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The Effect of Long-Term Exposure Conditions on the Concrete Resistivity of Polymer-Modified Concrete Repair Mortars

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Abstract

Polymer-modified cementitious repair mortars have been used extensively in recent years for concrete repairs in conjunction with electrochemical protection systems. The performance improvements of polymer additions to cementitious mortars generally come at the expense of increased mortar resistivity, an important consideration in the selection of repair mortars particularly when used in conjunction with electrochemical protection systems, such as impressed current cathodic protection and galvanic anode systems. In this paper, four-point Wenner probe resistivity tests of four commercially available mortars marketed as ‘low resistivity’ polymer-modified repair mortars were carried out over a period of 18 months. The experiment results indicated substantial increases in resistivity over time for all mortars in saturated and outdoor exposure conditions, which were beyond the short-term resistivity data of 28 days presented in manufacturers’ technical data sheets and perceived to be the long-term maximum mortar resistivity. The outcome of this paper suggests that polymer-modified mortar resistivity increases substantially over time. The increase of the repair mortar resistivity when used in conjunction with electrochemical protection systems may have a considerable impact on the performance of these systems.

Keywords: Concrete, Wenner Probe, Concrete Resistivity, Repair Mortars, Electrochemical Testing

Introduction

In the rectification process of reinforced concrete structures, one of the primary considerations made is the selection of concrete repair methodology and repair products [1]. The suitability of concrete repair products is determined by the structure’s function, and some of the main technical aspects which are considered include compressive strength, bond strength, shrinkage and expansion, tensile strength, chemical resistance, and flow characteristics [1]. In addition, in the case of an electrochemical protection treatment being specified, mortar resistivity becomes the primary consideration. The addition of polymers to concrete repair products is used to improve the former characteristics but generally at the expense of increased resistivity. While high concrete resistivity mortar could be beneficial for long-term corrosion protection when used for conventional patch repairs, the use of high resistivity mortars in conjunction with electrochemical protection systems can be problematic due to the ionic current flow required for electrochemical systems to operate.

Concrete resistivity is considered an important aspect in the selection of concrete repair materials [2], primarily in the repair of corrosion affected reinforced concrete structures, and the compatibility of concrete repair materials with electrochemical protection systems, such as impressed current cathodic protection systems and galvanic anode systems [3] [4]. This is seen in international standards such as the Australian Standard AS 2832.5 (R2018) [5] which states:

“Electrical resistivity surveys shall be carried out on representative areas of concrete to provide information for the design of the cathodic protection system. Core samples may also be obtained from the structure to evaluate volumetric concrete resistivity”.

“Overlay application may be combined with concrete repair. In such cases, the long-term electrical resistivity of concrete repair materials shall be within the range 50% to 150% of the parent concrete electrical resistivity”.

Although there are no exact limits in the applicable standards defining high and low resistivity mortars, providing resistivity data is becoming common for concrete repair mortars. Manufacturers are including resistivity data in their product technical data sheets (TDS) and are advising on the suitability of some of these mortars for repair use in conjunction with electrochemical protection systems.

Many manufacturers publish repair mortar resistivity values at 28 days from casting in saturated conditions mostly without reference to any test standard. Although product resistivity values are commonly noted in product technical data sheets, there are two areas which require further investigation and research:

1. The first is the study of resistivity change beyond the initial 28-day period. Generally, there is no available data beyond this short-term period and the resistivity performance of the repair mortars after the 28 days is unknown. It has been assumed that the published data represents the maximum resistivity of the mortar under service conditions.

2. The second aspect which requires research is the environmental condition under which the testing is being carried out. The current standards AASHTO designation: T358-19 [6] and ASTM C1876-19 [7] require the sealing, submerging or vacuum saturation of samples prior to testing. In most cases, the actual use of such repair mortars is not in saturated conditions. Many repair mortars are designed for use in atmospheric conditions only, and the saturated condition data may not be relevant in these circumstances.

It is likely that manufacturers assume that the resistivity of mortar is the same under saturated and atmospheric conditions, and the resistivity stops increasing at 28 days.

This paper presents resistivity data of four commercially available polymer-modified concrete repair mortar products. Cylindrical samples of each product were cast and tested in saturated and outdoor conditions. The samples were cast using four commercially available mortars marketed as low resistivity mortars and then tested periodically at the different exposure conditions for a duration of 564 days.

The primary objective of this research is to assess whether the repair mortar resistivity increases over time and whether the manufacturers reported short-term resistivity data for repair mortar under saturated conditions can be correlated to the actual long-term resistivity of the mortar at saturated and atmospheric conditions.

Materials and Methods

Four products were tested in this experiment. For the purpose of confidentiality, the products were labelled L, S, M and H. All products are commercially available concrete repair mortars marketed and are commonly used as low-resistivity repair mortars in conjunction with electrochemical repair systems. A total of fifteen cylindrical samples were cast. The samples were cast into ø100 x 250mm cylinders and cured for 24 hours in their PVC casts. After 24 hours, the samples were removed from their PVC casts and relocated to saturated and outdoor exposure conditions. The saturated samples were all submerged in potable water for the duration of the experiment. The sample labelling and exposure conditions are shown in Table 1.

