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Research paper



Experimental Comparability Among Different Accelerated Reinforced Steel Concrete Corrosion Methods

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Abstract

The objective of this paper is to inspect the effect of changing the density of the impressed current and wetting-drying condition on accelerated corrosion of reinforced concrete specimens by a galvanostatic method. Small-scale reinforced concrete columns were prepared and then artificially corroded by different setups of accelerated corrosion under an impressed current and also under different wetting-drying cycles for comparison. The density of the impressed current ranged between 50 and 500 µA/cm^2 with different wetting-drying cycles periods. Corrosion current, and cracking were monitored throughout the accelerated corrosion period to determine the level of damage caused by the development of expansive reinforcement steel corrosion products, appearance of the first crack, and pattern of cracking.The results indicated that the galvanostatic method with wetting-drying sequences can be utilized effectively to simulate the normal corrosion of steel reinforcement in the concrete structure. The usage of different intensities of the current has no influence on the crack pattern. Though, increasing the current level leads to a substantial increase in the crack width due to corrosion of the steel reinforcement in a shorter time.

Keywords: *Accelerated corrosion; corrosion rate, cracking; reinforced concrete columns; Reinforcement steel.*

1. Introduction

Consumption of fortification steel in cement is an electrochemical procedure. The rate of erosion of steel fortification is incredibly affected by the penetrability of cement. The presence of microcracks in the interfacial progress zone at the interface with steel and coarse total is the essential reason that solid is more penetrable than the relating hydrated concrete glue or mortar. It ought to be noticed that the entrance of air and water is a fundamental essential to consumption of the implanted steel in concrete[1]. Support steel erosion starts 80% of the fortified solid structures weakening [2].The way of steel consumption normally is moderate, requiring over ten years to cause extraordinary auxiliary harm. For example, Zhang et al [3], and others[4], and [5] who allowed the research center examples to rust normally, expected to sit tight over four years for beginning steel erosion and an additional two years for happening the primary splitting. They just obtained outrageous basic harm a short time later 20 years. These interims are not regularly given in research facility tests. Specialists, sensibly, require and continue to utilize a few strategies to quicken the steel erosion trying to lessen the required testing time. A few examinations have been expressed in the writing on quickened erosion of strengthened solid examples by means of awed current procedure (otherwise called galvanostatic strategy) joined with saline arrangement. El Maaddawy et al , [6] conducted an experiment on full-scale beams that were subjected to chloride attack at different durations under a current at a constant intensity of 215 mA. It was demonstrated that the average loss of steel mass ranged around 8.9, 14.2, 22.2, and 31.6%. However, the maximum crack widths were 0.9, 1.2, 2.3, and 2.9 mm at exposure durations 50, 110, 210, and 310 days, respectively. Malumbela et al., [7] tested full scale reinforced concrete beams with different strength exposed to accelerated corrosion under wetting and drying cycles of 5% NaCl solution. For accelerated steel corrosion exposure under a constant current of 150 mA (current, a density of 189, µA/cm^2) was imposed. A mass loss of steel of 1% causes a corrosion crack width of around 0.04 mm. likewise in the experimental research prepared by Elghazy et al., [8] adopted an equivalent acceleration process, the impressed current in the steel bars was 180 µA/cm^2 with equal wetting and drying cycles of 5% NaCl solution. Wang et al. [9] , inspected experimentally the accelerated steel corrosion of eight reinforced concrete slabs by applying an amount of continuous current of 50-200 µA/cm2 under different setups comprising wet-dry cycling, half immersion, and full immersion in a solution of 5% sodium chloride. They establish that the appropriate method of accelerated corrosion depends on the research objective. Both low current wet-dry cycling method and half emersion method were chosen if research emphases on corroded steel rebar itself, while, if bond deterioration between corroded steel and concrete or expansive cracking of the cover of concrete were of research attention, wet-dry cycling and a small impressed current are commended. Whereas, the partial immersion acceleration corrosion process (immersion up to 2/3 of the specimen height in 3.5 % saline solution) with high current at 1A to obtain the expansive cracking have been designated in the alternative study conducted by Kashi et al.[10]. Also, Sanz et al [11] , selected impressed current technique with a high constant current density of 400 µA/cm^2 and full immersion in calcium chloride solution to accelerate the loss of bond between the steel bar and concrete by corrosion. Kearsley and Joyce [12] implemented high current with an average density of 1087 µA/cm^2 and full immersion in 5%, NaCl, solution for accelerating the corrosion process. Kashani et

