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Results of Evaluation of Bolt Failures at the R.C. Byrd Locks and Dam

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Final Report

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Prepared for U.S. Army Corps of Engineers
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ABSTRACT: During rehabilitation of the roller gates at the R.C. Byrd Locks and Dam, Gallipolis, OH, the U.S. Army Engineer District, Huntington found some of the bolts had failed. Analysis by the Construction Engineering Research Laboratory found the primary cause of failure to be temper embrittlement. The microstructure of the bolt revealed a brittle fracture, with the fracture mode being intergranular. The presence of chlorides also accelerated the galvanic corrosion that occurred between the bolt and nut.

The temper embrittled bolts have approximately 10 times higher corrosion rate immersed in Ohio River water than the non-temper embrittled bolts. The non-temper embrittled bolts should have a 40 to 50 year service life expectancy, assuming the Ohio River water chemistry does not change significantly.

The suggested material replacement is a martensitic age-hardenable stainless steel combining the very good corrosion resistance characteristics of Type 304 stainless steel and the moderate strength characteristics of Type 410 stainless steel. Either ARMCO 17-4 PH stainless steel or Carpenter Custom 450 stainless steel is recommended for use in aqueous environments where high strength and corrosion resistance is required.

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Conversion Factors

U.S. standard units of measure can be converted to SI* units as follows:

Multiply	By	To Obtain
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32)$	degrees Celsius
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32) + 273.15$	kelvins
feet	0.3048	meters
inches	0.0254	meters
pounds (force) per square inch	0.006894757	megapascals

* SI: *Système International d'Unités* (International System of Measurement).

Preface

This study was conducted for U.S. Army Corps of Engineers, Huntington District. The technical monitor was Pedro Luciano, District Engineer.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Robert A. Weber. The technical editor was Linda L. Wheatley, Information Technology Laboratory — Champaign. Martin J. Savoie is Chief, CF-M, and L. Michael Golish is Chief, CF. The associated Technical Director was Dr. Paul A. Howdyshell. The Director of CERL is Dr. Alan W. Moore.

The authors would like to acknowledge the support of Pedro Luciano, Rodney Cremeans, and Pat Morgan, Huntington District, and Jim Bushman of James Bushman and Associates, Cleveland, OH. Mr. Luciano supported this effort from the beginning and provided liaison between the District and CERL. Mr. Bushman tested all the corrosion specimens and provided technical support during interpretation of the results.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

U.S. Army Engineer District, Huntington, was rehabilitating the roller gates of the R.C. Byrd Locks and Dam, Gallipolis, OH. There are eight gates with a span of approximately 125 ft and a damming height of 29.5 ft. The work included the replacement of the bolts connecting the rim gears to the barrels of all eight gates. The bolts were to be fabricated from Type 410 stainless steel and were to be heat treated to a strength level of 90,000 psi minimum yield strength and 120,000 psi minimum tensile strength. They were also to have a minimum elongation of 20 percent and minimum reduction in area of 40 percent. The nuts were to be fabricated from chromium, nickel, and manganese (Cr-Ni-Mn) stainless steel (brand name Nitronic 60). After several of the gates were completed, the painting inspectors noticed that some of the bolts were loose. Further investigation showed that they had failed. Huntington District personnel contacted an independent laboratory to investigate the failure of the bolts. Bodycote Taussig wrote a report on their findings, and Huntington District requested a review of the report by the U.S. Army Engineer Research and Development Center's Construction Engineering Research Laboratory (ERDC/CERL). The Rock Island District also furnished a report that addressed a similar failure that they had encountered with split bolts.

Bodycote Taussig

The Bodycote Taussig failure analyses report (Nakonechny 2001) covers the failure of several bolts from R.C. Byrd Dam roller gates 6 and 7. The report concludes that the failure was the result of stress corrosion cracking due to exposure to a chlorine-rich environment while under tensile loading conditions. After review of the photomicrographs, CERL does not agree with Bodycote's conclusions as to the point of origin of the fractures. It is agreed that the fracture mode is intergranular. The presence of chlorides in the corrosion deposit between the bolt and nut threads was also confirmed. It is CERL's conclusion that the chlorides accelerated the crevice and/or galvanic corrosion that occurred between the nut and bolt threads due to the two dissimilar grades of stainless steel used for the nut (Cr-Ni-Mn stainless steel) and bolt (400 series). However, it is felt that the primary mode of failure is not

chloride-induced stress corrosion cracking. Although chloride is present in the corrosion products, the high hardness indicates a temper embrittlement problem.

QC Metallurgical Laboratory, Inc.

The Q.C. Metallurgical Laboratory failure analysis report (Bloodsworth 1999) was submitted as a reference report on a failed split bolt. The report was produced for the Rock Island District on a different project. The report identified the failure mode of the bolt as intergranular and the failure caused by brittle fracture. The failure was the result of using a bolt material that had exceptionally low toughness due to incorrect tempering. Essentially, the report described a temper embrittlement of the bolt material due to improper heat treatment of the 410 stainless steel.

Objective

The objective of this work was to analyze the failed bolts for cause and, from the analysis, to determine the extent of cause in all bolts on the rim gears and to determine the remaining service life of the bolts and nuts as installed.

Approach

To accomplish the above objective, CERL researchers first analyzed a failed bolt from roller gate 7. Following this analysis, researchers conducted a site visit to the R.C. Byrd Locks and Dam to present results of the analysis and make recommendations for further testing. Bolts, nuts, and bolt/nut combinations from two different roller gates, as well as unused bolts, were laboratory-tested for hardness and corrosion resistance. A plan was presented to District personnel for analyzing the failures and making recommendations for correcting the situation.

Mode of Technology Transfer

The results of this work were presented in conference to personnel at Huntington District. This report and its data are the remaining part of technology transfer.

2 Failure Analysis of a Bolt

Fractography

The fracture surface of the failed rim gear bolt was examined visually and at high magnification in a scanning electron microscope (SEM). Figure 1 shows the failed bolt as received from the project site. The fracture surface had the appearance of brittle failure but had corrosion by-products on the surface that obscured high magnification viewing in the SEM to assess the structure of the fracture surface. Figures 2 and 3 show the cuts in the nut and the corrosion products in the space between the nut and the bolt. The bolt is much more affected by the corrosion than the nut, indicating some kind of galvanic corrosion in the space. The difference in chemical make-up of the two stainless steels is causing galvanic corrosion of the bolt. This process is aided by the presence of relatively high concentrations of chloride in the water.



Figure 1. Failed bolt as received from the project site.

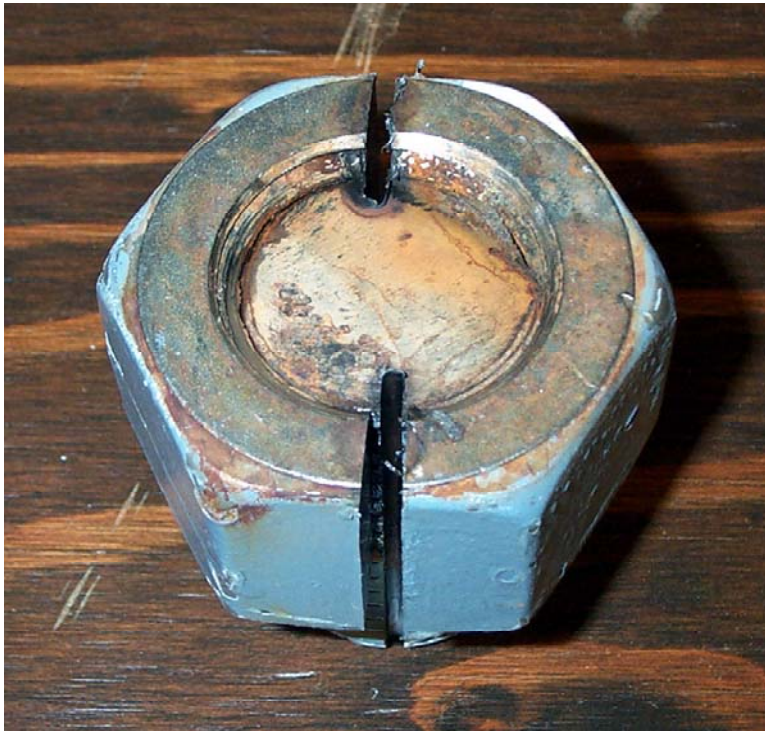


Figure 2. Cuts made to remove the nut from the bolt.



Figure 3. The bolt after the nut was removed.

Hardness Survey

Table 1 shows the results of the hardness survey along the diameter of the bolt. The range was from Rockwell ‘C’ 42.1 to 38.5 (394 – 357 BHN). The average hardness number is 39.84 Rockwell ‘C’ (370 BHN). This corresponds to a tensile strength of approximately 180,000 psi. The high hardness numbers indicate that the material has undergone some temper embrittlement during the heat treatment process.

Energy Dispersive Analysis

Sections of the nut and bolt were placed into the SEM and the corroded area analyzed with an energy dispersive x-ray (EDX). Figure 4 shows the results of the EDX analysis. The EDX spectrum of the corrosion deposit on the nut shows the presence of chlorides (approximately 0.08 wt. %). In addition, the water quality analysis (Table 2) indicates the chloride content of the river water at 24 mg/L. This quantity is not exceptionally high. Significant corrosion would occur at chloride levels over 100 mg/L. The difference in the chemical make-up of the bolt and nut will lead to galvanic corrosion in the space between the nut and the bolt in the thread area. The presence of chlorides in this space will accelerate the galvanic corrosion. Figures 5 and 6 are photomicrographs of the thread root and the corroded area.

Table 1. Results of the hardness survey through the thickness of the failed bolt (Rockwell “C”).

Sample A	42.1
	38.5
	39.2
	38.8
	40.4
	40.8
	39.9
	40.4
	40.1
	39.9
	39.0
	39.1
	40.3
	39.3
Average	39.84

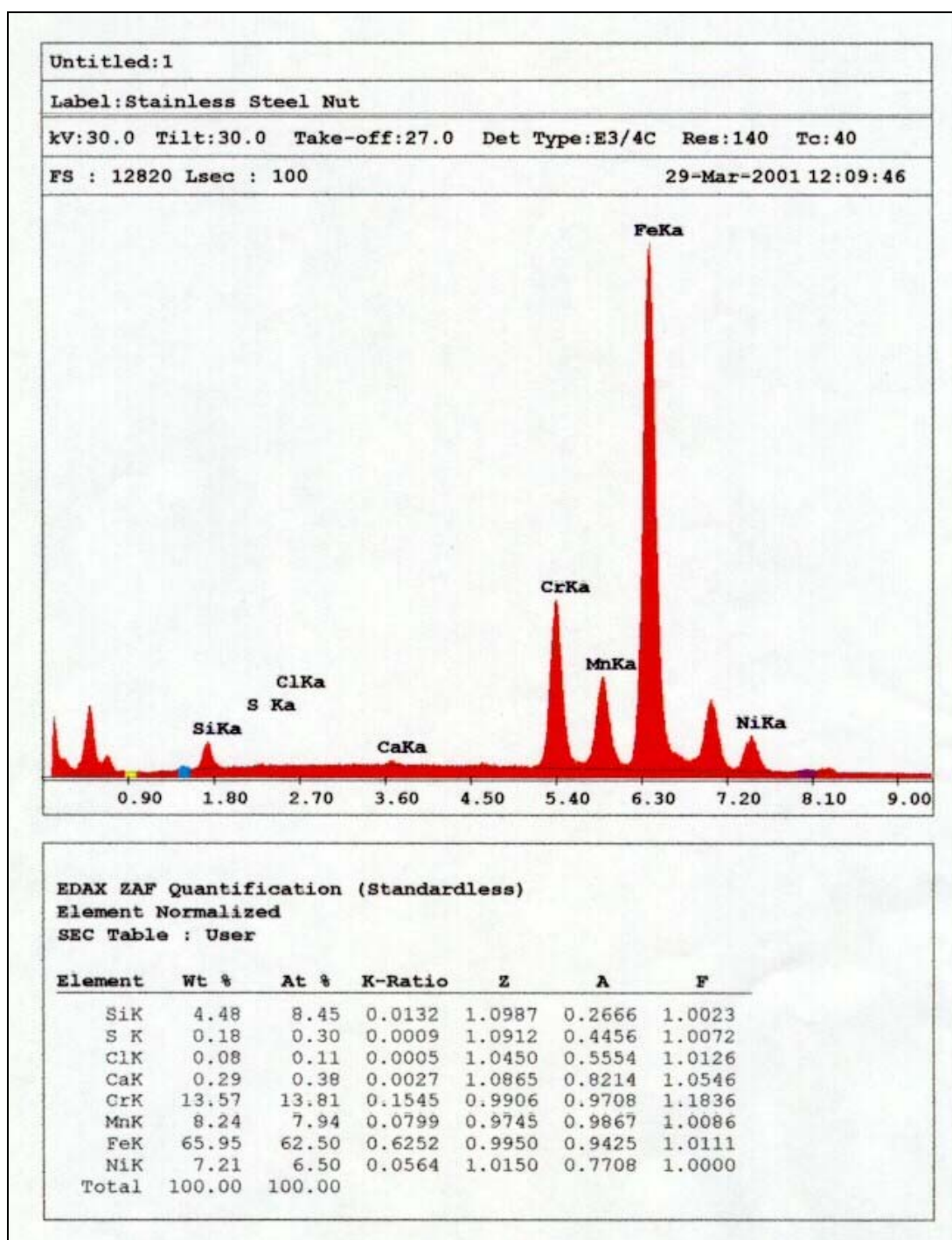


Figure 4. EDAX print out of results of X-ray analysis of the corrosion products in the threads.

Table 2. Hardness survey results (Rockwell "C") for R.C. Byrd Dam bolts.

	As-received Bolts					
Bolt Number	B42	B11	B11b	B32	B32b	B42b
	20.5	25.8	26.7	28.3	29.9	25.3
	17.9	26.5	27.1	32.2	29.4	25.7
	21.7	26.5	27.2	29.5	29.3	25.6
	23.2	26.5	27.5	26.6	28.8	25.6
	24.1	26.4	27.0	26.4	29.0	25.6
	24.0	26.5	26.4	26.9	28.5	24.2
	23.3	26.4	27.0	27.8	30.5	25.1
	23.6	26.7	27.5	28.3	205.4	25.4
	23.8	26.7	27.4	29.0		25.7
	23.8	26.6	27.6	28.8		25.6
	225.9	26.6	27.6	283.8		25.5
		26.5	27.2			26.3
		317.7	326.2			305.6
Average	22.59	26.48	27.18	28.38	29.34	25.47
	Bolts from Gate 2					
Bolt Number	2-D-1-5	2-D-3-1	2-D-5-4	2-D-8-3	2-D-10-2	2-D-12-6
	30.3	27.0	27.3	29.3	30.5	29.4
	30.5	27.4	28.1	29.8	31.3	29.8
	30.6	27.1	28.0	30.4	31.7	29.3
	30.9	27.3	28.0	30.6	31.7	28.7
	30.6	27.0	27.4	30.1	30.7	28.3
	30.9	27.6	28.1	30.9	31.9	28.6
	31.1	27.9	28.0	30.6	31.9	29.4
	30.7	28.0	27.8	30.4	31.9	29.9
	30.9	26.7	222.70	29.1	31.4	29.2
	30.7	246.00		271.20	283.00	262.60
	307.20					
Average	30.72	27.33	27.84	30.13	31.44	29.18
	Bolts from Gate 5					
Bolt Number	5-D1-5	5-D3-1	5-D5-4	5-D8-3	5-D10-2	5-D12-6
	22.2	27.9	26.6	27.0	25.4	28.1
	22.7	29.0	27.2	27.6	25.2	25.4
	23.2	29.2	27.5	28.0	25.3	26.8
	22.7	29.0	27.3	27.4	25.2	26.1
	22.2	28.7	27.0	27.2	25.6	25.2
	21.8	26.5	28.1	28.1	25.9	25.9
	23.3	27.5	27.9	28.1	26.0	26.5
	23.2	197.8	27.4	28.3	25.8	26.5
	23.6		26.1	28.2	25.1	27.1

	23.2		245.1	249.9	229.5	237.6
	22.8					
	250.9					
Average	22.81	28.26	27.23	27.77	25.50	26.40
	Bolts from Gate 7					
Bolt Number	7a	7b	7c			
	41.1	43.4	40.0			
	41.4	42.7	39.1			
	40.8	42.8	40.0			
	41.2	42.6	40.1			
	41.2	42.5	40.0			
	40.5	42.2	39.9			
	41.3	41.9	40.1			
	41.4	42.7	40.1			
	41.6	42.6	39.9			
	41.5	42.3	40.1			
	40.7	43.1	40.2			
	452.7	43.9	40.6			
		512.7	480.1			
Average	41.15	42.73	40.01			

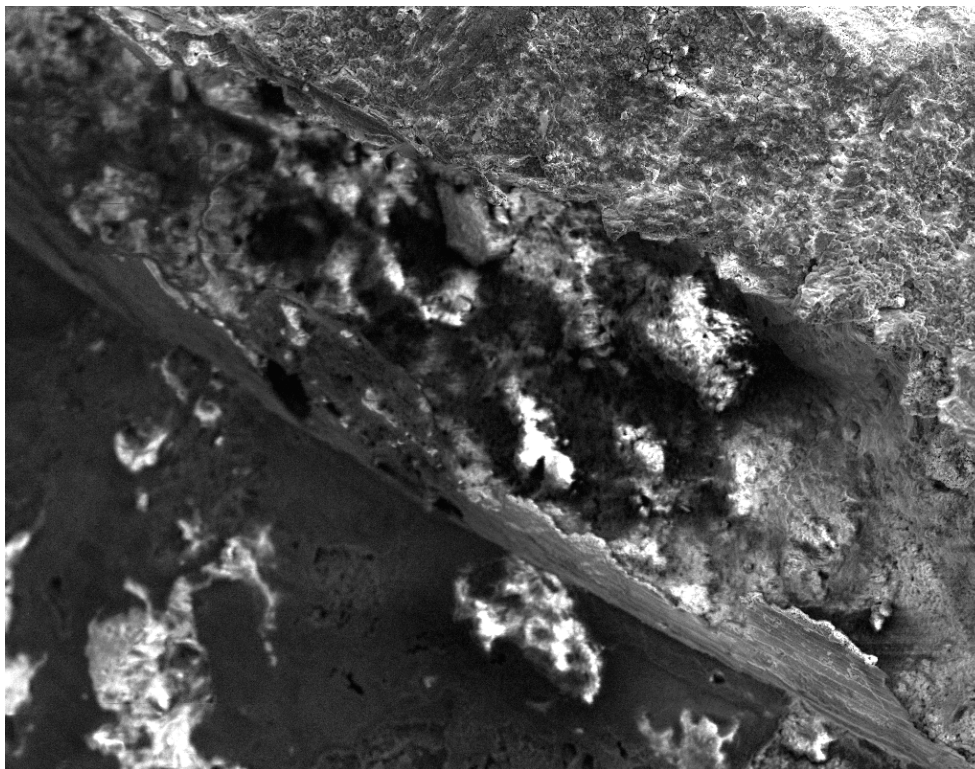


Figure 5. Photomicrograph of the root of the thread showing active corrosion area (300x).

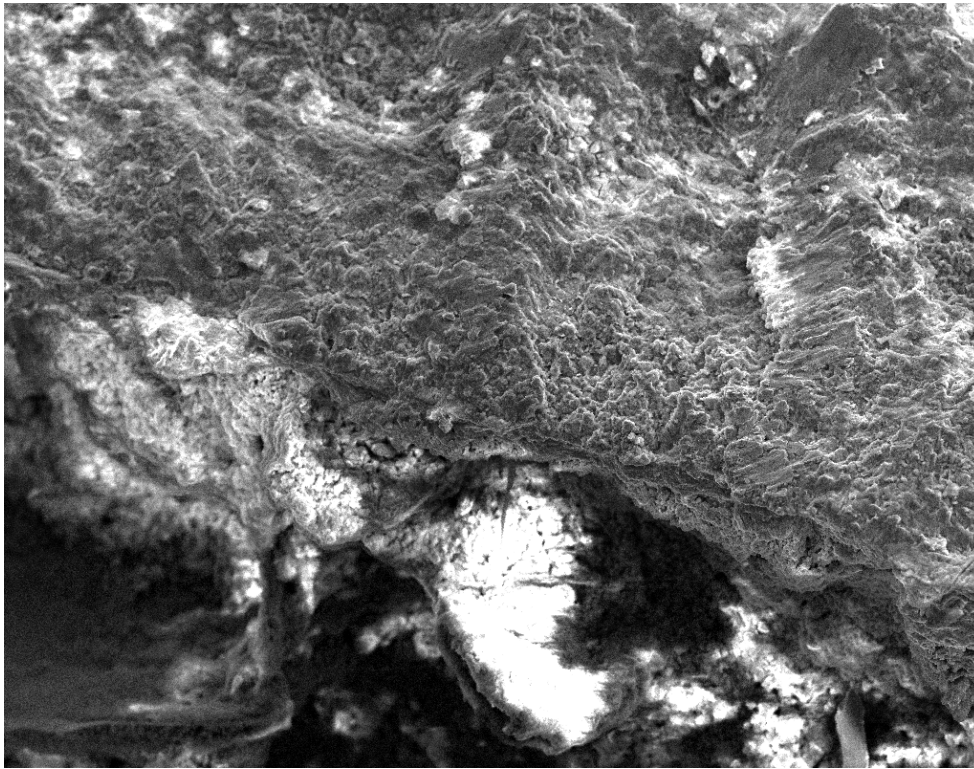


Figure 6. Photomicrograph of the probable crack initiation site at the thread root (300x).

Discussion of Results of Failure Analysis

The primary cause of failure of the bolt sampled from roller gates 6 and 7 at the R.C. Byrd Dam is temper embrittlement. The microstructure of the bolt revealed a brittle fracture, with the fracture mode being intergranular. The presence of chlorides accelerated the galvanic corrosion that occurred between the bolt and nut.

Type 410 stainless steel is subject to temper embrittlement during the heat treatment process. If the material is held too long in the 700 to 1,000 °F, it allows the precipitation of carbides, which reduce the toughness and increase the tensile strength and hardness. The tensile strength and hardness peak when the stainless steel is held at 885 °F for an extended period of time. If the material passes through this temperature range, then little precipitation occurs and, therefore, no embrittling effects affect the structure of the stainless steel. Even though the furnace temperature shows a fairly rapid movement through this range, the parts being heat treated can still be embrittled if they are clumped tightly together, thus affecting the overall mass that needs to be heated up or cooled down.

The suggested material replacement is a martensitic age-hardenable stainless steel combining the very good corrosion resistance characteristics of Type 304 stainless

steel and the moderate strength characteristics of Type 410 stainless steel. Either, ARMCO 17-4 PH stainless steel (American Society for Testing and Materials [ASTM] A-564) or Carpenter Custom 450 stainless steel (ASTM A-564) is recommended for use in aqueous environments where high strength and corrosion resistance is required. This recommendation is based on the results of the High Performance Materials and Systems Research Program study on the Advanced Materials Selection Guide for Lock, Dam, and Hydroelectric Plant Components (Kumar et al. 2002). It is also recommended that a sampling plan be instituted to remove selected bolts from the remaining gates and a metallurgical analysis be performed to determine the extent of the temper embrittlement problem. Until the extent of the temper embrittlement problem is known, a decision to replace all the bolts on the roller gates at R.C. Byrd Dam could not be made. It was therefore imperative that bolts from the remaining gates be sampled.

3 Site Visit

During a site visit to the R.C. Byrd Locks and Dam, a meeting was held at the District office where the results of the failure analysis were presented and discussed. At that same meeting, the corrosion study and additional hardness surveys were discussed, and a plan for implementation was devised. Bolts would be removed from two gates and sent to the laboratory for testing. Additional bolts would be taken from the unused selection and tested in the laboratory. All bolts at the laboratory would be tested for hardness and corrosion rate. The inspection team would go to the dam site to inspect the progress of bolt replacement and discuss the failures and history of roller gate rehabilitation with the dam staff. While at the site, samples of unused bolts would be identified for additional testing at the laboratory.

Reengineering of the gates began in 1993, and the gates were placed back in service starting in 1995. All the gates were back in service by 1999. Figure 7 shows a view of the dam and all eight of its gates. In the foreground are the bulkheads used to hold back the river during work on the gates. Figure 8 shows one refitted gate being installed on the dam. Figure 9 shows a gate after it has been reinstalled.



Figure 7. R.C. Byrd Locks and Dam, Ohio River.



Figure 8. Roller gate being installed at R.C. Byrd Dam on the Ohio River.



Figure 9. Roller gate installed at R.C. Byrd Dam, Ohio River.

4 Hardness Testing of New Bolts and Bolts from Gates 2, 5, and 7

One sure way to determine the presence of temper embrittlement is to check the hardness of the stainless steel. As stated in Chapter 2, brittleness can occur when the stainless steel is held too long in the 700 to 1,000 °F range, with maximum embrittlement at 885 °F. Type 410 stainless steel shows a marked increase in hardness when the temper temperature is held in this range too long. Studies show that hardness will exceed 40 Rockwell “C” (Peckner and Bernstein 1977). Samples of bolts from gates 2, 5, and 7, as well as some as-received bolts, were sectioned and a hardness survey was performed along the diameter of each bolt. A total of 61 bolts were tested for hardness, 21 in the laboratory and 40 in the field. Table 2 lists the results of the laboratory surveys. Only the three bolts from gate 7 showed a marked increase in hardness. The three bolts averaged from 40.01 to 42.73 Rockwell “C”. These bolts were all the same diameter (1 21/32 in.) and length (6 1/2 in.). They also were some of the failed bolts removed from gate 7. Table 3 lists the results of field hardness surveys conducted with a portable hardness test apparatus. Testing of the 1 21/32-in. diameter bolts that could be reached on the D1 casting on gates 6 and 7 showed that some of those bolts exceeded the Rockwell “C” of 35. They were subsequently replaced. Bolts that showed a Rockwell “C” of between 30 and 35 were evaluated on a case-by-case basis, and many were subsequently replaced. The test results led to the conclusion that only one lot of bolts (49 total) was improperly heat treated as evidenced by excessively high hardness numbers. The lot was purchased in August 1998.

Table 3. Field hardness test results for 1 21/32-in. diameter bolts.

Roller Gate 6 - Driven Side			
1L	30	40	32
2L	50	45	41
3L	61	55	61
5L	26	24	21
6L	20	18	21
8L	24	30	35
9L	35	32	34
10L	30	21	29
11L	30	27	
1R	25	20	19
2L	30	27	23
3R	24	27	23
4R	34	26	31
5R	29	27	28
6R	28	26	32
7R	30	25	20
8R	19	23	21
9R	30	32	34
10R	30	27	23
11R	23	24	32
12R	26	27	32
Roller Gate 7 – Driven Side			
1	30.0	28.0	30.0
2	25.5	34.6	34.9
3	25.3	27.1	22.0
4	33.9	37.0	30.4
5	31	38.9	38.4
6	29.8	29.9	31.8
7	35.7	34.2	31.4
8	28.3	33.4	28.9
9	34.8	23.2	27.6
10	28.7	26.8	30.1
11	30.5	25.5	31.1
Bolts Removed From Roller Gate 7			
1	43	41	45
2	41	42	40
Unused Bolts From Stock			
1	22	19	23
2	26	21	19
3	20	21	18
4	18	19	19

5 Corrosion Testing

Ohio River Water Analysis

Ohio River water was sampled at the dam and sent to the Illinois Water Survey for analysis. Table 4 shows the results of the analysis. The chlorine level in the water was somewhat elevated and was concentrated in the crevice between the nut and the bolt on the failed bolt tested in the laboratory. The water is not considered aggressive to ferrous-based metals. River water taken at the same time as the analyzed sample was used for all the immersion corrosion tests conducted on the nut and bolt combinations.

The presence of chlorides in the corrosion deposit (0.08 wt.%) and the water quality analysis, which showed the chloride content at 24 mg/L, support the conclusion that some accelerated galvanic and/or crevice corrosion is occurring between the bolt and the nut. This corrosion affects the life expectancy of the bolt and nut by reducing the load-bearing cross section. It is difficult to determine the actual year that the failure would occur based on the measured corrosion notch depth because of the limited exposure time (1 yr) and the fact that only one such bolt was received for analysis. The testing for the remaining bolts described in the next section is closely tied to the ability to determine the remaining life expectancy. Based upon analysis of the corrosion notch depth (0.032 in.) and the estimated rate of corrosion (33 mils/year), the potential exists for a significant reduction in the expected service life.

Table 4. Results of the water analysis at the R.C. Byrd Dam.

Temperature	6.8 °C
Conductivity	271 umho
Dissolved Oxygen	14.9 mg/L
pH	7.3 units
Alkalinity	60 mg/L
Calcium	28.1 mg/L
Magnesium	8.22 mg/L
Sodium	18.6 mg/L
Potassium	1.96 mg/L
Chloride	24.3 mg/L
Sulfate	54.2 mg/L
Hardness	104 mg/L
Total Dissolved Solids	188 mg/L

Corrosion Testing of Bolts, Nuts, and Combinations

A series of bolts were pulled from unused stock and removed from roller gates 2, 6, and 7 for corrosion testing to determine their corrosion resistance and predict the service life of the bolts in use at the R.C Byrd Locks and Dam. Roller gate 2 was in service for 2 years before the bolts were removed for testing. Corrosion rate testing was completed on unused bolts and bolts from gates 7 and 5, and the recent lot of bolts from gate 2. The corrosion rate for each bolt and nut individually, and in bolt and nut combinations, was determined in the laboratory using linear polarization resistance and potentiodynamic scans. Figures 10, 11, and 12 show the specimens as prepared for testing. All the testing was conducted with the specimens immersed in Ohio River water. Figures 13 and 14 show the specimens as tested. Figure 15 shows the test set-up, including the computer that measures the potential for each test sequence. The bolt and nut combinations were spaced 1 in. apart and immersed until the water level just reached the top edge of the nut standing on a flat side in the chamber. The bolt was stood on its threaded end, 1 in. from the nut. The submerged areas were calculated for the individual nuts and bolts and for combinations. At least three linear polarization scans were performed on each specimen. Table 5 contains the results of all the polarization resistance scans. The raw data from these tests are presented in Appendix A.



Figure 10. The Nitronic 60 stainless steel nut ready for testing.



Figure 11. A Type 410 stainless steel bolt ready for testing.

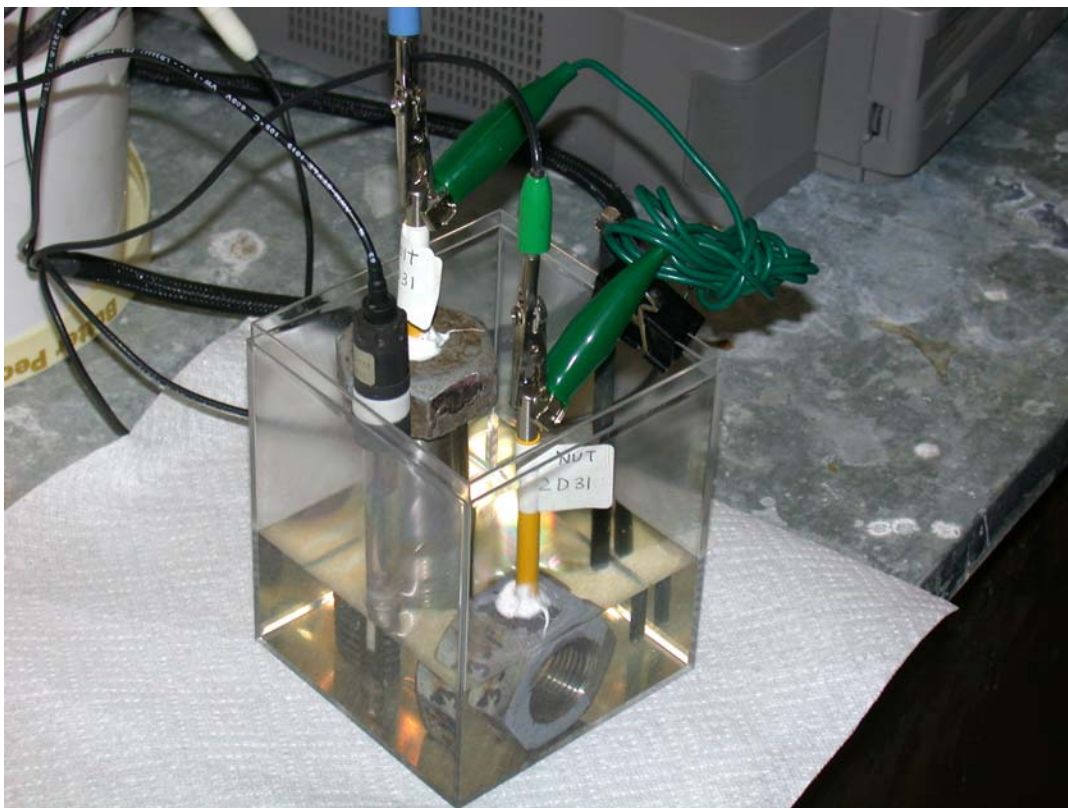


Figure 12. A nut and bolt connected for testing in Ohio River water.



Figure 13. A nut being tested in Ohio River water.



Figure 14. A bolt being tested in Ohio River water.

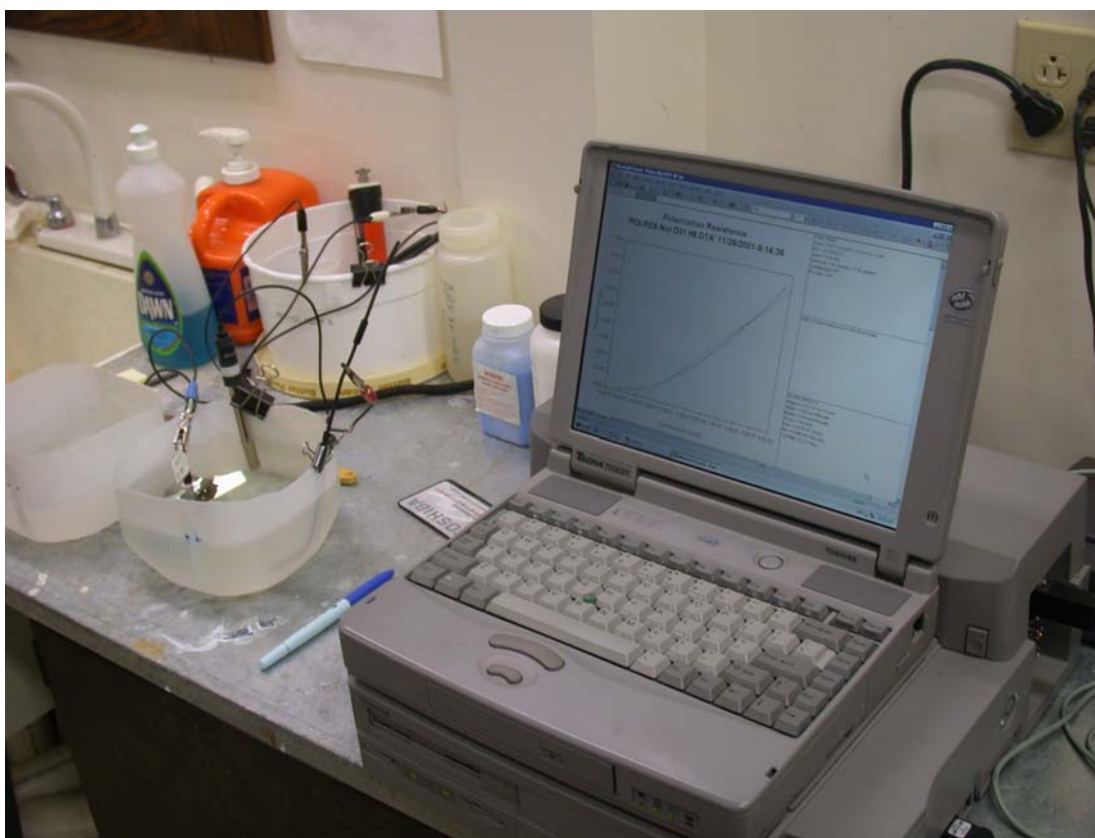


Figure 15. The test set-up for the scans of a nut and bolt combination in Ohio River water.

Table 5. Corrosion rate data for nuts and bolts from R.C. Byrd Locks and Dam.

Date	Scan No.	Item	Ident #	Corrosion Rate (mpy)
2/11/03	1	Nut	2D31	0.076
2/11/03	1a	Nut	2D31	0.072
2/11/03	2	Nut	2D31	0.077
2/11/03	3	Nut	2D31	0.191
2/11/03	4	Nut	2D31	0.180
2/11/03	5	Nut	2D83	0.064
2/11/03	6	Nut	2D83	0.051
2/11/03	7	Nut	2D83	0.049
2/11/03	8	Nut	2D126	0.067
2/11/03	9	Nut	2D126	0.056
2/11/03	10	Nut	2D126	0.062
2/11/03	11	Nut	2D102	0.056
2/11/03	12	Nut	2D102	0.049
2/11/03	13	Nut	2D54	0.121
2/11/03	14	Nut	2D54	0.120
2/11/03	15	Nut	2D15	0.070
2/11/03	16	Nut	2D15	0.064
2/12/03	17	Bolt	2D15	0.123

Date	Scan No.	Item	Ident #	Corrosion Rate (mpy)
2/12/03	18	Bolt	2D15	0.102
2/12/03	19	Bolt	2D15	0.120
2/12/03	20	Bolt	2D54	0.136
2/12/03	21	Bolt	2D54	0.116
2/12/03	22	Bolt	2D54	0.112
2/12/03	23	Bolt	2D102	0.008
2/12/03	24	Bolt	2D102	0.015
2/11/03	25	Bolt	2D102	0.017
2/12/03	26	Bolt	2D126	0.045
2/12/03	27	Bolt	2D126	0.042
2/12/03	28	Bolt	2D126	0.043
2/12/03	29	Bolt	2D83	0.007
2/12/03	30	Bolt	2D83	0.007
2/12/03	31	Bolt	2D83	0.006
2/12/03	32	Bolt	2D31	0.141
2/12/03	33	Bolt	2D31	0.136
2/12/03	34	Bolt	2D31	0.133
2/13/03	35	Nut-Bolt	2D31	0.119
2/13/03	36	Nut-Bolt	2D31	0.118
2/13/03	37	Nut-Bolt	2D31	0.119
2/11/03	38	Nut-Bolt	2D83	0.022
2/11/03	39	Nut-Bolt	2D83	0.018
2/11/03	40	Nut-Bolt	2D83	0.020
2/11/03	41	Nut-Bolt	2D126	0.022
2/13/03	42	Nut-Bolt	2D126	0.022
2/13/03	43	Nut-Bolt	2D126	0.020
2/13/03	44	Nut-Bolt	2D102	0.017
2/13/03	45	Nut-Bolt	2D102	0.014
2/13/03	46	Nut-Bolt	2D102	0.018
2/13/03	47	Nut-Bolt	2D54	0.073
2/13/03	48	Nut-Bolt	2D54	0.065
2/13/03	49	Nut-Bolt	2D54	0.071
2/13/03	50	Nut-Bolt	2D15	0.138
2/13/03	51	Nut-Bolt	2D15	0.131
2/13/03	52	Nut-Bolt	2D15	0.118
2/13/03	53	Nut-Bolt	2D15	0.726
2/12/03	54	Nut-Bolt	2D54	0.181
2/12/03	55	Nut-Bolt	2D102	0.061
2/12/03	56	Nut-Bolt	2D126	0.122
2/12/03	57	Nut-Bolt	2D83	0.086
2/12/03	58	Nut-Bolt	2D31	0.695

Date	Scan No.	Item	Ident #	Corrosion Rate (mpy)
11/29/01	59	Bolt	5D15	0.060
11/28/01	60	Bolt	5D15	0.230
11/28/01	61	Bolt	7B	0.628
11/29/01	62	Bolt	7B	0.817
11/30/01	63	Bolt	7B	0.940
11/29/01	64	Bolt	7C	0.825
11/28/01	65	Bolt	7C	0.845
11/30/01	66	Bolt	7C	0.988
11/29/01	67	Bolt	B11	0.091
11/28/01	68	Bolt	B11B	0.078
11/28/01	69	Bolt	B11B	0.085
11/28/01	70	Bolt	B11B	0.098
11/30/01	71	Bolt	B42	1.097
11/29/01	72	Bolt	B42	1.119
11/29/01	73	Bolt	B42B	0.034
11/30/01	74	Bolt	5-D10-2	0.639
11/29/01	75	Bolt	5-D10-2	0.644
11/29/01	76	Bolt	5-D12-6	0.665
11/30/01	77	Bolt	5-D3-1	0.794
11/29/01	78	Bolt	5-D3-1	0.900
11/30/01	79	Bolt	5-D3-1	1.049
11/30/01	80	Bolt	5-D3-1	1.495
11/29/01	81	Bolt	5-D5-4	0.417
11/30/01	82	Bolt	5-D5-4	0.658
11/29/01	83	Bolt	5-D8-3	0.820
11/30/01	84	Bolt	5-D8-3	0.854
11/29/01	85	Bolt	B32	0.790
11/30/01	86	Bolt	B32	0.812
11/29/01	87	Bolt	B-32-B	0.714
11/30/01	88	Bolt	B-32-B	0.758
12/3/01	89	Nut-Bolt	7A to D15	0.880
12/3/01	90	Nut-Bolt	7A to D15	0.902
12/3/01	91	Nut-Bolt	7C to 7C	1.071
12/3/01	92	Nut-Bolt	7C to B11B	1.154
12/3/01	93	Nut-Bolt	B11B to B11B	0.273
12/3/01	94	Nut-Bolt	5-D3-1 to D-83	0.949
11/30/01	95	Nut	7C	0.036
11/29/01	96	Nut	7C	0.070
11/29/01	97	Nut	B42B	0.039
11/29/01	98	Nut	A54	0.047
11/29/01	99	Nut	B32	0.282

Date	Scan No.	Item	Ident #	Corrosion Rate (mpy)
11/29/01	100	Nut	D126	0.100
11/29/01	101	Nut	D31	0.223
11/28/01	102	Nut	D31	0.234
11/29/01	103	Nut	D31	0.244
11/29/01	104	Nut	D83	0.011
11/30/01	105	Nut	D83	0.032

The corrosion rates, both as measured and as physically observed, of all the temper embrittled specimens were dramatically different than the remaining specimens. The corrosion rate for the temper embrittled bolts averaged 0.8 mils per year (mpy), resulting in a metal loss of between 0.17 to a low of 0.086 pounds of metal over 20 years. The non-temper embrittled bolts such as those retrieved from gate 2 had an average of 0.07 mpy. The nuts had a corrosion rate of 0.07 mpy. The nut and bolt combinations had, as expected, a slightly higher corrosion rate of 0.12 mpy. The slightly higher corrosion rate for the nut and bolt combination is a result of galvanic corrosion occurring between the 400 series stainless steel bolts and the Cr-Ni-Mn stainless steel nuts. The low corrosion rates for the non-temper embrittled bolts would result in a metal loss of approximately 0.008 pounds over 20 years. The metal loss of the nuts would be approximately the same. The nut and bolt combinations would result in a slightly higher loss over 20 years. Figures 16 and 17 show the differences in corrosion products on the temper embrittled versus the non-temper embrittled bolts.



Figure 16. The corrosion products on a temper embrittled bolt after 48 hours immersion in Ohio River water.



Figure 17. A non-temper embrittled bolt after 48 hours in Ohio River water.

6 Conclusions and Recommendations

The primary cause of failure of the bolts sampled from roller gates 6 and 7 at the R.C. Byrd Dam is temper embrittlement. The microstructure of the bolts examined revealed brittle fractures, with the fracture mode being intergranular. The presence of chlorides accelerated the galvanic corrosion that occurred between the bolts and nuts.