Table 1

Sample Labelling and Exposure Condition

Product	Saturated Condition	Outdoor Conditions
L	L1, L2	L5
S	S1, S2	S5, S6
M	M1, M2	M5, M6
H	H1, H2	H5, H6

The testing was performed over a period of 564 days from the date of casting with the first testing date 7 days after casting on the 5th February 2019, and the last test date on the 5th August 2020. Twenty sets of readings were carried out during this period. The resistivity testing was performed using a Proceq 50mm four-point Wenner probe (operating at a digitally generated 40 Hz AC current), with a testing procedure in accordance to AASHTO designation: T358-19 [2] for the samples in saturated conditions. For samples in outdoor conditions, testing was performed with a four-point Wenner probe with the use of 15mm embedded stainless-steel screws [8]. A total of sixteen 316 stainless steel screws were drilled into each outdoor sample. Four SS screws were drilled at 50mm spacing at 0, 90, 180 and 270 degrees as displayed in Figure 1. Embedded SS screws were used to carry out the outdoor measurements in order to attain measurements without the addition of surface saturation (which can cause variations in measurement accuracy). The outdoor testing was performed during periods of dry conditions and after heavy rain to obtain representative results simulating existing structures located in atmospheric conditions.

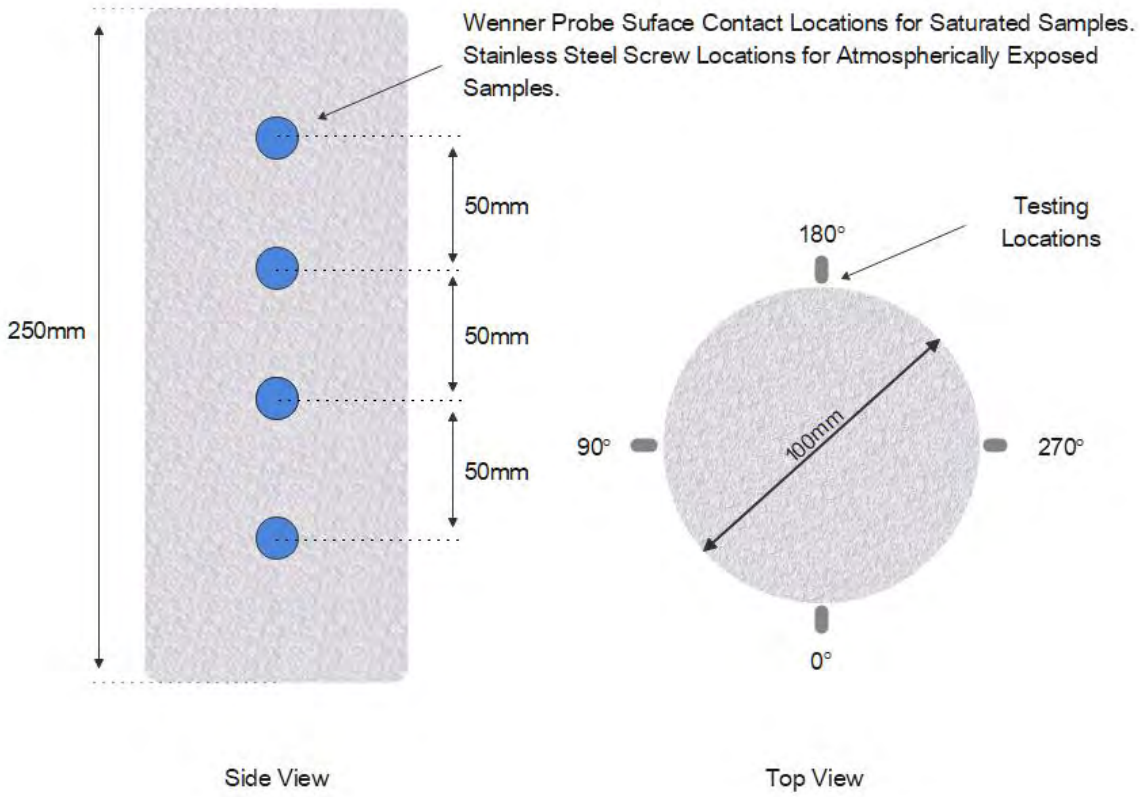

Figure 1: Concrete Resistivity Testing Cylinders

Results and Discussion

Manufacturer TDS vs Laboratory Resistivity Testing

Figure 2 displays the comparison between the resistivity data presented in each product's technical data sheets (TDS) at 28 days and the data obtained from the laboratory-conducted saturated condition experimental samples. The reported TDS resistivity data at 28 days under saturated conditions for products M and H are equivalent to the data for both products obtained in this experiment. For products L and S, the resistivity data obtained in the experiment at 28 days under saturated conditions is substantially greater than the manufacturers' reported TDS resistivity data. A possible contributing factor for the inconsistency between the resistivity recorded in the TDS of Samples L and H is that the manufacturer testing is not reported to be performed to any recognised standard. The primary aim of this experiment is not to verify the commercial product resistivity data at 28 days but to assess the changes in the data over time.