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al. [13] studied the behavior of corroded steel reinforcing bars and achieved a high rate of corrosion by using 1100 – 2400 µA/cm^2 with full immersion in 3% NaCl solution. Contrary, Pritzl et al.[14] applied accelerated corrosion technique using low current density at a range between 30 and 45 µA/cm2 with wetting and drying cycles of 6% NaCl solution . Locally, Al-Galawi et al. [15] utilized impressed current accelerated corrosion technique in order to attain simulated exposure times comparable of 5 and 25 years normal exposure conditions, the impressed constant currents of 50-100 µA with continues wetting. Also, other locally study established by Hassan [16], employed the impressed current technique to accelerated the steel corrosion on a concrete beam, the current density 600 µA/cm^2 with partial emersion. Hassan achieves 26% mass loss of steel bar after 60 days from starting the accelerated process.

In spite of, numerous researches have been published in the impressed current accelerated corrosion technique for steel in the laboratory concrete specimens. Unfortunately, there are no standardized procedures for accelerated steel corrosion on laboratory concrete specimens. So, it requires additional researches for the realizing the appropriate accelerated corrosion arrangements in the laboratory tests that simulate the normal corrosion of steel reinforcement in the concrete structure. Reinforced concrete columns, like concrete piles, columns in highways bridges and marine structure, are valuable structural elements which are basically vulnerable for corrosion of embedded steel due to exposing the moisture and harsh environment, leads to extreme reductions in the load carrying capacity and structural integrity of the columnar supportive elements.

In this experimental work, small-scale reinforced columns were artificially accelerated corroded using different impressed current setups attempting to discover the differences among them and lastly to determine the most appropriate one, depending on changing the intervals of wetting and drying cycles and ranges of impressed current. Furthermore, inspect the different between continuous providing current and supplying current on the wetting only.

2.Materials and experimental works

The experimental program is designed to assess the artificially accelerated corrosion system by comparing the final performance of different types of columns subjected to different impressed current. A total of twelve reinforced concrete cylinders simulated as short columns with a diameter of 100 mm and height of 300 mm were deliberated with different configurations of accelerated corrosion. The specified concrete compressive strength was 40 MPa based on 100 mm cube at 28 days.

2.1. Materials

A summarization was adopted to the properties of reinforced concrete fabrication materials were used in this investigation including cement, sand, gravel, and reinforcing bars. The cement used in production concrete was high sulfate resistance cement conforming to ASTM 150 [17] Type V cement as demonstrated in Tables 1 and Table 2 [18] as demonstrated in Tables 3 and Table 4 respectively. The adopted concrete mix proportion was designed according to ACI 211[19], the mix was 1:1.75: 3.5 (cement: sand: gravel) and the water to cement ratio equaled to 0.38. In addition, deformed steel bars with the nominal diameter of 6 mm were used for the main reinforcements and 4 mm plain steel bars were used as spiral stirrups. The reinforcement steel bars were compatible to ASTM A 615-15 [20]. All reinforced concrete columns were cured in tap water for 28 days. Figure 1 shows the column details.

Table 1: Chemical composition and main compounds of cement

Oxide composition	Abbreviation	%-by weight	Limits of ASTM 150
Lime	CaO	62.52	-
Silica	SiO_2	21.85	-
Alumina	Al_2O_3	3.86	-
Iron oxide	Fe_2O_3	4.67	-
Sulphate	SO_3	1.68	≤ 2.3%
Magnesia	MgO	1.58	≤ 6%
Loss on Ignition	L.O.I.	0.93	≤ 3%
Lime saturation factor	L.S.F.	0.97	0.66-1.02
Insoluble residue	I.R.	0.70	≤ 0.75
Main compounds (Bogues eq.)		% by weight of cement	
Tricalcium silicate	(C_3S)	51.05	
Diacalcium silicate	(C_2S)	24.14	
Tricalcium aluminate	(C_3A)	2.31	
Tetracalcium aluminoferrite	(C_4AF)	14.2	