The temper embrittled bolts have approximately 10 times higher corrosion rate immersed in Ohio River water than the non-temper embrittled bolts. The non-temper embrittled bolts should have a 40- to 50-year service life expectancy, assuming the Ohio River water chemistry does not change significantly.

The suggested material replacement is a martensitic age-hardenable stainless steel combining the very good corrosion resistance characteristics of Type 304 stainless steel and the moderate strength characteristics of Type 410 stainless steel. Either ARMCO 17-4 PH stainless steel or Carpenter Custom 450 stainless steel is recommended for use in aqueous environments where high strength and corrosion resistance is required.

References

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Bloodsworth, John O., 1999, "Examination of a Failed Split Nut Bolt," Report No. 16961, Q.C. Metallurgical Laboratory, Inc., 17048 215th Street, Davenport, IA 52804, August 30, 1999.

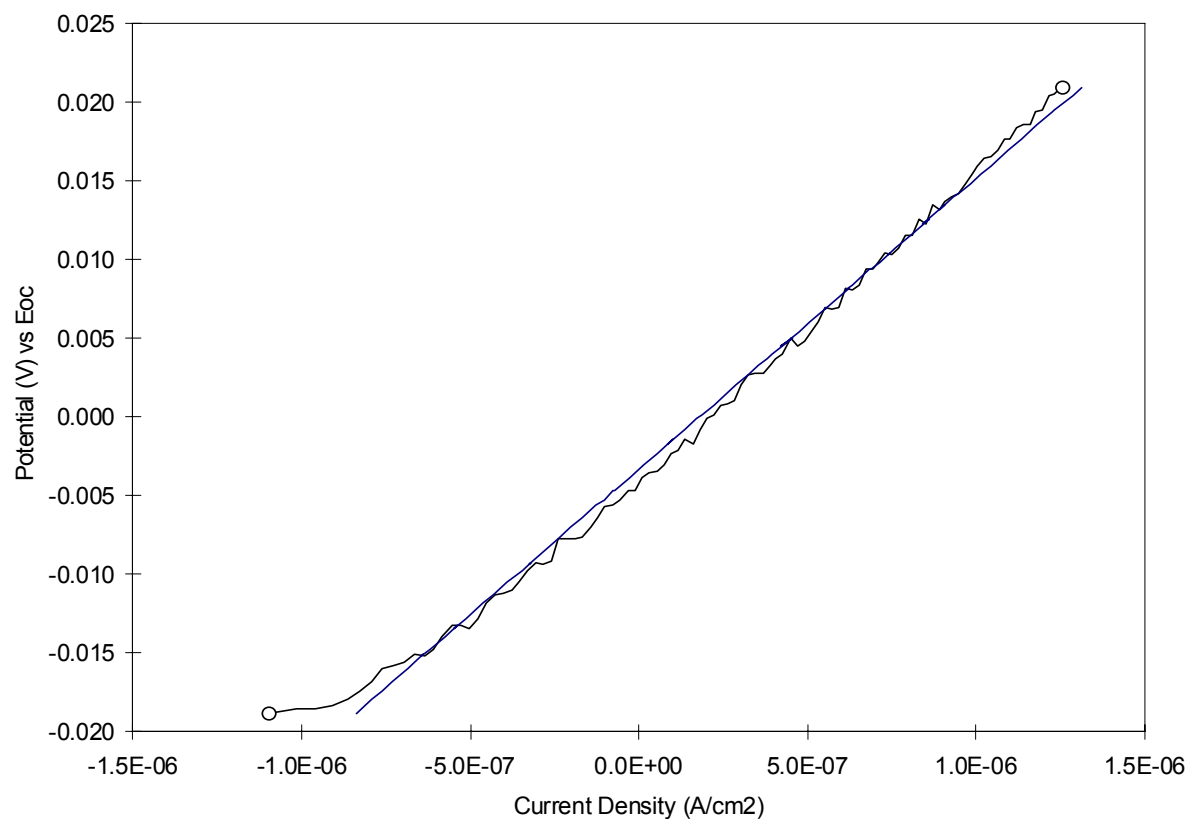
Kumar, Ashok, L.D. Stephenson, and Paul Willis, 2002, *Advanced Materials Selection Guide for Lock, Dam, and Hydroelectric Plant Components*, U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) Technical Report (TR)-02-7, January 2002.

Nakonechny, Michael J., 2001, "Examination of Failed Bolt Samples from Roller Gates 6 & 7," Reference No. T100985, BodyCote Taussig, Inc., 7530 Frontage Road, Skokie, IL, 60077, February 20, 2001.

Peckner, Donald and I.M. Bernstein, 1977, *Handbook of Stainless Steels*, McGraw-Hill Book Company, NY.

Appendix A: Linear Polarization Test Data on Stainless Steel Bolts and Nuts for the R.C. Byrd Locks and Dam

Polarization Resistance
'POLRES Bolt 5-D10-2 #10.DTA' 11/29/2001-
11:37:28

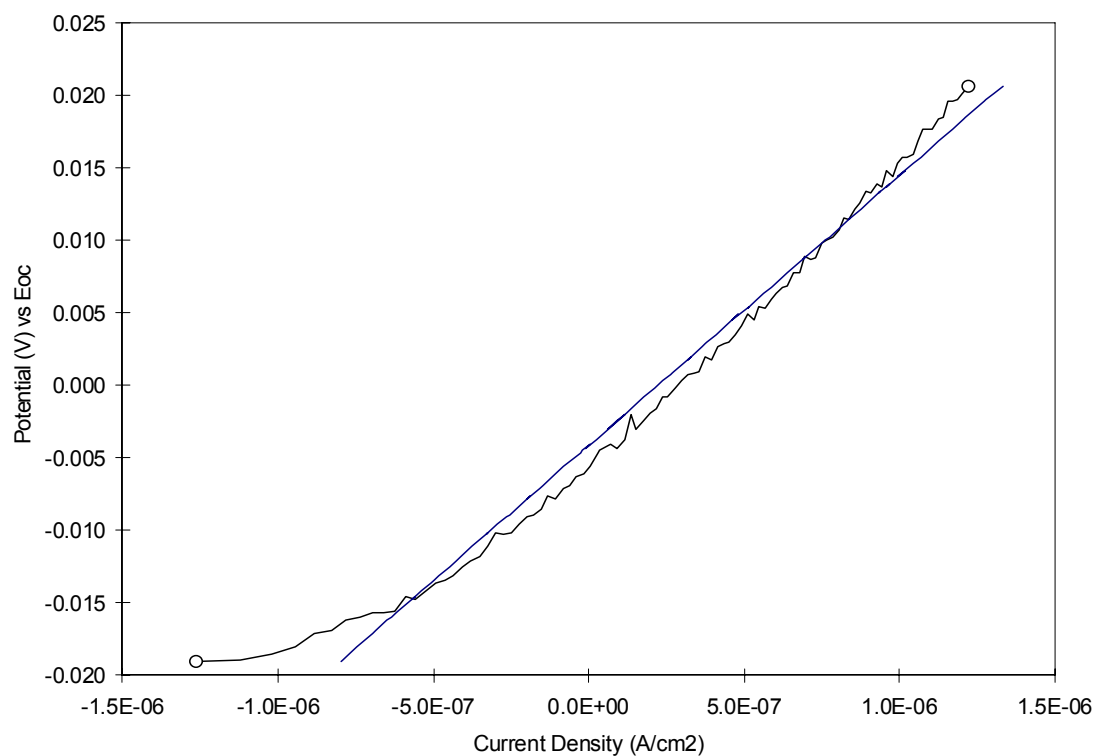


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.410032 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -18.8 mV to 21.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -413.3 mV
 Icorr = 1.409E-06 A/cm2
 Rp = 1.849E+04 Ohm cm2
 CorrRate = 0.644 mpy

Polarization Resistance
'POLRES Bolt 5-D10-2 #30.DTA' 11/30/2001-
13:36:17

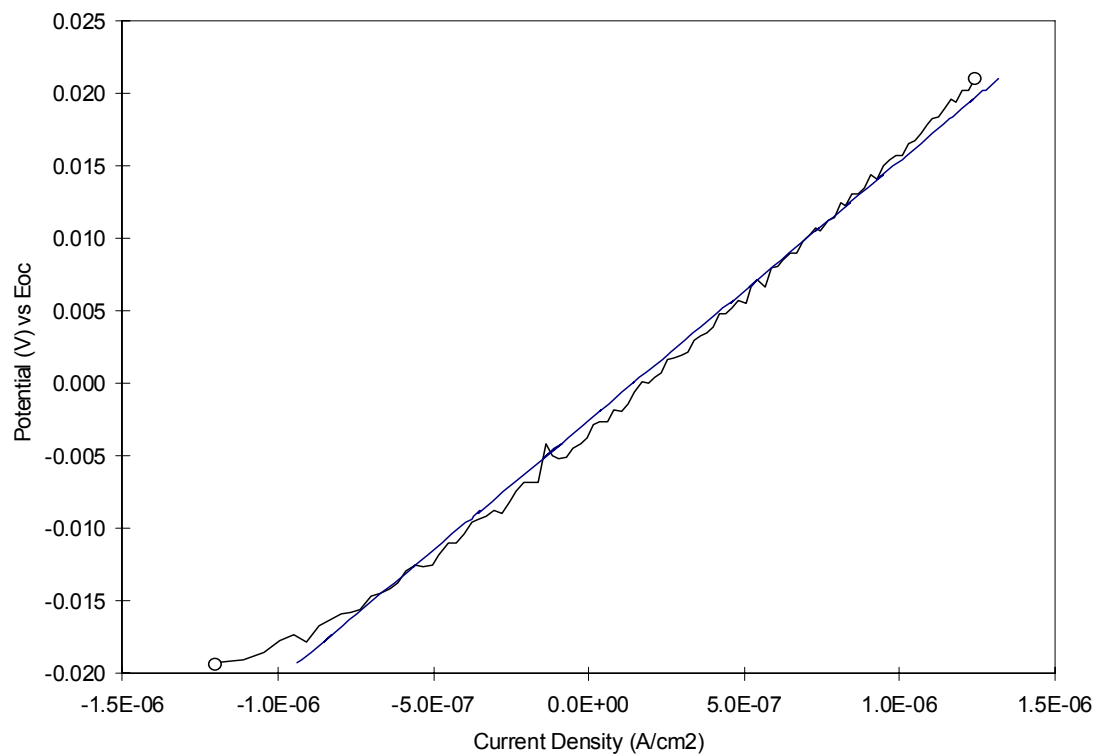


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.311038 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -19.0 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -315.2 mV
 Icorr = 1.398E-06 A/cm2
 Rp = 1.864E+04 Ohm cm2
 CorrRate = 0.639 mpy

Polarization Resistance
'POLRES Bolt 5-D12-6 #9.DTA' 11/29/2001-
10:57:11

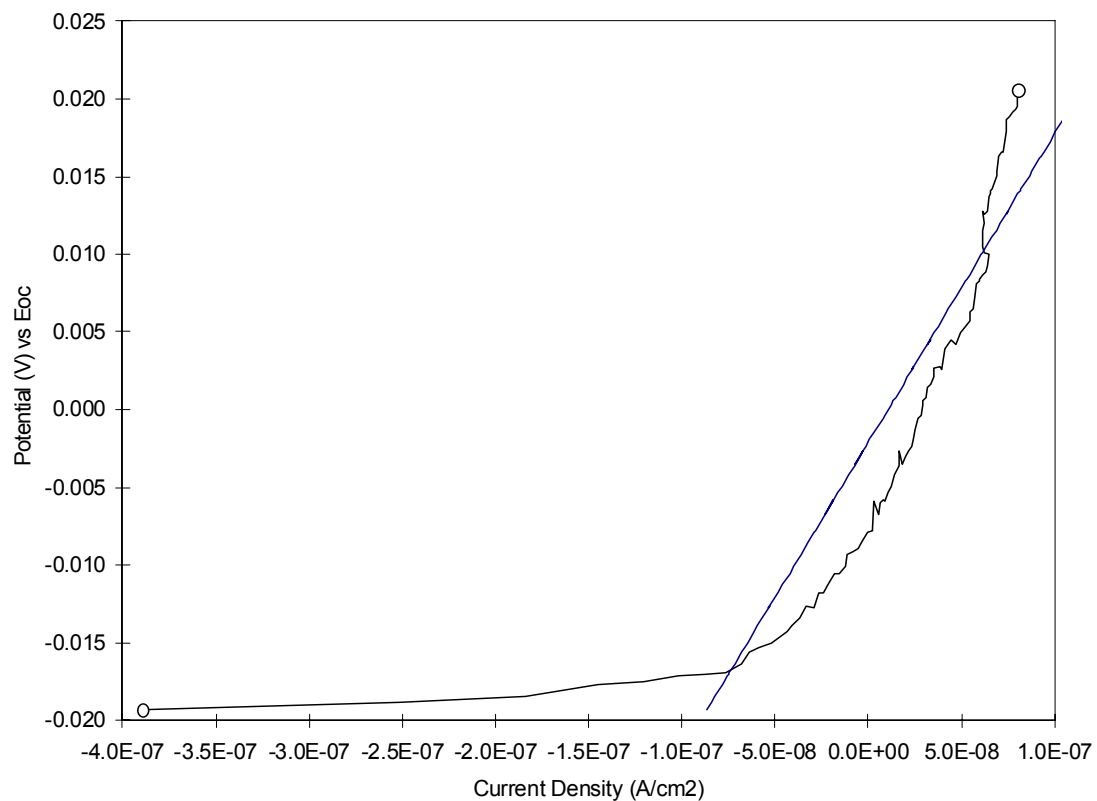


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.456049 V
 Area: 91.941 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on Small Size Bolt

POLRES RESULTS
 Region = -19.3 mV to 21.1 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -458.6 mV
 Icorr = 1.456E-06 A/cm2
 Rp = 1.790E+04 Ohm cm2
 CorrRate = 0.665 mpy

Polarization Resistance **'POLRES Bolt 5D15 #18.DTA' 11/29/2001-14:45:0**

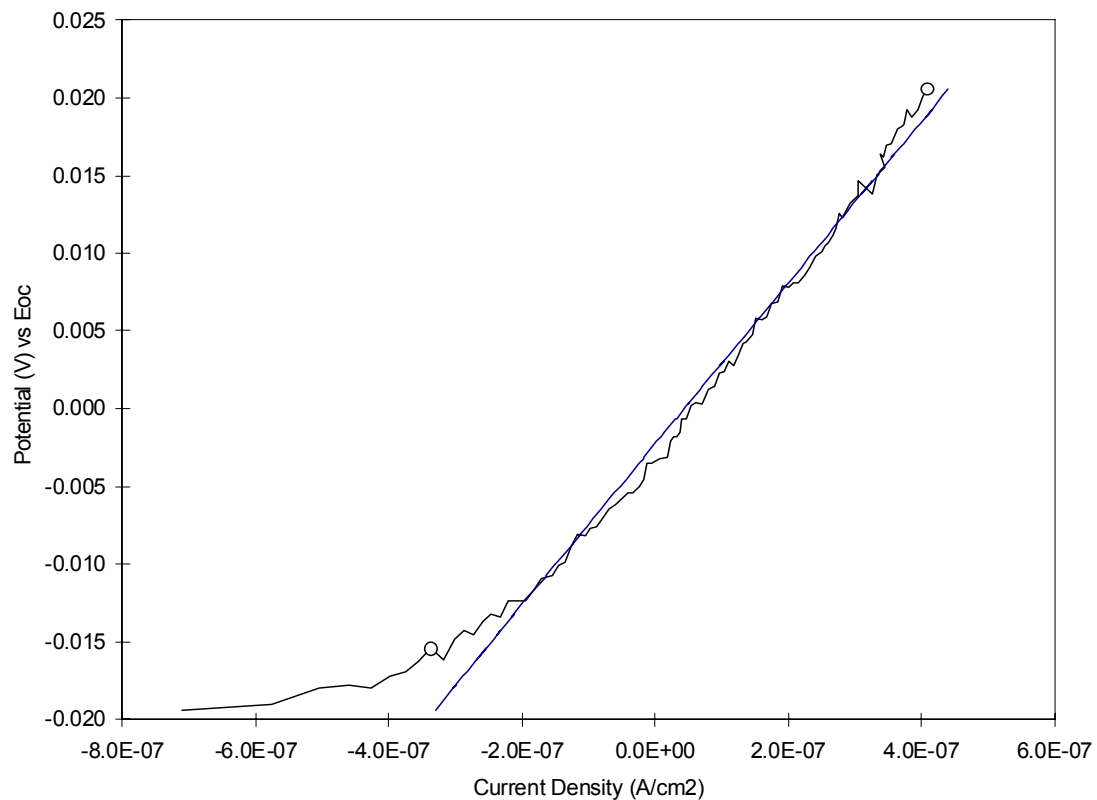


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.152018 V
 Area: 121.6 cm²
 Electrode: 7.87 gm/cm³, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio river Water on large size bolt

POLRES RESULTS
 Region = -19.3 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -154.1 mV
 Icorr = 1.310E-07 A/cm²
 Rp = 1.990E+05 Ohm cm²
 CorrRate = 0.060 mpy

Polarization Resistance **'POLRES Bolt 5D15 #6.DTA' 11/28/2001-18:7:29**

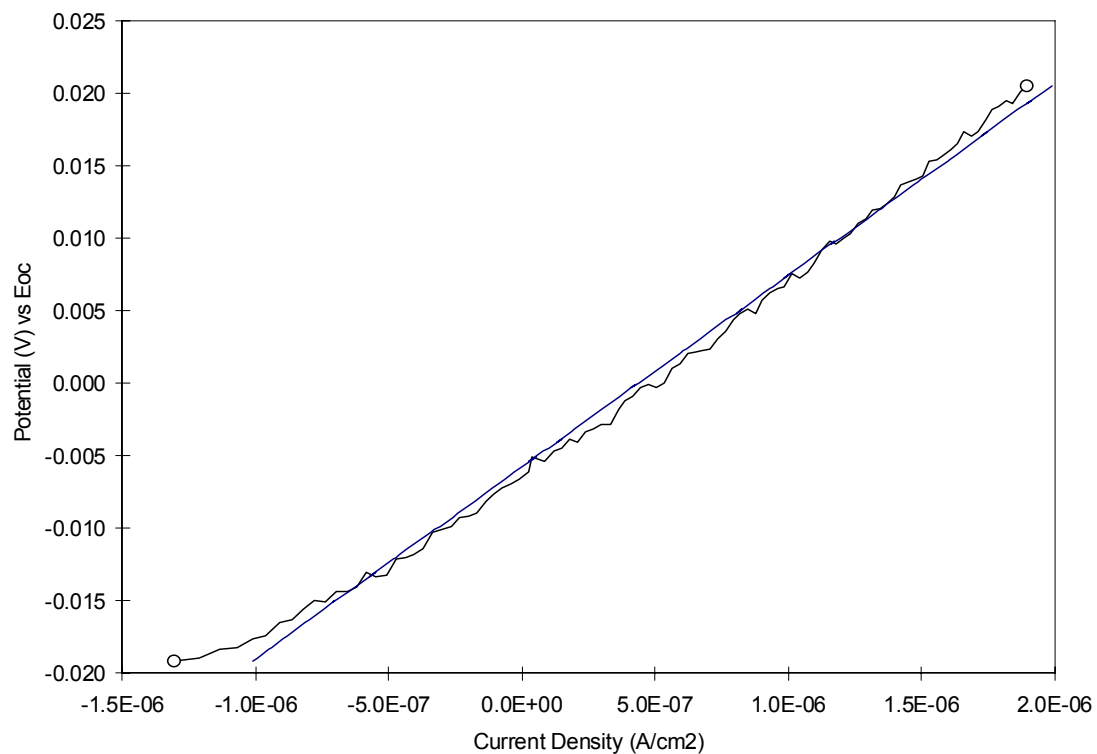


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.269736 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water

POLRES RESULTS
 Region = -15.4 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -272.0 mV
 Icorr = 5.025E-07 A/cm2
 Rp = 5.185E+04 Ohm cm2
 CorrRate = 0.230 mpy

Polarization Resistance
'POLRES Bolt 5-D3-1 #11.DTA' 11/29/2001-
11:54:26

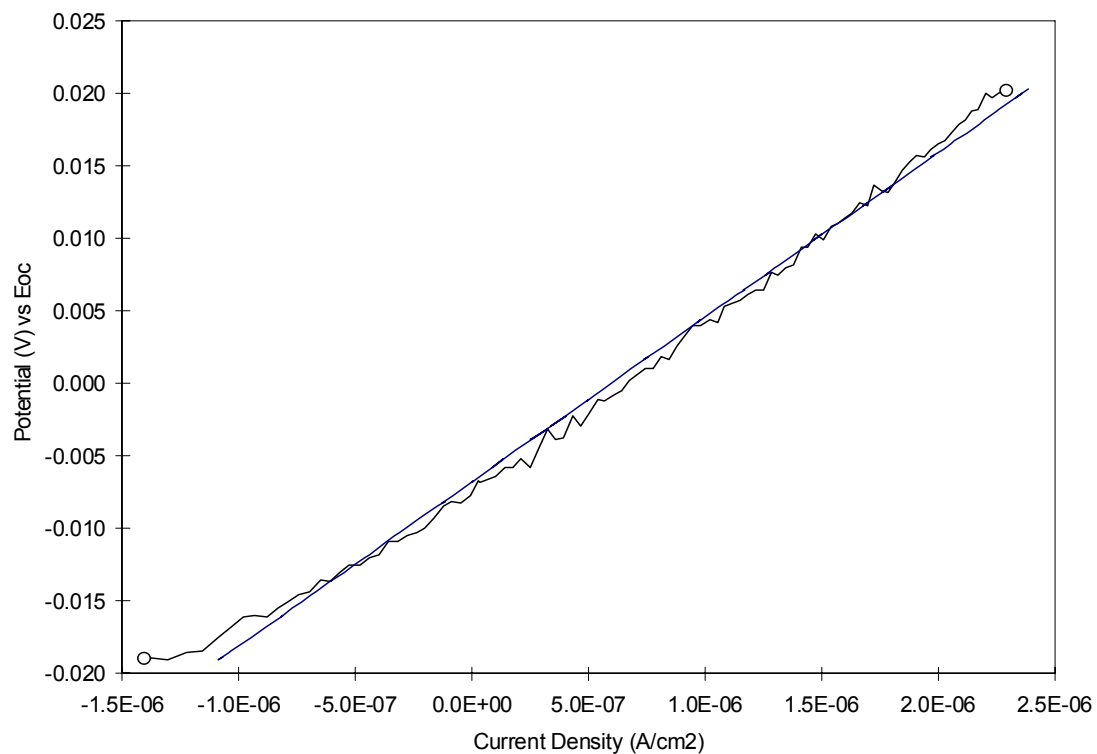


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.545332 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt
 Lots of scoring and scuffing marks on shank of bolt

POLRES RESULTS
 Region = -19.1 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -551.1 mV
 Icorr = 1.970E-06 A/cm2
 Rp = 1.323E+04 Ohm cm2
 CorrRate = 0.900 mpy

Polarization Resistance
'POLRES Bolt 5-D3-1 #31.DTA' 11/30/2001-
13:46:2

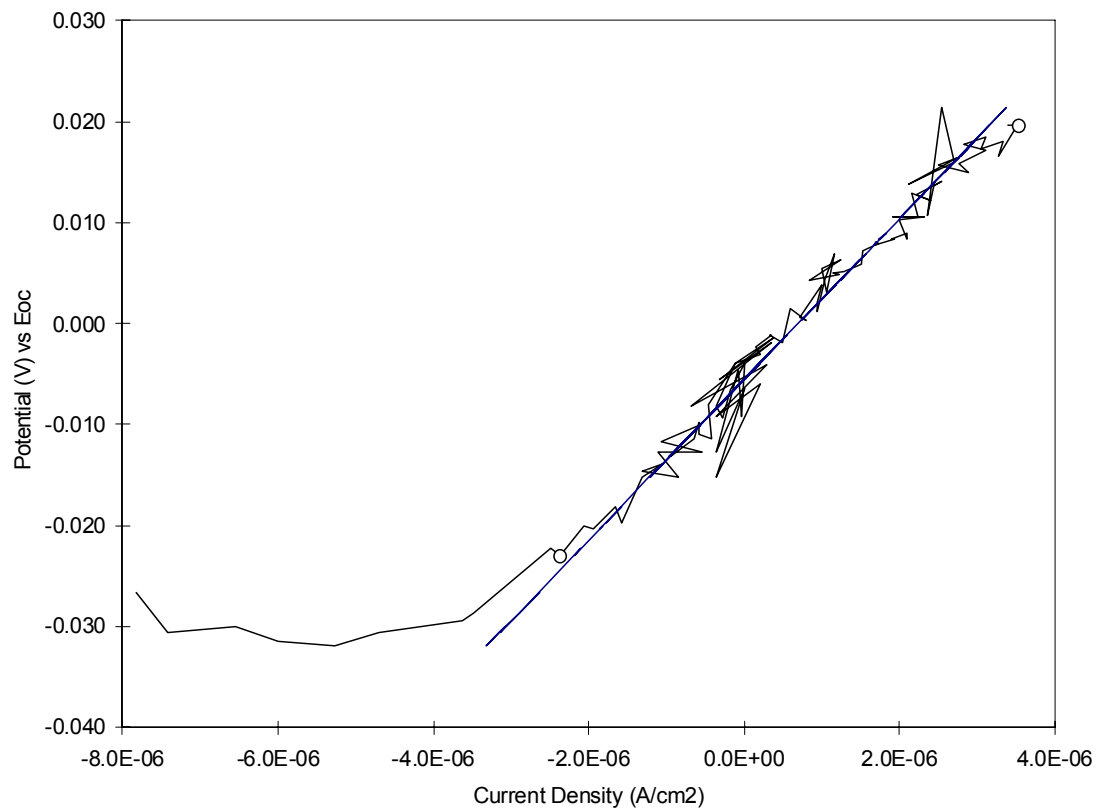


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.531264 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -18.9 mV to 20.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -538.0 mV
 Icorr = 2.297E-06 A/cm2
 Rp = 1.135E+04 Ohm cm2
 CorrRate = 1.049 mpy

Polarization Resistance **'POLRES Bolt 5-D3-1 #39.DTA' 11/30/2001-16:35:59**

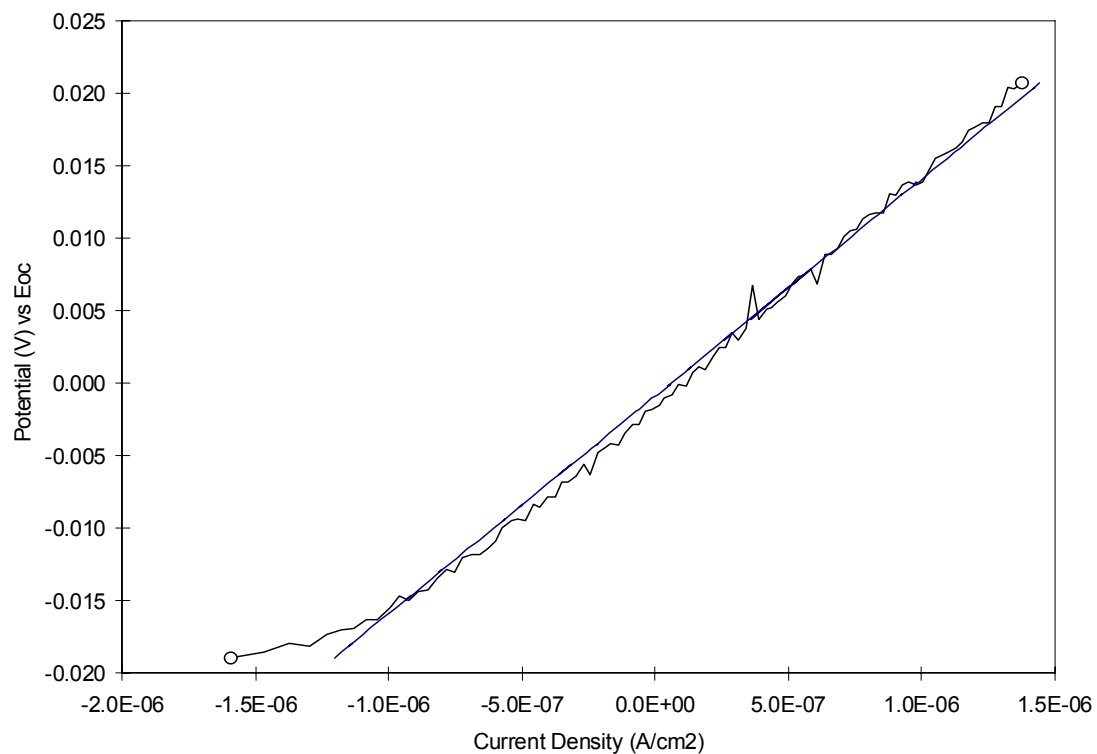


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.542734 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: ON

Ohio River Water on Small Size bolt with Galling on Shank, ReRun with IR Comp on

POLRES RESULTS
 Region = -23.0 mV to 19.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -548.3 mV
 Icorr = 3.271E-06 A/cm2
 Rp = 7.966E+03 Ohm cm2
 CorrRate = 1.495 mpy

Polarization Resistance
'POLRES Bolt 5-D3-1 #40.DTA' 11/30/2001-
17:14:13

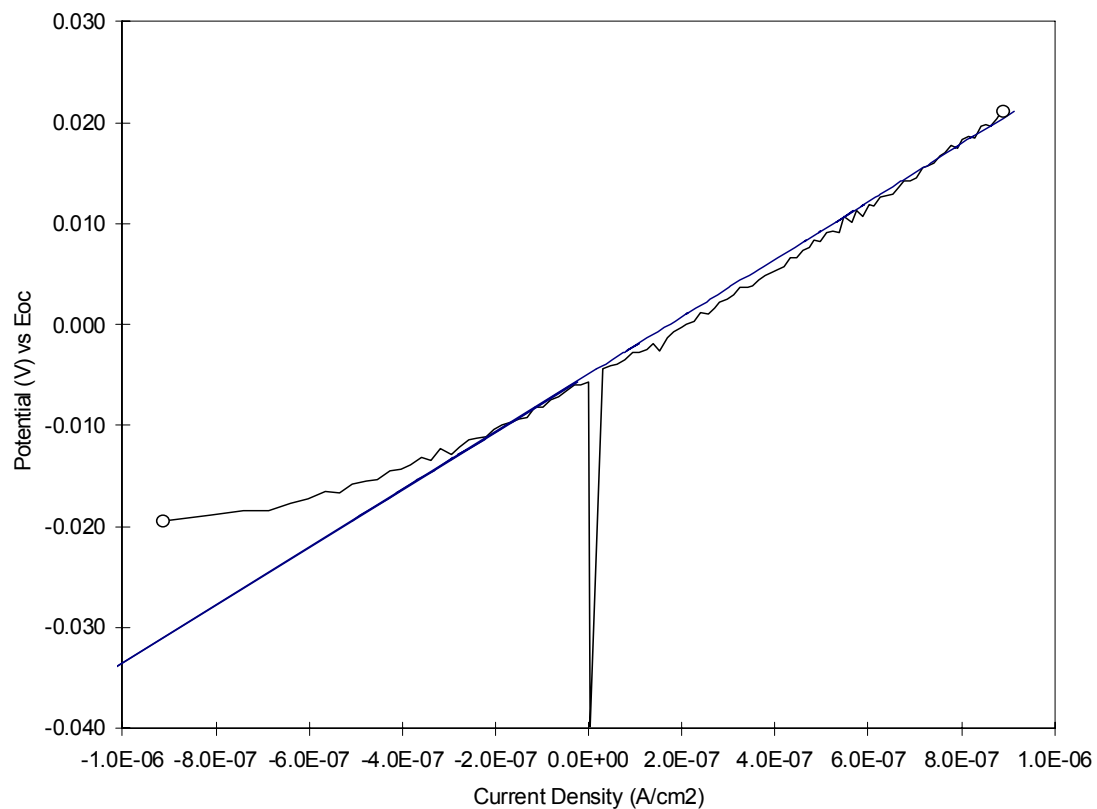


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.54282 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Rerun without IR comp - all other same conditions as #39

POLRES RESULTS
 Region = -18.9 mV to 20.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -543.7 mV
 Icorr = 1.738E-06 A/cm2
 Rp = 1.499E+04 Ohm cm2
 CorrRate = 0.794 mpy

Polarization Resistance **'POLRES Bolt 5-D5-4 #13.DTA' 11/29/2001-12:17:47**

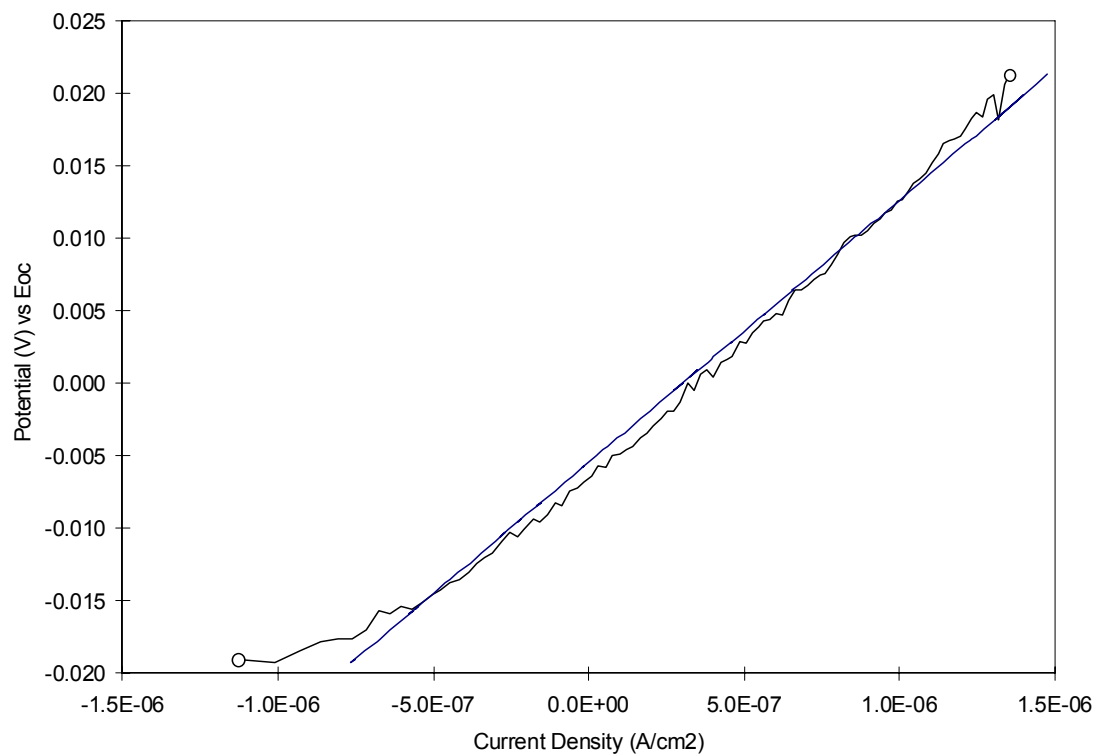


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.292617 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -19.4 mV to 21.2 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -297.6 mV
 Icorr = 9.127E-07 A/cm2
 Rp = 2.855E+04 Ohm cm2
 CorrRate = 0.417 mpy

Polarization Resistance
'POLRES Bolt 5-D5-4 #33.DTA' 11/30/2001-
14:12:2

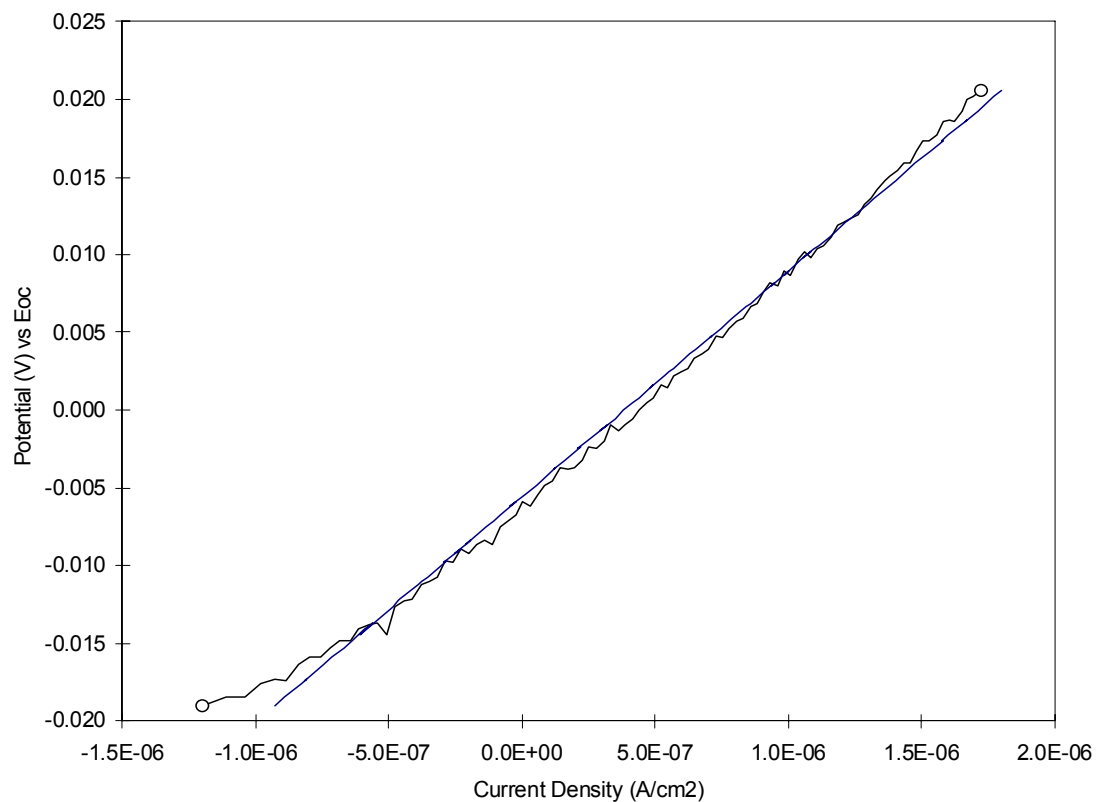


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.315464 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on Small Bolt Rerun

POLRES RESULTS
 Region = -19.1 mV to 21.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -320.9 mV
 Icorr = 1.439E-06 A/cm2
 Rp = 1.811E+04 Ohm cm2
 CorrRate = 0.658 mpy

Polarization Resistance **'POLRES Bolt 5-D8-3 #15.DTA' 11/29/2001-14:6:1**

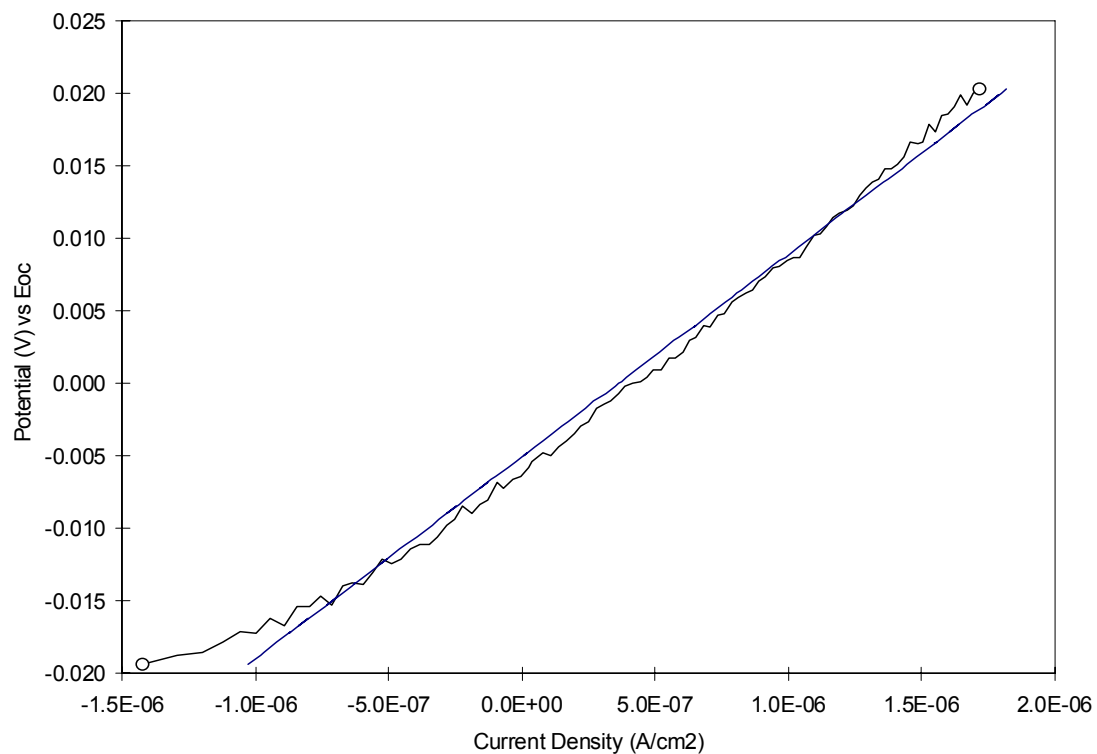


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.567638 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -19.0 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -573.2 mV
 Icorr = 1.794E-06 A/cm2
 Rp = 1.453E+04 Ohm cm2
 CorrRate = 0.820 mpy

Polarization Resistance
'POLRES Bolt 5-D8-3 #35.DTA' 11/30/2001-
14:38:41



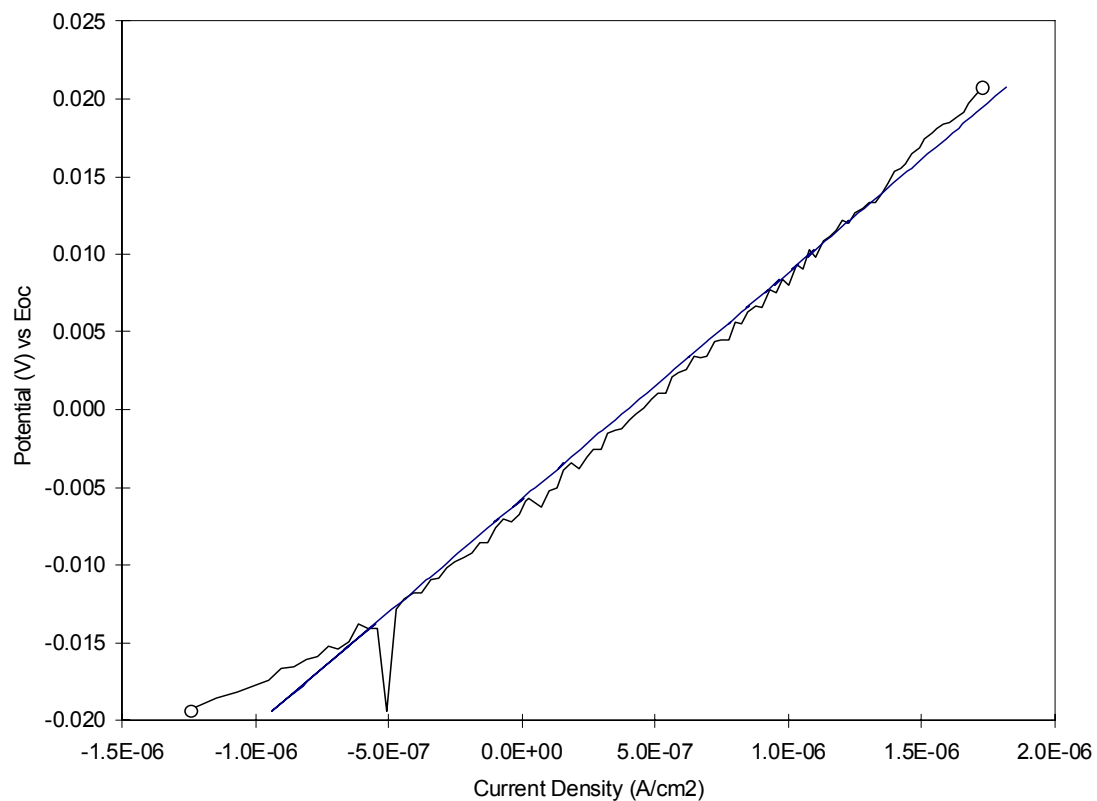
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.503013 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small bolt

