliable. Dry exposure conditions were identified as optimum, since less contact with water decreased the likelihood of rusting. These results underscore the significance of material selection, cover depth, and protective coatings in reducing corrosion in reinforced concrete buildings.

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