Table 2: Physical properties of cement

Physical properties	Test result	Limits of ASTM 150
Specific surface area, Blaine Method, (m^2/kg).	305	>260
Setting time (Vicat's method)		
-Initial setting(min.)	200	≥ 45 min.
-Final setting (min.)	290	≤ 375 min.
Compressive strength (MPa):		
3-days	30.5	≥ 15
7-days	37.5	≥ 21
Soundness(Autoclave),%	0.04	≤ 0.8

Table 3: Properties of Fine Aggregate

Sieve size (mm)	Cumulative Passing%	Limits of ASTM 33
9.5	100	100
4.75	100	95-100
2.36	81	80-100
1.18	63	50-85
0.600	43	25-60
0.300	17	5-30
0.150	3	0-10
Material Finer than 75-µm	3.20	5% (Maximum)
SO_3	0.296	0.5 (Maximum)

Table 4: Properties of Coarse Aggregate

Sieve size (mm)	Cumulative Passing%	Limits of ASTM 33
12.5	100	100
9.5	100	90-100
4.75	23	20-55
2.36	5	5-30
1.18	-	0-10
Material Finer than 75-µm	0.5	1% (Maximum)
SO_3	0.07	0.1 (Maximum)

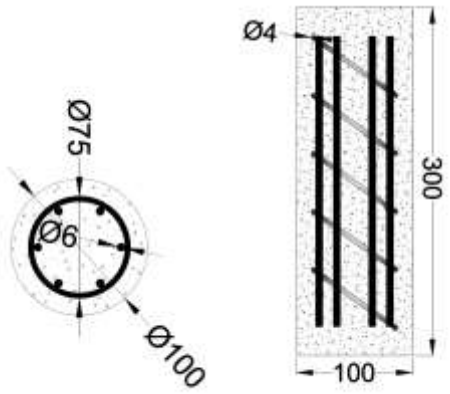


Fig. 1: details of the column in this study

2.2. Accelerated corrosion

Outside current methodologies have been successfully used to make quickened erosion in steel strengthening bars. Using outside electrical flows is extremely basic and includes making an electrochemical circuit utilizing an outer power supply. The fortifying bars go about as an anode in the cell and an outside material goes about as the cathode [2]. Following 28 days of relieving, the strengthened solid sections were submerged in a 3.5% NaCl answer for 3 days, the test examples were shrouded in tempered steel work with wipe substance filling the hole between the fortifying examples and the work A consistent current was connected between the anode (strengthening steel bars in the example) and the cathode (outside hardened steel work) from a DC control source. The flows connected were 50, 200, 500 μA/cm2.

The cycles of wetting and drying were joined with current to quicken the steel consumption. Two methodologies of wetting and drying were received; first, half of the examples were presented to a 1 day wetting period pursued by a multi day drying period; second, the rest of the examples were presented to a 1 day wetting period pursued by a multi day drying period.

Every one of the segments examples exposed to interchange wetting and drying, nonetheless, half of segments examples incompletely submerged in saline arrangement around 33% of the aggregate tallness. Through the drying time frames, the current was killed and the examples were expelled from the wipe and presented to air in the lab for drying periods for the half examples, the rest of the examples the current ceaselessly connected in wetting and drying cycles. Table 5 outlines the data of the of quickened erosion process for all segments in this investigation. Figure 2 shows the arraignments of the quickening consumption process.

The development of cracks on the surface of the specimen was detected twice per day. Corrosion current, circumferential expansion and cracking were observed through the accelerated corrosion stage to determine, the magnitude of damage caused by the formation of expansive corrosion products; and the pattern of cracking.

3. Results and Discussion

3.1. Damage Shape and Corrosion Products

The damage shape due to the growth of corrosion in the reinforcement steel bar was monitored for each column. Principally, two types of the damage shape were observed in most of the specimen. Figure 3 and Figure 4 display the different damage shape observed in this experimental study. The first type of damage shape in columns with wetting and drying cycles only (Col.2, Col.3, Col.5, and Col.6), most of the corroded columns had surface cracks in the side of column comparable to the main reinforcement steel bar was detected. Whereas, Col.2, Col.4 do not exhibit any surface damage after 20 and 12 wetting and drying cycles respectively (about 80 days).