POLRES RESULTS
 Region = -19.3 mV to 20.4 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -508.0 mV
 Icorr = 1.869E-06 A/cm2
 Rp = 1.394E+04 Ohm cm2
 CorrRate = 0.854 mpy

Polarization Resistance

'POLRES Bolt 7-B #19.DTA' 11/29/2001-14:57:1

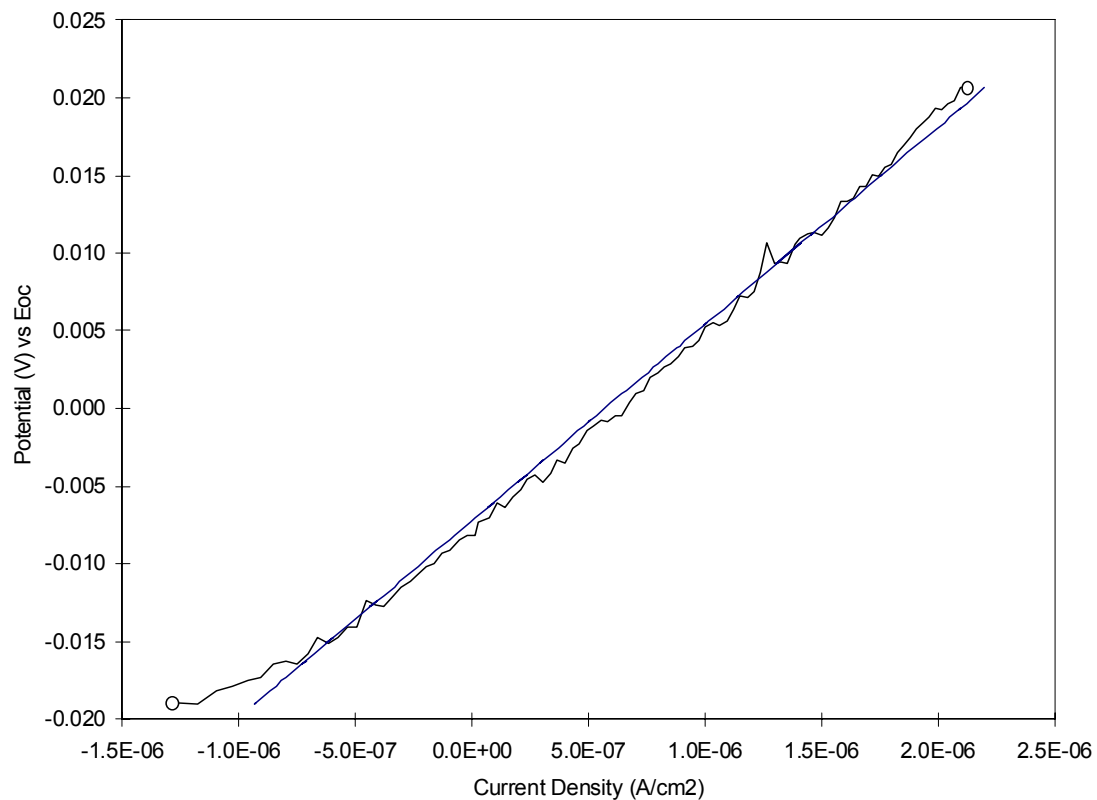


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.503189 V
Area: 121.6 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

Ohio River Water on large size bolt

POLRES RESULTS
Region = -19.4 mV to 20.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -508.9 mV
Icorr = 1.789E-06 A/cm2
Rp = 1.457E+04 Ohm cm2
CorrRate = 0.817 mpy

Polarization Resistance **'POLRES Bolt 7-B #28.DTA' 11/30/2001-13:11:54**

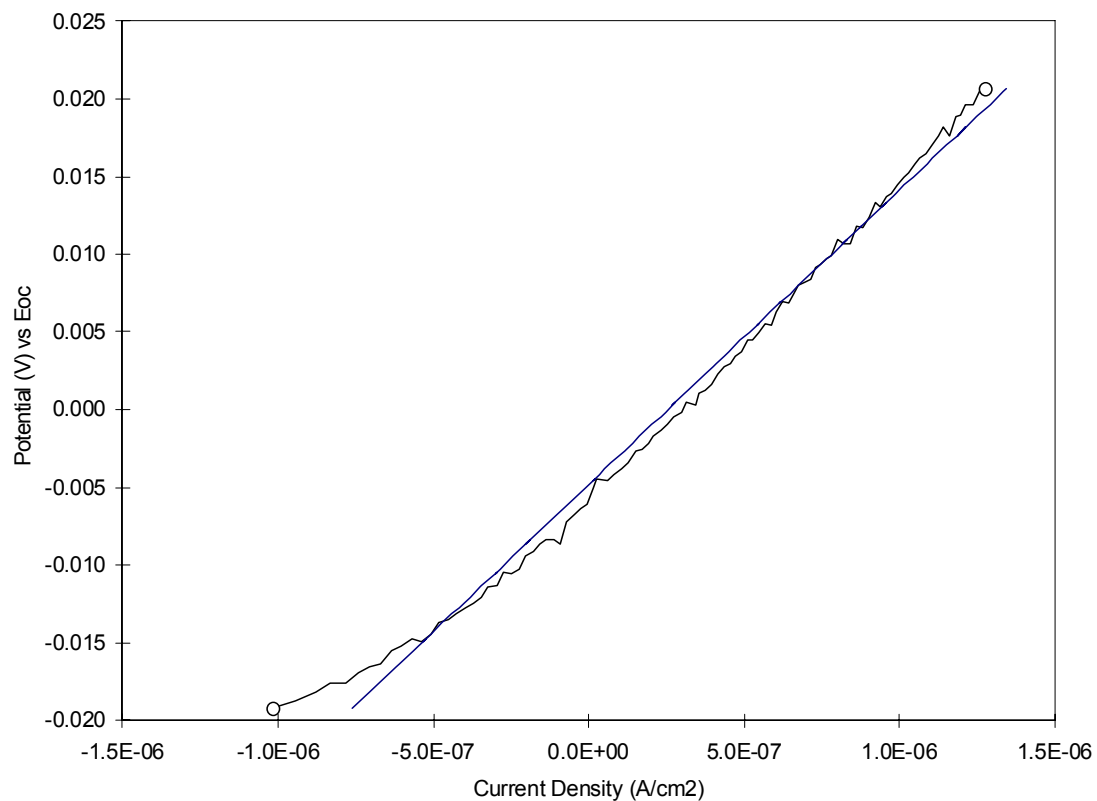


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.444487 V
 Area: 121.6 cm²
 Electrode: 7.87 gm/cm³, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on large size bolt

POLRES RESULTS
 Region = -19.0 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -451.7 mV
 Icorr = 2.058E-06 A/cm²
 Rp = 1.266E+04 Ohm cm²
 CorrRate = 0.940 mpy

Polarization Resistance
'POLRES Bolt 7B #4.DTA' 11/28/2001-17:29:0

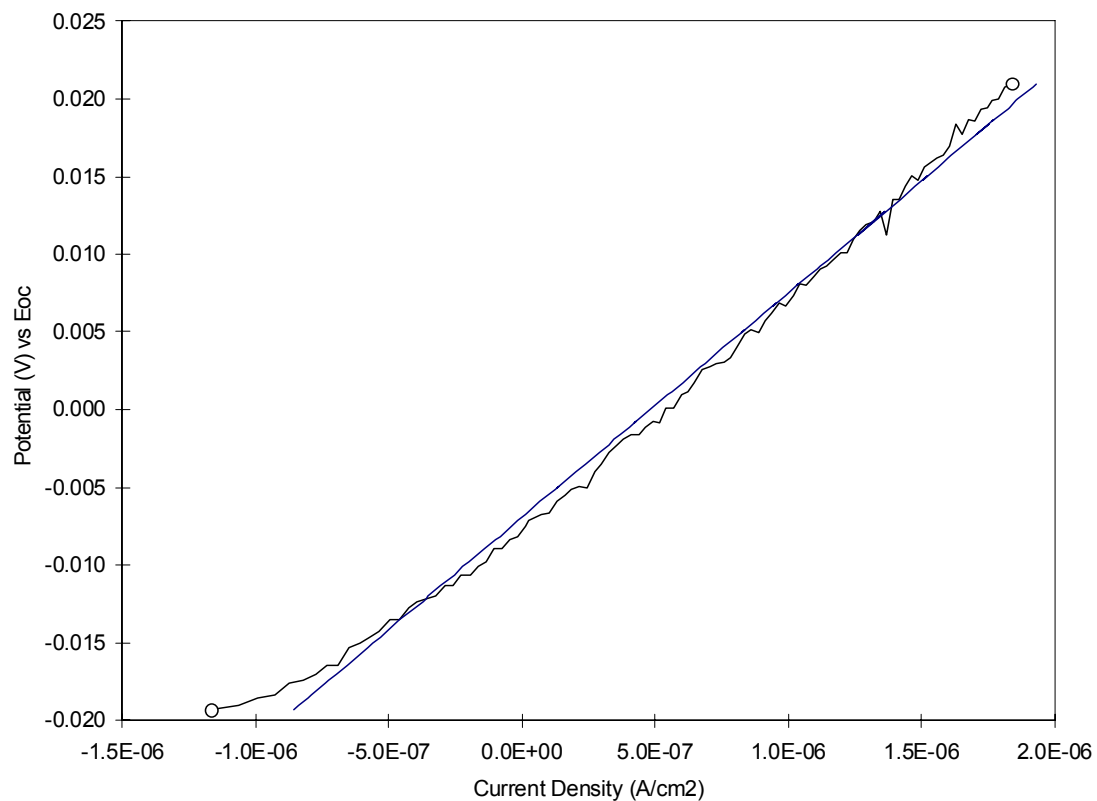


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.555103 V
Area: 121.6 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

Ohio River Water

POLRES RESULTS
Region = -19.2 mV to 20.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -559.9 mV
Icorr = 1.375E-06 A/cm2
Rp = 1.896E+04 Ohm cm2
CorrRate = 0.628 mpy

Polarization Resistance **'POLRES Bolt 7-C #20.DTA' 11/29/2001-15:17:47**

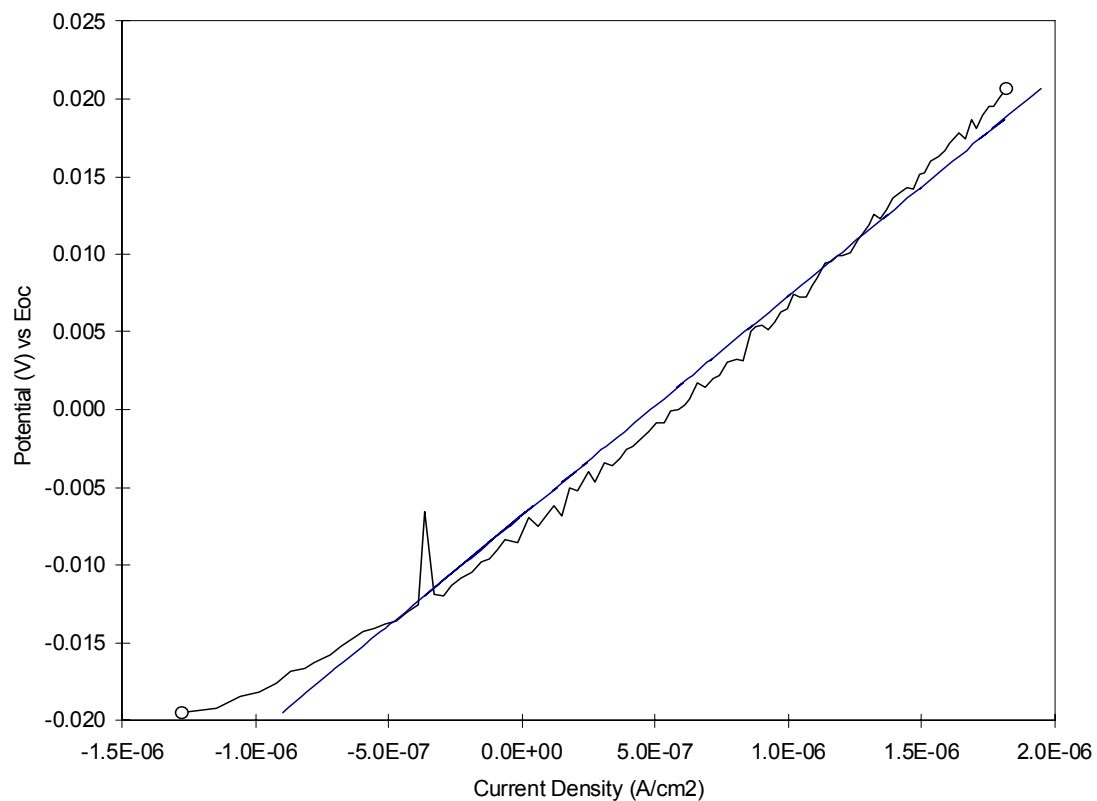


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.477217 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on large size bolt

POLRES RESULTS
 Region = -19.3 mV to 21.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -484.1 mV
 Icorr = 1.805E-06 A/cm2
 Rp = 1.444E+04 Ohm cm2
 CorrRate = 0.825 mpy

Polarization Resistance **'POLRES Bolt 7C #5.DTA' 11/28/2001-17:45:59**

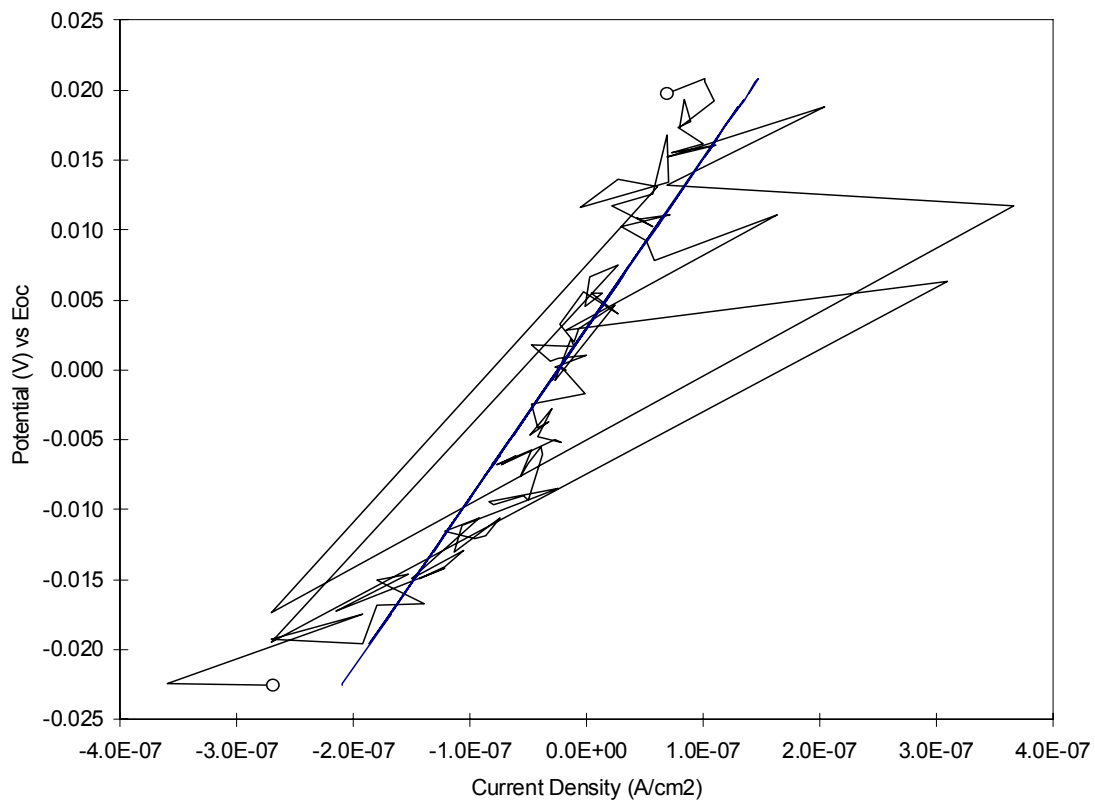


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.52536 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water

POLRES RESULTS
 Region = -19.5 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -532.2 mV
 Icorr = 1.848E-06 A/cm2
 Rp = 1.410E+04 Ohm cm2
 CorrRate = 0.845 mpy

Polarization Resistance **'POLRES Bolt B11 #1.DTA' 11/28/2001-16:38:59**



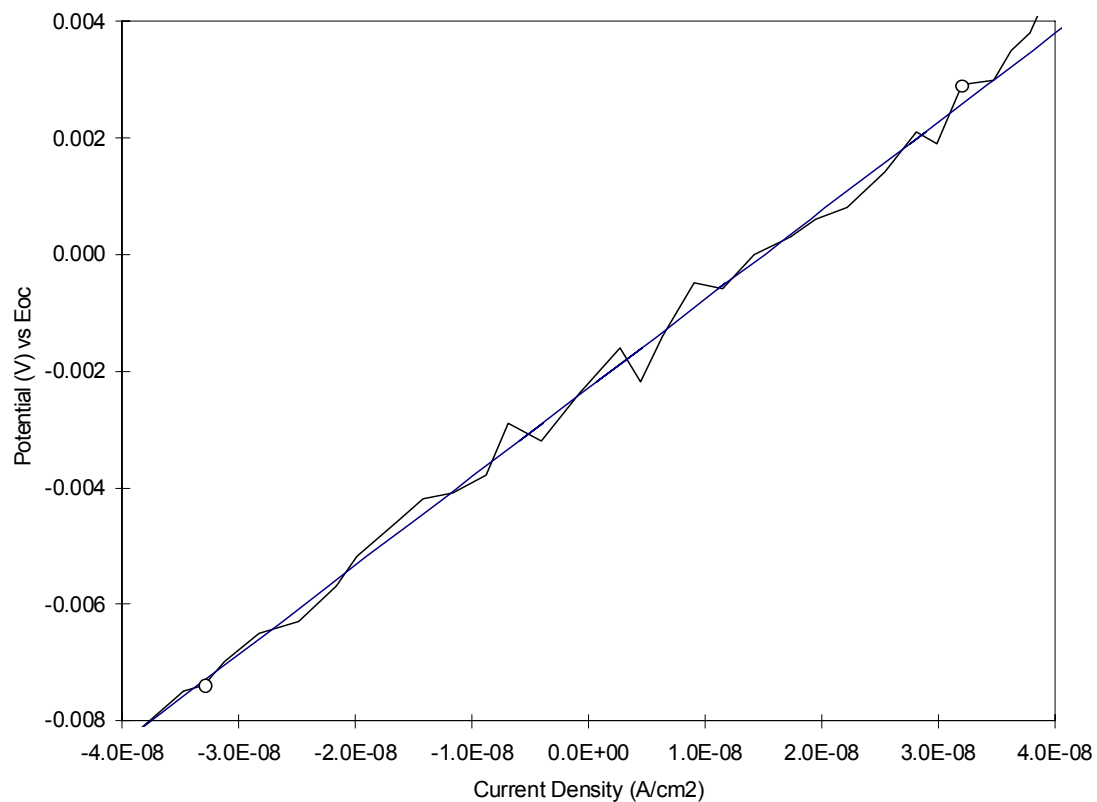
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.233188 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: ON

Ohio River Water

POLRES RESULTS
 Region = -22.5 mV to 19.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -230.2 mV
 Icorr = 2.150E-07 A/cm2
 Rp = 1.212E+05 Ohm cm2
 CorrRate = 0.098 mpy

Polarization Resistance

'POLRES Bolt B11 #2.DTA' 11/28/2001-16:59:11

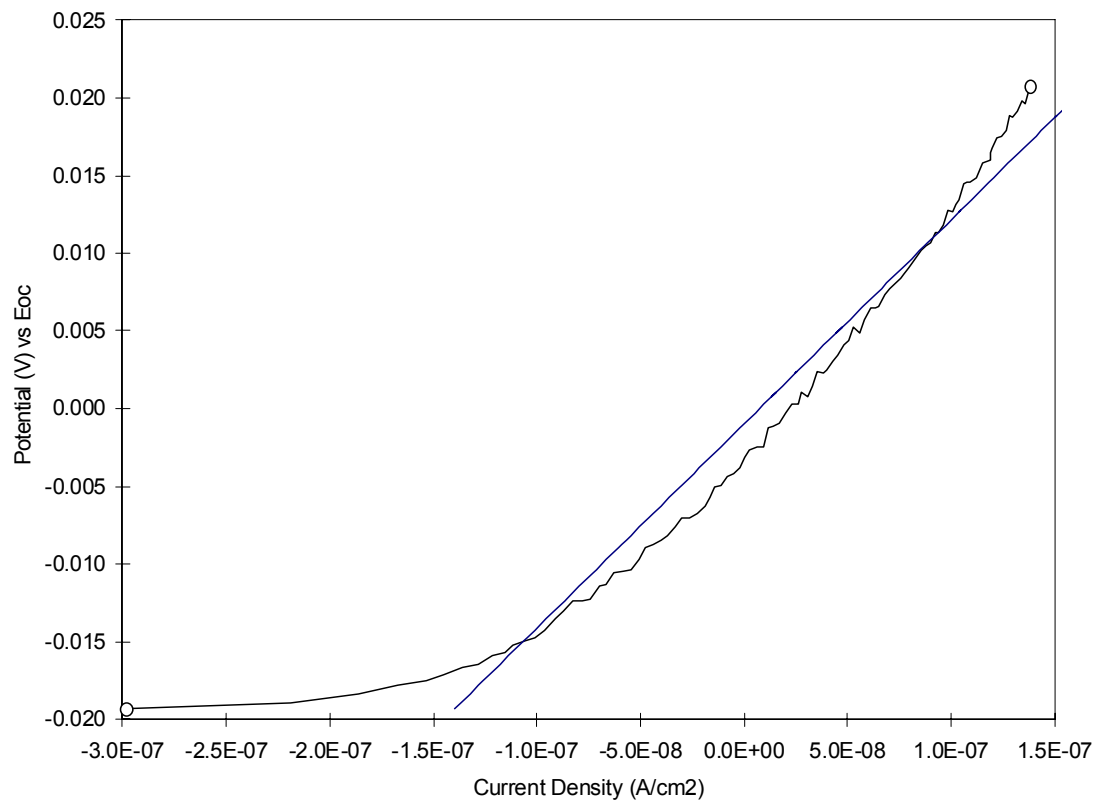


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.211261 V
Area: 121.6 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

NOTES
Ohio River Water

POLRES RESULTS
Region = -7.4 mV to 2.9 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -213.5 mV
Icorr = 1.713E-07 A/cm2
Rp = 1.522E+05 Ohm cm2
CorrRate = 0.078 mpy

Polarization Resistance **'POLRES Bolt B11 #21.DTA' 11/29/2001-15:28:34**



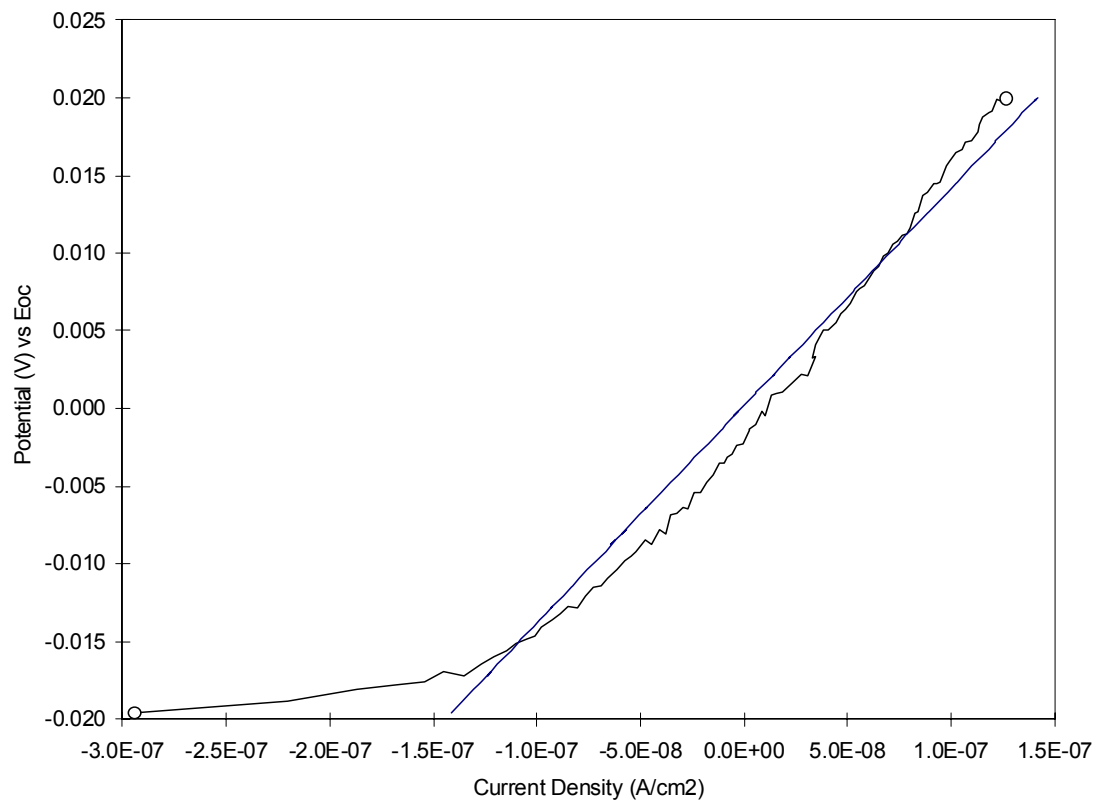
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.208511 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on large size bolt

POLRES RESULTS
 Region = -19.3 mV to 20.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -209.5 mV
 Icorr = 1.983E-07 A/cm2
 Rp = 1.314E+05 Ohm cm2
 CorrRate = 0.091 mpy

Polarization Resistance

'POLRES Bolt B11 #3.DTA' 11/28/2001-17:7:29



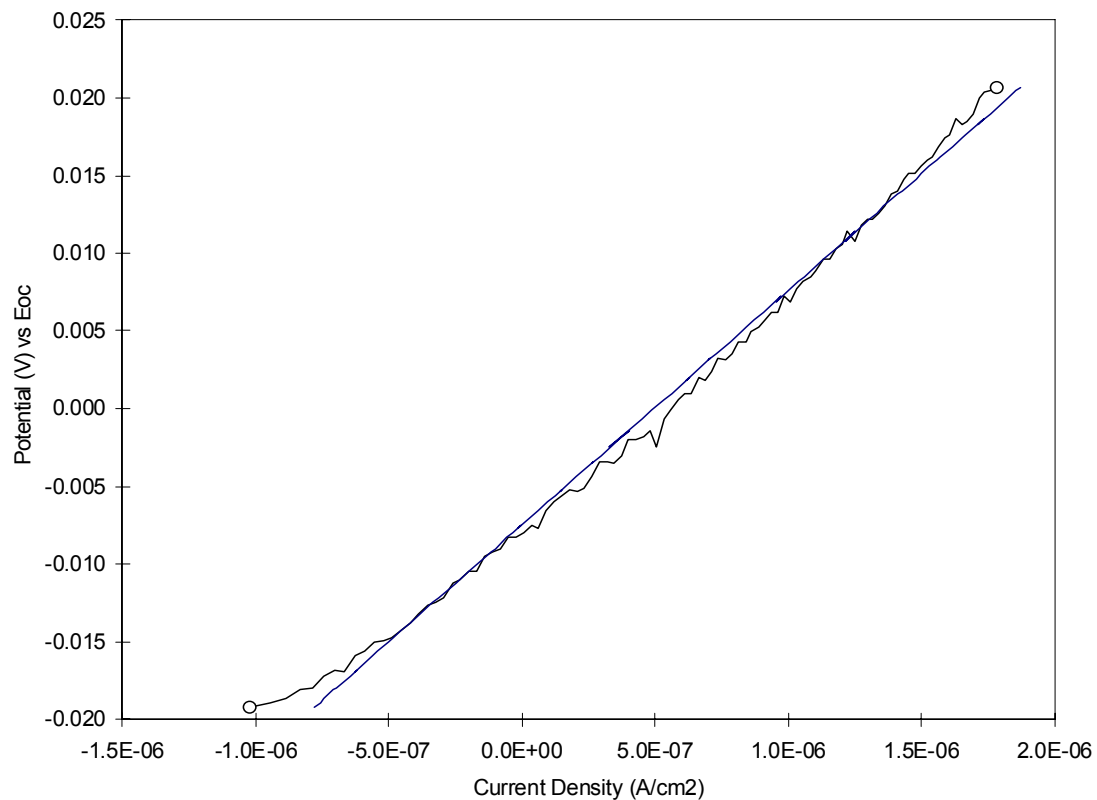
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.212166 V
Area: 121.6 cm²
Electrode: 7.87 gm/cm³, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

NOTES

POLRES RESULTS

Region = -19.6 mV to 20.0 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -212.0 mV
Icorr = 1.861E-07 A/cm²
Rp = 1.400E+05 Ohm cm²
CorrRate = 0.085 mpy

Polarization Resistance **'POLRES Bolt B32 #12.DTA' 11/29/2001-12:6:46**

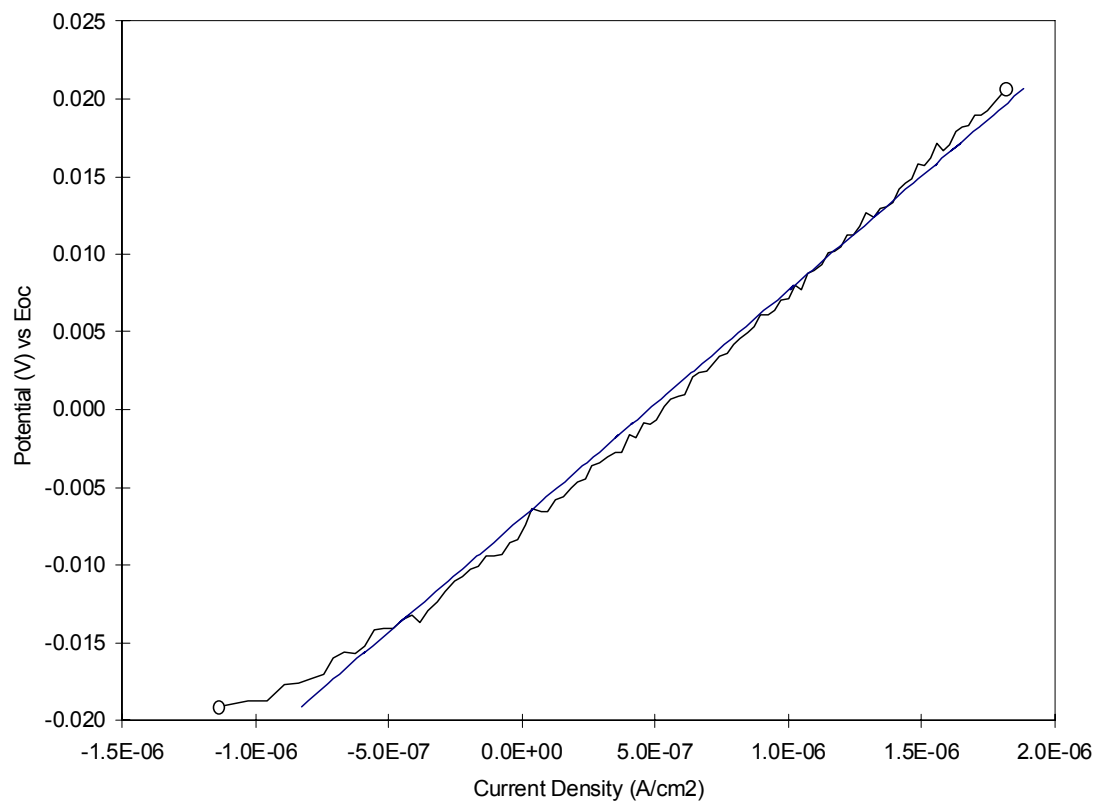


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.450449 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -19.2 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -457.9 mV
 Icorr = 1.730E-06 A/cm2
 Rp = 1.506E+04 Ohm cm2
 CorrRate = 0.790 mpy

Polarization Resistance
'POLRES Bolt B32 #32.DTA' 11/30/2001-13:55:52

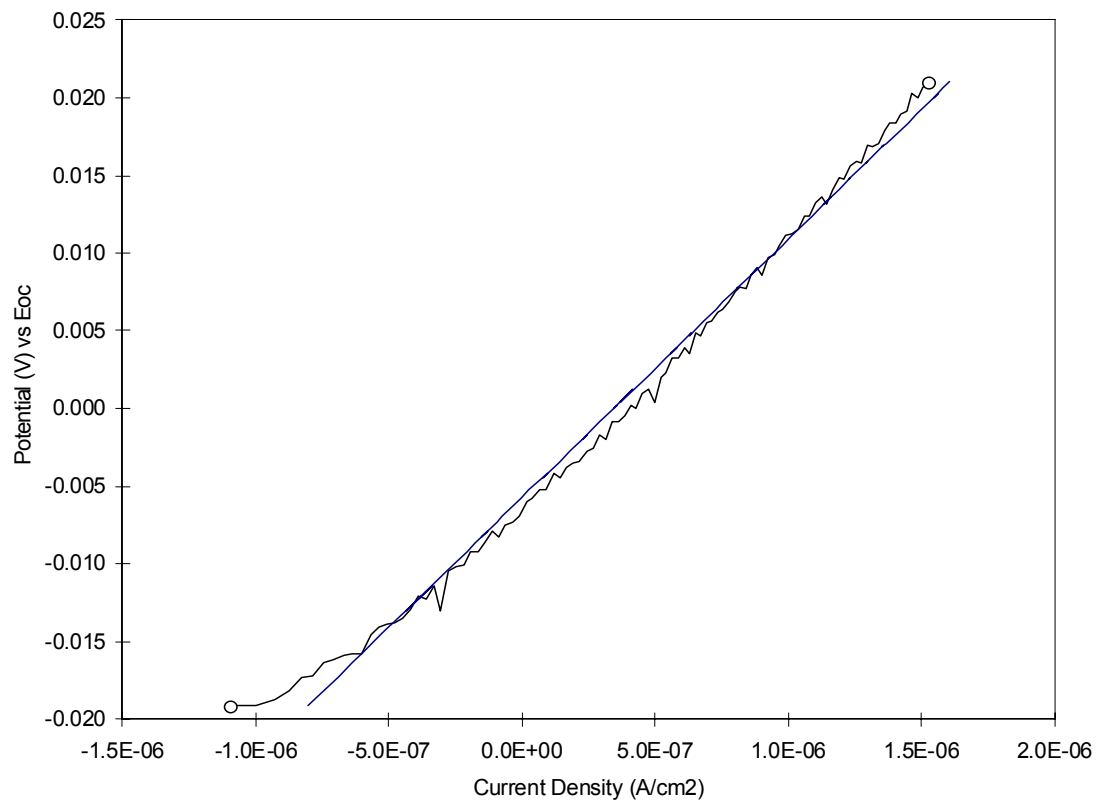


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.361408 V
Area: 91.9 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

NOTES

POLRES RESULTS
Region = -19.1 mV to 20.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -368.4 mV
Icorr = 1.778E-06 A/cm2
Rp = 1.466E+04 Ohm cm2
CorrRate = 0.812 mpy

Polarization Resistance **'POLRES Bolt B32-B #14.DTA' 11/29/2001-13:4:30**

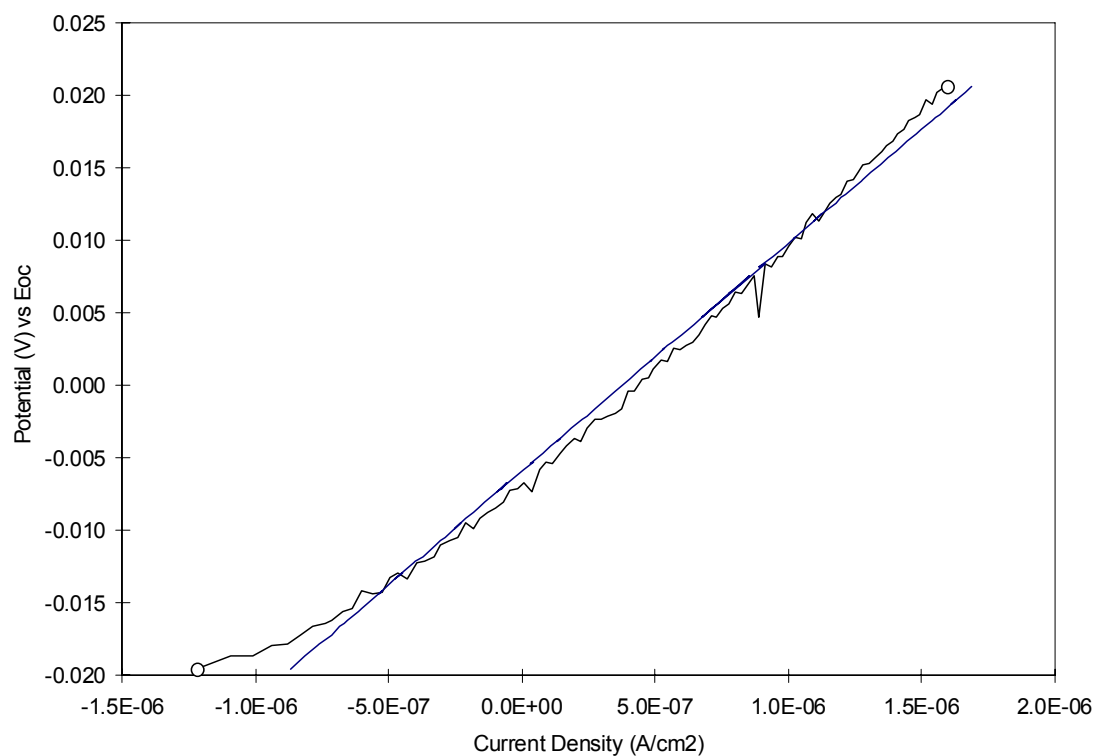


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.397269 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on Small Size Bolt

POLRES RESULTS
 Region = -19.2 mV to 21.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -403.0 mV
 Icorr = 1.563E-06 A/cm2
 Rp = 1.667E+04 Ohm cm2
 CorrRate = 0.714 mpy

Polarization Resistance
'POLRES Bolt B-32-B #34.DTA' 11/30/2001-
14:23:43

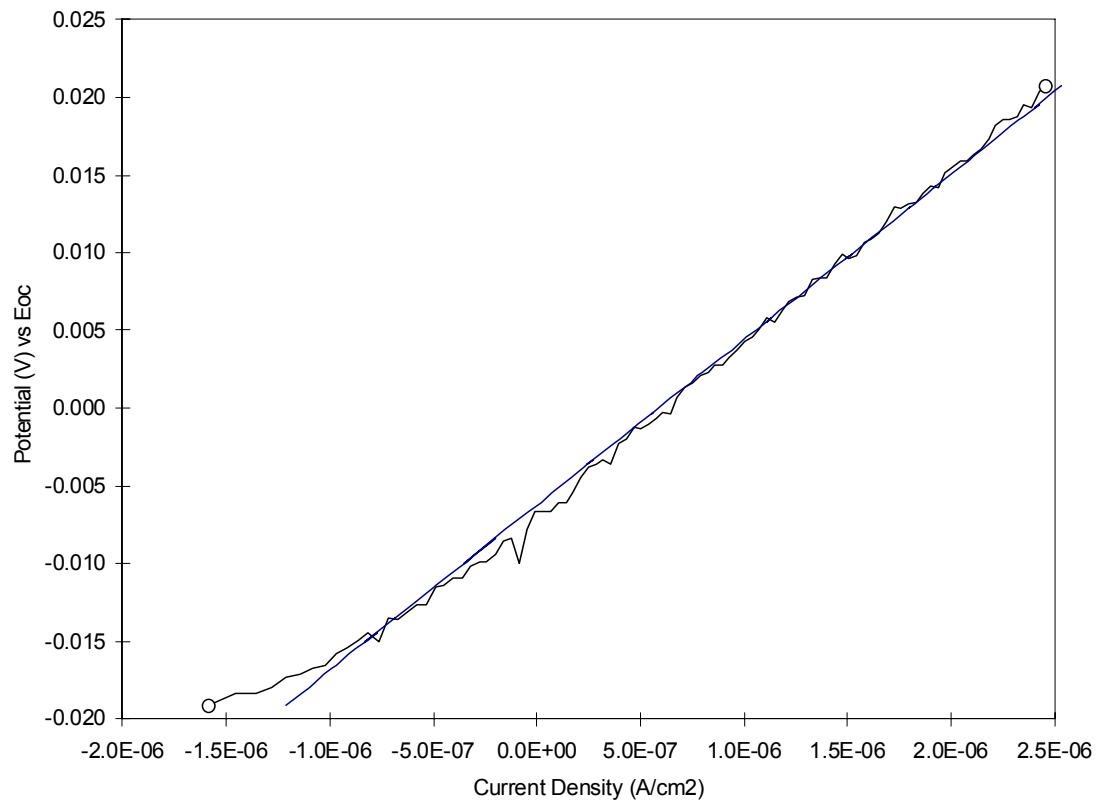


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.321293 V
 Area: 91.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size bolt

POLRES RESULTS
 Region = -19.6 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -327.2 mV
 Icorr = 1.658E-06 A/cm2
 Rp = 1.572E+04 Ohm cm2
 CorrRate = 0.758 mpy

Polarization Resistance **'POLRES Bolt B42 #16.DTA' 11/29/2001-14:19:5**



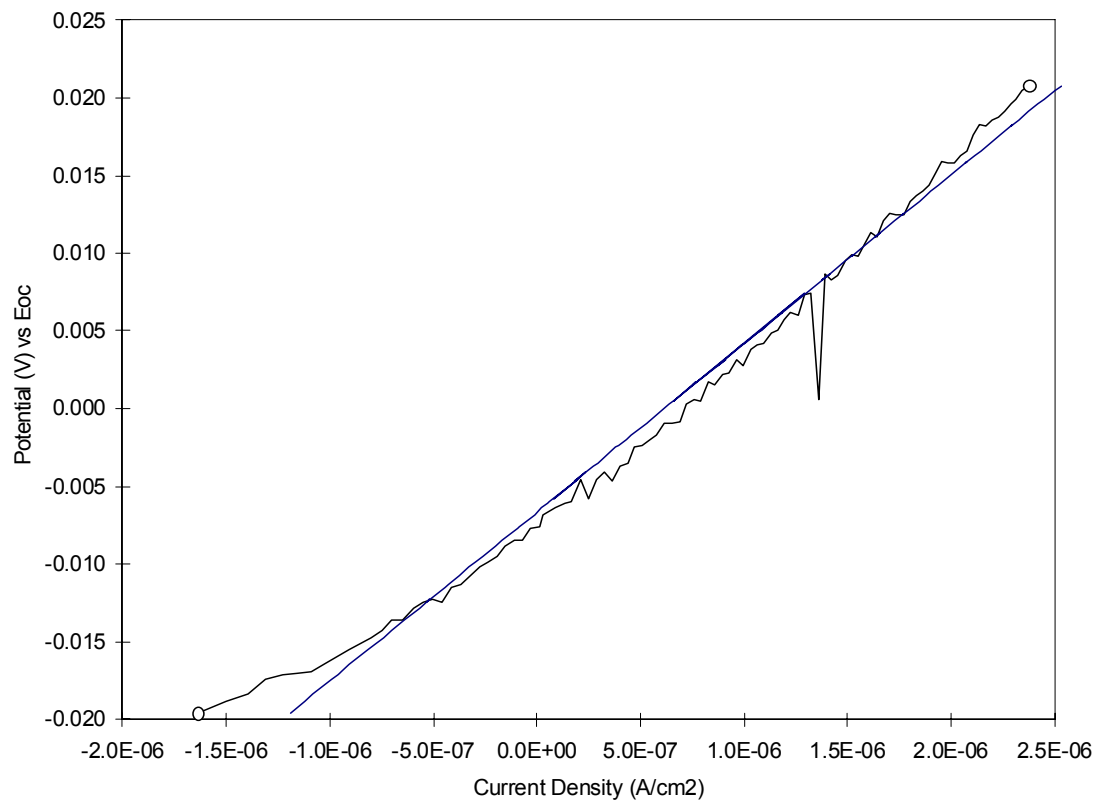
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.529298 V
 Area: 104.8 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on medium size bolt