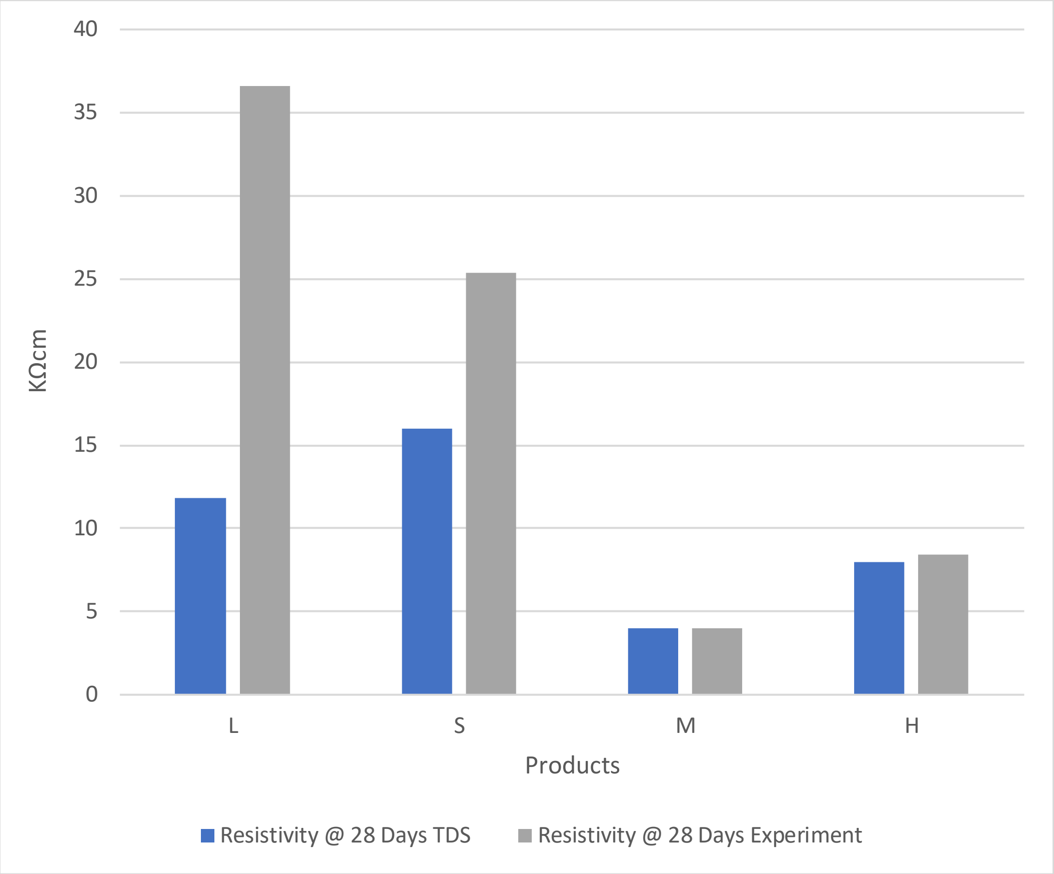

Figure 2: Comparison Between Resistivity Based on Manufacturers (TDS) and Resistivity Based on Experiment at 28 Days in Saturated Conditions

Long Term Resistivity Trends

Figures 3 and 4 display the resistivity trends of saturated and outdoor samples between days 7 and 564 from casting. Figure 3 shows a trend of increasing resistivity over time for all products under saturated conditions. There is a sharp increase of resistivity for products L, S and M while for product H, the resistivity increase is relatively gradual over time. Although product M had the initial lowest resistivity value of 3 kΩcm at 7 days, long term resistivity measurements showed a sharper increase in resistivity than product H. The level of resistivity increase over time is related to the type of admixtures/polymers used in each product’s composition and this is outside the scope of this research. As different mixtures result in different resistivity trends, the long-term testing is necessary to provide an indication of the long-term resistivity performance of the specific product.