The second type of the damage shape in partially immersed columns (Col.7, Col.8, Col.9, Col.10, Col.11, and Col.12) in which the cracks and the damage were identified in the lower parts of the columns that immersed in the saline solution. In spite of the severe damage in the lower part of the columns in this type of damage, the remaining part of the column still without any visual damage and cracks during the accelerated process.

Table1: the details of the corrosion process for each column

Column Designation	Applied current		Wetting and Drying Cycles	
	Density μA/cm^2	Status	Duration (Days)	Status
Col.1	50	In wetting only	1W -3D	W and D cycles only
Col.2	200	In wetting only	1W -3D	W and D cycles only
Col.3	500	In wetting only	1W -3D	W and D cycles only
Col.4	50	In wetting only	1W -6D	W and D cycles only
Col.5	200	In wetting only	1W -6D	W and D cycles only
Col.6	500	In wetting only	1W -6D	W and D cycles only
Col.7	50	Continues	1W -3D	Wand D cycles joined with partial immersion
Col.8	200	Continues	1W -3D	Wand D cycles joined with partial immersion
Col.9	500	Continues	1W -3D	Wand D cycles joined with partial immersion
Col.10	50	Continues	1W -6D	Wand D cycles joined with partial immersion
Col.11	200	Continues	1W -6D	Wand D cycles joined with partial immersion
Col.12	500	Continues	1W -6D	Wand D cycles joined with partial immersion

Note : W : Wetting duration in day , D: drying duration in day

Based on the visual observation for corrosion product for corroded columns, the green rust was detected in the corrosion area for the partial immersion area, while the drake black rust was detected in the columns that subjected to wetting and drying cycles.

The different type of damage shape and the corrosion products between the specimens that subjected to impressed current and wetting and drying cycles only with that specimens subjected to continuous current and partially immersion with wetting and drying cycles due to the dissimilar the oxygen availability in wetting and drying only specimens more than the partially submerged specimens led to the more uniform expansion corrosion. There are different types of corrosion products depending on composing of Fe together with OH and / or O [21].



Fig. 2: the arrangement of the accelerated corrosion for all the specimens

3.2. Visible First Surface Crack

The time wanted for the growth of visible first crack on the specimen surface was changed for different impressed current. Table 2 illustrates the required duration to identify the visible first surface cracks for the corroded specimens. Based on the visual observations during the accelerated process for the columns, the visible first surface crack for columns with wetting and drying cycles only (Col.2, Col.3, Col.5, and Col.6), most of the corroded columns had surface cracks in the side of column comparable to the main reinforcement steel bar was distinguished as presented in Fig 5. the required duration for crack for 1 wetting -6 drying cycles slightly shorter than crack 1 wetting - 3 drying cycles for corresponding impressed current. While, Col.2, Col.4 do not exhibit any surface cracks after 20 and 12 wetting and drying

cycles, respectively (about 80 days). The visible first surface crack for partially immersed columns (Col.7, Col.8, Col.9, Col.10, Col.11, and Col.12), in which the crack was identified in the lower parts of the columns that immersed in the saline solution only and also. the required duration for a crack for 1 wetting -6 drying cycles slightly shorter than crack 1 wetting - 3 drying cycles for corresponding impressed current. When comparing the required duration for a visible first surface crack for partially immersed columns and columns with wetting and drying cycles only, the former required less duration. Likewise, the impressed current density effect on the first crack of the corroded columns, the higher density the sorter in the duration of the appearing the first crack, for instance at wetting and drying cycles only, the duration of the first crack were (no crack, 36, 76 days) for columns (Col.1, Col.2,and Col.3) respectively , this trend was observed by researchers[22]and[23].

4. Conclusion

The impact of changing the awed current to quicken the steel fortifying erosion in solid sections examples was tentatively reviewed. The investigation evaluated the solid harm shape, time and split relationship result from quickened consumption up to the development of unmistakable first surface break on solid section example. The primary ends from this examination are as per the following:

1-The dimension of current connected had no impact at first glance break design. For all test segments examples, the surface breaks because of quickened consumption of steel fortification were parallel to the fortifying bars randomly of the dimension of current connected to make the erosion of support.

2- Time requested the development of obvious first surface break on the solid examples diminish with the expansion in inspired current thickness.