POLRES RESULTS
 Region = -19.2 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -535.5 mV
 Icorr = 2.449E-06 A/cm2
 Rp = 1.064E+04 Ohm cm2
 CorrRate = 1.119 mpy

Polarization Resistance

'POLRES Bolt B42 #36.DTA' 11/30/2001-14:52:12

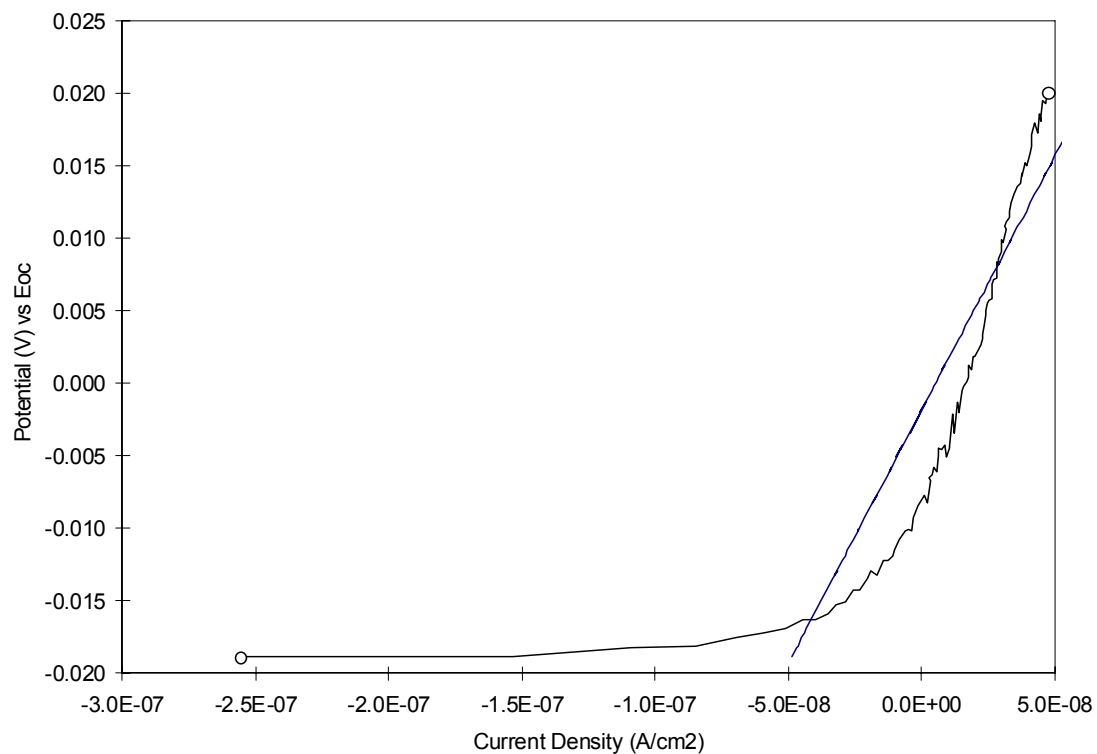


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.396741 V
Area: 104.8 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

Ohio River Water on medium size bolt

POLRES RESULTS
Region = -19.6 mV to 20.8 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -403.4 mV
Icorr = 2.400E-06 A/cm2
Rp = 1.086E+04 Ohm cm2
CorrRate = 1.097 mpy

Polarization Resistance
'POLRES Bolt B42B #17.DTA' 11/29/2001-
14:30:25

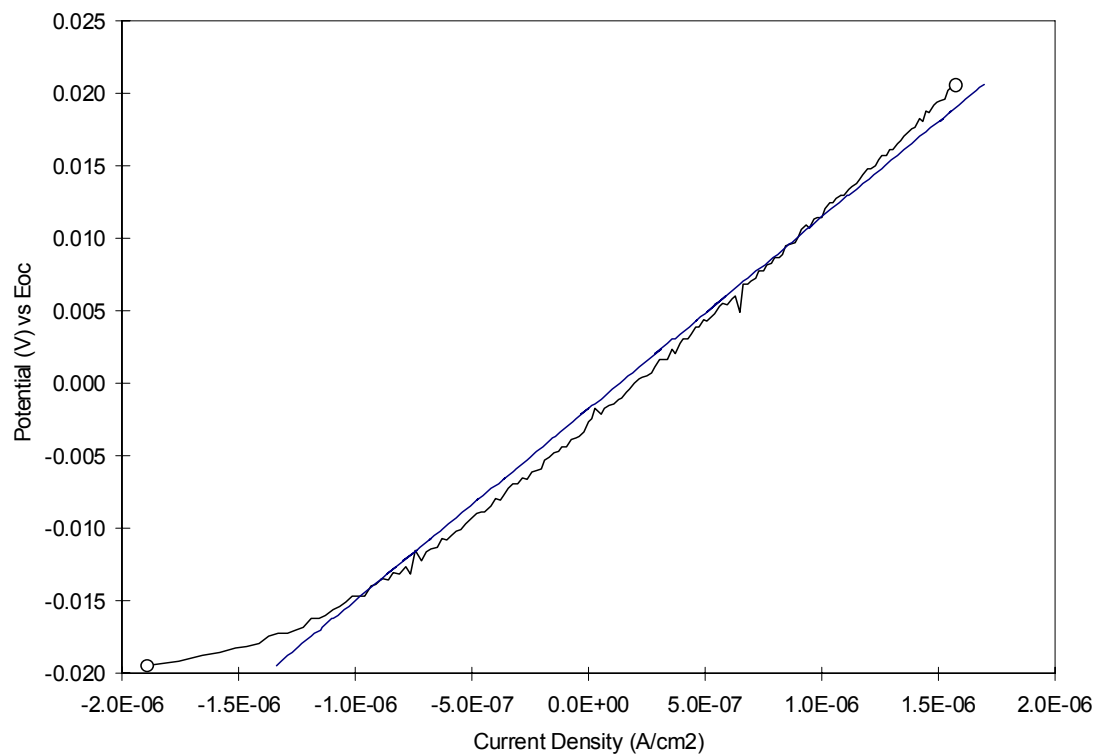


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.119764 V
 Area: 104.8 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River water on medium size bolt

POLRES RESULTS
 Region = -18.9 mV to 20.1 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -121.6 mV
 Icorr = 7.453E-08 A/cm2
 Rp = 3.496E+05 Ohm cm2
 CorrRate = 0.034 mpy

Polarization Resistance
'Large Bolt 7A to Large Nut D15 #41.DTA'
12/3/2001-10:18:18

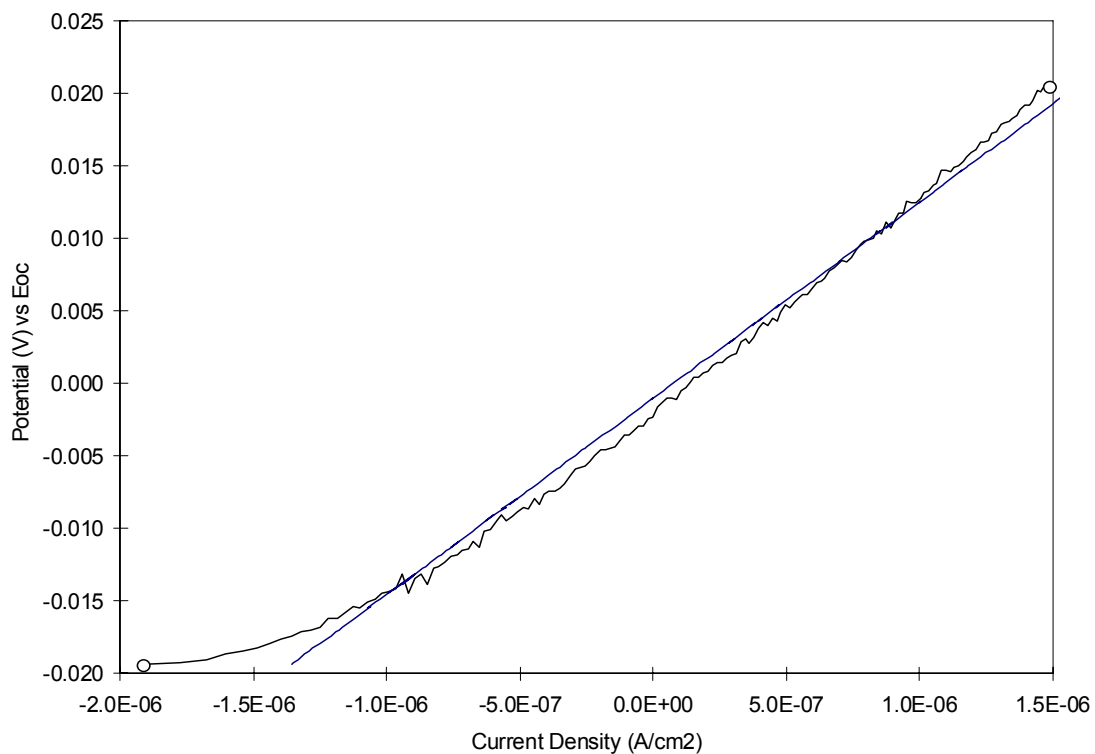


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.125 mV/s, 2 s/pt
 EOC: -0.411096 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Sample connected to each other thru 100 ohm resistor in Ohio River Water after 48 hours immersion unconnected. 26.98 mV across 100 ohm resistor = .0002698 amperes with bolt anode

POLRES RESULTS
 Region = -19.5 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -412.8 mV
 Icorr = 1.973E-06 A/cm2
 Rp = 1.321E+04 Ohm cm2
 CorrRate = 0.902 mpy

Polarization Resistance
'Large Bolt 7A to Large Nut D15 #42.DTA'
12/3/2001-10:39:25

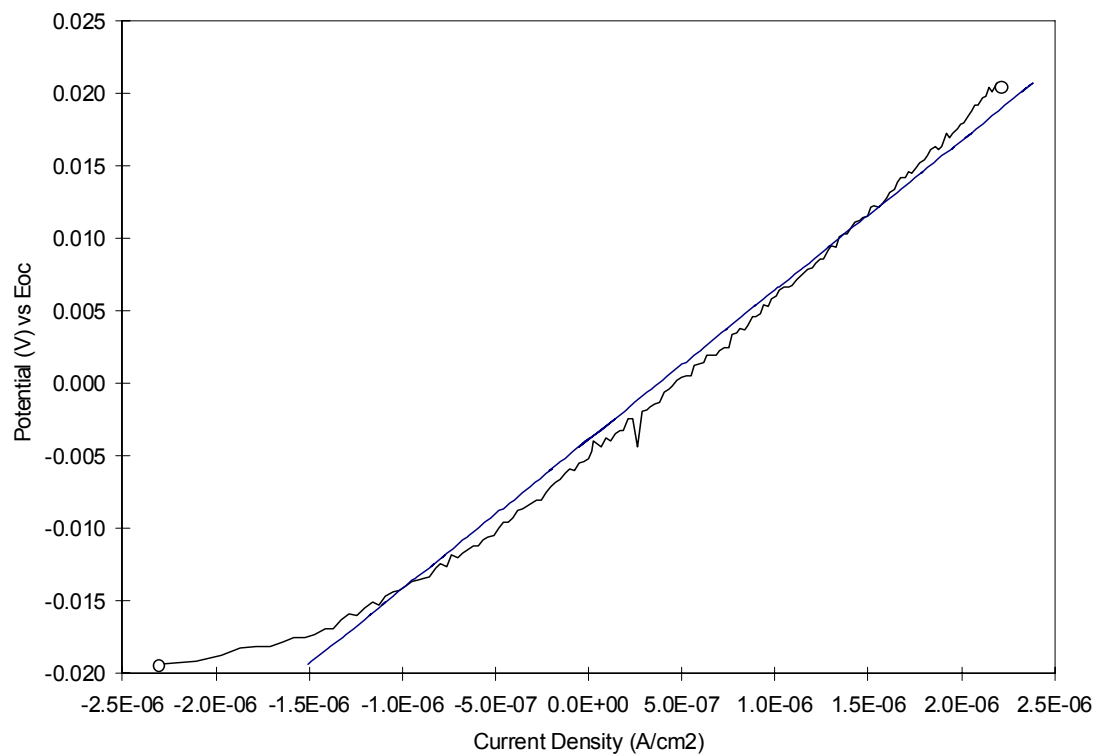


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.125 mV/s, 2 s/pt
 EOC: -0.416758 V
 Area: 121.6 cm²
 Electrode: 7.87 gm/cm³, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Sample connected to each other thru 100 ohm resistor in Ohio River Water after 48 hours immersion unconnected. 26.99 mV across 100 ohm resistor = .0002699 amperes with bolt anode

POLRES RESULTS
 Region = -19.4 mV to 20.5 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -417.8 mV
 Icorr = 1.926E-06 A/cm²
 Rp = 1.353E+04 Ohm cm²
 CorrRate = 0.880 mpy

Polarization Resistance
'Large Bolt 7B to Large Nut B11B #44.DTA'
12/3/2001-11:27:24

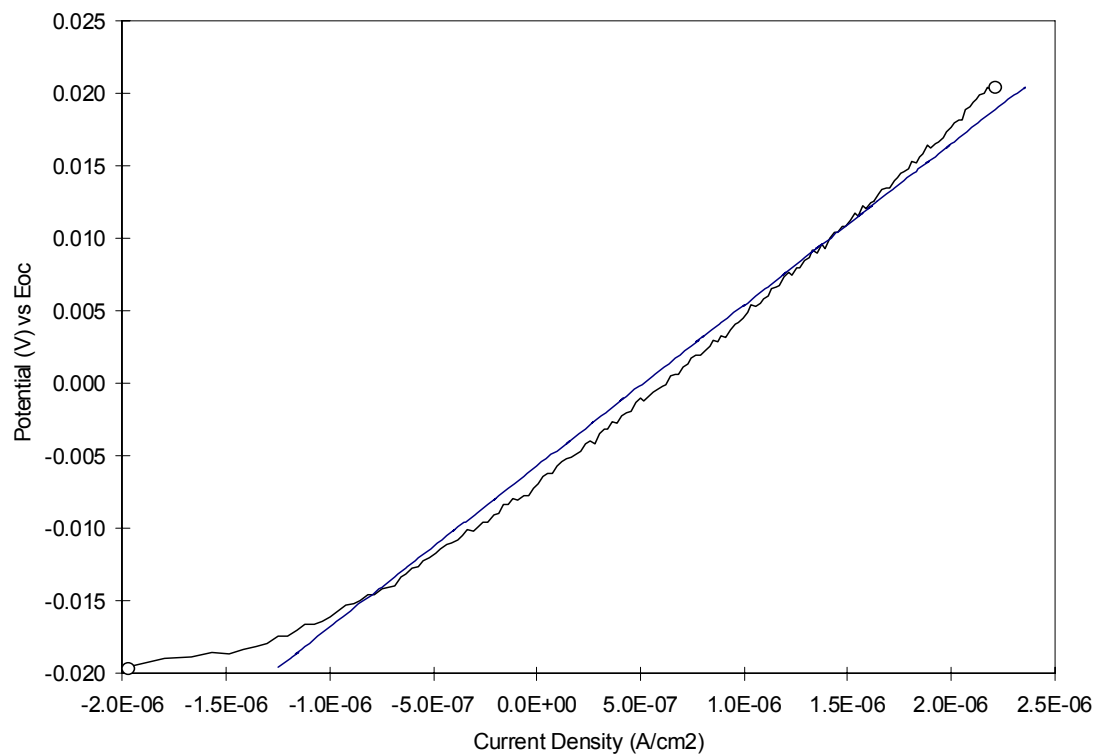


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.125 mV/s, 2 s/pt
 EOC: -0.402666 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Sample connected to each other thru 100 ohm resistor in Ohio River Water after 48 hours immersion unconnected. +19.305 mV across 100 ohm resistor = .00019305 amperes with bolt anode

POLRES RESULTS
 Region = -19.4 mV to 20.5 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -406.5 mV
 Icorr = 2.526E-06 A/cm2
 Rp = 1.032E+04 Ohm cm2
 CorrRate = 1.154 mpy

Polarization Resistance
'Large Bolt 7C to Large Nut 7C #45.DTA'
12/3/2001-11:44:22

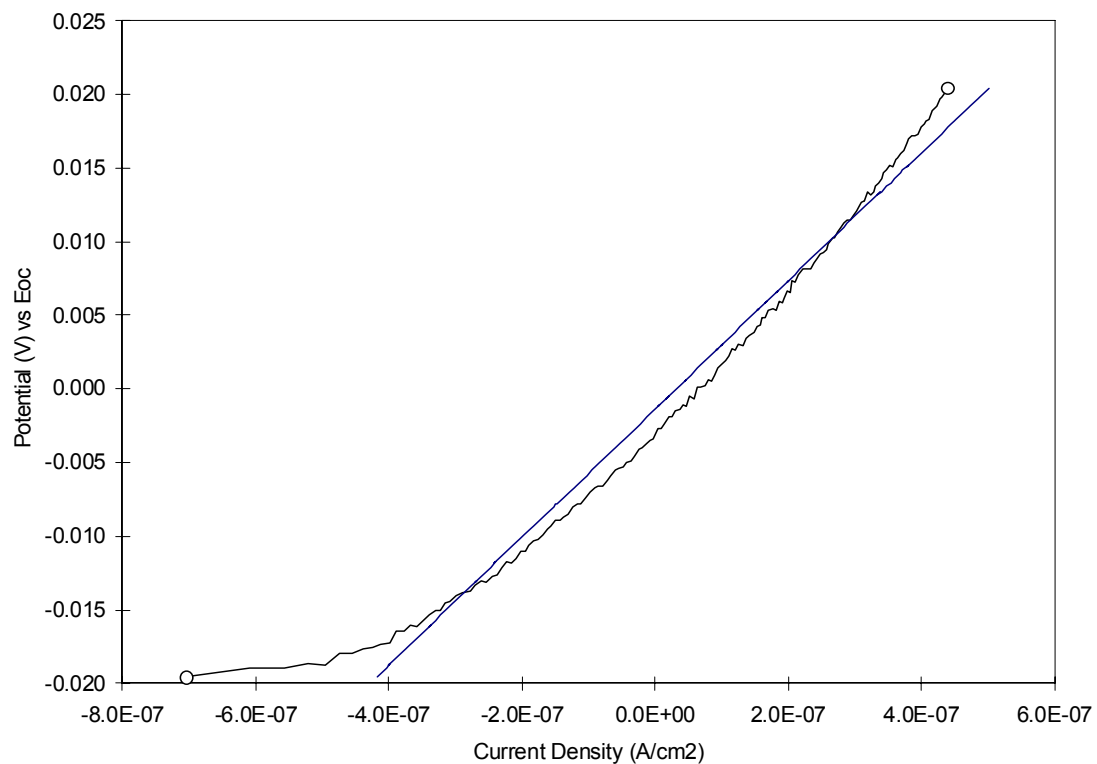


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.125 mV/s, 2 s/pt
 EOC: -0.392538 V
 Area: 121.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Sample connected to each other thru 100 ohm resistor in Ohio River Water after 48 hours immersion unconnected. +25.325 mV across 100 ohm resistor = .00025325 amperes with bolt anode

POLRES RESULTS
 Region = -19.6 mV to 20.5 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -398.2 mV
 Icorr = 2.345E-06 A/cm2
 Rp = 1.111E+04 Ohm cm2
 CorrRate = 1.071 mpy

Polarization Resistance
'Large Bolt B11B to Large Nut B11B #43.DTA'
12/3/2001-10:57:43

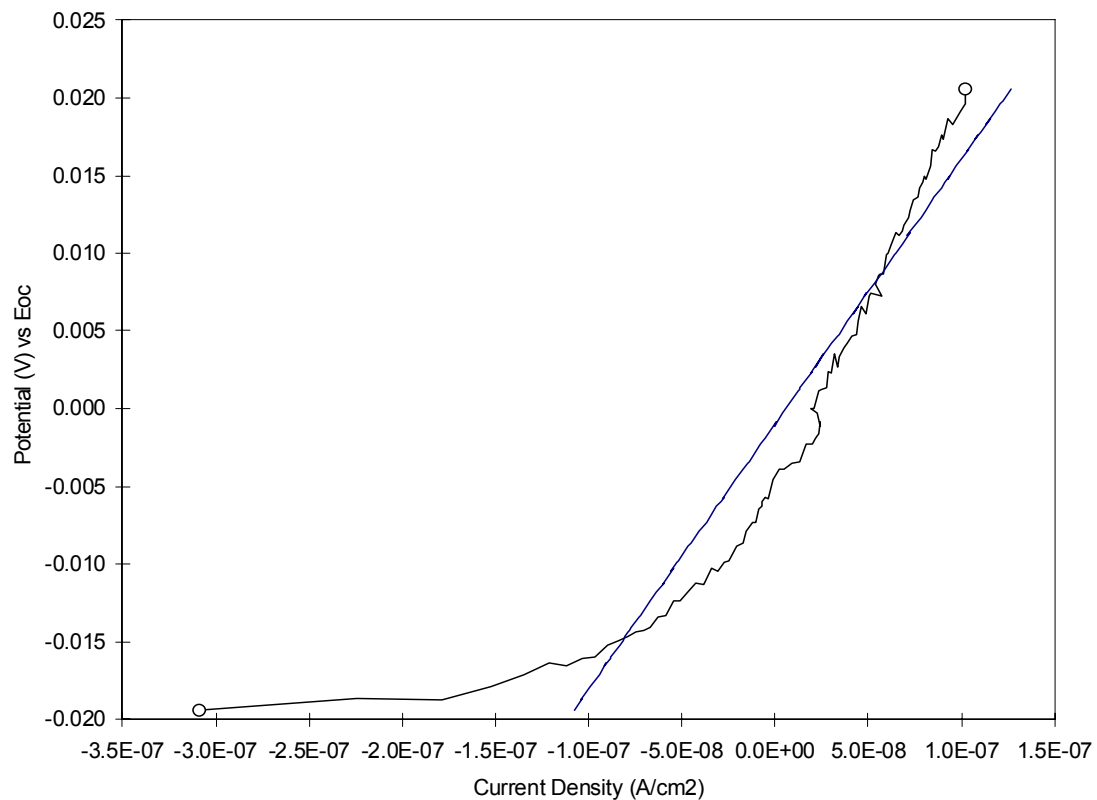


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.125 mV/s, 2 s/pt
 EOC: -0.246873 V
 Area: 159.6 cm²
 Electrode: 7.87 gm/cm³, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Sample connected to each other thru 100 ohm resistor in Ohio River Water after 48 hours immersion unconnected. -6.520 mV across 100 ohm resistor = .00006520 amperes with nut anode

POLRES RESULTS
 Region = -19.6 mV to 20.4 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -248.2 mV
 Icorr = 5.985E-07 A/cm²
 Rp = 4.354E+04 Ohm cm²
 CorrRate = 0.273 mpy

Polarization Resistance **'POLRES Nut 7-C #27.DTA' 11/29/2001-16:41:27**

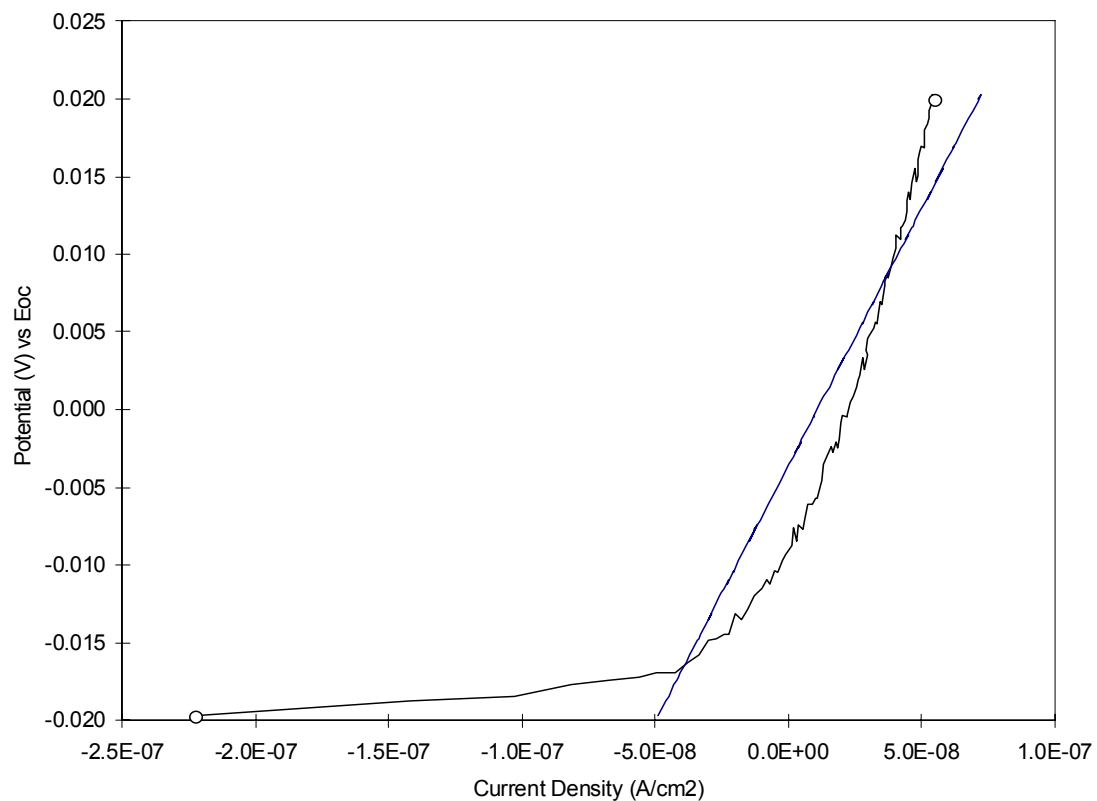


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.199054 V
 Area: 159.6 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on large nut

POLRES RESULTS
 Region = -19.4 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -200.0 mV
 Icorr = 1.528E-07 A/cm2
 Rp = 1.705E+05 Ohm cm2
 CorrRate = 0.070 mpy

Polarization Resistance **'POLRES Nut 7C #38.DTA' 11/30/2001-15:43:23**

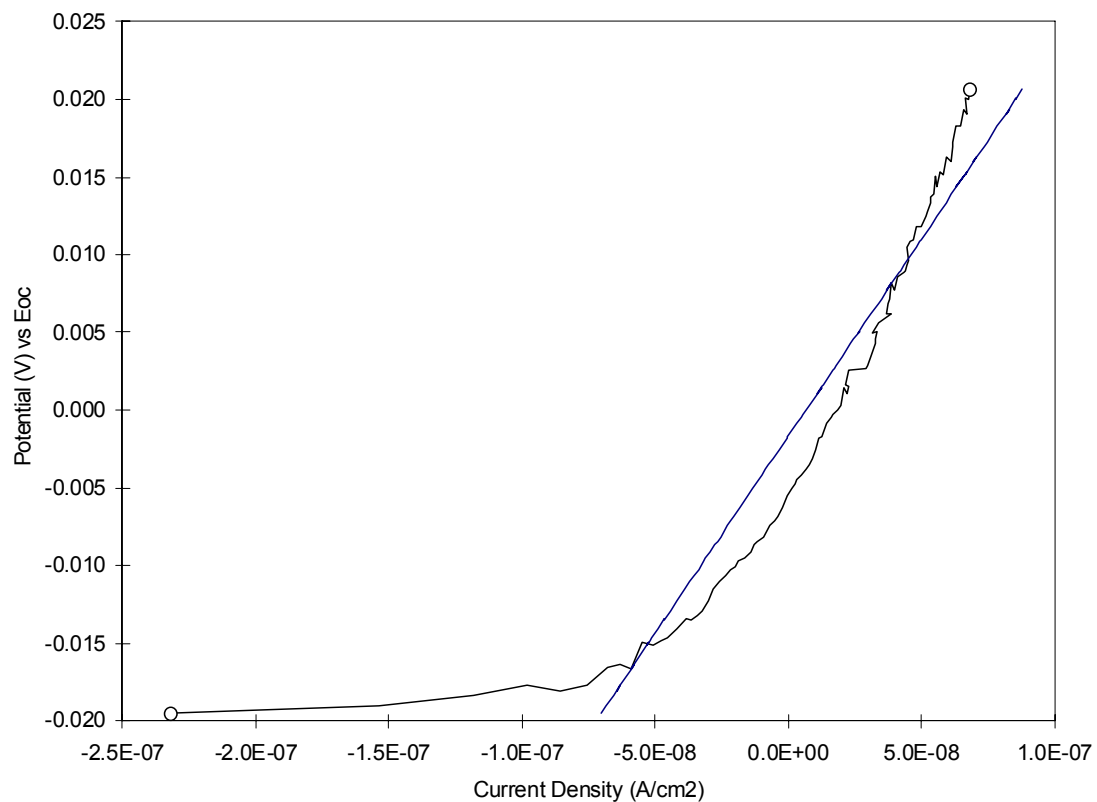


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.177808 V
 Area: 159.2 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on large size nut

POLRES RESULTS
 Region = -19.7 mV to 20.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -181.4 mV
 Icorr = 7.897E-08 A/cm2
 Rp = 3.300E+05 Ohm cm2
 CorrRate = 0.036 mpy

Polarization Resistance **'POLRES Nut A54 #22.DTA' 11/29/2001-15:42:48**

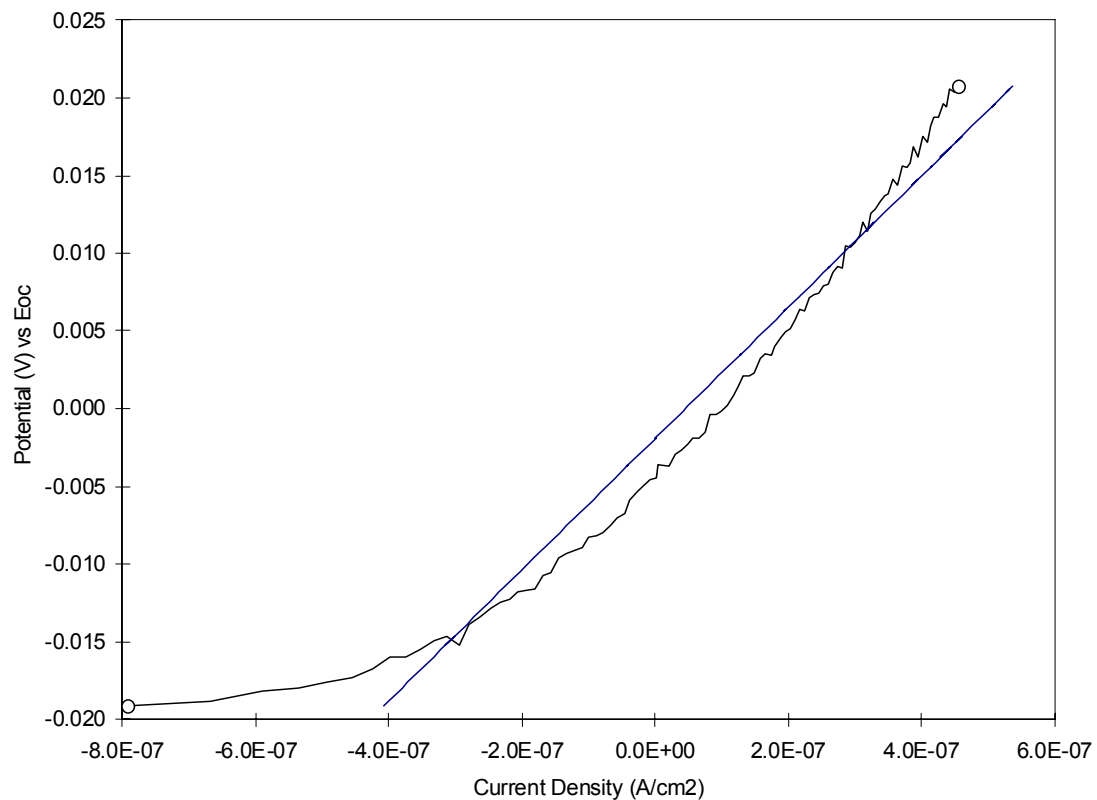


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.183812 V
 Area: 110.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size nut

POLRES RESULTS
 Region = -19.5 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -185.5 mV
 Icorr = 1.027E-07 A/cm2
 Rp = 2.538E+05 Ohm cm2
 CorrRate = 0.047 mpy

Polarization Resistance
'POLRES Nut B32 #23.DTA' 11/29/2001-15:57:16

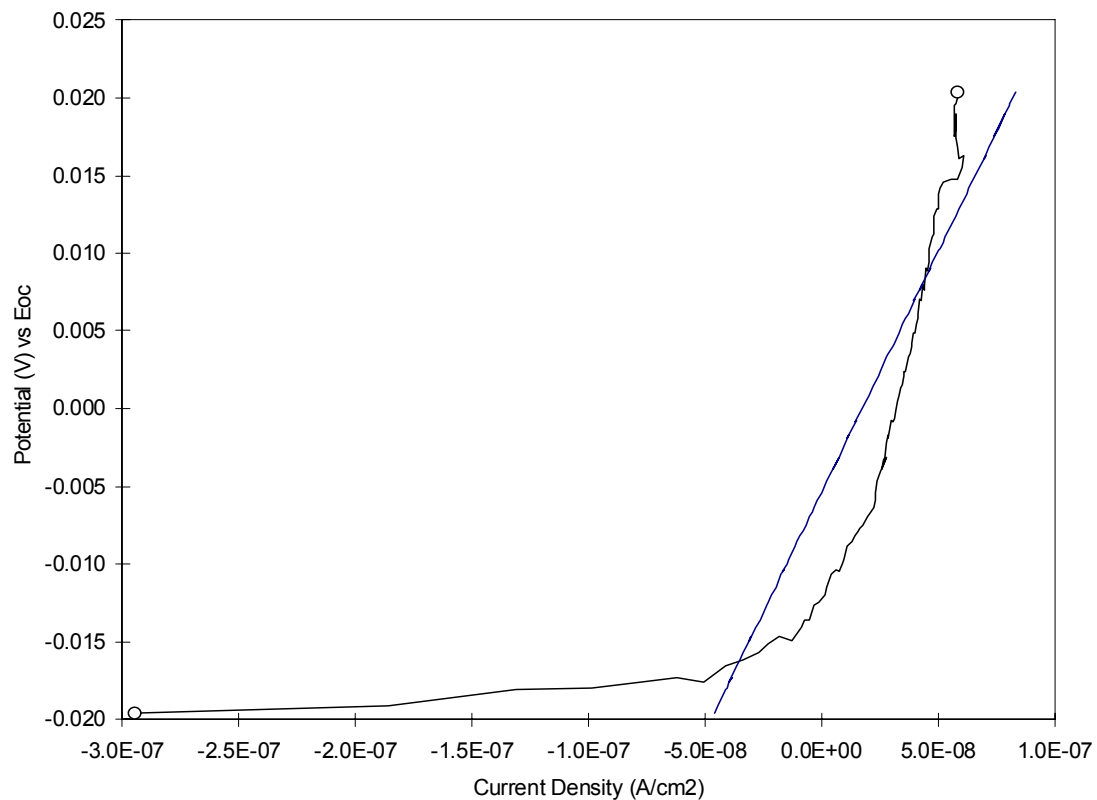


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.2809 V
Area: 110.9 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

Ohio River Water on small size nut

POLRES RESULTS
Region = -19.2 mV to 20.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -282.8 mV
Icorr = 6.166E-07 A/cm2
Rp = 4.226E+04 Ohm cm2
CorrRate = 0.282 mpy

Polarization Resistance **'POLRES Nut B42B #26.DTA' 11/29/2001-16:32:10**



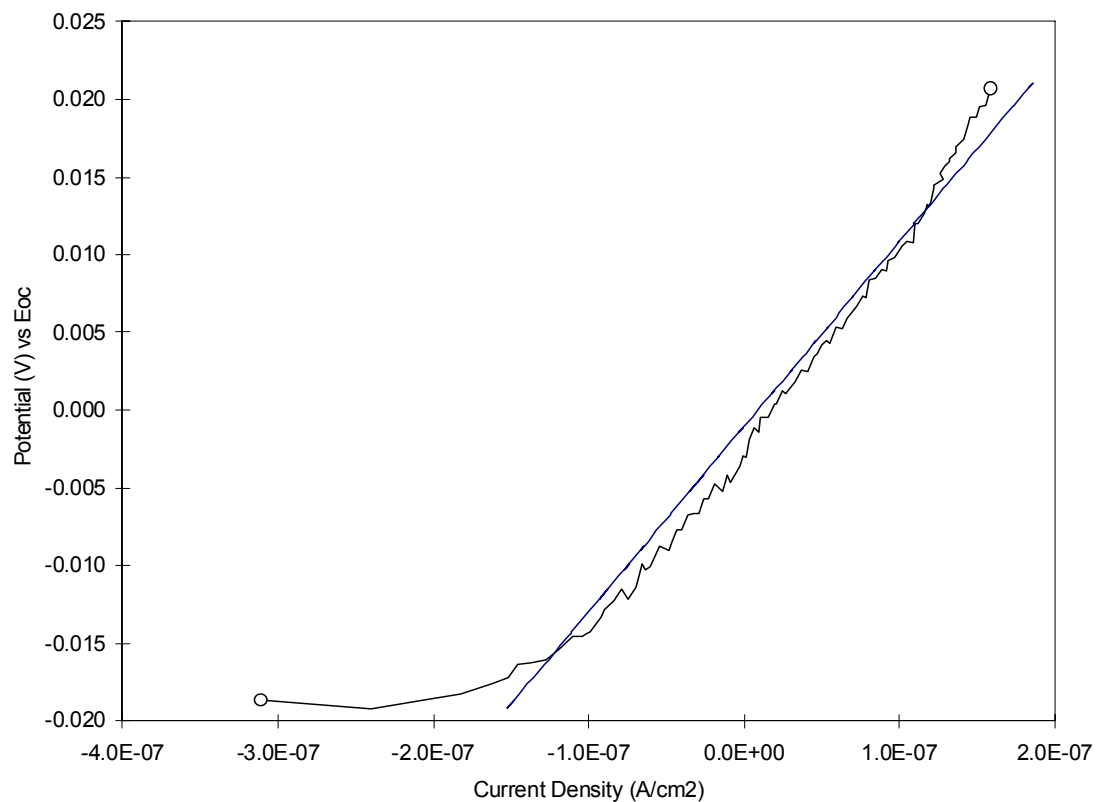
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.102361 V
 Area: 137.5 cm²
 Electrode: 7.87 gm/cm³, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on medium size nut

POLRES RESULTS
 Region = -19.6 mV to 20.4 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -107.7 mV
 Icorr = 8.429E-08 A/cm²
 Rp = 3.091E+05 Ohm cm²
 CorrRate = 0.039 mpy

Polarization Resistance

'POLRES Nut D126 #24.DTA' 11/29/2001-16:8:59

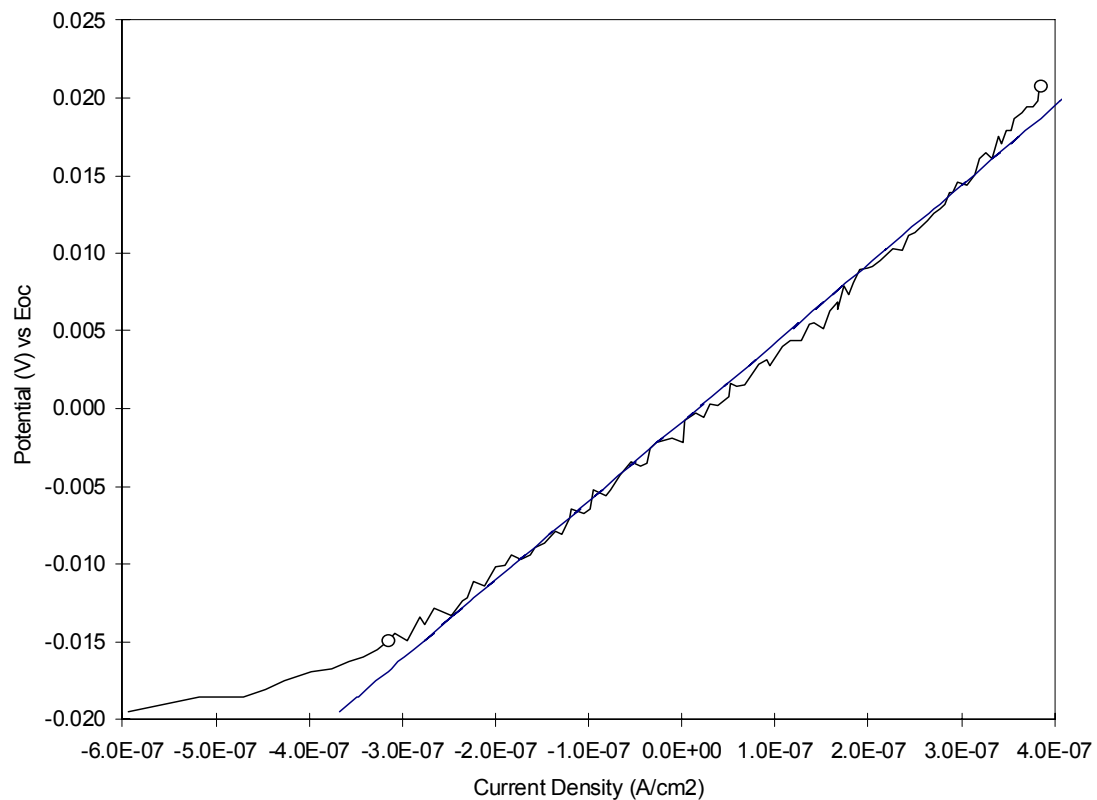


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.2671 V
Area: 110.9 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

Ohio River Water on small size nut

POLRES RESULTS
Region = -18.7 mV to 20.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -268.2 mV
Icorr = 2.187E-07 A/cm2
Rp = 1.191E+05 Ohm cm2
CorrRate = 0.100 mpy