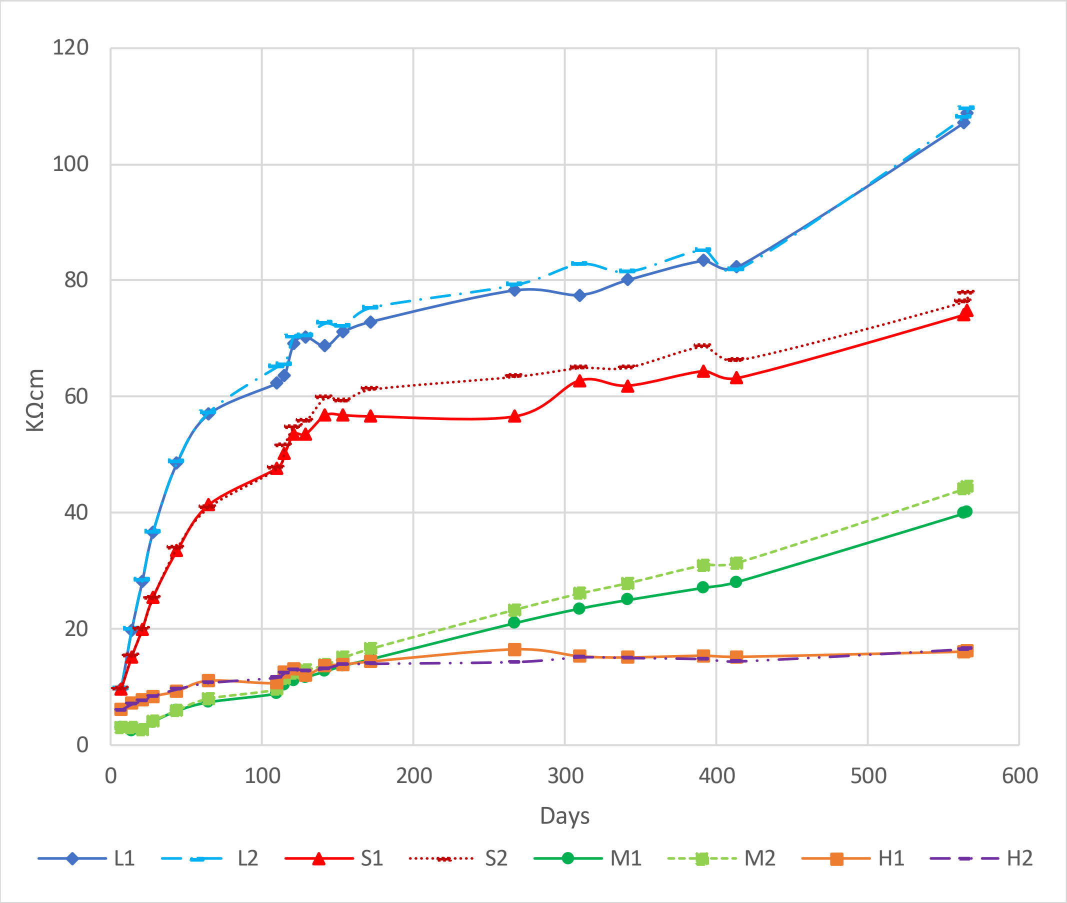

Figure 3: Resistivity Trend of Saturated Samples Over 564 Days

For the saturated samples between day 7 and day 28, samples L1 and L2 displayed a resistivity increase of 281%. Between day 28 and day 564, L1 resistivity increased by 197% and L2 by 199%.

Between day 7 and day 28, samples S1 and S2 displayed a resistivity increase of 164% and 160%. Between day 28 and day 564, S1 resistivity increased by 194% and S2 by 207%.

Samples L1, L2 and S1, S2 displayed the highest resistivities measured after 28 days in both saturated conditions and based on the TDS data. These samples also have the sharpest overall increase in resistivities in the first 120 days, followed by a period of increasing resistivity but at a decreasing rate.

Between day 7 and day 28, samples M1 and M2 displayed a resistivity increase of 29% and 36%. Between day 28 and day 564, M1 resistivity increased by 905% and M2 by 987%. Samples M1 and M2 displayed an initially small increase in resistivity in the first 28 days but showed a constant linear increase following the 28-day period for the entire duration of the testing up to day 564.

Between day 7 and day 28, samples H1 and H2 displayed a resistivity increase of 37% and 40%. Between day 28 and day 564, H1 resistivity increased by 92% and H2 by 98%.

The trends from Figure 3 confirm that resistivity continues to increase well after the commonly quoted 28 days.

The results indicate that the polymers used in products M & H are more effective in maintaining lower resistivities than products L and S.