3-In the other drying-wetting cycles, expanding the drying term over the wetting span in all test sections examples was more influenced in the splitting and harm and breaking.

4-The oxygen and moisture availability had opposite effect on the rust product, the oxygen more available in the specimen subjected wetting-drying than that subjected immersion in saline lead to more expansive rust product.

5- Consequently, for research laboratory based investigation, alternate drying wetting procedure only and impressed current method were found to be a more appropriate method for accelerating the corrosion for simulating naturally corrosion process. Nevertheless, when combined partly immersion specimen way did not be similar to naturally corrosion process.

6-Accelerated corrosion method by impressed current and alternate drying wetting procedure only is established to be an effective technique to study the process of the steel corrosion in the concrete structure, and its influences on the concrete cover damage.

Table 2: the required time for visible first surface cracks for the corroded specimens.

Column Designation	Applied Current Density µA/cm^2	Visible First Surface Cracks Duration	
		No. of Cycles	Duration (Days)
Col.1	50	--	--
Col.2	200	19	76
Col.3	500	9	36
Col.4	50	--	--
Col.5	200	9	63
Col.6	500	4	28
Col.7	50	12.5	50
Col.8	200	8	33
Col.9	500	4	16
Col.10	50	5.5	39
Col.11	200	4	28
Col.12	500	1.5	11



Fig.3: the damage shape in the partial immersion columns



Fig.4: the damage shape in the wetting and drying only specimens.

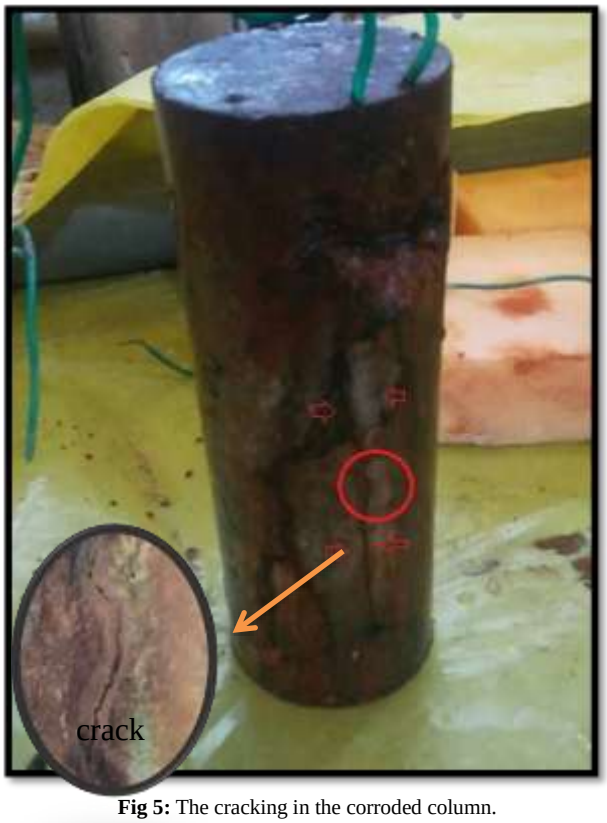


Fig 5: The cracking in the corroded column.