Polarization Resistance **'POLRES Nut D31 #7.DTA' 11/28/2001-18:30:48**

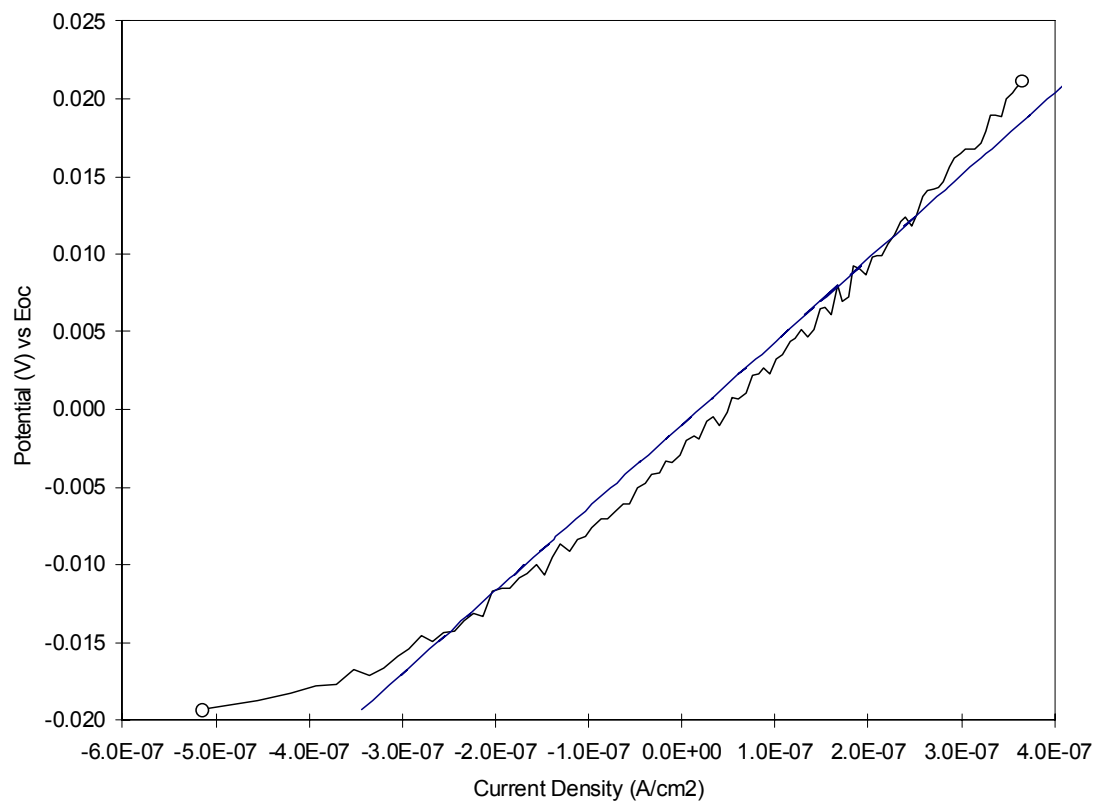


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.308534 V
 Area: 110.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water, Smallest Nut

POLRES RESULTS
 Region = -14.9 mV to 20.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -309.4 mV
 Icorr = 5.128E-07 A/cm2
 Rp = 5.082E+04 Ohm cm2
 CorrRate = 0.234 mpy

Polarization Resistance **'POLRES Nut D31 #8.DTA' 11/29/2001-9:14:36**



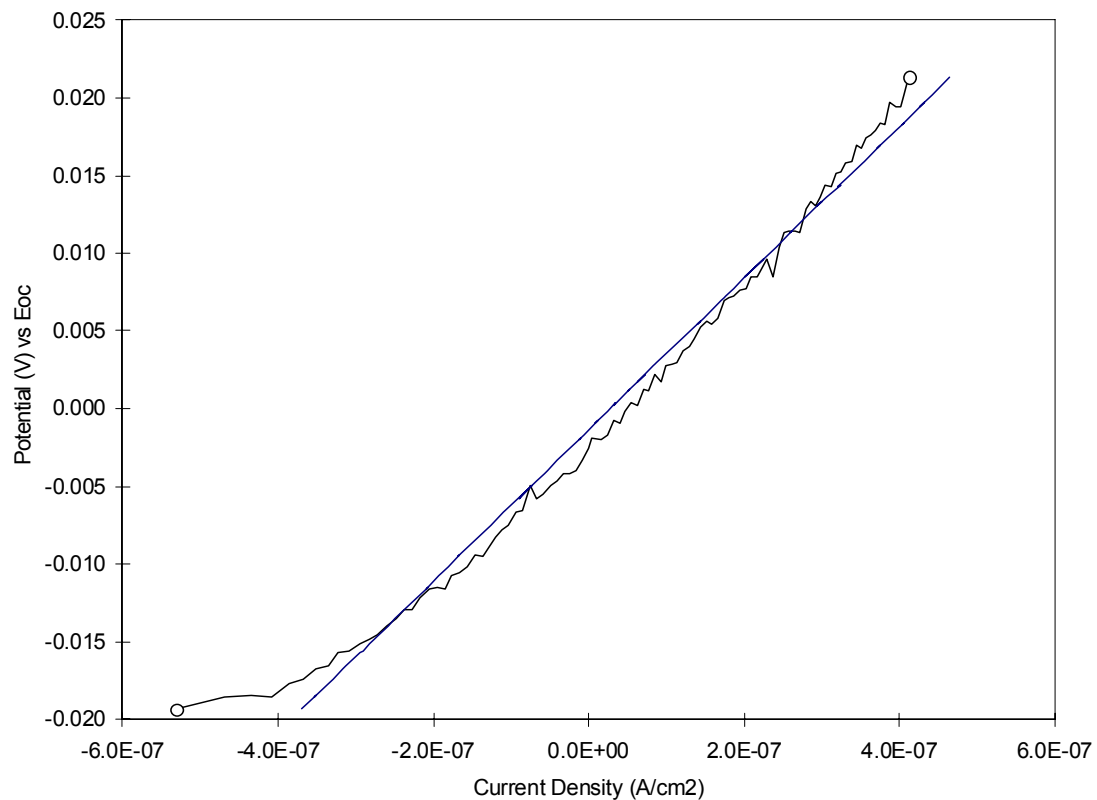
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.303923 V
 Area: 110.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

After 12 hours immersion in Ohio River Water

POLRES RESULTS

Region = -19.3 mV to 21.2 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -304.9 mV
 Icorr = 4.877E-07 A/cm2
 Rp = 5.344E+04 Ohm cm2
 CorrRate = 0.223 mpy

Polarization Resistance **'POLRES Nut D31 #8A.DTA' 11/29/2001-11:21:20**

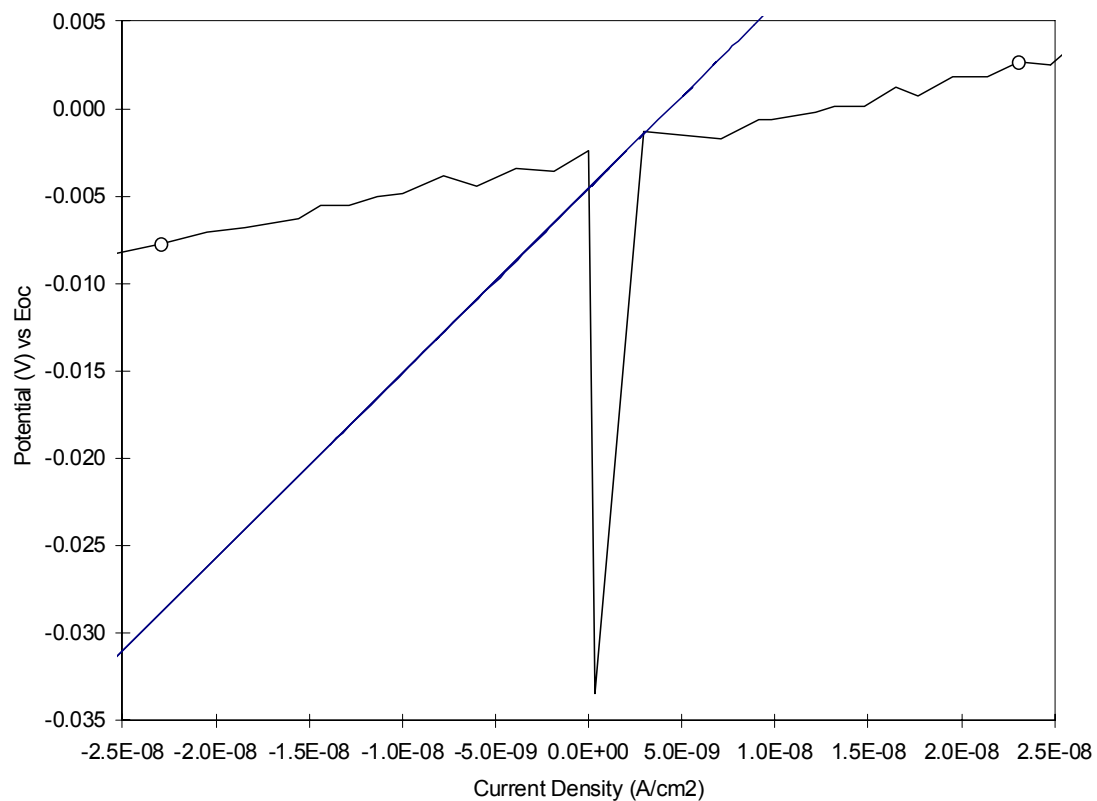


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.288883 V
 Area: 110.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Re-Run in Freshened Water (Ohio River)

POLRES RESULTS
 Region = -19.4 mV to 21.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -290.2 mV
 Icorr = 5.343E-07 A/cm2
 Rp = 4.877E+04 Ohm cm2
 CorrRate = 0.244 mpy

Polarization Resistance
'POLRES Nut D83 #25.DTA' 11/29/2001-16:18:50

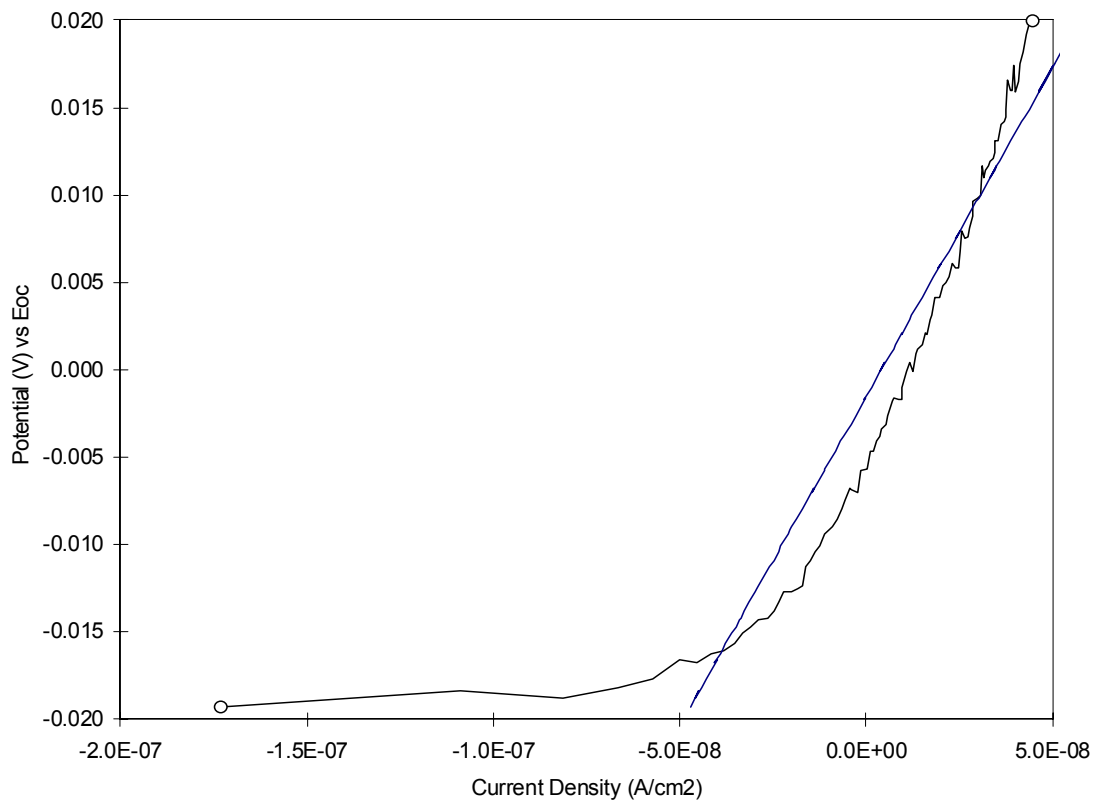


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.198414 V
Area: 110.9 cm2
Electrode: 7.87 gm/cm3, 27.92 g/equiv
Conditioning: OFF
IR Comp.: OFF

Ohio River Water on small size nut

POLRES RESULTS
Region = -7.7 mV to 2.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -203.0 mV
Icorr = 2.467E-08 A/cm2
Rp = 1.056E+06 Ohm cm2
CorrRate = 0.011 mpy

Polarization Resistance **'POLRES Nut D83 #37.DTA' 11/30/2001-15:31:12**

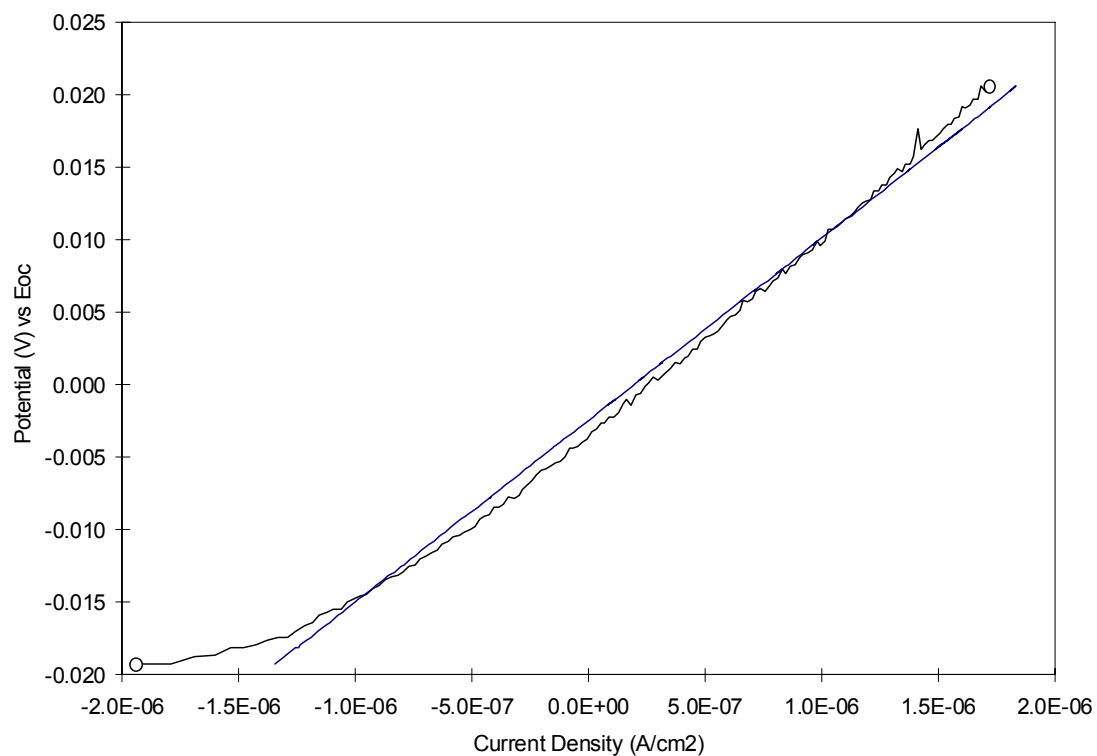


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.192347 V
 Area: 110.9 cm2
 Electrode: 7.87 gm/cm3, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Ohio River Water on small size nut

POLRES RESULTS
 Region = -19.3 mV to 20.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -193.9 mV
 Icorr = 6.921E-08 A/cm2
 Rp = 3.765E+05 Ohm cm2
 CorrRate = 0.032 mpy

Polarization Resistance
'Small Bolt 5-D3-1 to Small Nut D83 #46.DTA'
12/3/2001-16:48:13

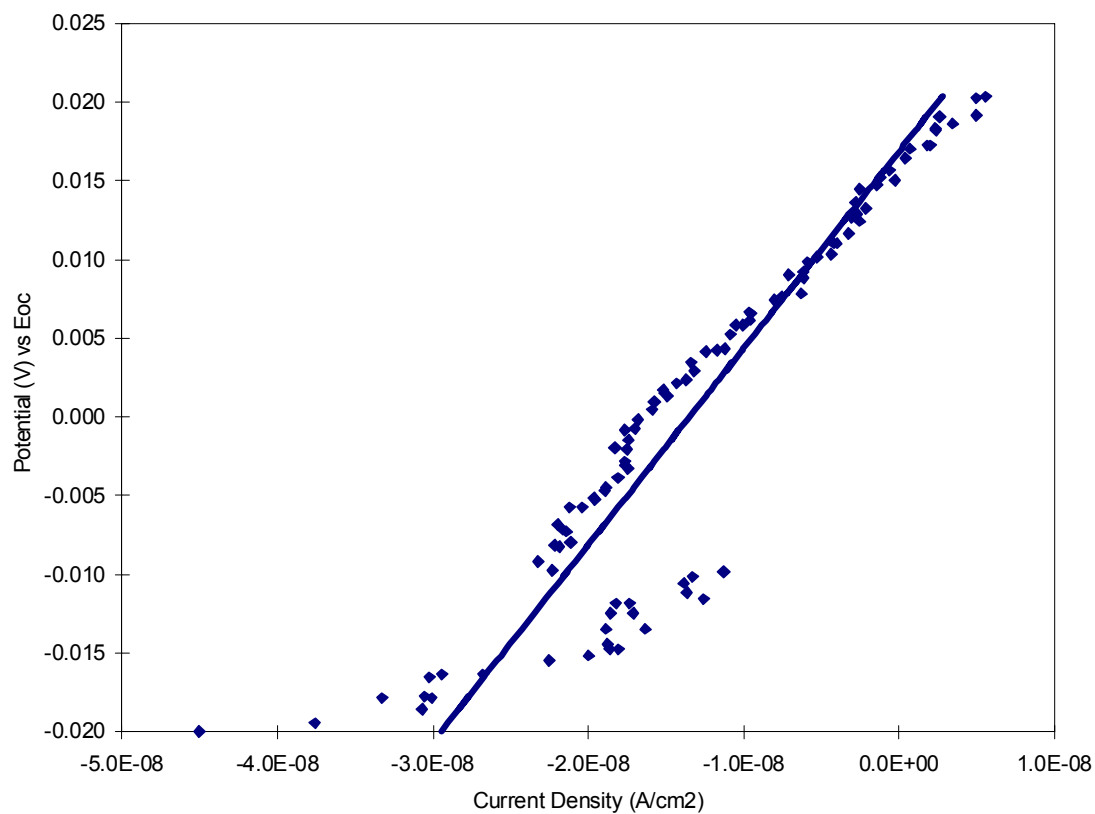


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.125 mV/s, 2 s/pt
 EOC: -0.441669 V
 Area: 91.9 cm²
 Electrode: 7.87 gm/cm³, 27.92 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Small Bolt coupled to Small Nut with 100 ohm resistor, both nut & both immerse in Ohio River Water at 4 PM 11/28/01. (22.443mV = .00022443 amperes

POLRES RESULTS
 Region = -19.3 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -444.1 mV
 Icorr = 2.077E-06 A/cm²
 Rp = 1.255E+04 Ohm cm²
 CorrRate = 0.949 mpy

Polarization Resistance
'CERL BOLT 2D102 Linear Pol Scan #23.DTA'



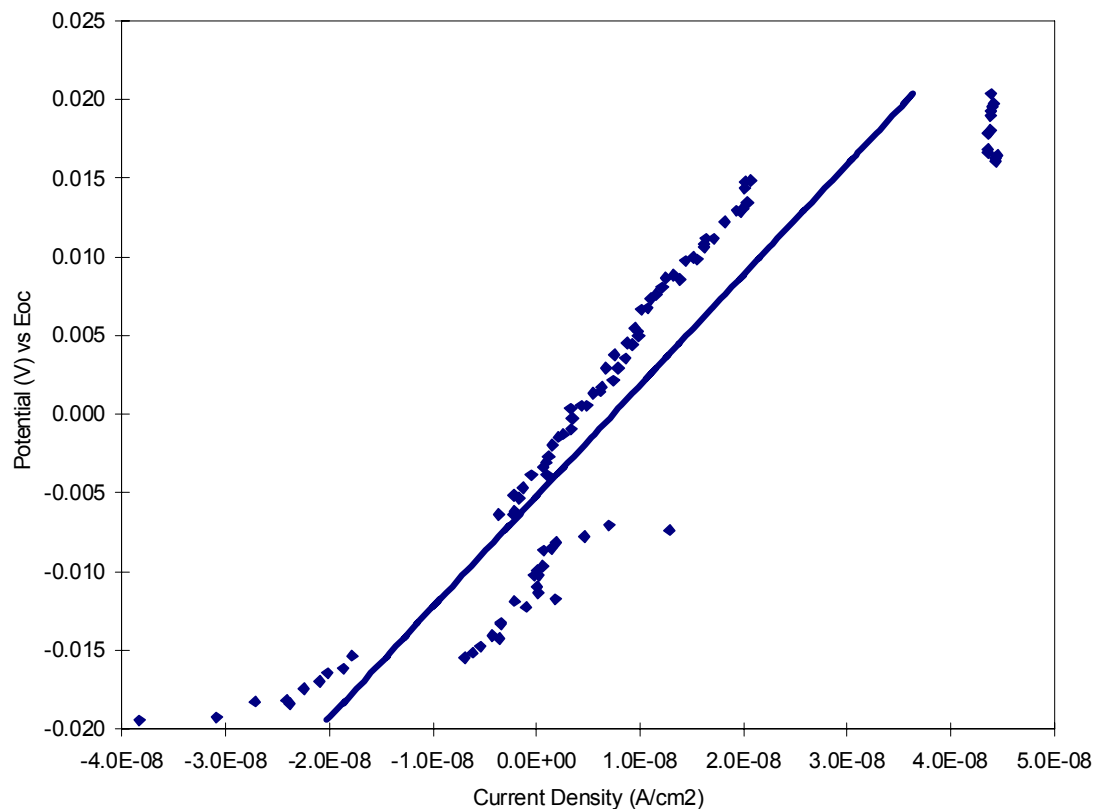
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.167679 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS

Region = -20.0 mV to 20.2 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -150.8 mV
 Icorr = 2.084E-08 A/cm²
 Rp = 1.250E+06 Ohm cm²
 CorrRate = 0.008 mpy

Polarization Resistance
'CERL BOLT 2D102 Linear Pol Scan #24.DTA'

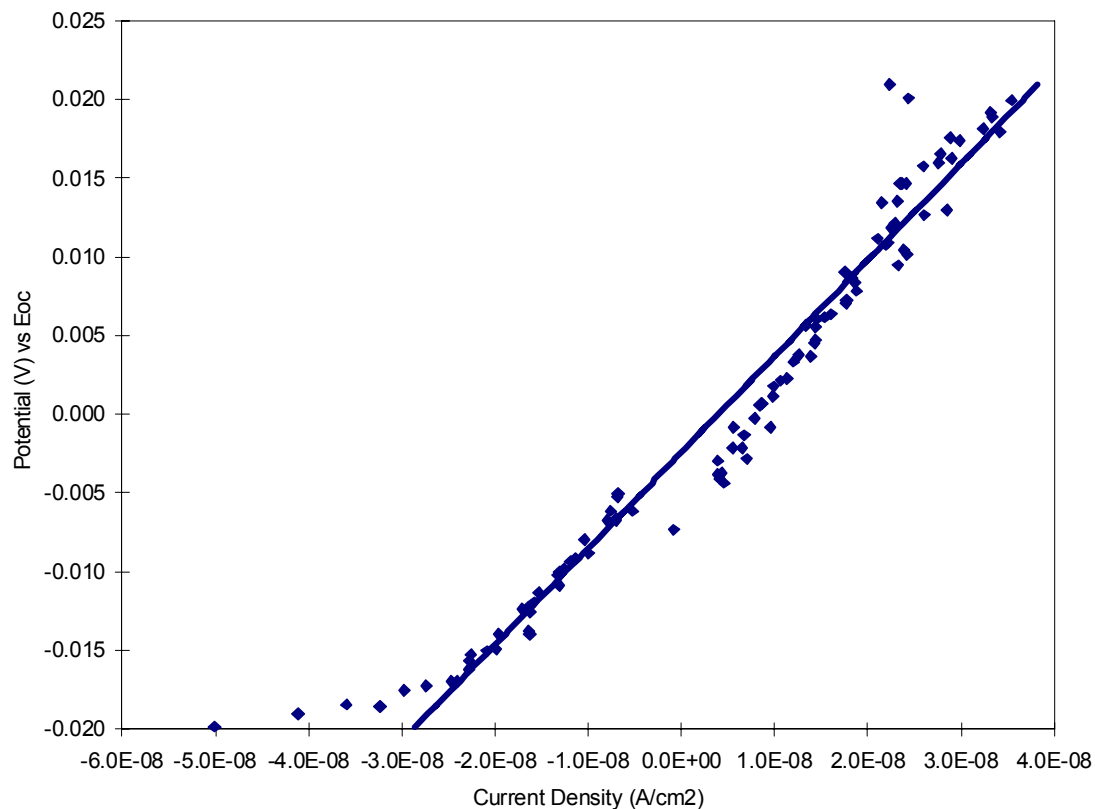


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.150378 V
Area: 46.82 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
Region = -19.5 mV to 19.7 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -155.6 mV
Icorr = 3.706E-08 A/cm²
Rp = 7.032E+05 Ohm cm²
CorrRate = 0.015 mpy

**Polarization Resistance
'CERL BOLT 2D102 Linear Pol Scan #25.DTA'**

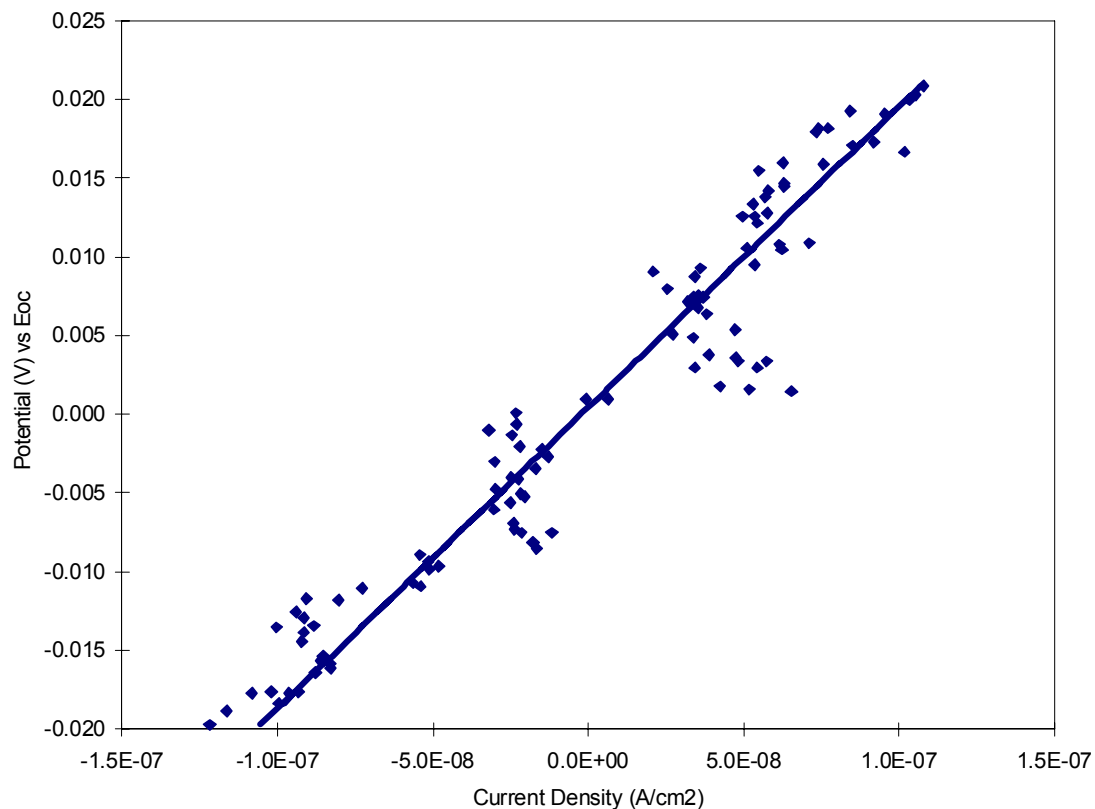


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.177185 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
 Region = -19.9 mV to 20.9 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -179.6 mV
 Icorr = 4.266E-08 A/cm²
 Rp = 6.108E+05 Ohm cm²
 CorrRate = 0.017 mpy

Polarization Resistance
'CERL NUT 2D102 Linear Pol Scan #11.DTA

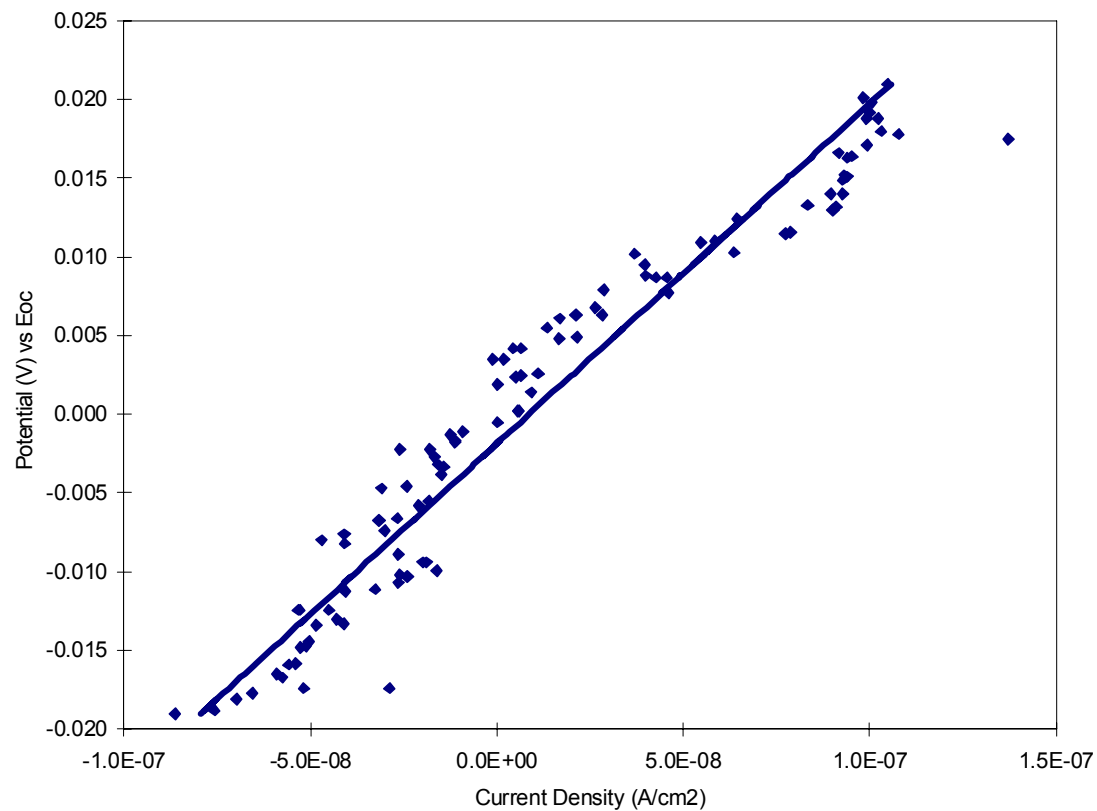


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.386398 V
Area: 49.893 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water.
Paint on nut, 45% clean metal (49.893) surface area.

POLRES RESULTS
Region = -19.8 mV to 20.8 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -386.0 mV
Icorr = 1.363E-07 A/cm²
Rp = 1.911E+05 Ohm cm²
CorrRate = 0.056 mpy

Polarization Resistance
'CERL NUT 2D102 Linear Pol Scan #12.DTA'



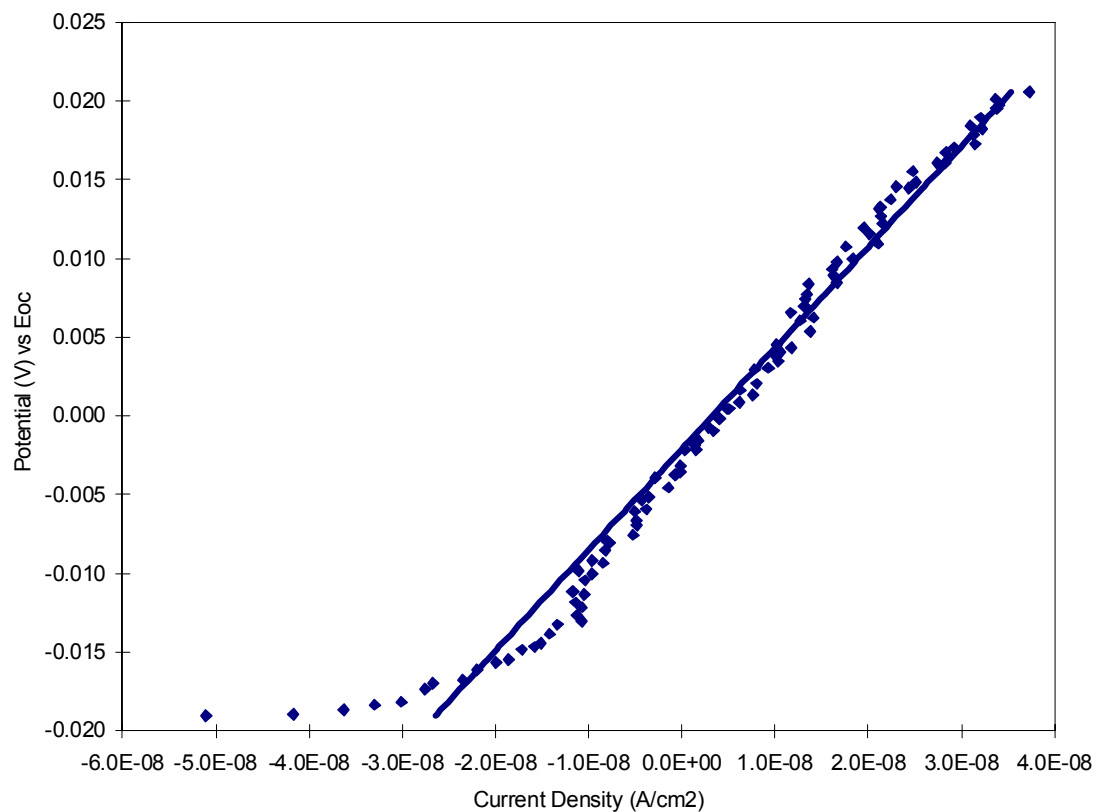
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.36452 V
 Area: 49.893 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water.
 Paint on nut, 45% clean metal (49.893) surface area.

POLRES RESULTS

Region = -19.0 mV to 21.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -366.4 mV
 Icorr = 1.206E-07 A/cm²
 Rp = 2.161E+05 Ohm cm²
 CorrRate = 0.049 mpy

Polarization Resistance
'CERL Nut-Bolt 2D102 Linear Pol Scan #44.DTA'



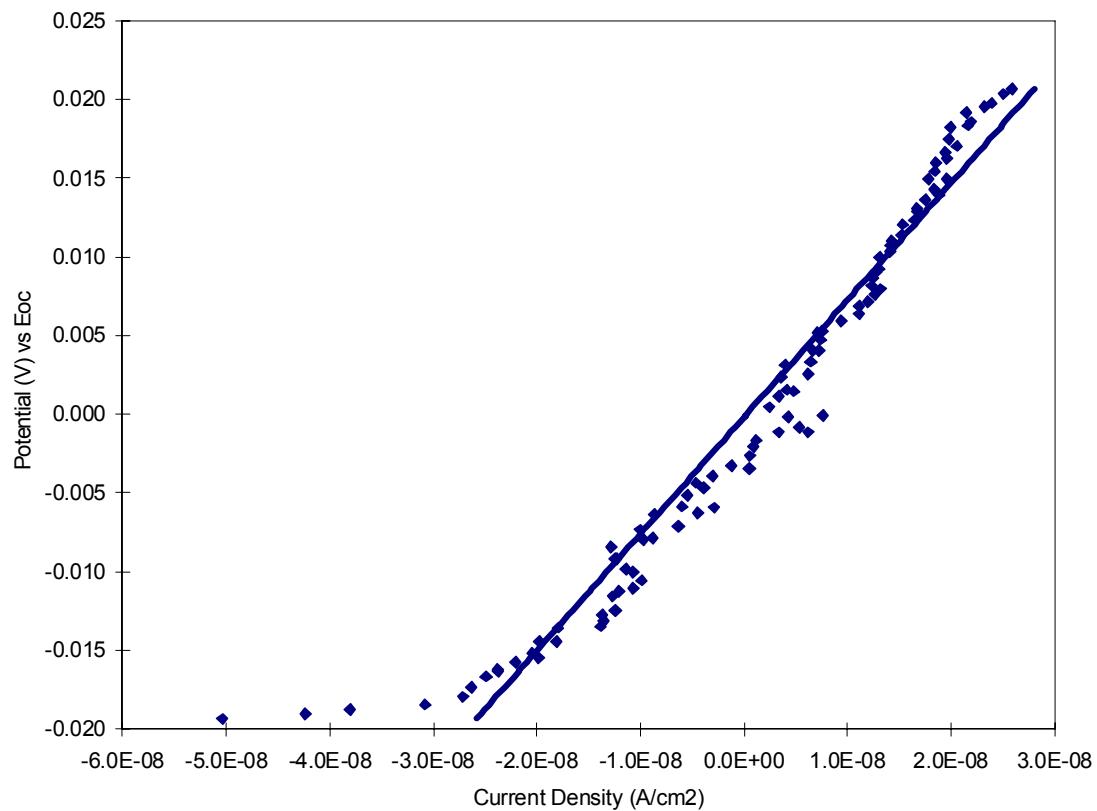
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.249083 V
Area: 96.713 cm2
Electrode: 7.94 gm/cm3, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Nut and Bolt connected, Nut 45% Bare Metal in
Ohio River Water

POLRES RESULTS

Region = -19.1 mV to 20.5 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -251.2 mV
Icorr = 4.065E-08 A/cm2
Rp = 6.410E+05 Ohm cm2
CorrRate = 0.017 mpy

Polarization Resistance
'CERL Nut-Bolt 2D102 Linear Pol Scan #45.DTA'

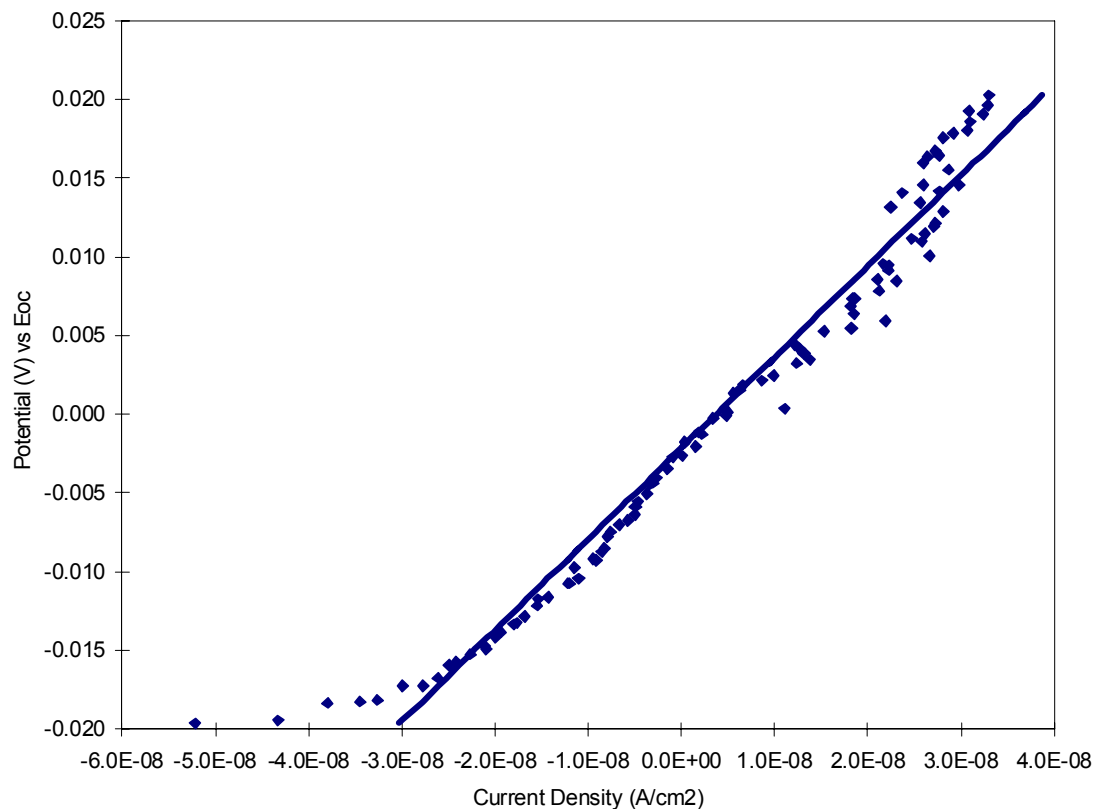


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.253983 V
 Area: 96.713 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Nut and Bolt connected, Nut 45% Bare Metal in
 Ohio River Water

POLRES RESULTS
 Region = -19.4 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -254.2 mV
 Icorr = 3.506E-08 A/cm²
 Rp = 7.432E+05 Ohm cm²
 CorrRate = 0.014 mpy

Polarization Resistance
'CERL Nut-Bolt 2D102 Linear Pol Scan #46.DTA'



Pstat: PStat3

Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt

EOC: -0.252084 V

Area: 96.713 cm²

Electrode: 7.94 gm/cm³, 25.12 g/equiv

Conditioning: OFF

IR Comp.: OFF

Nut and Bolt connected, Nut 45% Bare Metal in
Ohio River Water

POLRES RESULTS

Region = -19.7 mV to 20.2 mV

BetaC = 120.0 mV/Decade

BetaA = 120.0 mV/Decade

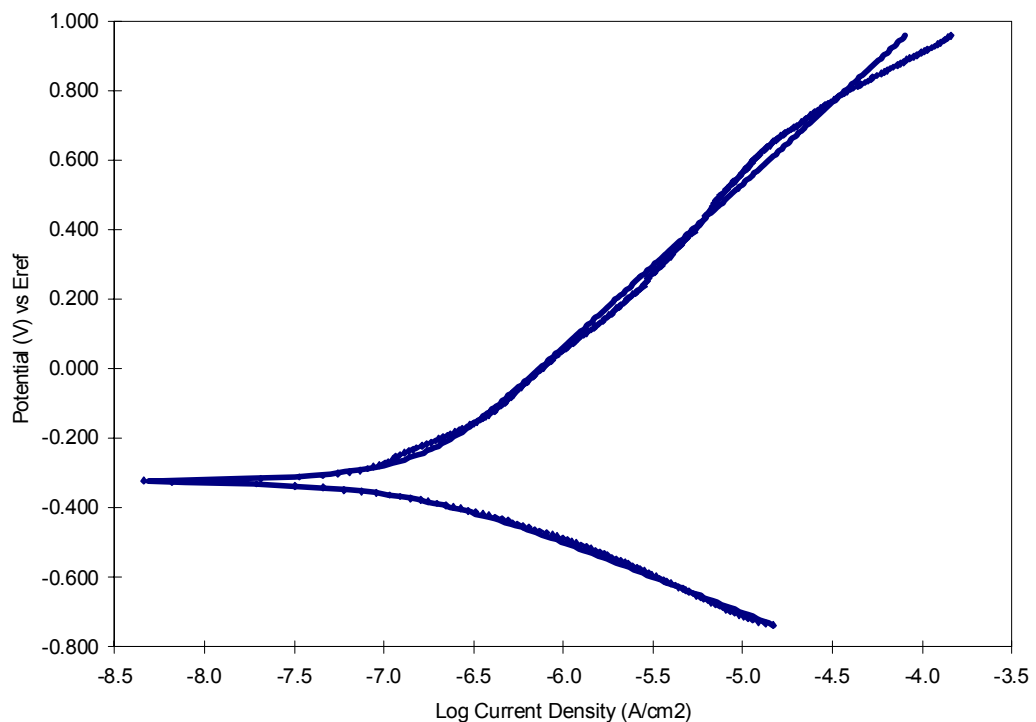
Ecorr = -254.2 mV

Icorr = 4.507E-08 A/cm²

Rp = 5.782E+05 Ohm cm²

CorrRate = 0.018 mpy

**Potentiodynamic Scan
'CERL POTDYN Scan on Bolt-Nut Combo #2D102
Scan#3.DTA'**



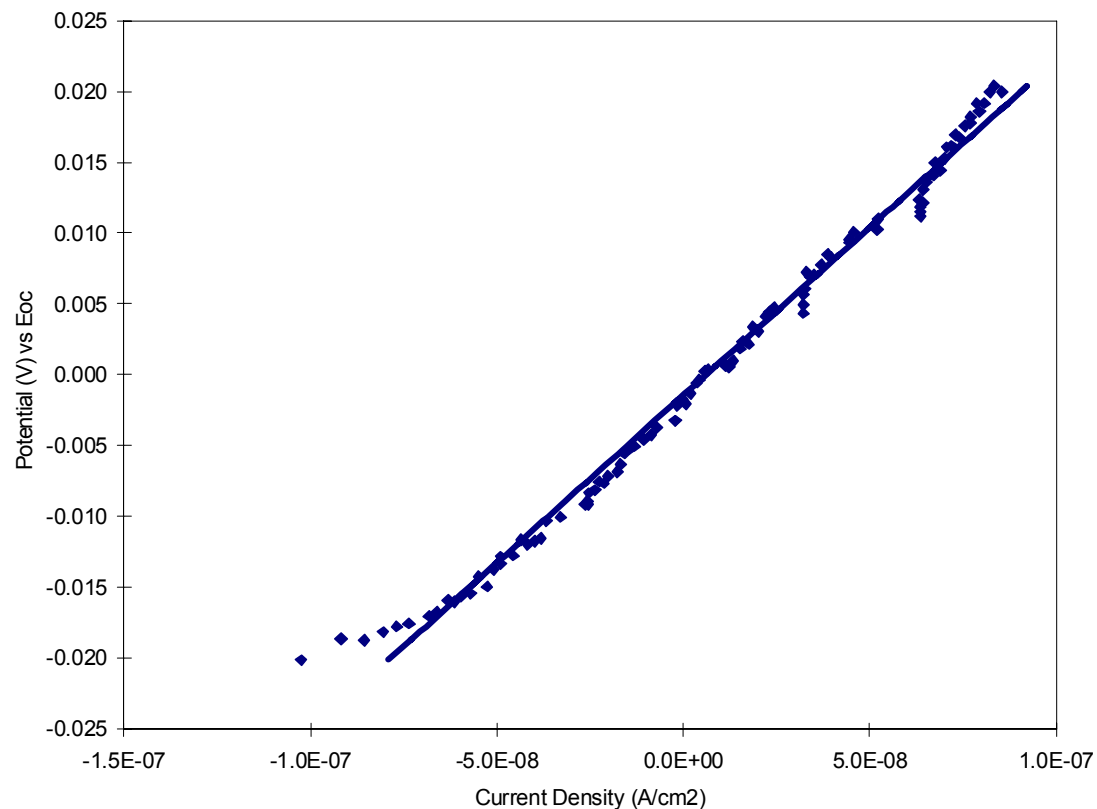
Pstat: PStat3
 Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
 EOC: -0.242763 V
 Area: 96.713 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/Equiv
 Conditioning: OFF
 IR Comp.: OFF

Potntio-Dynamic Scan on Nut and bolt connected,
 and submerged in Ohio River Water.