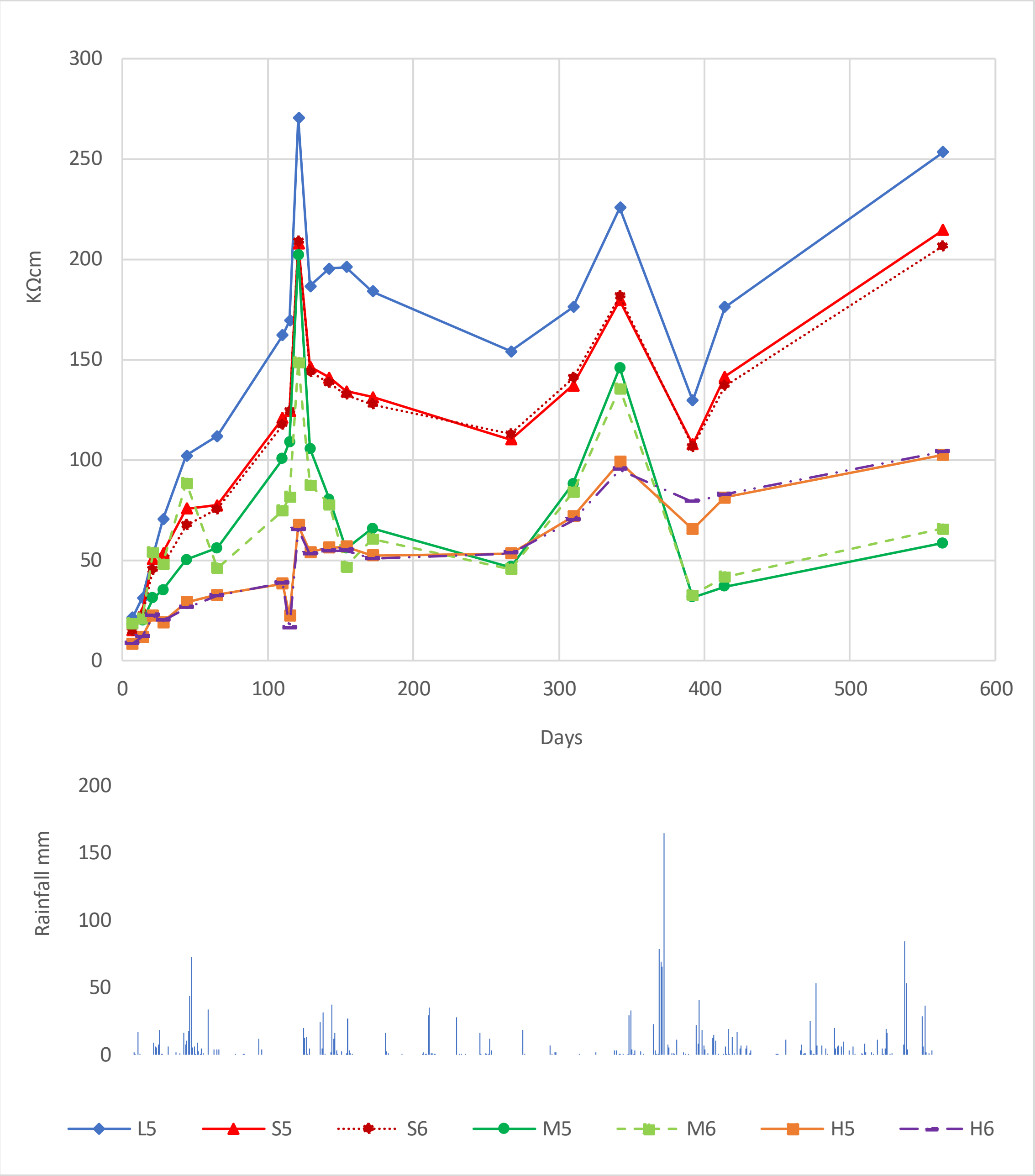

Figure 4: Resistivity Trend of Outdoor Samples Over 564 Days

Figure 4 displays the resistivity trend of the outdoor exposed samples over the 564-day testing period. The figure shows an overall increase in resistivity values with time with a sample range of between 16 kΩcm and 270 kΩcm after 28 days from casting. All four products followed the same trends with fluctuations in resistivity values influenced by outdoor environmental conditions. The samples were exposed to outdoor temperature fluctuations and precipitation in Sydney, Australia. A spike in resistivity measurement is visible at day 121 and day 129. The spike at day 121 was caused by 23 days of no rainfall at a monthly mean temperature of 22.7°C. The following testing date at day 129 was carried out after 3 consecutive days of rainfall totalling 36mm at a monthly mean of 18.6°C.

The impact of exposure conditions on the resistivity data is well documented and the fluctuation of resistivity due to rain or dry conditions is well evident in Figure 4. The test data indicates that overall there is correlation between the resistivity value in saturated and atmospheric conditions. The two products H and M which showed relatively lower long-term resistivity under saturated conditions, showed relatively low resistivity under atmospheric conditions although not in the same order. The same applied for products L and S which showed relatively higher resistivity in saturated conditions and under atmospheric conditions.

The data in Figure 4 shows that product H although not having the lowest long-term resistivity is the least prone to environmental fluctuations. Product H displayed the most consistent trends during the 564-day experimental period. Sample L exhibited the highest resistivity values.

Two samples of each composition were tested in each exposure condition (only one L sample in outdoor conditions). Regardless of the exposure conditions (fully saturated or in outdoor exposure conditions), all samples in the same exposure conditions displayed consistent resistivity measurements. This indicates that the resistivity data for the samples in these experiments were consistent, accurate, and reproducible.