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References

[1] P. K. Mehta and P. J. M. Monteiro, "Concrete: microstructure, properties, and materials," *Concrete*. p. 684, 2006.
[2] M. A. El-Reedy, *Steel-Reinforced Concrete Structures: Assessment and Repair of Corrosion*, Second Edi. CRC Press, 2018.
[3] R. Zhang, A. Castel, and R. François, "Serviceability Limit State criteria based on steel-concrete bond loss for corroded reinforced concrete in chloride environment," *Materials and Structures/Materiaux et Constructions*, vol. 42, no. 10, pp. 1407–1421, 2009.
[4] R. Zhang, A. Castel, and R. François, "Concrete cover cracking with reinforcement corrosion of RC beam during chloride-induced corrosion process," *Cement and Concrete Research*, vol. 40, no. 3, pp. 415–425, 2010.
[5] R. Zhang, A. Castel, and R. François, "The corrosion pattern of reinforcement and its influence on serviceability of reinforced concrete members in chloride environment," *Cement and Concrete Research*, vol. 39, no. 11, pp. 1077–1086, 2009.
[6] T. El Maaddawy, K. Soudki, and T. Topper, "Long-term performance of corrosion-damaged reinforced concrete beams," *ACI Structural Journal*, vol. 102, no. 5, pp. 649–656, 2005.
[7] G. Malumbela, M. Alexander, and P. Moyo, "Lateral deformation of RC beams under simultaneous load and steel corrosion," *Construction and Building Materials*, vol. 24, no. 1, pp. 17–24, 2010.
[8] M. Elghazy, A. El Refai, U. Ebead, and A. Nanni, "Effect of corrosion damage on the flexural performance of RC beams strengthened with FRCM composites," *Composite Structures*, vol. 180, pp. 994–1006, 2017.
[9] X. Wang, X. Song, M. Zhang, and X. Du, "Experimental comparison of corrosion unevenness and expansive cracking between accelerated corrosion methods used in laboratory research," *Construction and Building Materials*, vol. 153, pp. 36–43, 2017.
[10] A. Kashi, A. A. Ramezanianpour, and F. Moodi, "Durability evaluation of retrofitted corroded reinforced concrete columns with FRP sheets in marine environmental conditions," *Construction and Building Materials*, vol. 151, pp. 520–533, 2017.
[11] [B. Sanz, J. Planas, and J. M. Sancho, "Study of the loss of bond in reinforced concrete specimens with accelerated corrosion by means of push-out tests," *Construction and Building Materials*, vol. 160, pp. 598–609, 2018.
[12] E. P. Kearsley and A. Joyce, "Effect of corrosion products on bond strength and flexural behaviour of reinforced concrete slabs," *Journal of the South African Institution of Civil Engineering*, vol. 56, no. 2, pp. 21–29, 2014.
[13] M. M. Kashani, A. J. Crewe, and N. A. Alexander, "Nonlinear stress-strain behaviour of corrosion-damaged reinforcing bars including inelastic buckling," *Engineering Structures*, vol. 48, pp. 417–429, 2013.
[14] M. D. Pritzl, H. Tabatabai, and A. Ghorbanpoor, "Laboratory Evaluation of Select Methods of Corrosion Prevention in Reinforced Concrete Bridges," *International Journal of Concrete Structures and Materials*, vol. 8, no. 3, pp. 201–212, 2014.
[15]]N. M. Al-Galawi, A. A. H. Al-Tameemi, and S. H. Al-Jarrah, "Effect Of Age And Concrete Cover Thickness On Steel Reinforcement Corrosion At Splash Zone In Reinforced Concrete Hydraulic Structures," *International journal of Scientific & Te Chnology Research*, vol. 5, no. 9, pp. 129–133, 2016.
[16] Q. F. Hassan, "effect of accelerated corrosion on tension reinforcement on bending behavior of renforced concrte beams," *AL-TAQANI*, vol. 26, no. 5, pp. A30–A44, 2013.
[17] ASTM-C150-15, "Standard Specification for Portland Cement," *Annual Book of ASTM Standards American Society for Testing and Materials, Vol. 04.01, 2015*.
[18] ASTM-C33-13, "Standard Specification for Concrete Aggregates," *Annual Book of ASTM Standards American Society* for Testing and Materials, Vol. 04.02, 2015.
[19] ACI 211.1-91 (reapporoved 2009), "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete," Reported byACI Committee 211, *ACI Manual of Concrete Practice*, *American Concrete Institute*, 2013.
[20] ASTM-A615-15, "Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete," *Annual Book of ASTM Standards American Society for Testing and Materials, Vol. 01.04, 2015*.
[21] W. Zhao, Y., & Jin, "Steel Corrosion in Concrete," *Steel Corrosion-Induced Concrete Cracking*, p. cp.2 19–29, 2016.
[22] S. Altoubat, M. Maalej, and F. U. A. Shaikh, "Laboratory Simulation of Corrosion Damage in Reinforced Concrete," vol. 10, no. 3, pp. 383–391, 2016.
[23] S. Patil, S. Goyal, and B. Karkare, "Performance evaluation of accelerated corrosion techniques using electrochemical measurements and acoustic emission parameters." 2016 IEEE International Conference on Prognostics and Health Management (ICPHM) , 20-22 June 2016, DOI: 10.1109/ICPHM.2016.7542873.