TAFEL RESULTS

Region = -737.5 mV to 952.5 mV
 Ecorr = -324.7 mV
 Icorr = 1.509E-07 A/cm²
 BetaC = 207.2 mV/Decade
 BetaA = 469.8 mV/Decade
 Rp = 4.138E+05 Ohm cm²
 CorrRate = 0.061 mpy

Polarization Resistance
'CERL BOLT 2D126 Linear Pol Scan #26.DTA'

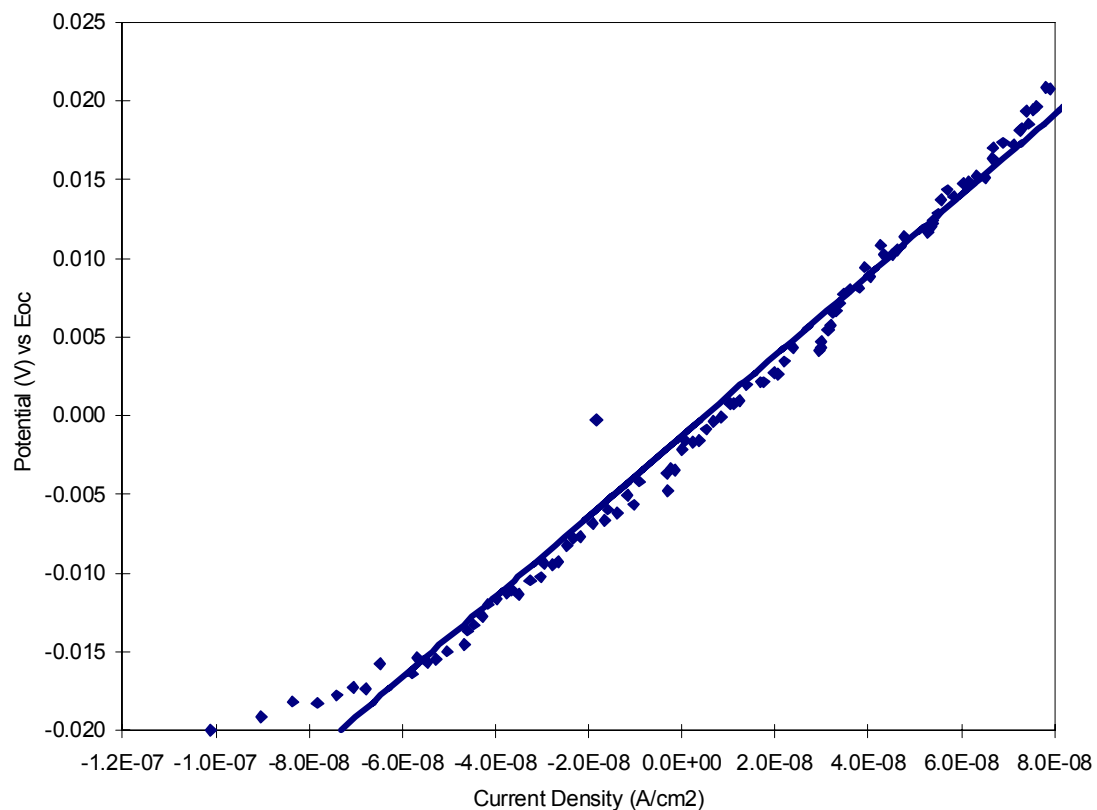


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.325411 V
Area: 46.82 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
Region = -20.1 mV to 20.0 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -326.8 mV
Icorr = 1.100E-07 A/cm²
Rp = 2.369E+05 Ohm cm²
CorrRate = 0.045 mpy

Polarization Resistance
'CERL BOLT 2D126 Linear Pol Scan #27.DTA'



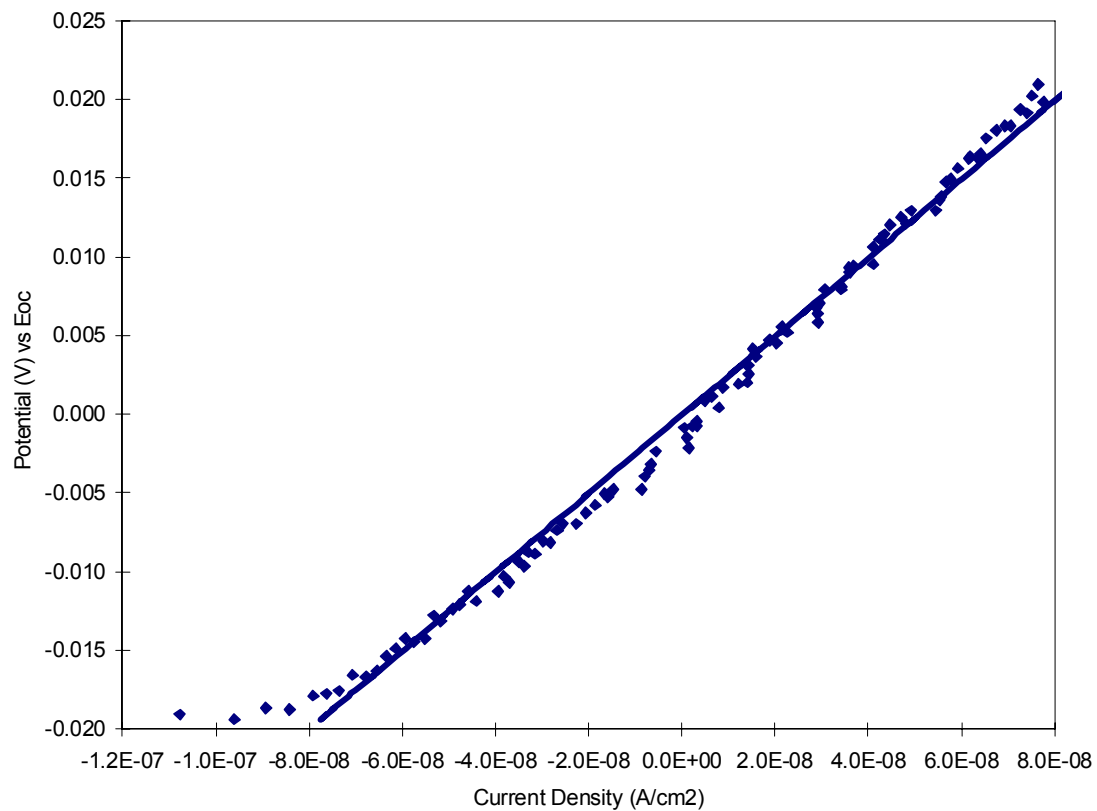
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.332473 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS

Region = -20.0 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -333.8 mV
 Icorr = 1.020E-07 A/cm²
 Rp = 2.554E+05 Ohm cm²
 CorrRate = 0.042 mpy

Polarization Resistance
'CERL BOLT 2D126 Linear Pol Scan #28.DTA'



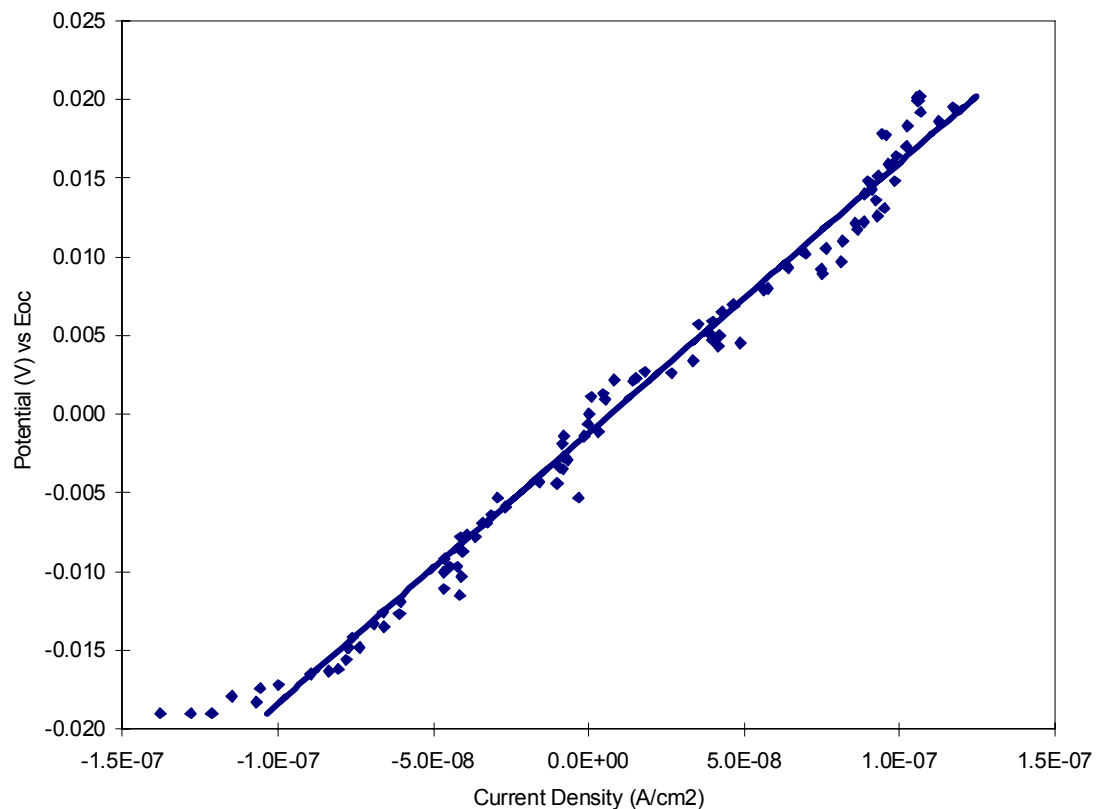
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.338163 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS

Region = -19.1 mV to 19.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -338.2 mV
 Icorr = 1.044E-07 A/cm²
 Rp = 2.496E+05 Ohm cm²
 CorrRate = 0.043 mpy

Polarization Resistance
'CERL NUT 2D126 Linear Pol Scan #10.DTA



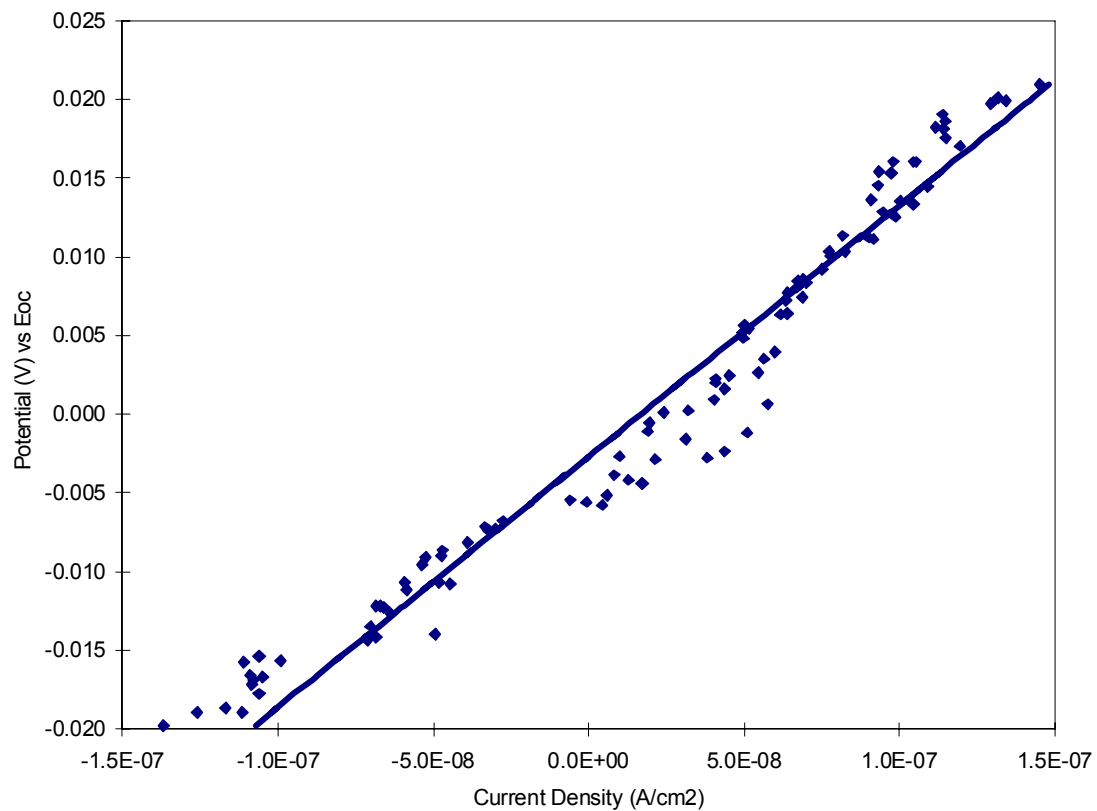
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.397737 V
 Area: 39.609 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water.
 Paint on nut, 25% clean metal (39.609) for surface area.

POLRES RESULTS

Region = -19.0 mV to 20.1 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -399.0 mV
 Icorr = 1.520E-07 A/cm²
 Rp = 1.715E+05 Ohm cm²
 CorrRate = 0.062 mpy

Polarization Resistance
'CERL NUT 2D126 Linear Pol Scan #8.DTA



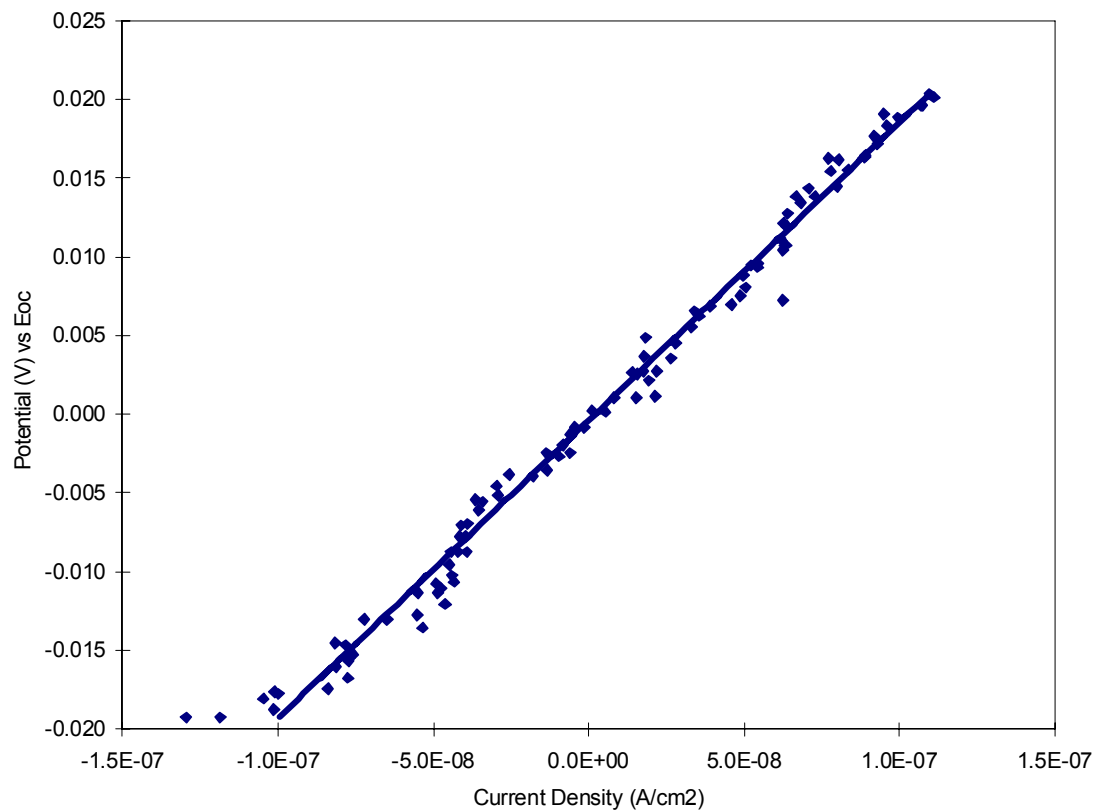
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.393665 V
 Area: 39.609 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water
 Paint on nut, 25% clean metal (39.609) for surface
 area

POLRES RESULTS

Region = -19.8 mV to 20.9 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -396.4 mV
 Icorr = 1.635E-07 A/cm²
 Rp = 1.594E+05 Ohm cm²
 CorrRate = 0.067 mpy

Polarization Resistance
'CERL NUT 2D126 Linear Pol Scan #9.DTA

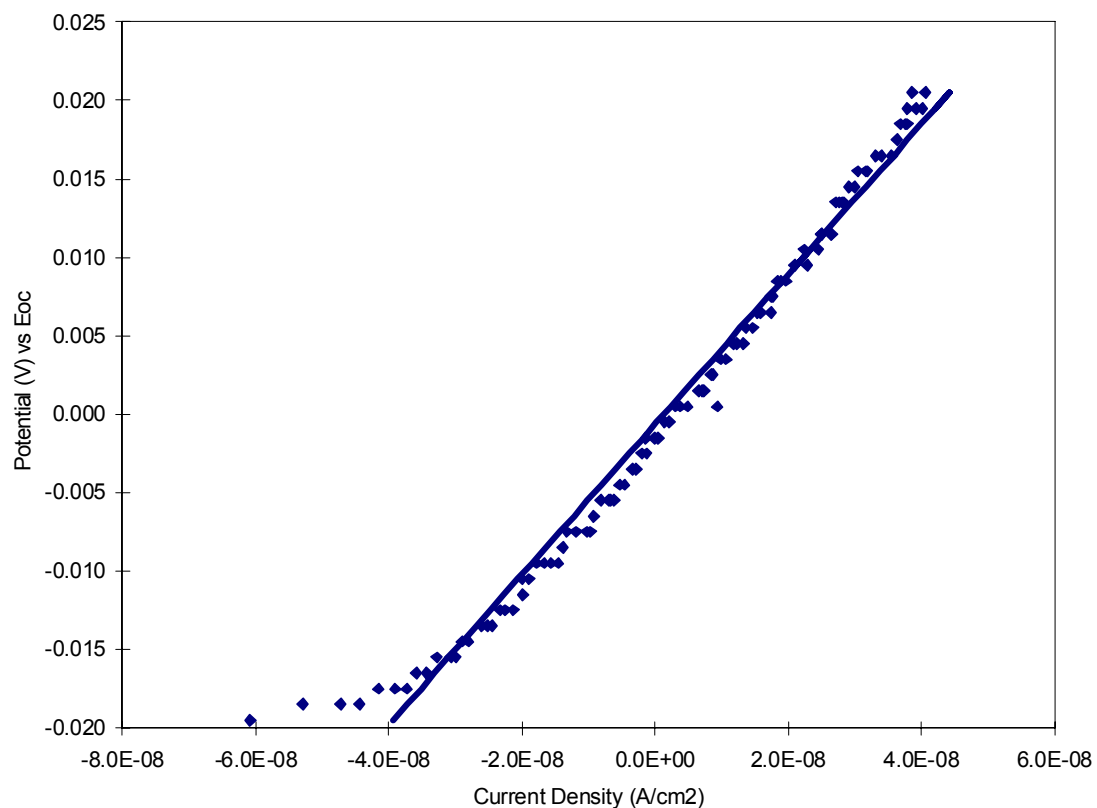


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.395681 V
 Area: 39.609 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
 Region = -19.3 mV to 20.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -396.1 mV
 Icorr = 1.377E-07 A/cm²
 Rp = 1.893E+05 Ohm cm²
 CorrRate = 0.056 mpy

Polarization Resistance
'CERL Nut-Bolt 2D126 Linear Pol Scan #41.DTA

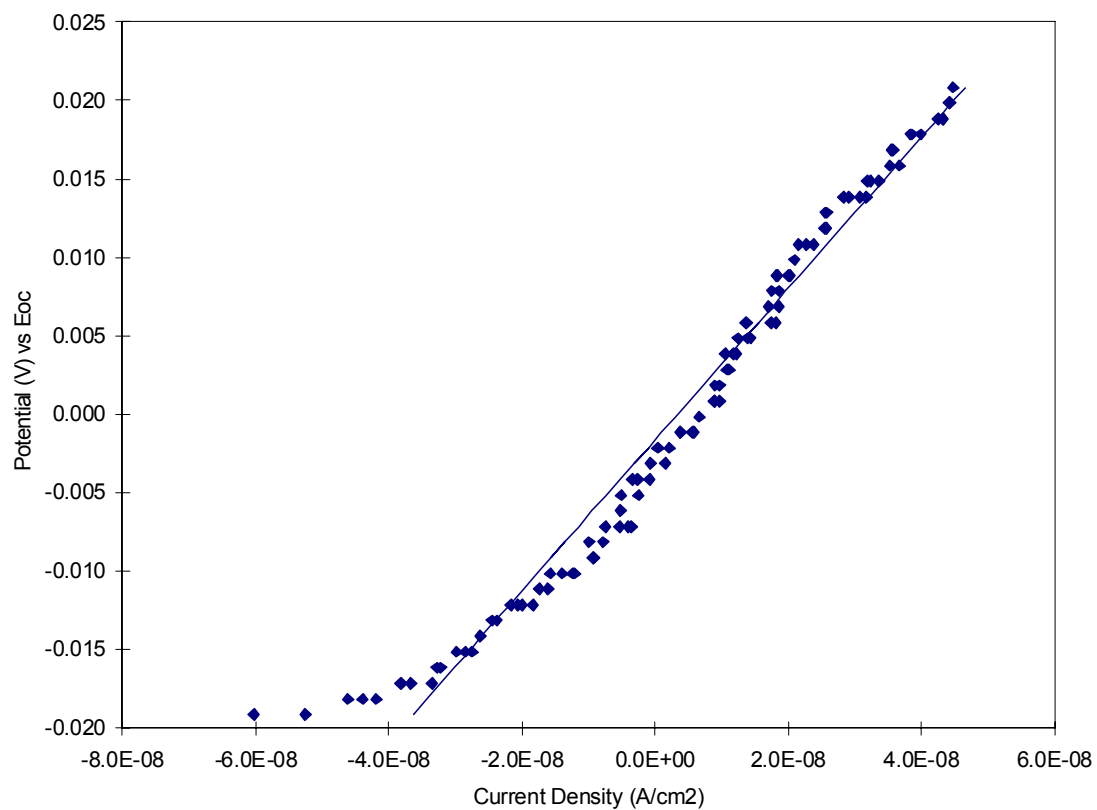


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.313498 V
Area: 86.4 cm2
Electrode: 7.94 gm/cm3, 25.1 g/equiv
Conditioning: OFF
IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
together -Nut 45% Bare Metal

POLRES RESULTS
Region = -19.5 mV to 20.5 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -314.1 mV
Icorr = 5.442E-08 A/cm2
Rp = 4.789E+05 Ohm cm2
CorrRate = 0.022 mpy

Polarization Resistance
'CERL Nut-Bolt 2D126 Linear Pol Scan #42.DTA



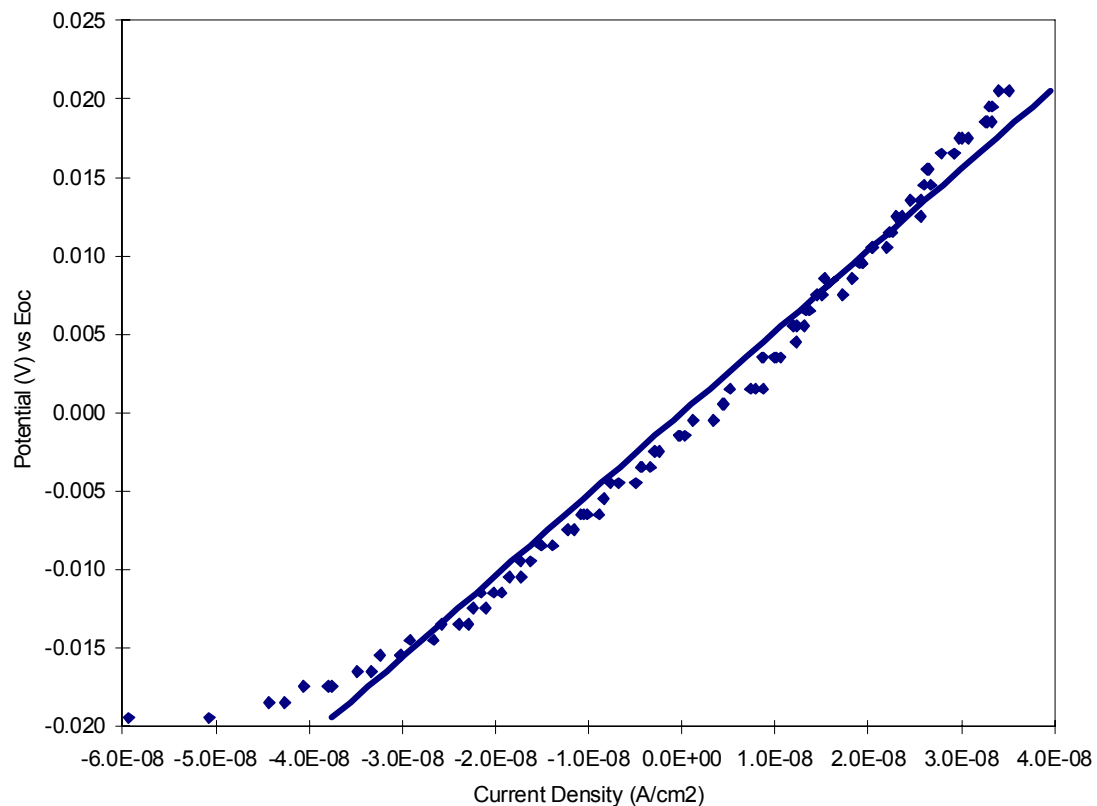
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.313842 V
 Area: 86.4 cm2
 Electrode: 7.94 gm/cm3, 25.1 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled together -Nut 45% Bare Metal

POLRES RESULTS

Region = -19.2 mV to 20.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -315.5 mV
 Icorr = 5.409E-08 A/cm2
 Rp = 4.818E+05 Ohm cm2
 CorrRate = 0.022 mpy

Polarization Resistance
'CERL Nut-Bolt 2D126 Linear Pol Scan #43.DTA



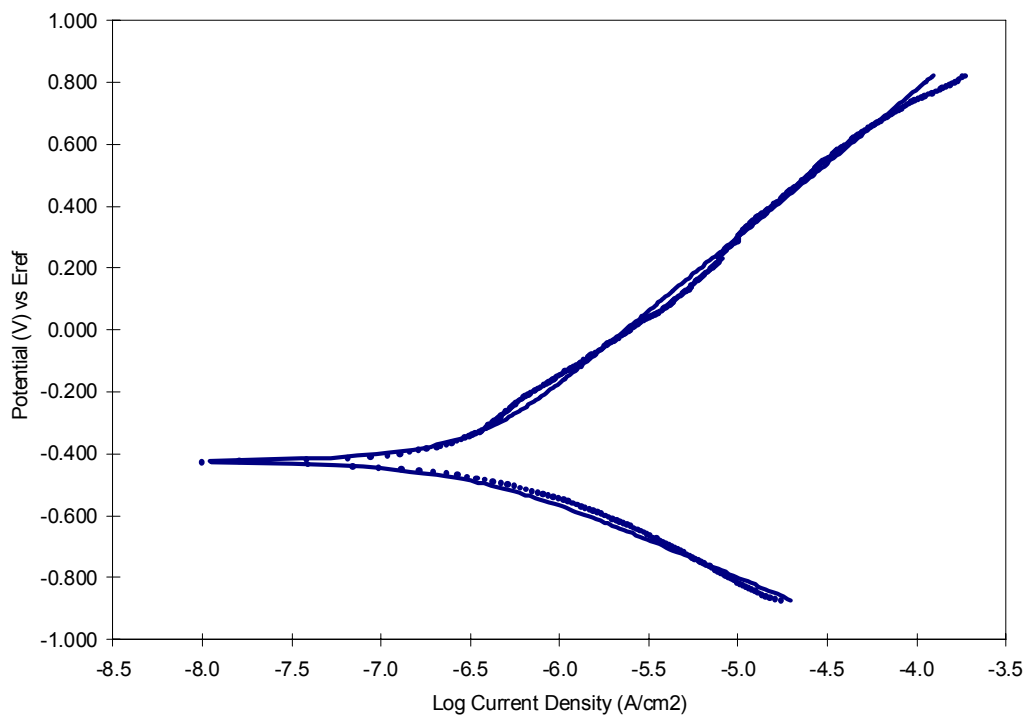
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.312523 V
Area: 86.4 cm²
Electrode: 7.94 gm/cm³, 25.1 g/equiv
Conditioning: OFF
IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
together -Nut 45% Bare Metal

POLRES RESULTS

Region = -19.5 mV to 20.5 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -312.5 mV
Icorr = 5.024E-08 A/cm²
Rp = 5.187E+05 Ohm cm²
CorrRate = 0.020 mpy

**Potentiodynamic Scan
'CERL POTDYN Scan on Bolt-Nut Combo #2D126
Scan#4.DTA**

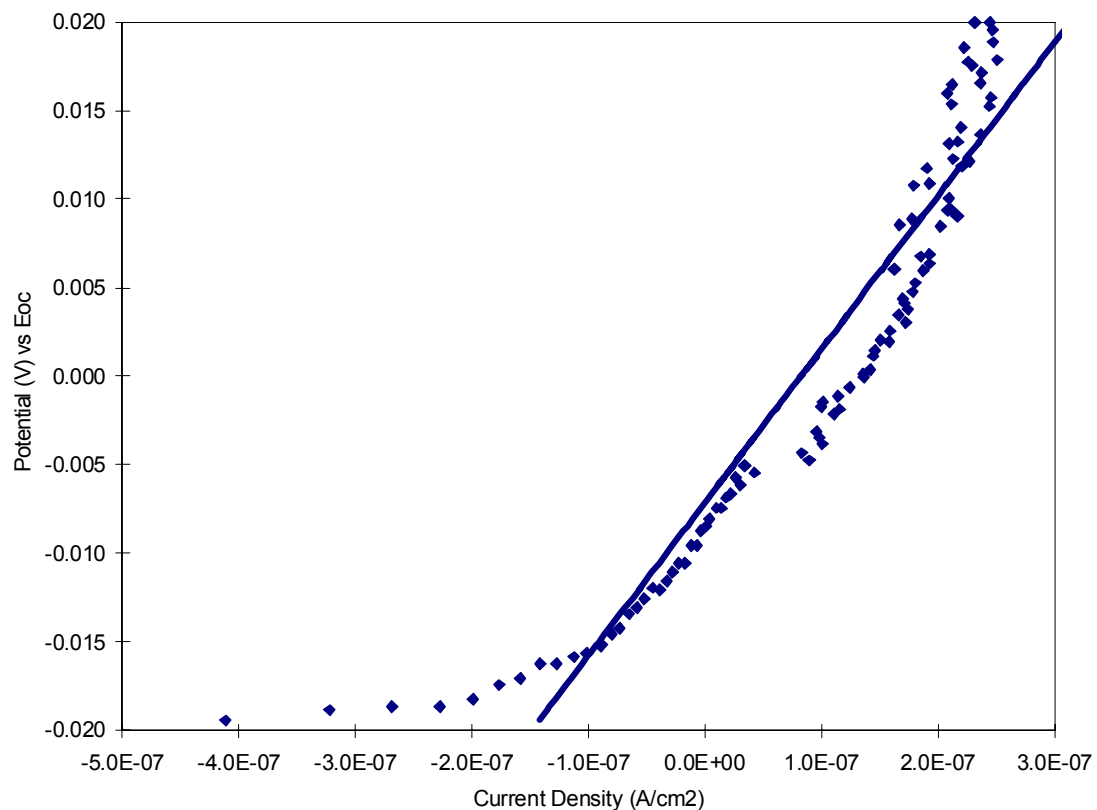


Pstat: PStat3
Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
EOC: -0.377349 V
Area: 86.429 cm²
Electrode: 7.94 gm/cm³, 25.12 g/Equiv
Conditioning: OFF
IR Comp.: OFF

Potntio-Dynamic Scan on Nut and bolt connected, and submerged in Ohio River Water.

TAFEL RESULTS
Region = -872.3 mV to 818.1 mV
Ecorr = -424.9 mV
Icorr = 3.004E-07 A/cm²
BetaC = 246.1 mV/Decade
BetaA = 476.4 mV/Decade
Rp = 2.345E+05 Ohm cm²
CorrRate = 0.122 mpy

Polarization Resistance
'cerl bolt 2d15 linear pol scan #17.dta'

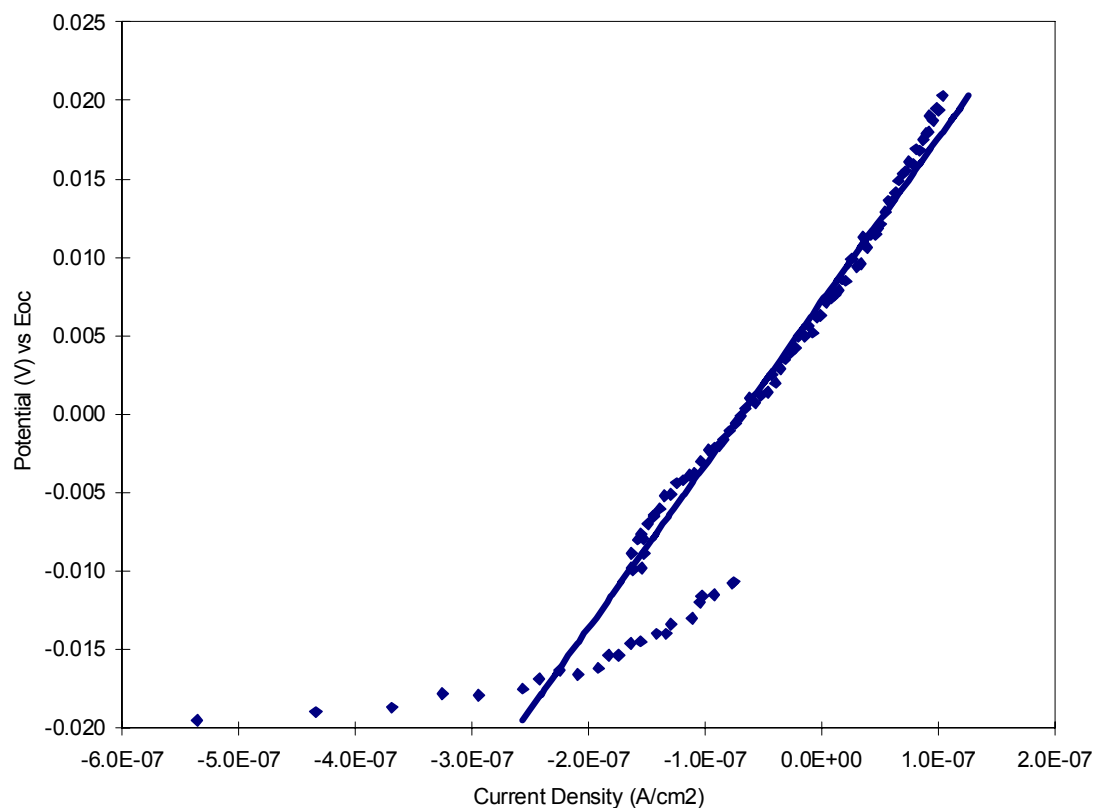


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.1416 V
 Area: 91.207 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Larger Bolt (1 total this size) in Ohio River Water.

POLRES RESULTS
 Region = -19.5 mV to 20.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -148.7 mV
 Icorr = 3.011E-07 A/cm2
 Rp = 8.656E+04 Ohm cm2
 CorrRate = 0.123 mpy

Polarization Resistance
'cerl bolt 2d15 linear pol scan #18.dta'



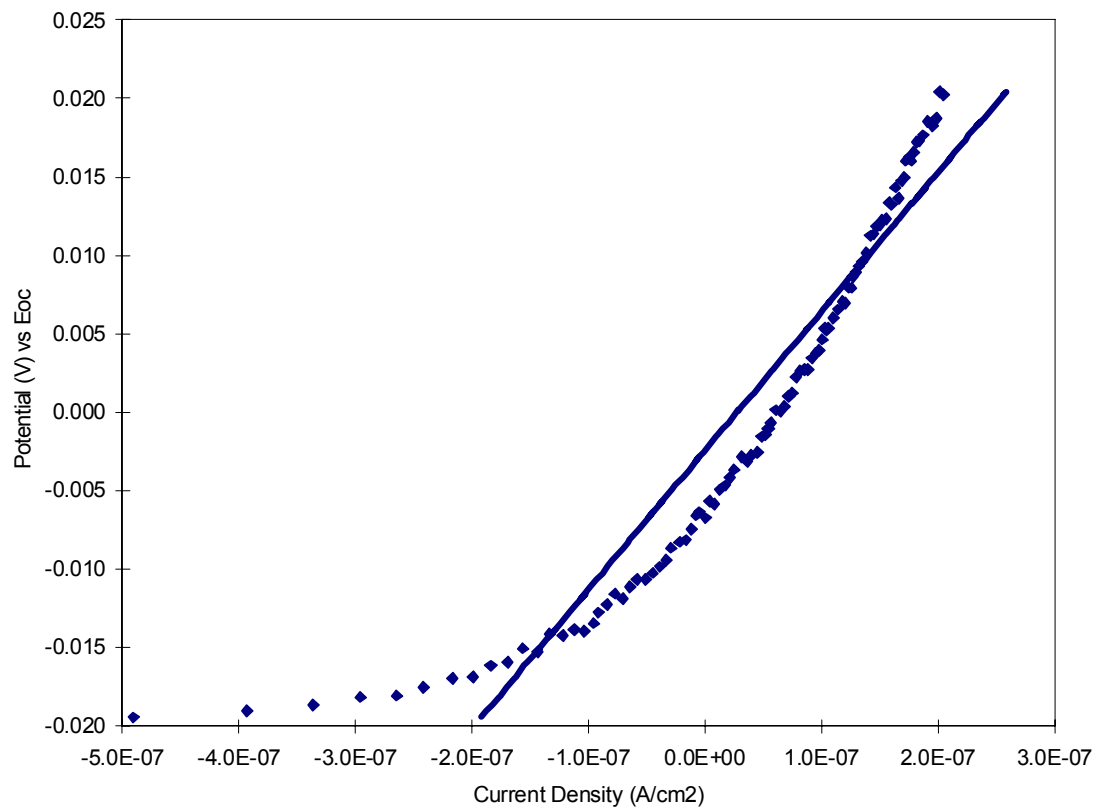
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.196448 V
 Area: 91.207 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Larger Bolt (1 total this size) in Ohio River Water.

POLRES RESULTS

Region = -19.5 mV to 20.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -189.3 mV
 Icorr = 2.506E-07 A/cm2
 Rp = 1.040E+05 Ohm cm2
 CorrRate = 0.102 mpy

Polarization Resistance
'cerl bolt 2d15 linear pol scan #19.dta'



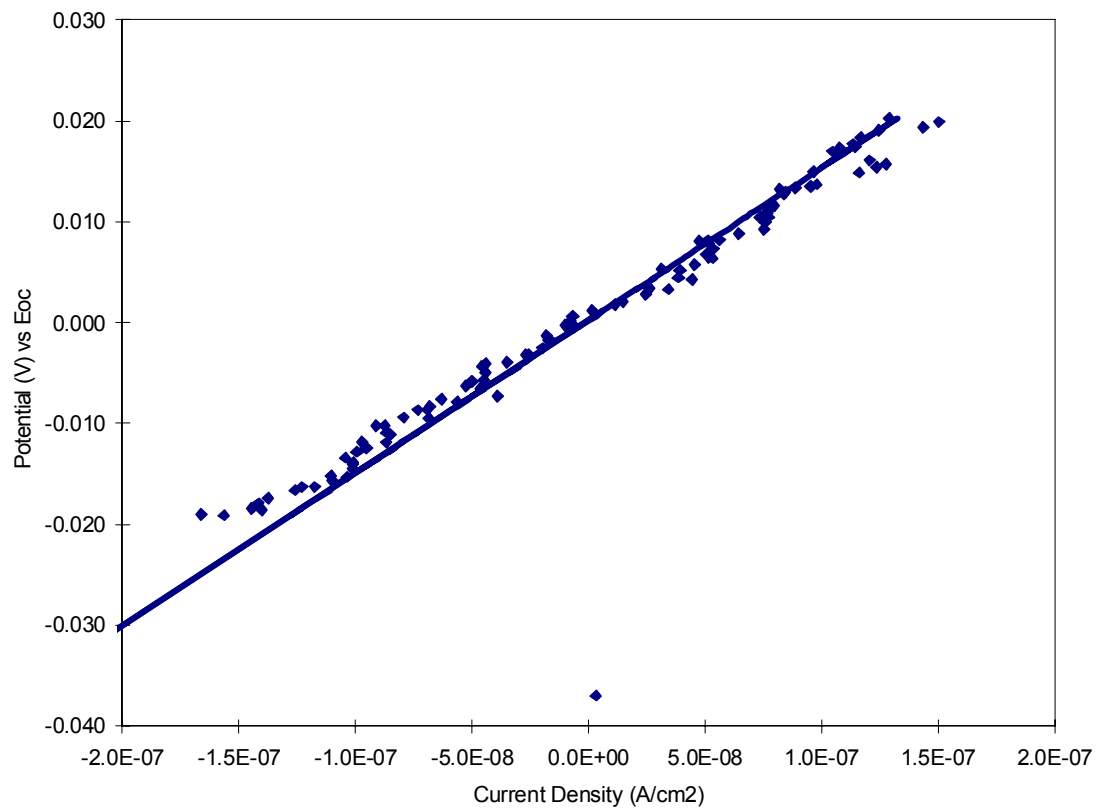
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.180189 V
 Area: 91.207 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Larger Bolt (1 total this size) in Ohio River Water.