28-Day and 564-Day Resistivity Comparison

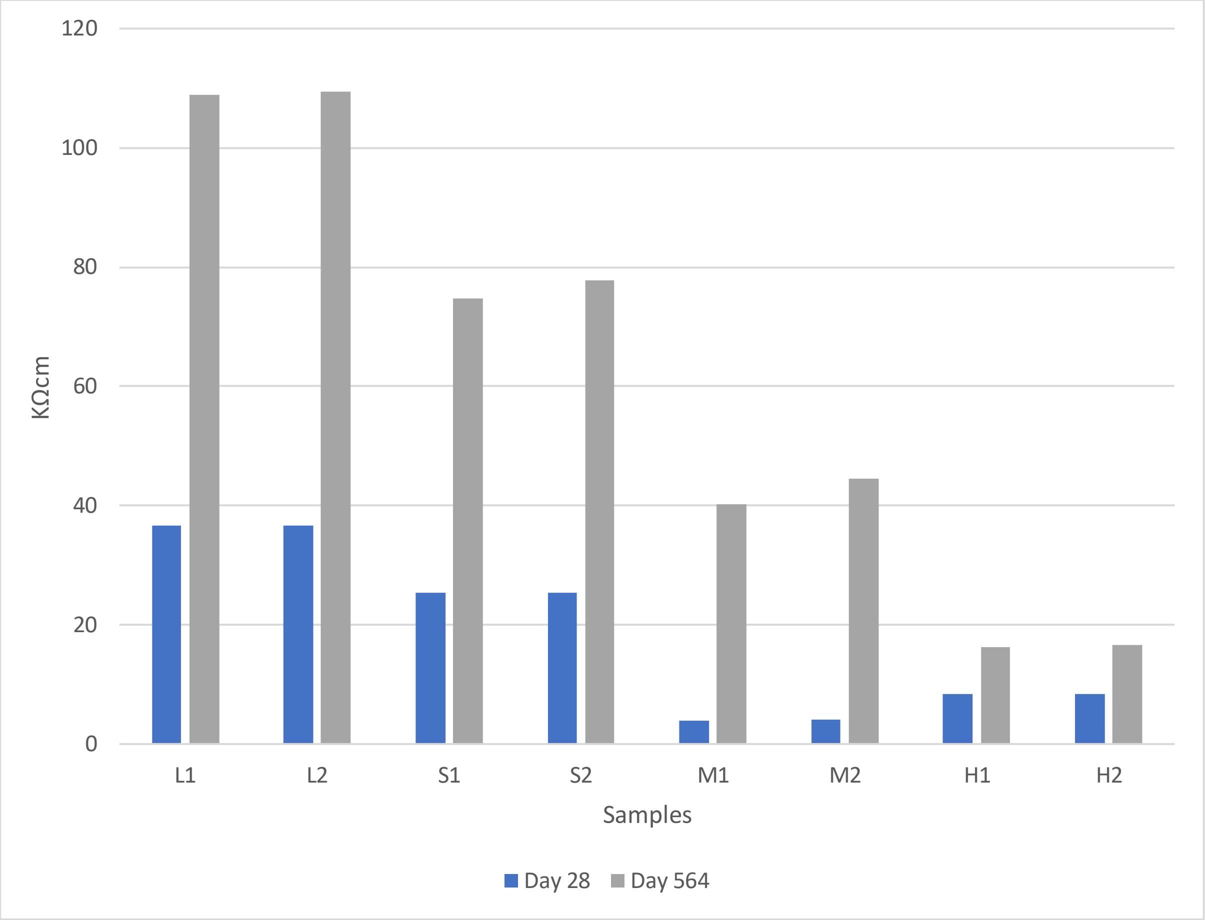

Figure 5: Comparison Between Resistivity at 28 Days and Resistivity at 564 Days in Saturated Conditions

Figure 5 displays the resistivity values measured at days 28 and 564 for the water-saturated samples. The graph shows a major disparity in resistivity values between the two measurement dates. The graph shows that 28-day data is not representative of the long-term resistivity values. In the case of these four products, at 28 days product M displayed the lowest resistivity value, but when conducting long-term resistivity monitoring, product H displayed the lowest long-term resistivity values.