POLRES RESULTS

Region = -19.5 mV to 20.2 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -182.6 mV
 Icorr = 2.941E-07 A/cm²
 Rp = 8.860E+04 Ohm cm²
 CorrRate = 0.120 mpy

Polarization Resistance
'CERL NUT 2D15 Linear Pol Scan #15.DTA'



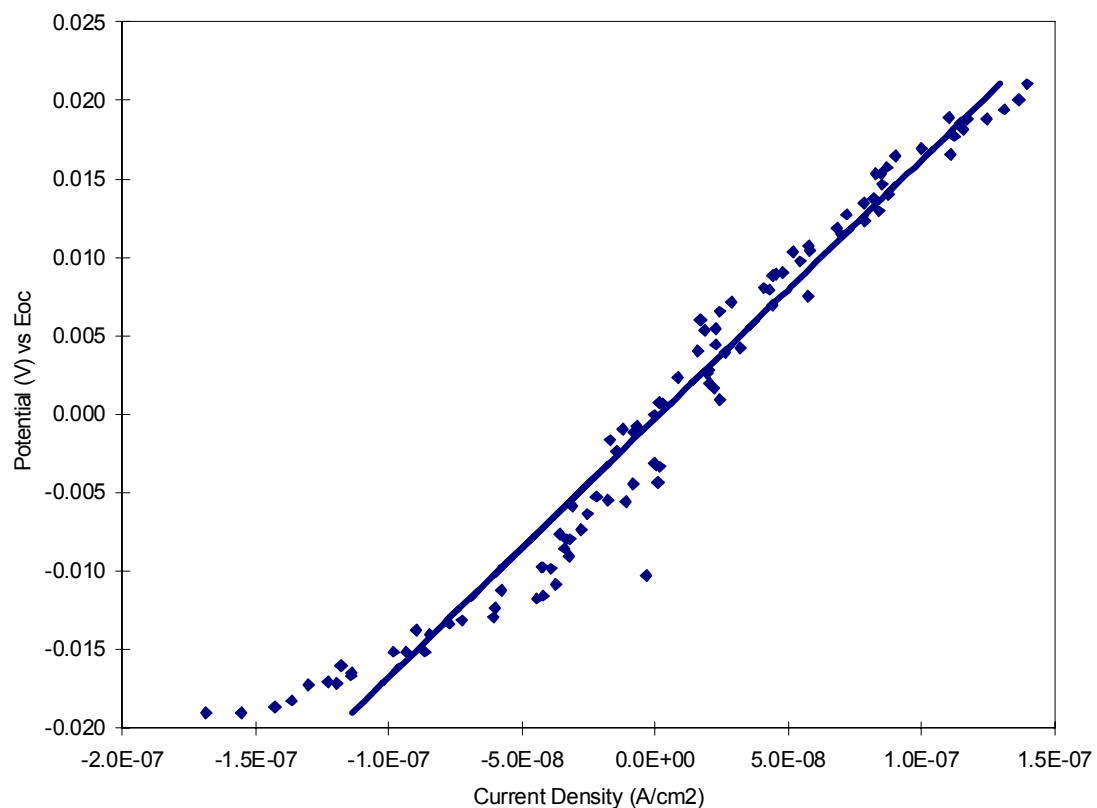
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.46684 V
 Area: 102.49 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Larger Nut (1 total this size) in Ohio River Water.
 Paint on nut, 40% clean metal (102.49) surface area.

POLRES RESULTS

Region = -19.0 mV to 15.4 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -466.6 mV
 Icorr = 1.722E-07 A/cm2
 Rp = 1.513E+05 Ohm cm2
 CorrRate = 0.070 mpy

**Polarization Resistance
'CERL NUT 2D15 Linear Pol Scan #16.DTA'**



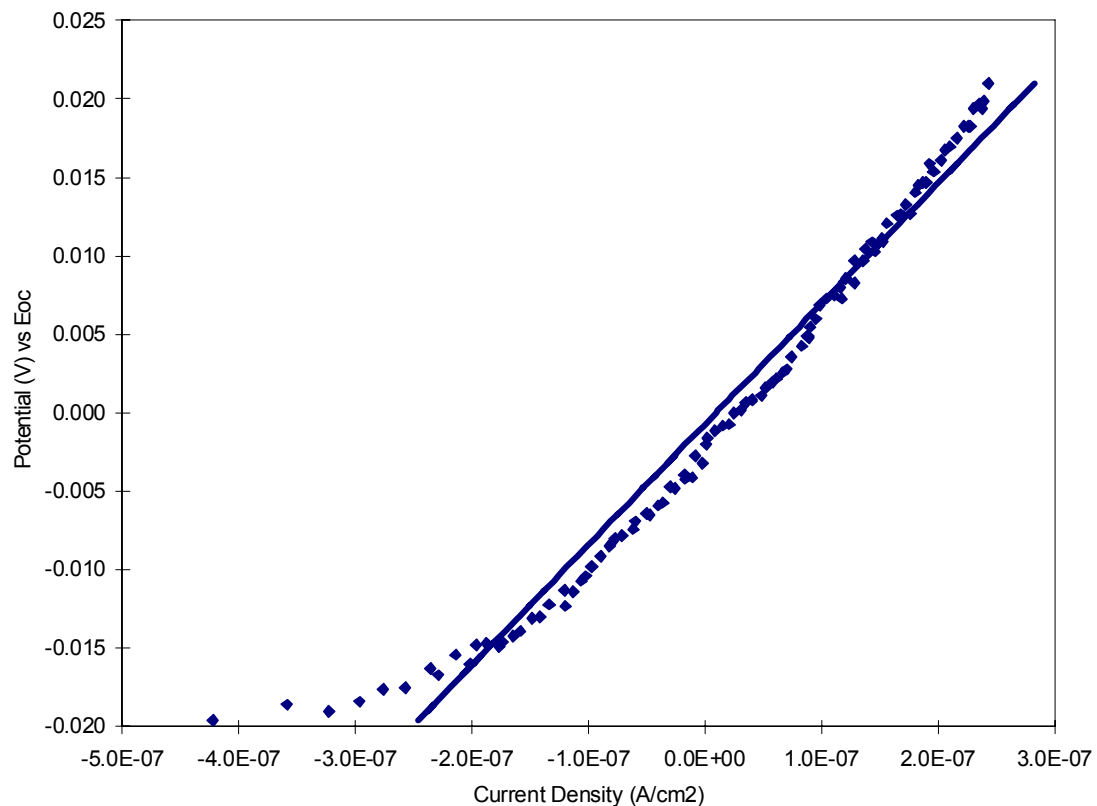
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.459787 V
 Area: 102.49 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Larger Nut (1 total this size) in Ohio River Water.
 Paint on nut, 40% clean metal (102.49) surface area.

POLRES RESULTS

Region = -19.1 mV to 21.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -460.1 mV
 Icorr = 1.581E-07 A/cm²
 Rp = 1.648E+05 Ohm cm²
 CorrRate = 0.064 mpy

Polarization Resistance
'CERL Nut-Bolt 2D15 Linear Pol Scan #50.DTA'

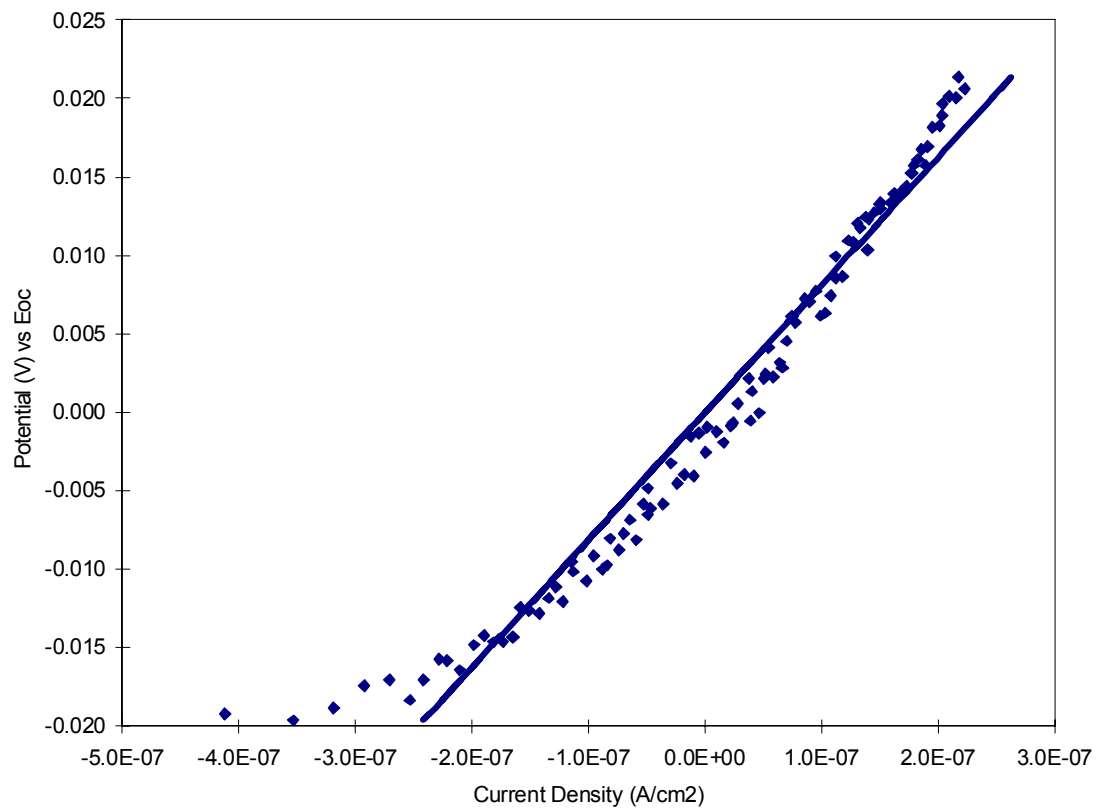


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.334721 V
Area: 193.697 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Nut and Bolt connected, Nut 40% Bare Metal in
Ohio River Water

POLRES RESULTS
Region = -19.6 mV to 21.0 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -335.4 mV
Icorr = 3.393E-07 A/cm²
Rp = 7.681E+04 Ohm cm²
CorrRate = 0.138 mpy

Polarization Resistance
'CERL Nut-Bolt 2D15 Linear Pol Scan #51.DTA'

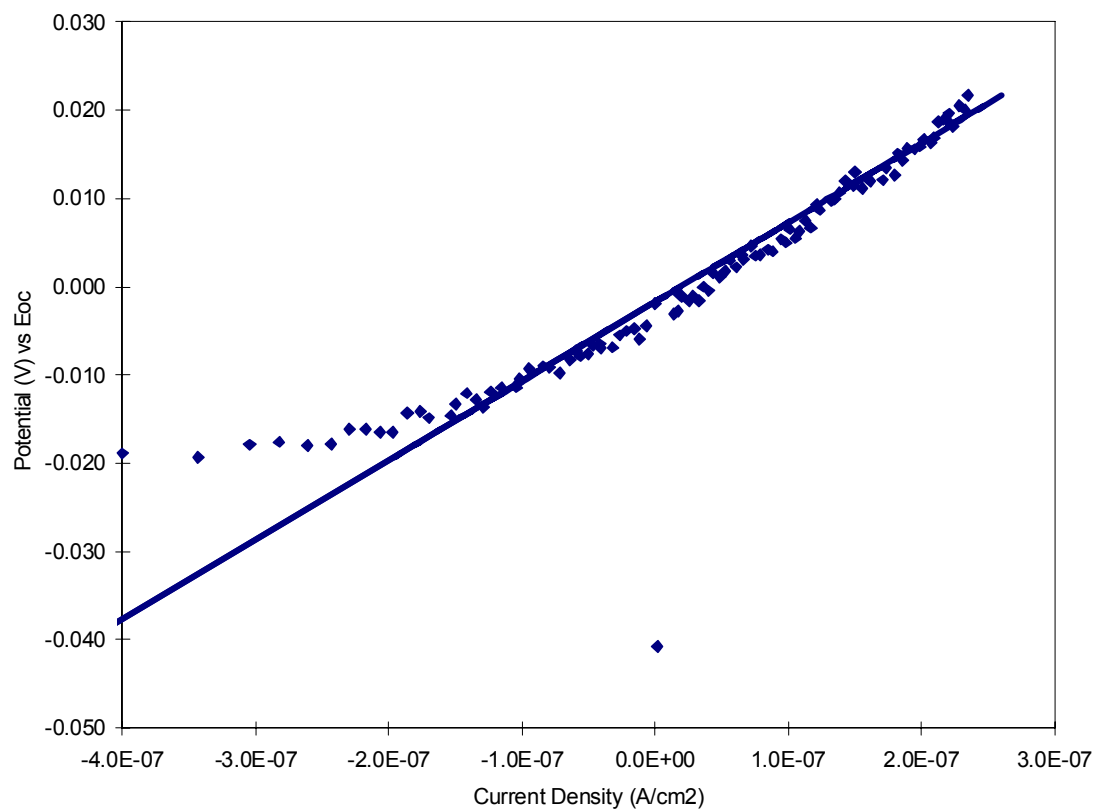


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.329694 V
Area: 193.697 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Nut and Bolt connected, Nut 40% Bare Metal in
Ohio River Water

POLRES RESULTS
Region = -19.3 mV to 20.6 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -329.7 mV
Icorr = 3.204E-07 A/cm²
Rp = 8.132E+04 Ohm cm²
CorrRate = 0.131 mpy

Polarization Resistance
'CERL Nut-Bolt 2D15 Linear Pol Scan #52.DTA'



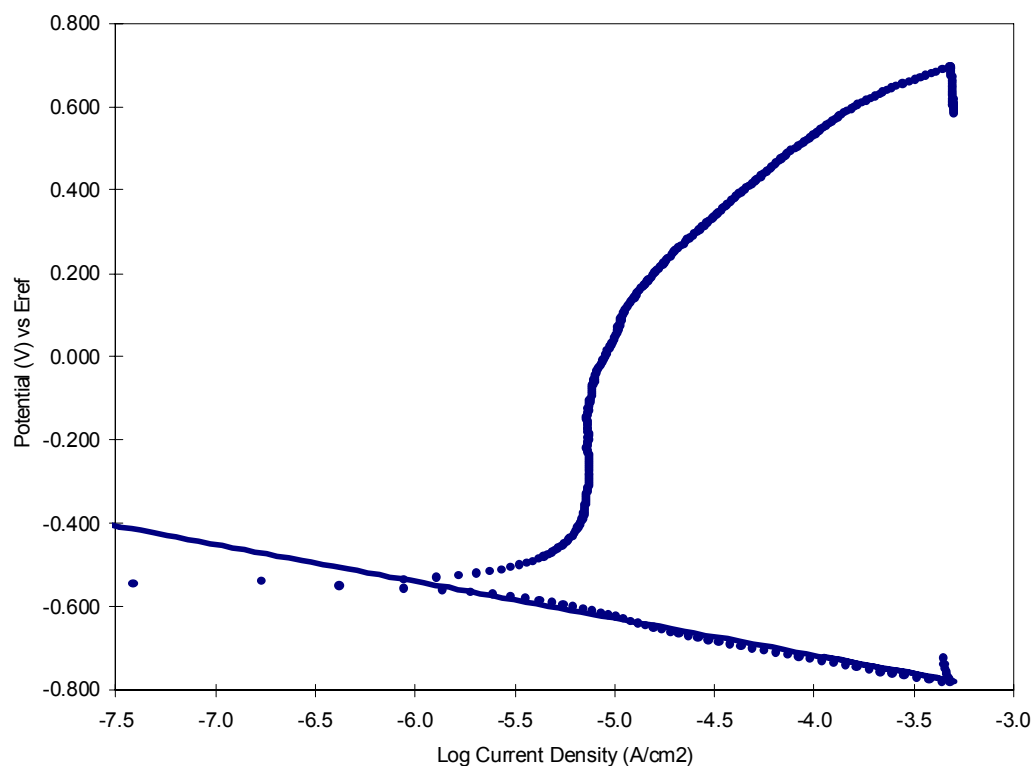
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.327157 V
 Area: 193.697 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Nut and Bolt connected, Nut 40% Bare Metal in
 Ohio River Water

POLRES RESULTS

Region = -18.9 mV to 21.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -328.9 mV
 Icorr = 2.896E-07 A/cm2
 Rp = 8.997E+04 Ohm cm2
 CorrRate = 0.118 mpy

**Potentiodynamic Scan
'CERL Nut-Bolt Combo #2D15 POTDYN Scan #1.DTA'**



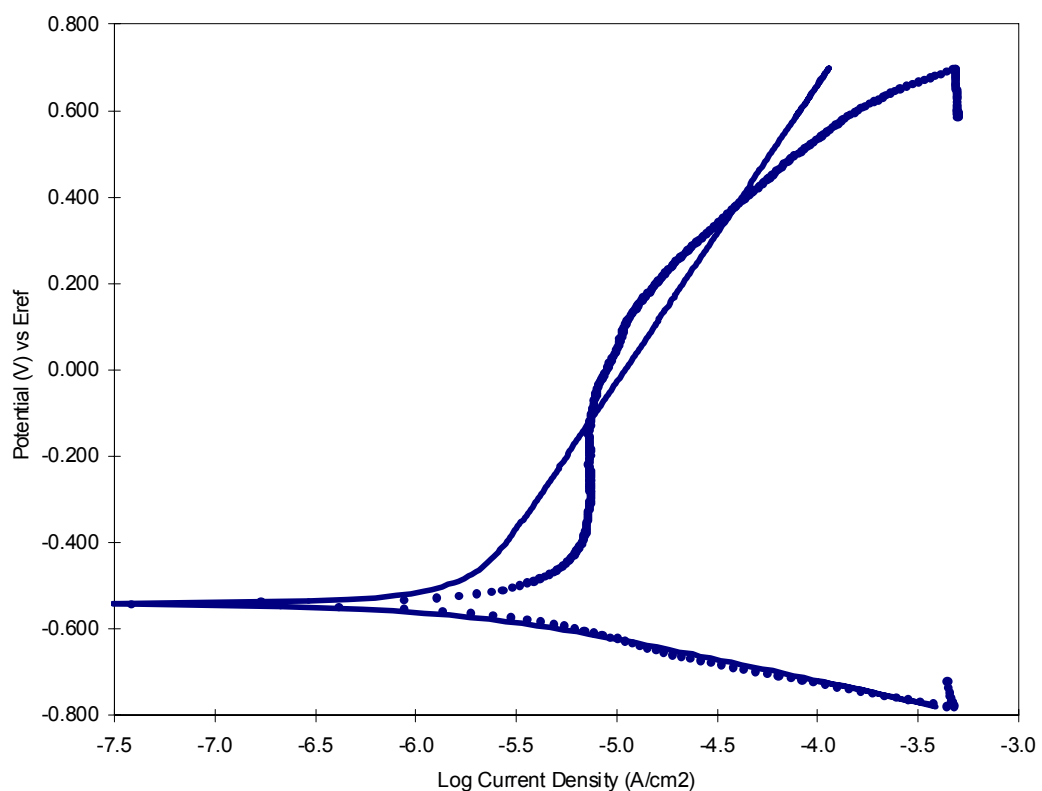
Pstat: PStat3
 Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
 EOC: -0.328384 V
 Area: 194 cm2
 Electrode: 7.94 gm/cm3, 25.1 g/Equiv
 Conditioning: OFF
 IR Comp.: OFF

Potential-Dynamic Scan for **ELogI Analysis** on Nut connected to Bolt in Ohio River Water - Same data as used for TAFEL Analysis

ELOGI RESULTS

Region = -721.0 mV to -603.0 mV
 Ecorr = -543.0 mV
 Icorr = 1.105E-06 A/cm2
 Beta = 88.7 mV (Cathodic)
 CorrRate = 0.450 mpy

**Potentiodynamic Scan
'CERL Nut-Bolt Combo #2D15 POTDYN Scan #1.DTA'**



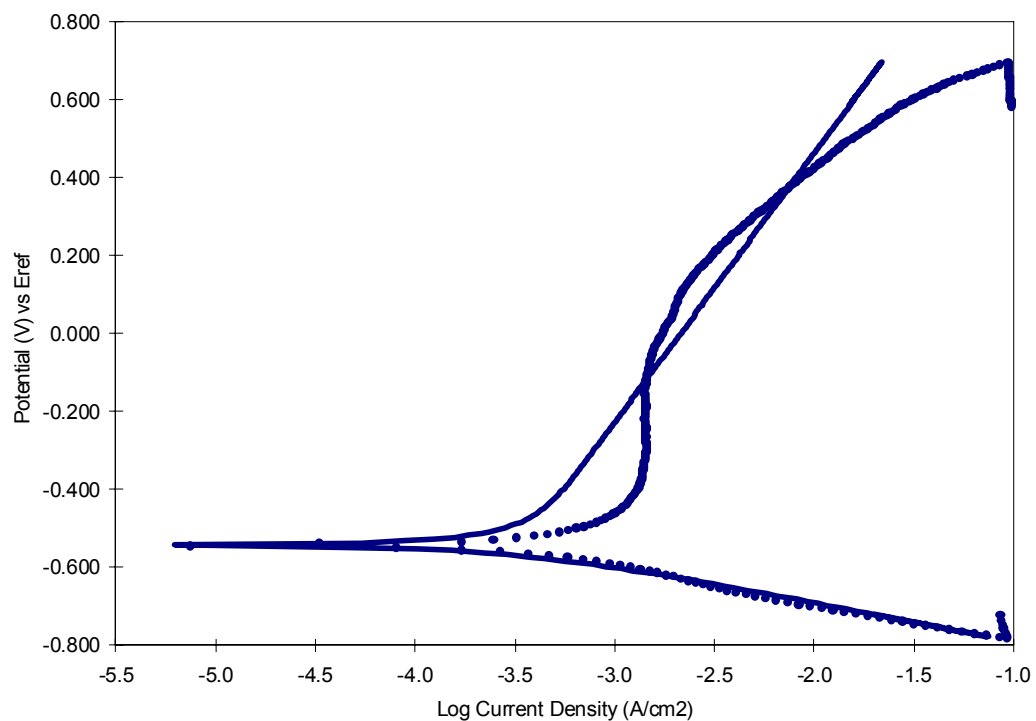
Pstat: PStat3
 Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
 EOC: -0.328384 V
 Area: 194 cm2
 Electrode: 7.94 gm/cm3, 25.1 g/Equiv
 Conditioning: OFF
 IR Comp.: OFF

Potential-Dynamic Scan for **Tafel Analysis** on Nut
 connected to Bolt in Ohio River Water

TAFEL RESULTS

Region = -721.0 mV to 589.0 mV
 Ecorr = -543.7 mV
 Icorr = 1.783E-06 A/cm2
 BetaC = 100.7 mV/Decade
 BetaA = 688.5 mV/Decade
 Rp = 2.140E+04 Ohm cm2
 CorrRate = 0.726 mpy

**Potentiodynamic Scan
'POTDYN Scan on Bolt-Nut Combo #2D15
Scan#1.DTA'**



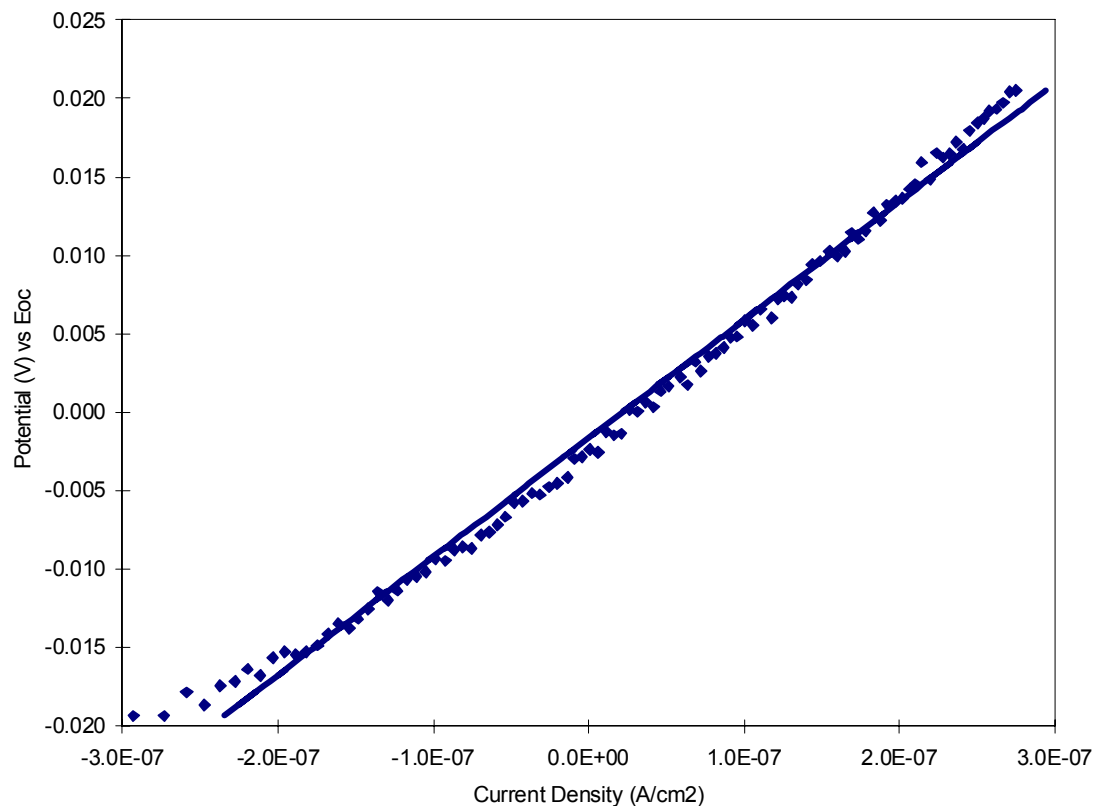
Pstat: PStat3
 Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
 EOC: -0.328384 V
 Area: 1 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/Equiv
 Conditioning: OFF
 IR Comp.: OFF

Potential-Dynamic Scan for Tafel Analysis on Nut
 connected to Bolt in Ohio River Water

TAFEL RESULTS

Region = -721.5 mV to 589.3 mV
 Ecorr = -543.7 mV
 Icorr = 3.495E-04 A/cm²
 BetaC = 101.0 mV/Decade
 BetaA = 691.5 mV/Decade
 Rp = 1.095E+02 Ohm cm²
 CorrRate = 142.437 mpy

Polarization Resistance **'CERL BOLT 2D31 Linear Pol Scan #32.DTA'**

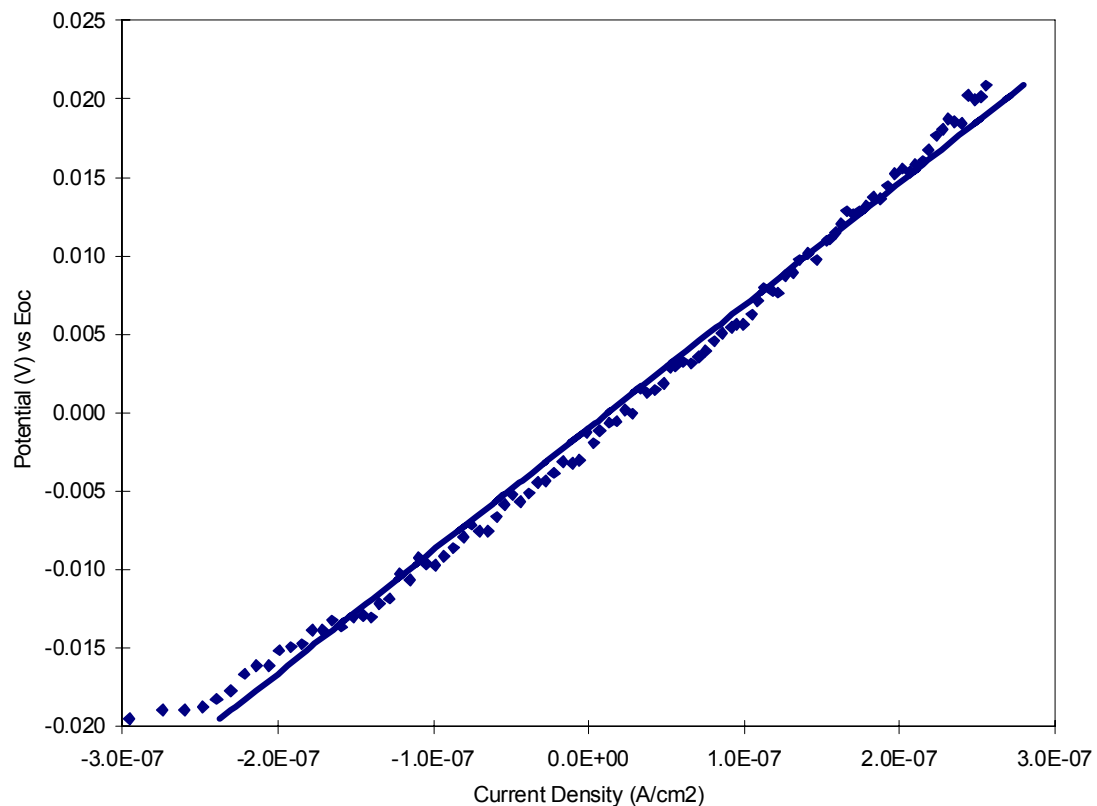


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.382884 V
 Area: 46.82 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
 Region = -19.4 mV to 20.5 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -384.6 mV
 Icorr = 3.455E-07 A/cm2
 Rp = 7.542E+04 Ohm cm2
 CorrRate = 0.141 mpy

Polarization Resistance
'CERL BOLT 2D31 Linear Pol Scan #33.DTA'



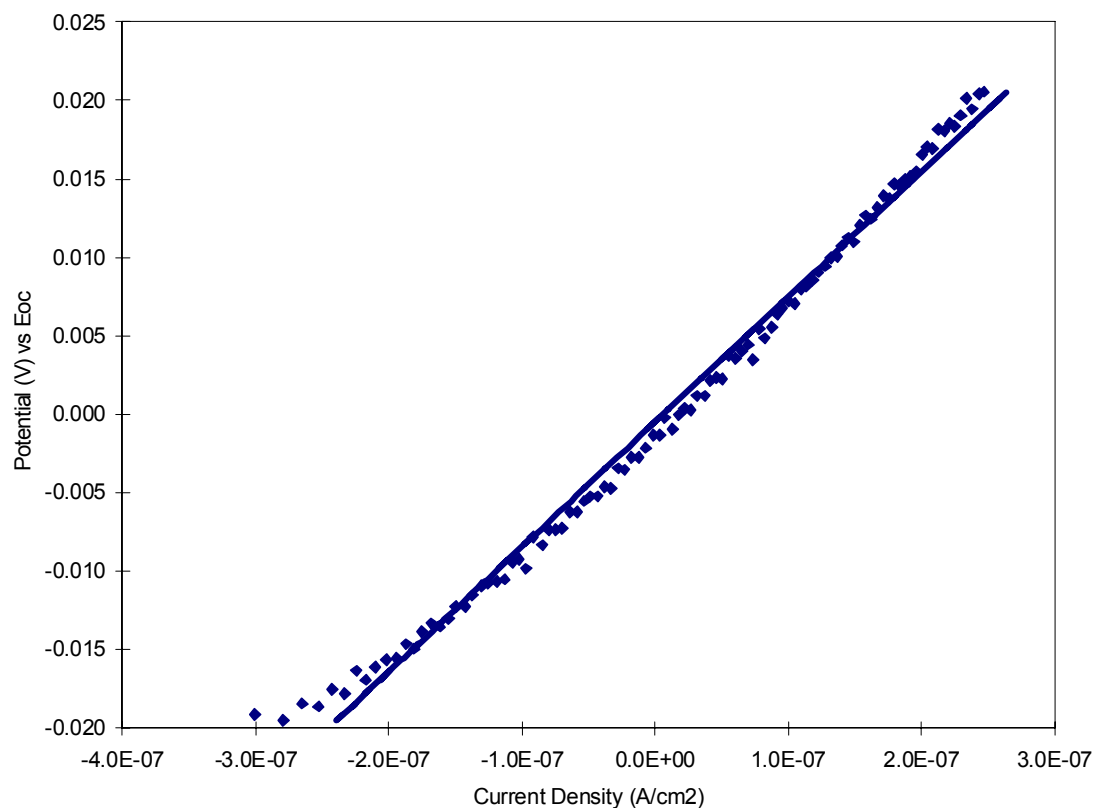
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.388803 V
Area: 46.82 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS

Region = -19.5 mV to 20.9 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -389.8 mV
Icorr = 3.335E-07 A/cm²
Rp = 7.813E+04 Ohm cm²
CorrRate = 0.136 mpy

Polarization Resistance
'CERL BOLT 2D31 Linear Pol Scan #34.DTA'

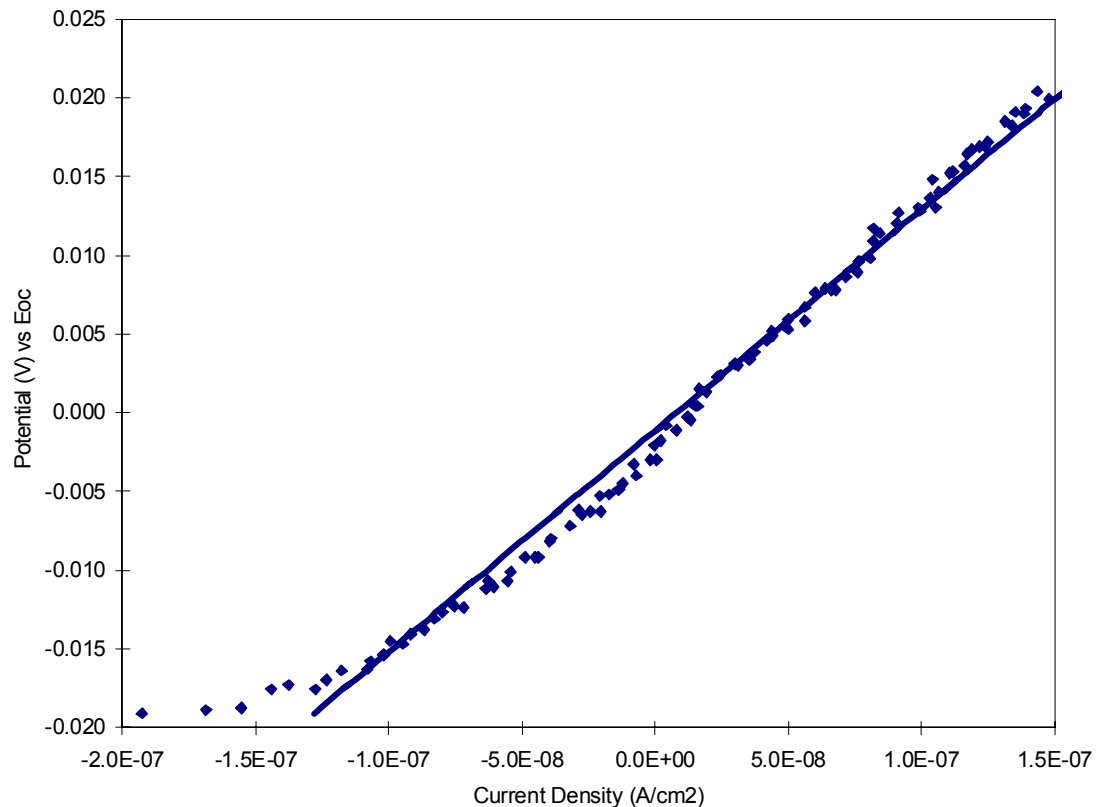


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.391701 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
 Region = -19.1 mV to 20.6 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -392.2 mV
 Icorr = 3.270E-07 A/cm²
 Rp = 7.968E+04 Ohm cm²
 CorrRate = 0.133 mpy

Polarization Resistance
'CERL NUT 2D31 Linear Pol Scan #1.DTA

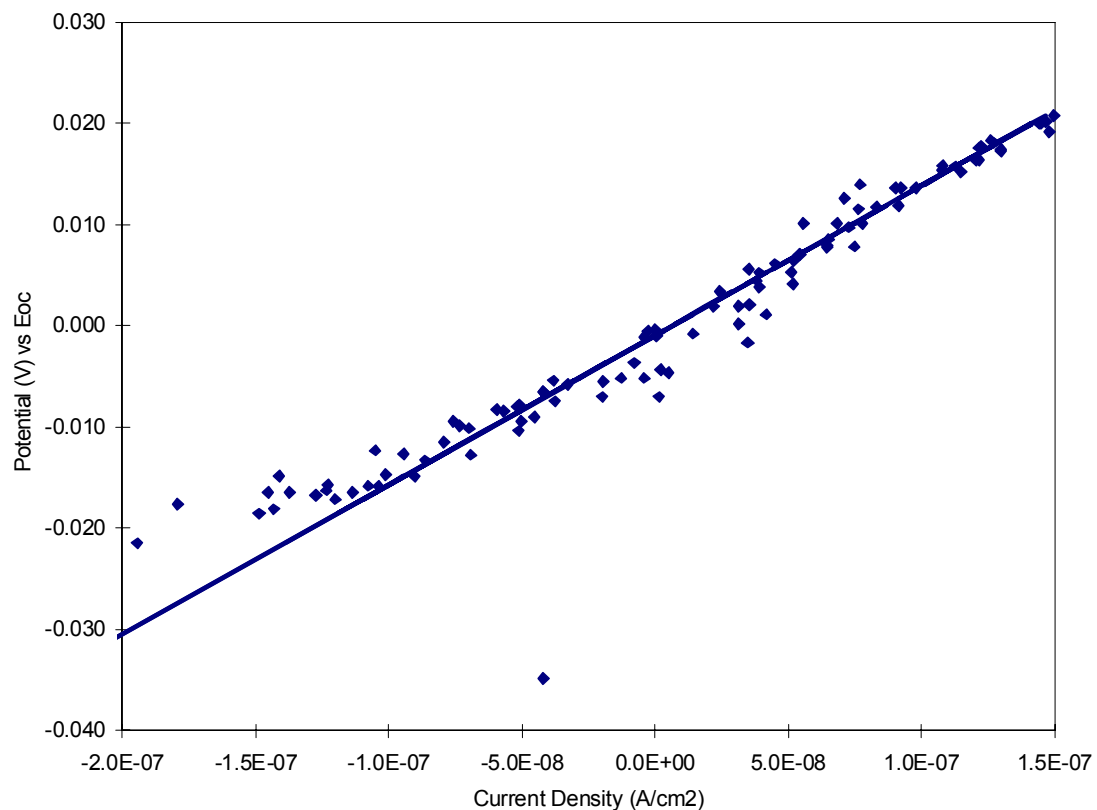


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.305448 V
Area: 78.173 cm2
Electrode: 7.94 gm/cm3, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
Region = -19.1 mV to 19.9 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -306.6 mV
Icorr = 1.856E-07 A/cm2
Rp = 1.404E+05 Ohm cm2
CorrRate = 0.076 mpy

Polarization Resistance
'CERL NUT 2D31 Linear Pol Scan #1a.DTA

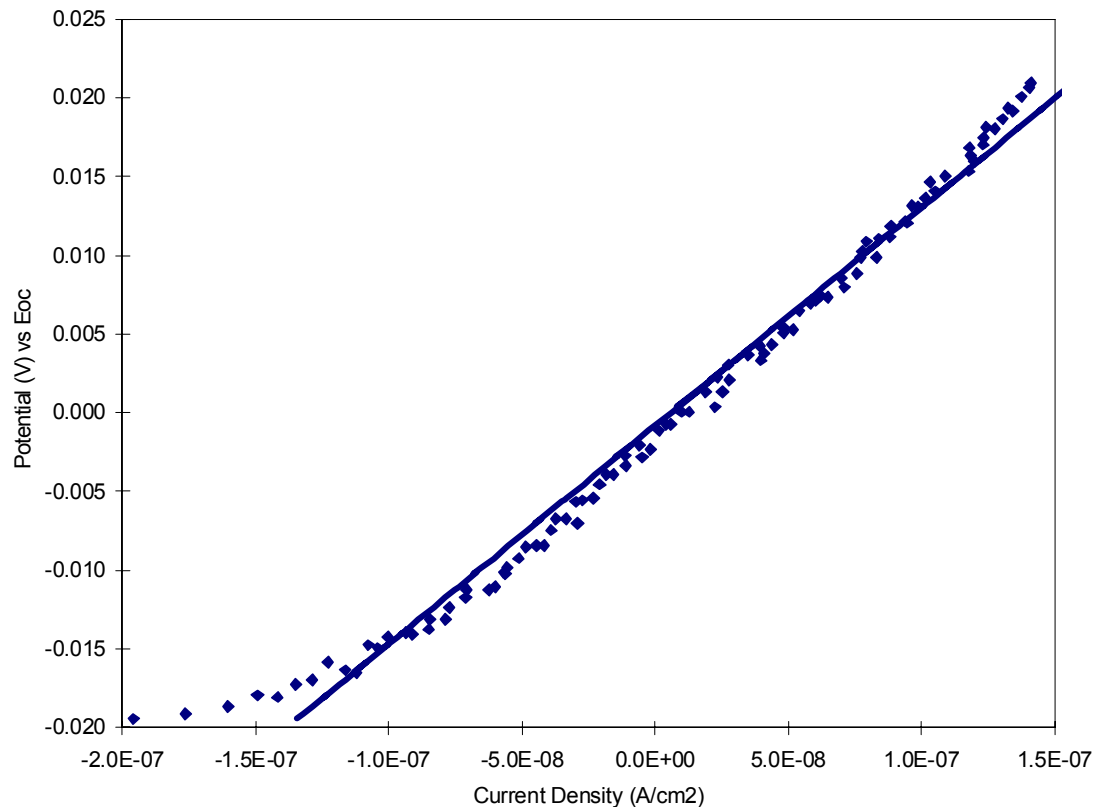


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.310795 V
 Area: 78.173 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: ON

ReRun with IR Comp ON Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
 Region = -21.5 mV to 20.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -311.7 mV
 Icorr = 1.763E-07 A/cm²
 Rp = 1.478E+05 Ohm cm²
 CorrRate = 0.072 mpy