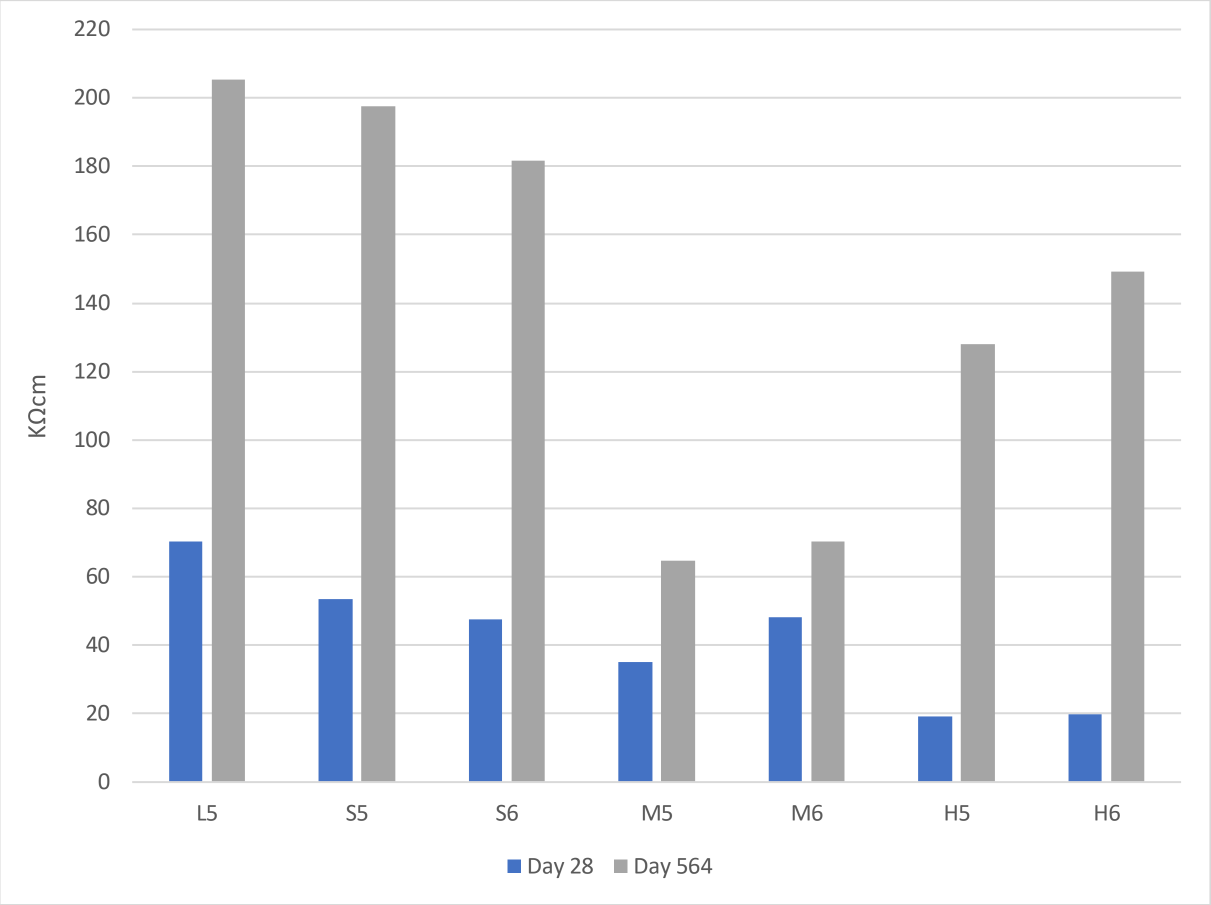

Figure 6: Resistivity Comparison of Outdoor Samples at 28 Days and 564 Days

Figure 6 displays the resistivity values measured at days 28 and 564 for the outdoor samples. Samples L and S displayed the highest overall resistivity values at 28 and 564 days. Resistivity results of products M and H in outdoor conditions were not consistent with the saturated conditions data. As shown in Figure 5 resistivity in saturated conditions, sample H displayed the lowest resistivity out of the four products. In outdoor conditions, the resistivity measurements of sample H were significantly higher than that of product M. Consistent trends between day 28 and day 564 (Figures 5 and 6) cannot be identified for products M and H. The data suggests resistivity testing in saturated conditions as per the current standards will in some cases, not resemble resistivity behaviour of samples in non-saturated outdoor conditions.

Resistivity Comparison of Saturated and Outdoor Exposed Samples

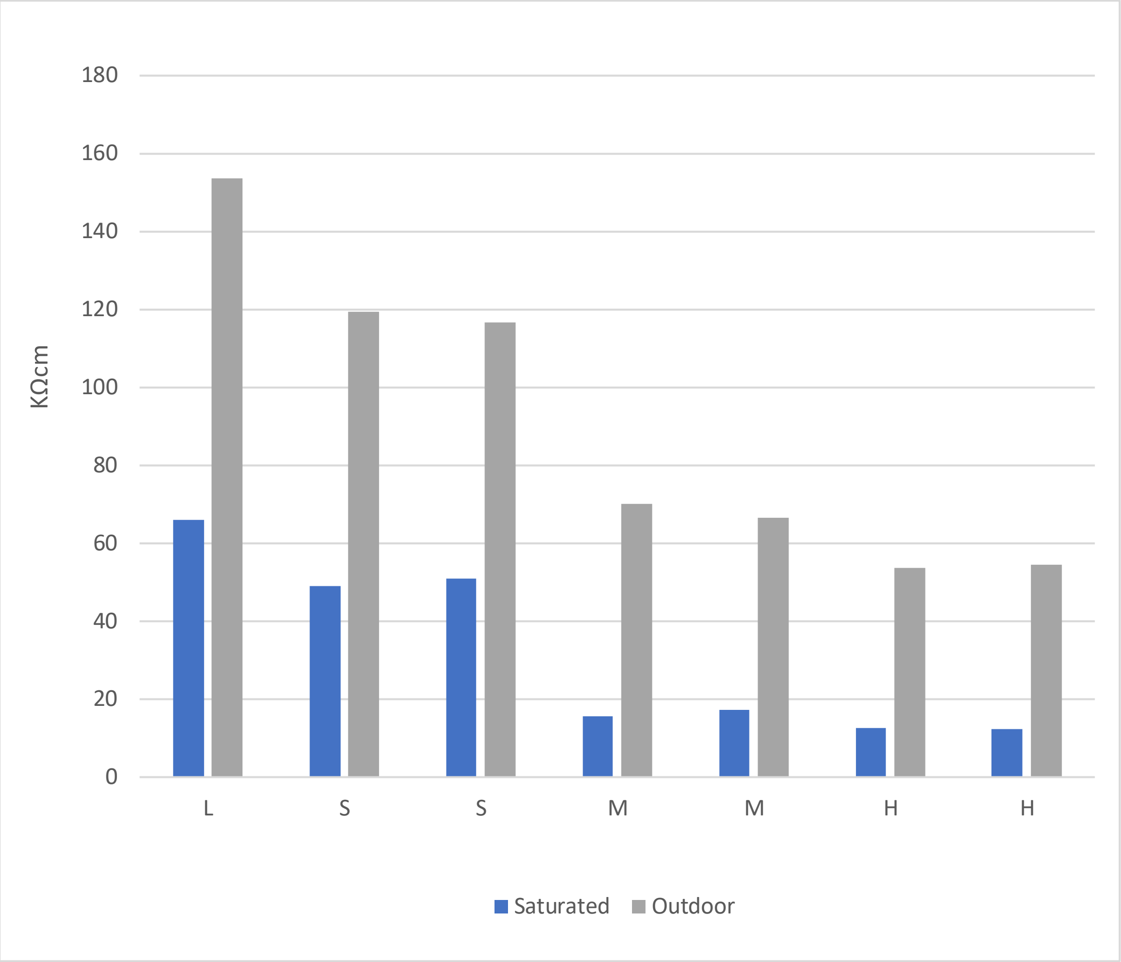

Figure 7: Averaged Resistivity of Outdoor and Saturated Samples

Figure 7 shows the resistivity values between days 7 and 564 averaged and divided by the number of measurement periods. Product L displayed a 138% resistivity increase, product S a 137% resistivity increase, product M a 312% resistivity increase, and product H a 335% resistivity increase between saturated and outdoor conditions. When averaging out the total resistivity value of each product, a consistent trend can be observed. Products which displayed the highest resistivity values continued to exhibit the highest outdoor condition values with all product's resistivities performing in the same high to low positions. Figure 7 highlights a large discrepancy between resistivity measurements conducted using the current standards with samples measured in saturated conditions compared to samples measured in outdoor conditions which is the actual environment exposure conditions.

Discussion

Resistivity trends were found to substantially vary with time and between products. The resistivity of the four tested repair mortars increased over time under both saturated and outdoor conditions. Data showed a major difference between resistivity values at 28 days and at 564 days for all products in saturated and outdoor exposure conditions. Based on this experiment, the 28-day resistivity data typically reported in manufacturer technical data sheets are not indicative of the true resistivity of the material under the same conditions over the longer test period of 564 days.

The experiment in outdoor conditions reflects the influence of weather conditions on concrete resistivity however, it also confirmed that the overall resistivity trend is toward resistivity increase over time. For outdoor conditions and as expected, the resistivity increase is higher in comparison to saturated conditions.

The average resistivity of the four tested products in saturated conditions was 18.6 kΩcm at 28 days, and 61 kΩcm at 564 days. The average resistivity increase in saturated conditions between 28 days and 564 days is 227.9%.

The average resistivity of the four tested products in outdoor conditions was 41.9 kΩcm at 28 days, and 142.4 kΩcm at 564 days. The average resistivity increase in saturated conditions between 28 days and 564 days is 239.8%.

The average resistivity of the four tested products in outdoor conditions at 28 days indicates a resistivity increase of 125% in comparison to saturated conditions.

The average resistivity of the four tested products in outdoor conditions at 564 days indicates a resistivity increase of 142.4% in comparison to saturated conditions.

Conclusion

The following observation and conclusion can be drawn from this paper:

- Manufacturers in most cases are not noting the methodology for resistivity testing. Inconsistencies with two of the four products were identified during a comparison between the resistivity data presented in each product technical data sheet (TDS) at 28 days, and the data obtained from the laboratory-conducted saturated condition experimental samples. Products L and S displayed substantially greater reported resistivity data than the manufacturers' TDS. Manufacturers need to specify the method of resistivity testing utilised.
- Based on the resistivity trend increase of all four products, it is likely that the resistivity will continue to increase beyond the 564 days period. The resistivity mortar data should be tested and reported over an extended period of time up until there is no further increase of resistivity under saturated and outdoor conditions.
- The experiment confirms that the 28-resistivity data of polymer-modified repair mortar in saturated conditions is substantially lower than the long-term mortar resistivity under both saturated and atmospheric conditions. 28-day resistivity measurements in saturated conditions cannot be considered as the actual long-term resistivity of the mortar under outdoor conditions.
- Resistivity measurements in outdoor exposure conditions were consistently higher than those in saturated conditions. The resistivity measurement under saturated conditions based on the current resistivity standards [6] [7], which measure samples in saturated conditions, will not be representative of real exposure conditions and therefore would not be applicable for the structures located in atmospheric outdoor conditions.
- The test results indicate that the type of admixtures and polymers added to the mortar influences the magnitude of resistivity increase. The increase of concrete resistivity for products M and H was substantially lower than for products S and L.
- The experiment results indicate that the suitability of the use of polymer-modified repair mortars in conjunction with electrochemical protection systems must be

further investigated. In the absence of any polymer-modified mortar with reliable long-term, low resistivity, the use of cementitious material with no added polymers should be considered for use in conjunction with electrochemical protection systems.

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