Polarization Resistance
'CERL NUT 2D31 Linear Pol Scan #2.DTA



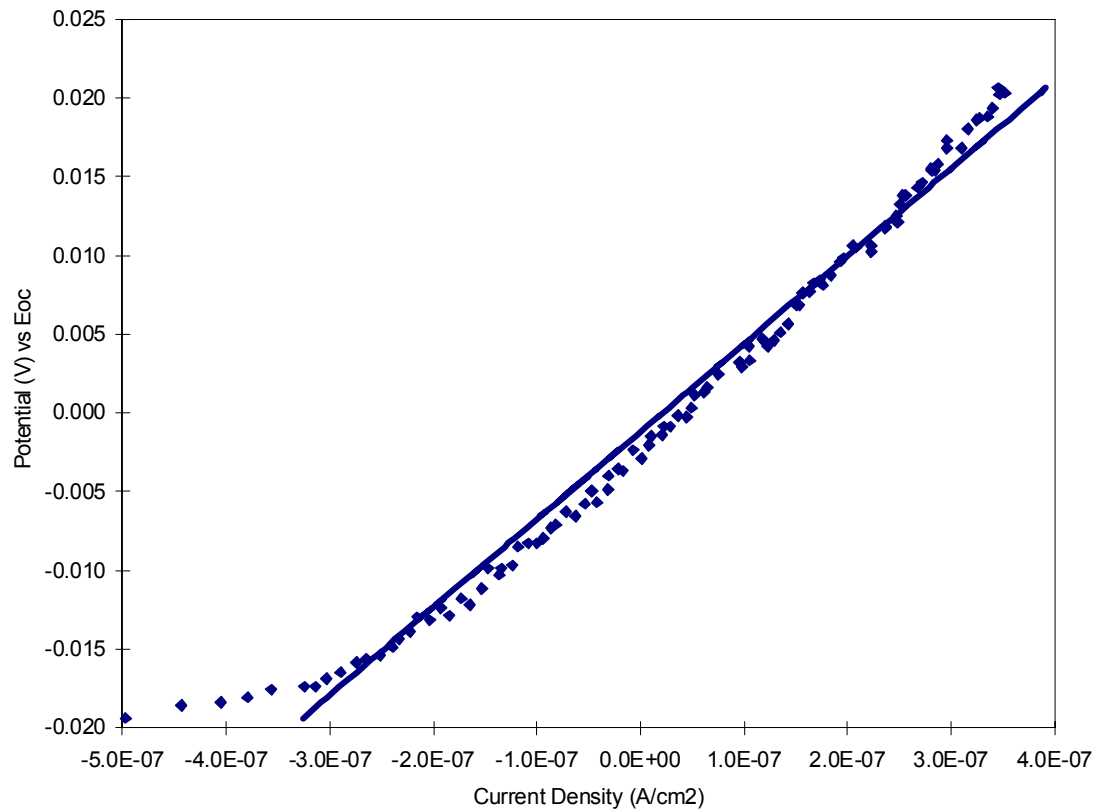
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.310485 V
Area: 78.173 cm2
Electrode: 7.94 gm/cm3, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS

Region = -19.5 mV to 20.9 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -311.3 mV
Icorr = 1.879E-07 A/cm2
Rp = 1.386E+05 Ohm cm2
CorrRate = 0.077 mpy

**Polarization Resistance
'CERL NUT 2D31 Linear Pol Scan #3.DTA**

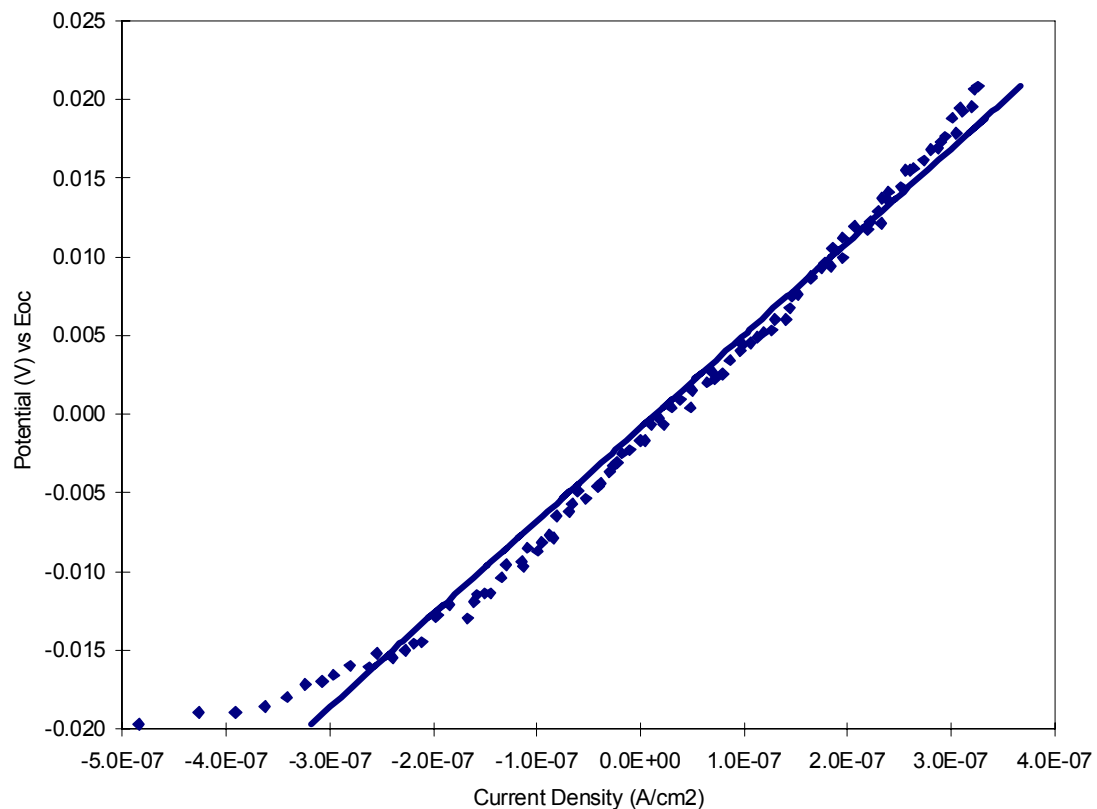


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.311461 V
 Area: 31.896 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
 Region = -19.4 mV to 20.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -312.7 mV
 Icorr = 4.676E-07 A/cm²
 Rp = 5.572E+04 Ohm cm²
 CorrRate = 0.191 mpy

Polarization Resistance
'cerl nut 2d31 linear pol scan #4.dta

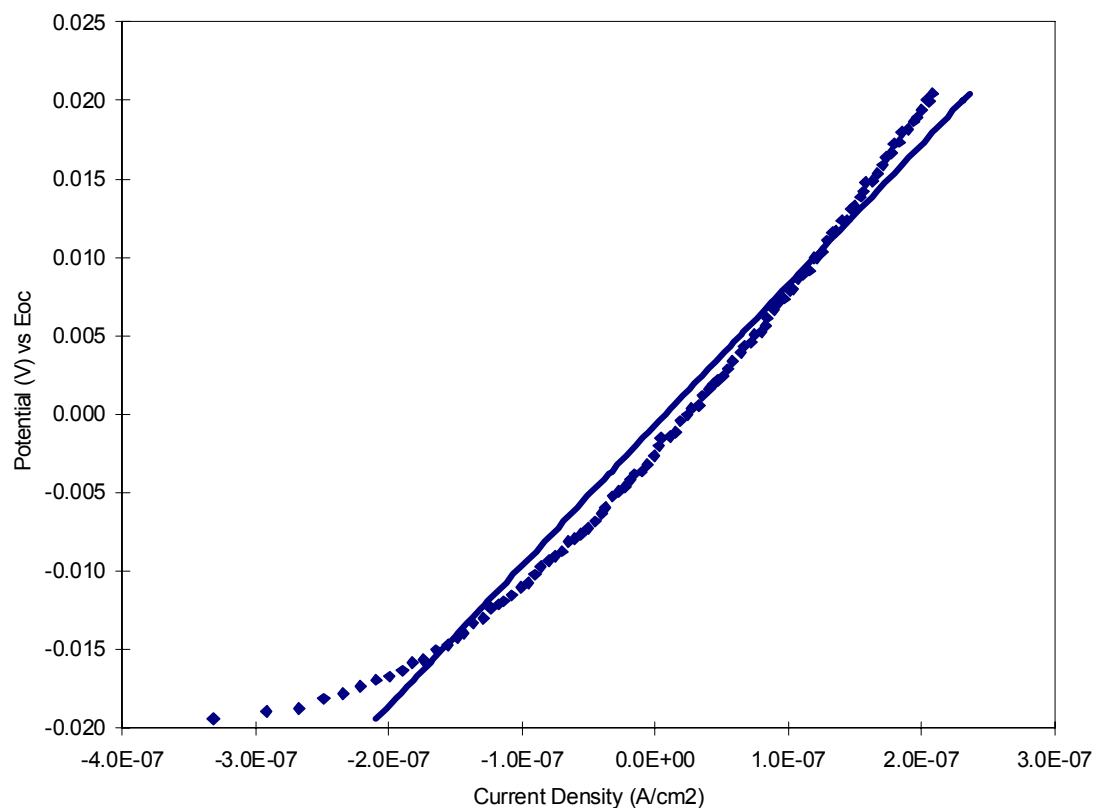


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.310059 V
Area: 31.896 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
Region = -19.7 mV to 20.8 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -310.9 mV
Icorr = 4.412E-07 A/cm²
Rp = 5.905E+04 Ohm cm²
CorrRate = 0.180 mpy

Polarization Resistance
'CERL Nut-Bolt 2D31 Linear Pol Scan #35.DTA'



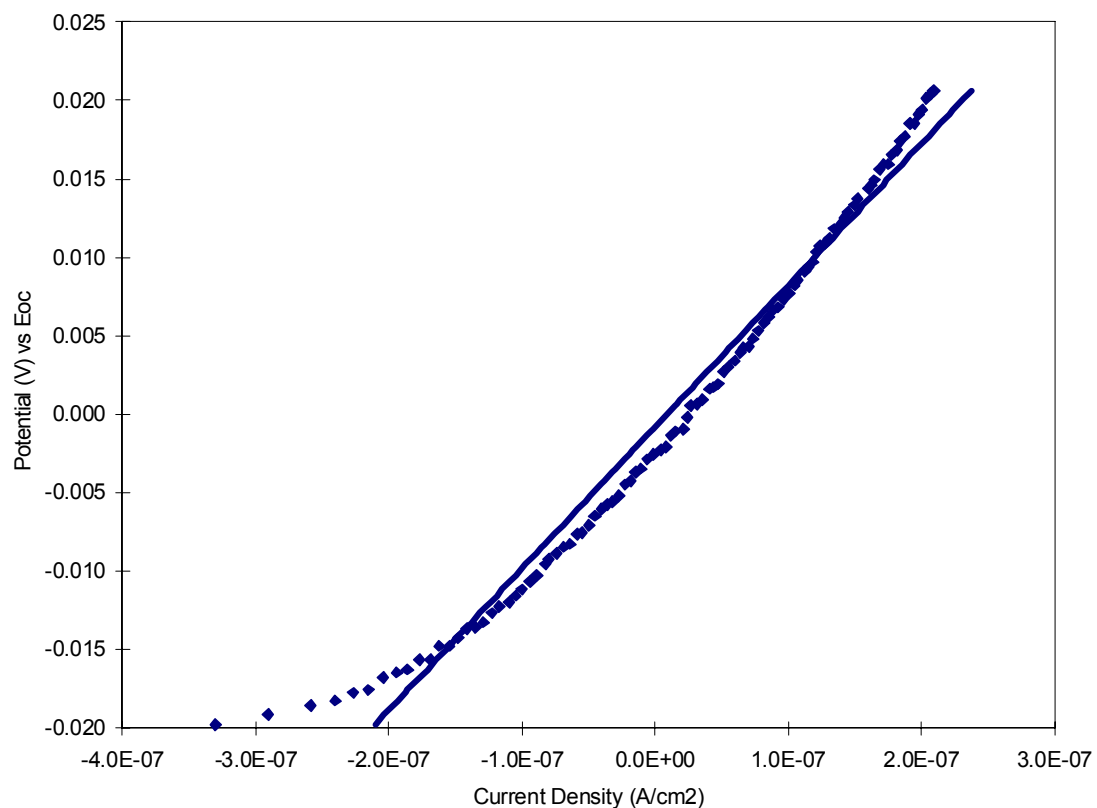
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.344708 V
 Area: 73.626 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
 together -Nut 10% Bare Metal

POLRES RESULTS

Region = -19.4 mV to 20.5 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -345.4 mV
 Icorr = 2.910E-07 A/cm²
 Rp = 8.955E+04 Ohm cm²
 CorrRate = 0.119 mpy

Polarization Resistance
'CERL Nut-Bolt 2D31 Linear Pol Scan #36.DTA'



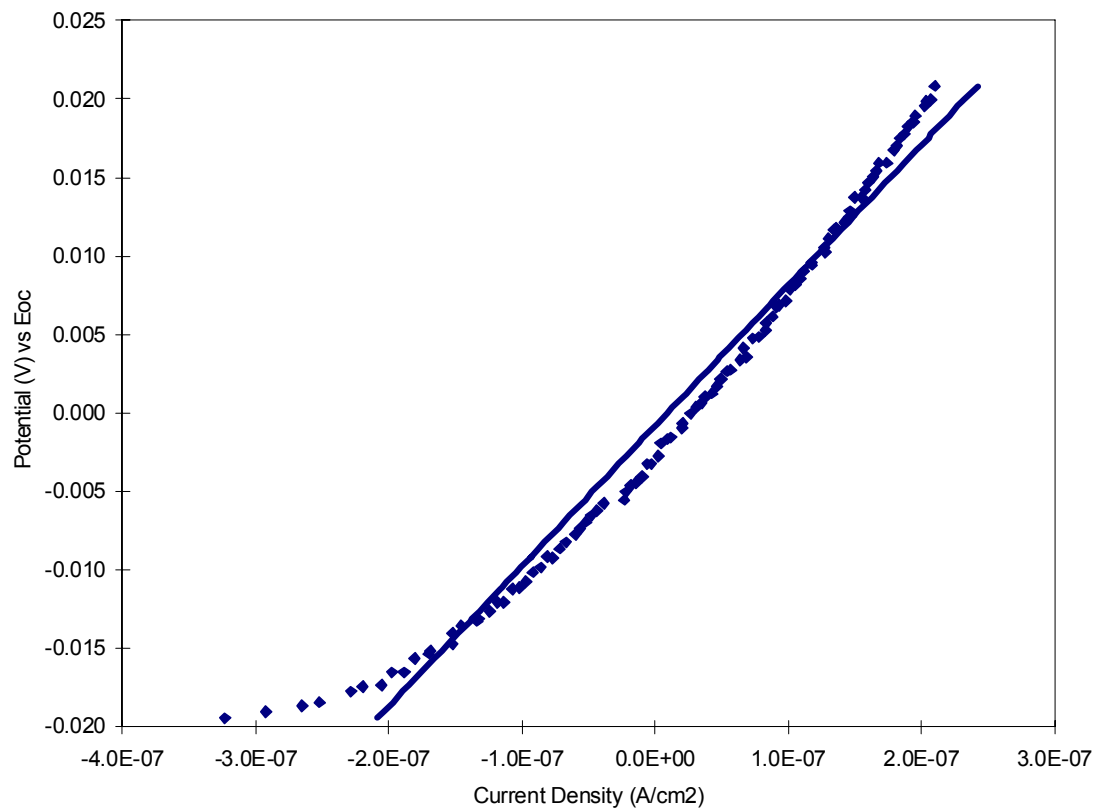
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.341574 V
Area: 73.626 cm2
Electrode: 7.94 gm/cm3, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
together -Nut 10% Bare Metal

POLRES RESULTS

Region = -19.8 mV to 20.6 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -342.4 mV
Icorr = 2.885E-07 A/cm2
Rp = 9.031E+04 Ohm cm2
CorrRate = 0.118 mpy

Polarization Resistance
'CERL Nut-Bolt 2D31 Linear Pol Scan #37.DTA'



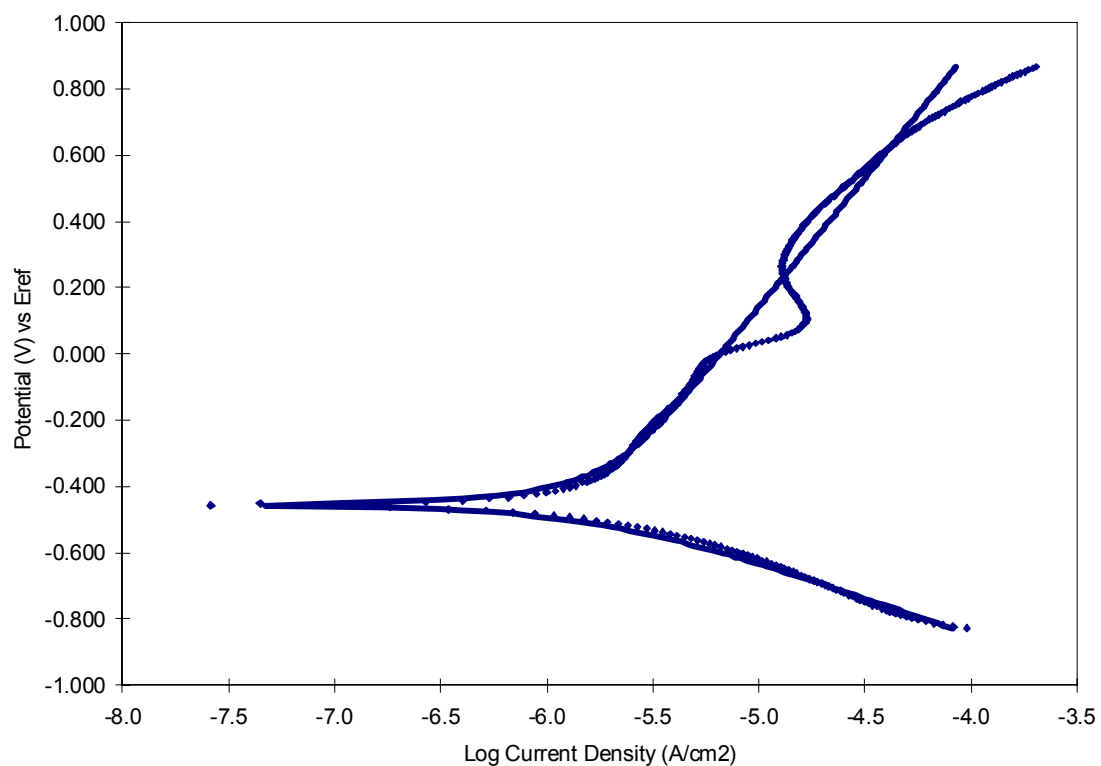
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.340598 V
 Area: 73.626 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
 together -Nut 10% Bare Metal

POLRES RESULTS

Region = -19.5 mV to 20.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -341.4 mV
 Icorr = 2.910E-07 A/cm2
 Rp = 8.953E+04 Ohm cm2
 CorrRate = 0.119 mpy

**Potentiodynamic Scan
'CERL POTDYN Scan on Bolt-Nut Combo #2D31
Scan#6.DTA'**

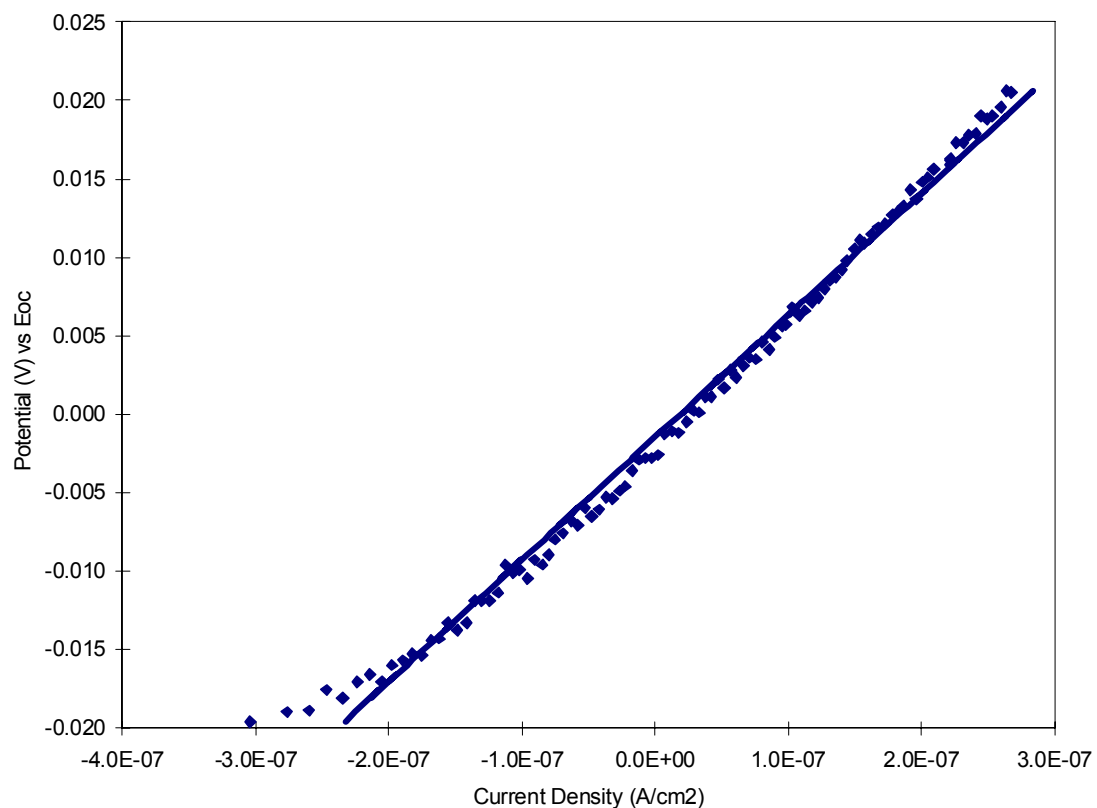


Pstat: PStat3
Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
EOC: -0.332991 V
Area: 73.626 cm²
Electrode: 7.94 gm/cm³, 25.12 g/Equiv
Conditioning: OFF
IR Comp.: OFF

Potntio-Dynamic Scan on Nut and bolt connected,
and submerged in Ohio River Water.

TAFEL RESULTS
Region = -827.5 mV to 862.1 mV
Ecorr = -455.8 mV
Icorr = 1.705E-06 A/cm²
BetaC = 221.0 mV/Decade
BetaA = 779.0 mV/Decade
Rp = 4.386E+04 Ohm cm²
CorrRate = 0.695 mpy

Polarization Resistance
'CERL BOLT 2D54 Linear Pol Scan #20.DTA'

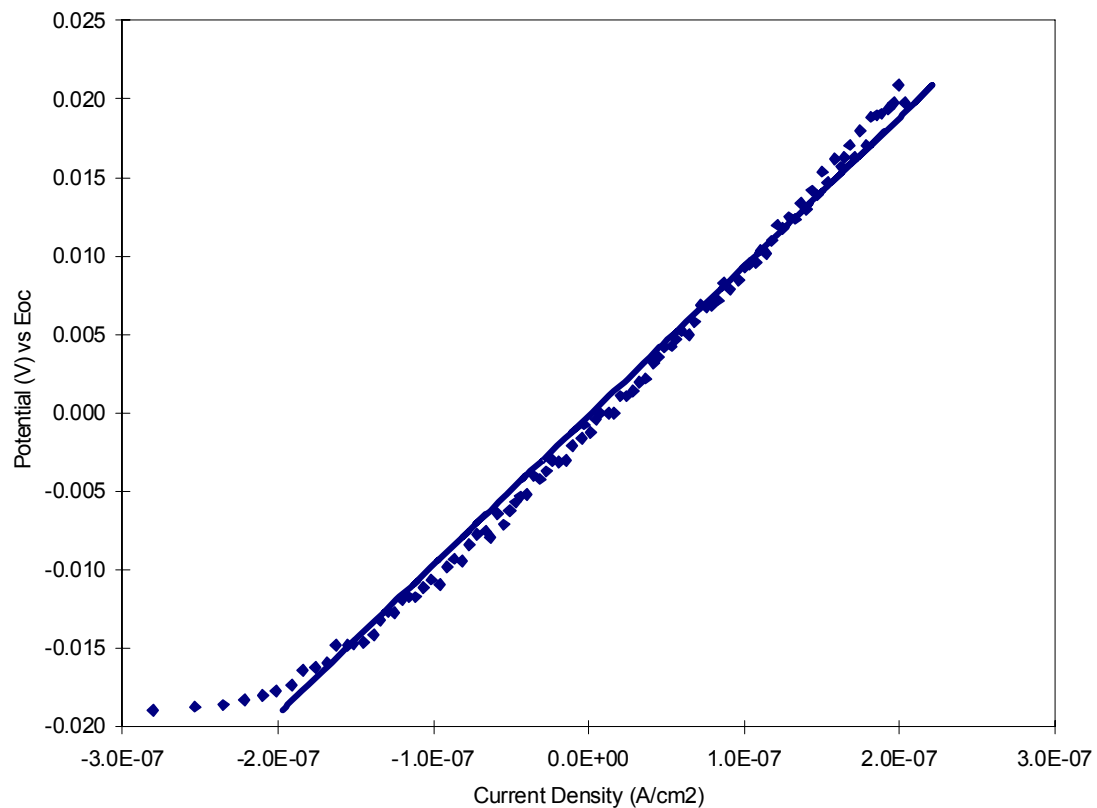


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.371057 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
 Region = -19.6 mV to 20.5 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -372.5 mV
 Icorr = 3.349E-07 A/cm²
 Rp = 7.782E+04 Ohm cm²
 CorrRate = 0.136 mpy

Polarization Resistance
'CERL BOLT 2D54 Linear Pol Scan #22.DTA'



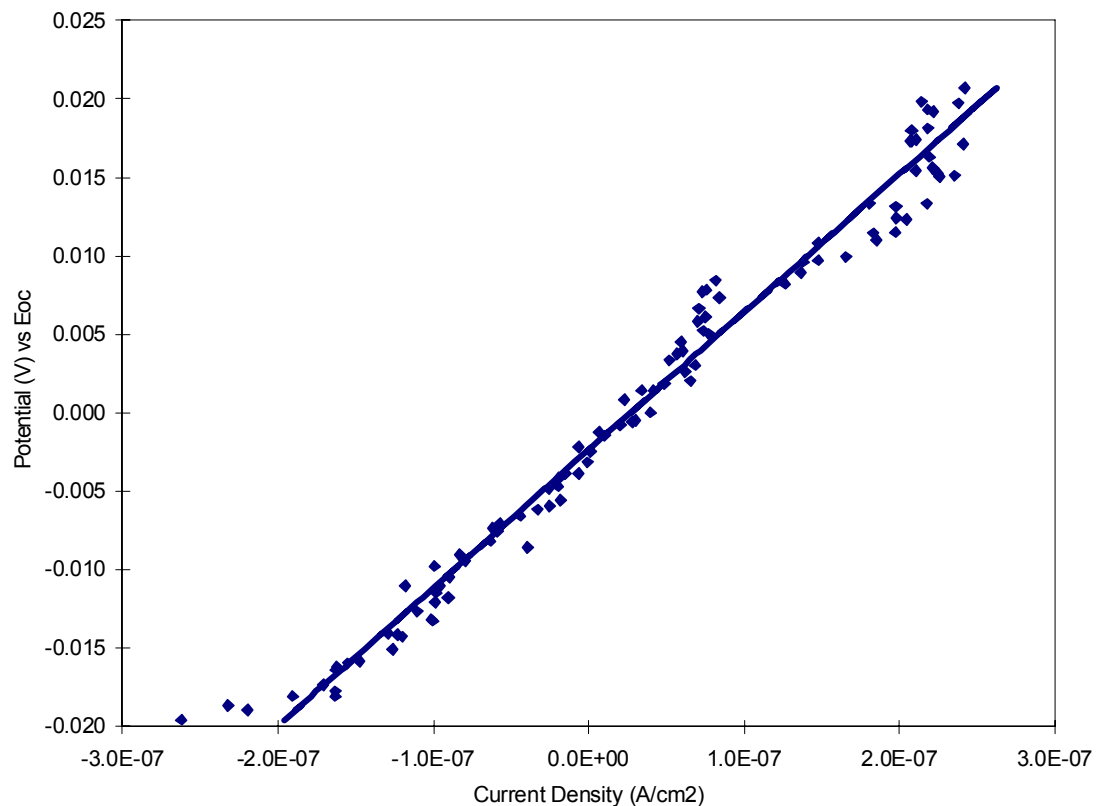
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.372823 V
Area: 46.82 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS

Region = -18.9 mV to 19.8 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -373.0 mV
Icorr = 2.741E-07 A/cm²
Rp = 9.505E+04 Ohm cm²
CorrRate = 0.112 mpy

Polarization Resistance
'CERL NUT 2D54 Linear Pol Scan #13.DTA'



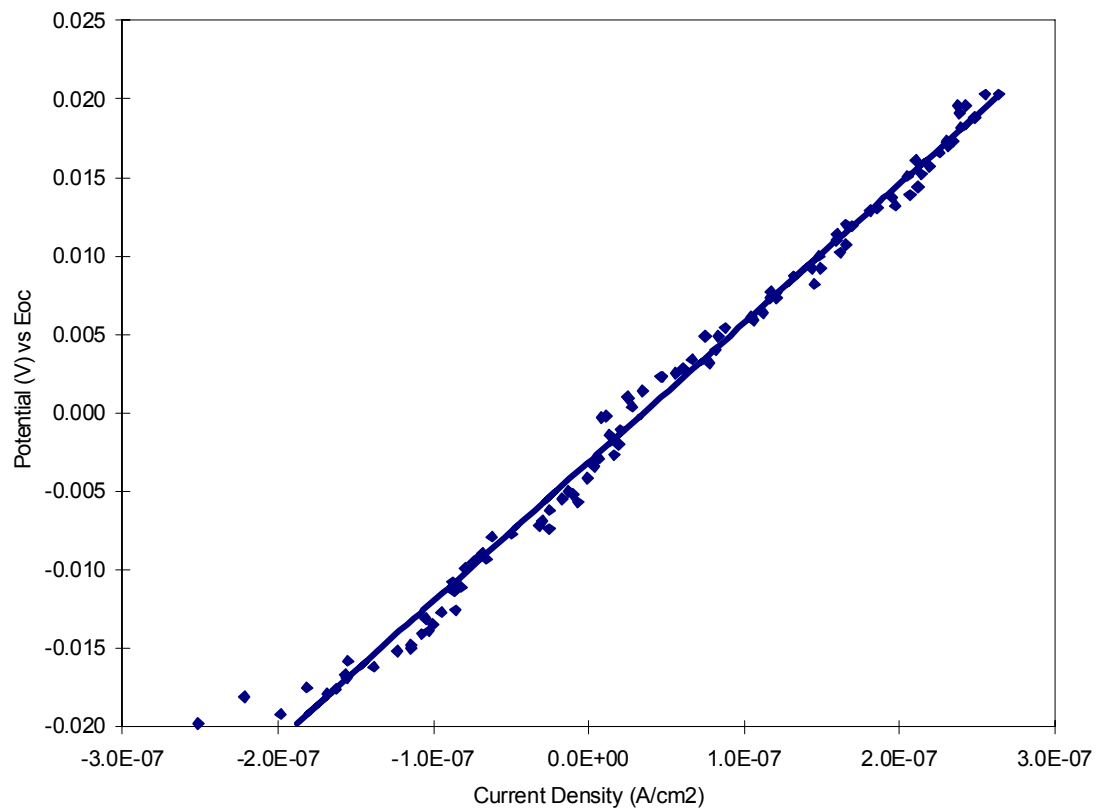
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.353975 V
 Area: 49.893 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water.
 Paint on nut, 45% clean metal (49.893) surface area.

POLRES RESULTS

Region = -19.6 mV to 19.7 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -356.4 mV
 Icorr = 2.964E-07 A/cm²
 Rp = 8.793E+04 Ohm cm²
 CorrRate = 0.121 mpy

Polarization Resistance
'CERL NUT 2D54 Linear Pol Scan #14.DTA'



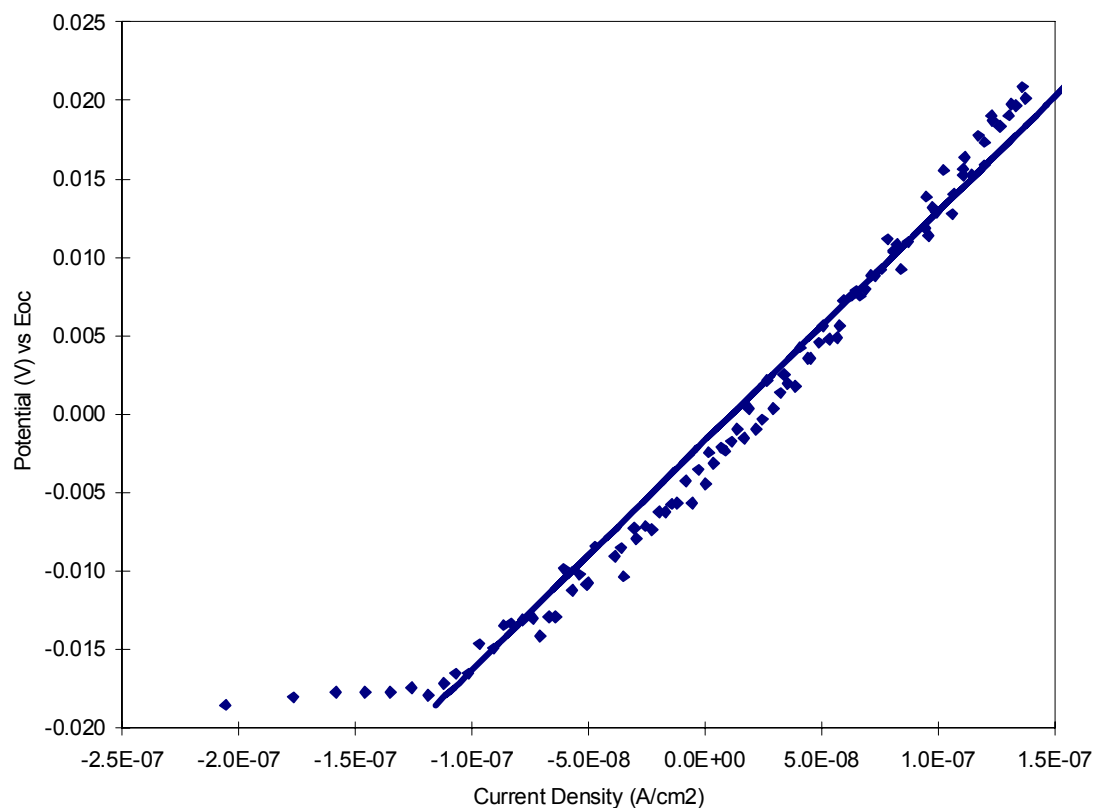
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.360851 V
Area: 49.893 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water.
Paint on nut, 45% clean metal (49.893) surface area.

POLRES RESULTS

Region = -19.8 mV to 20.3 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -364.0 mV
Icorr = 2.943E-07 A/cm²
Rp = 8.855E+04 Ohm cm²
CorrRate = 0.120 mpy

Polarization Resistance
'CERL Nut-Bolt 2D54 Linear Pol Scan #47.DTA'



Pstat: PStat3

Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt

EOC: -0.352806 V

Area: 96.713 cm²

Electrode: 7.94 gm/cm³, 25.12 g/equiv

Conditioning: OFF

IR Comp.: OFF

Nut and Bolt connected, Nut 45% Bare Metal in
Ohio River Water

POLRES RESULTS

Region = -18.5 mV to 20.2 mV

BetaC = 120.0 mV/Decade

BetaA = 120.0 mV/Decade

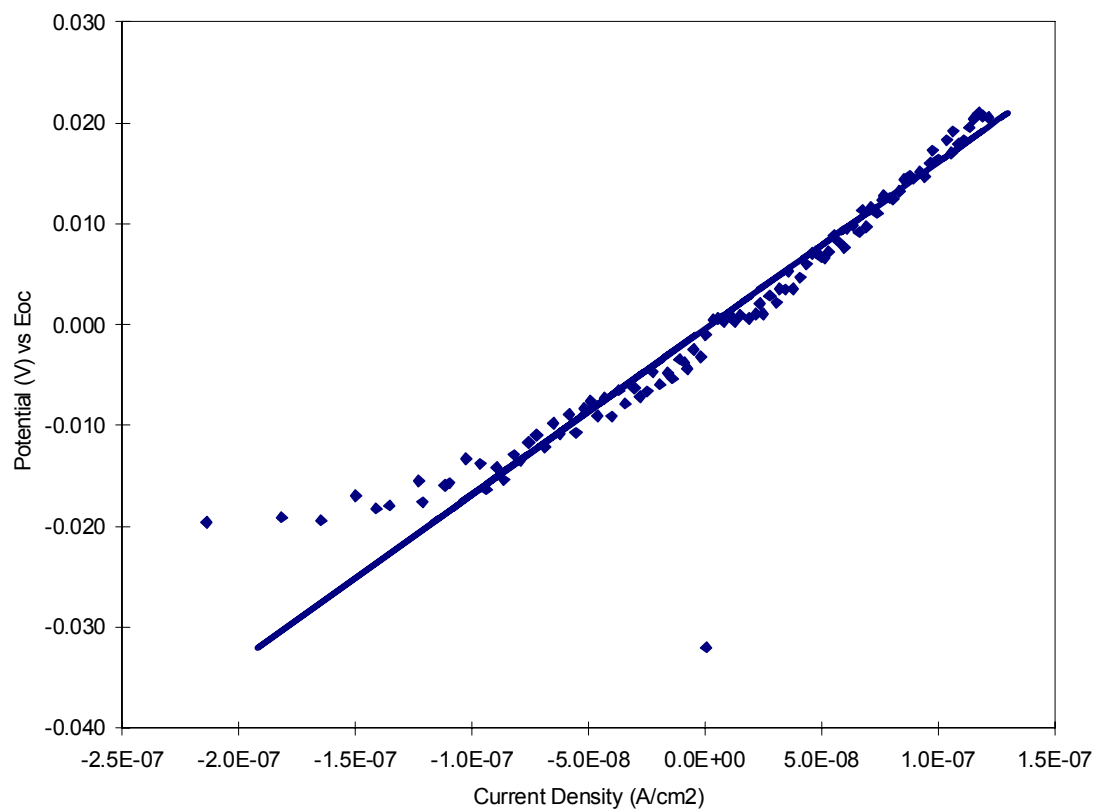
Ecorr = -354.5 mV

Icorr = 1.784E-07 A/cm²

Rp = 1.461E+05 Ohm cm²

CorrRate = 0.073 mpy

Polarization Resistance
'CERL Nut-Bolt 2D54 Linear Pol Scan #48.DTA'

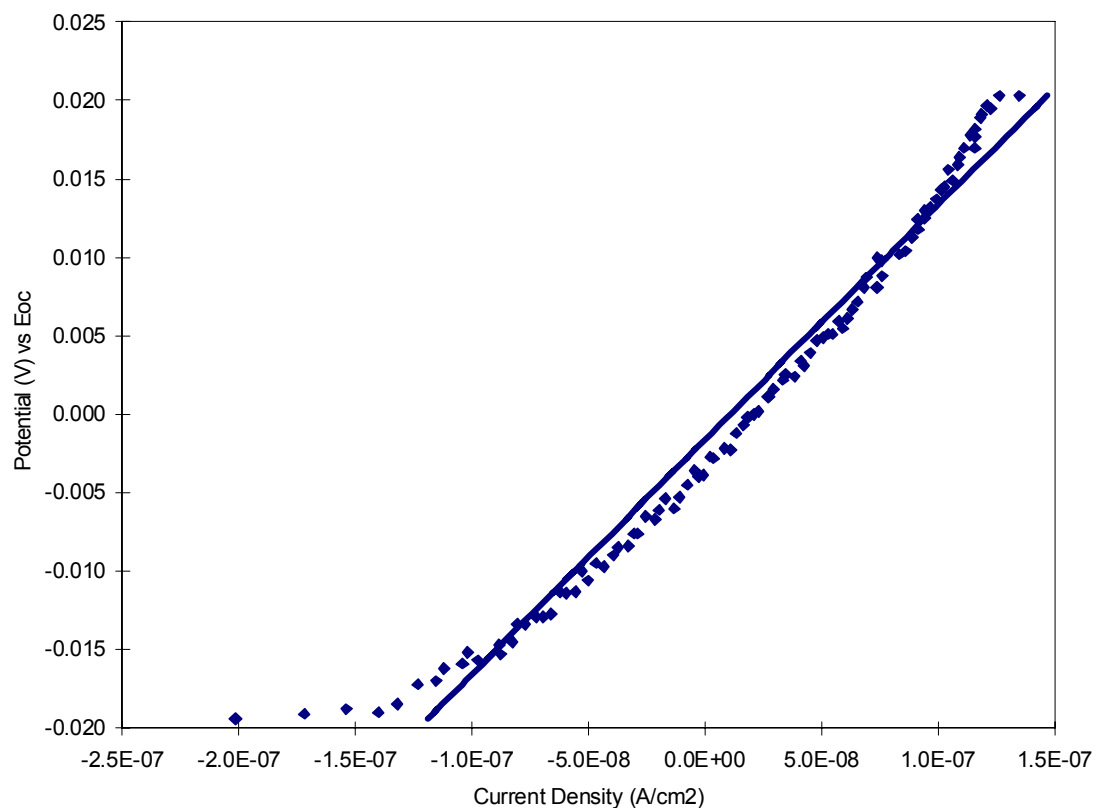


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.355519 V
Area: 96.713 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Nut and Bolt connected, Nut 45% Bare Metal in
Ohio River Water

POLRES RESULTS
Region = -19.6 mV to 20.6 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -355.9 mV
Icorr = 1.584E-07 A/cm²
Rp = 1.645E+05 Ohm cm²
CorrRate = 0.065 mpy

Polarization Resistance
'CERL Nut-Bolt 2D54 Linear Pol Scan #49.DTA'

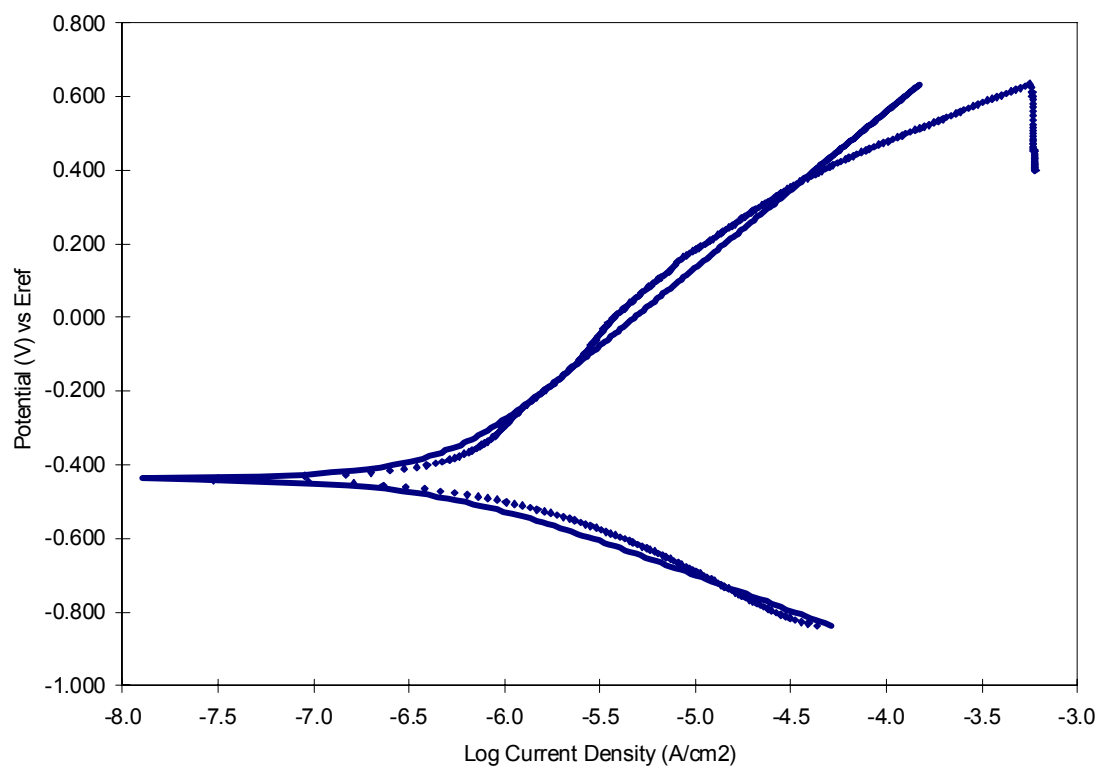


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.355643 V
 Area: 96.713 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Nut and Bolt connected, Nut 45% Bare Metal in
 Ohio River Water

POLRES RESULTS
 Region = -19.4 mV to 20.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -357.2 mV
 Icorr = 1.743E-07 A/cm²
 Rp = 1.495E+05 Ohm cm²
 CorrRate = 0.071 mpy

Potentiodynamic Scan
'CERL POTDYN Scan on Bolt-Nut Combo #2D54
Scan#2.DTA'

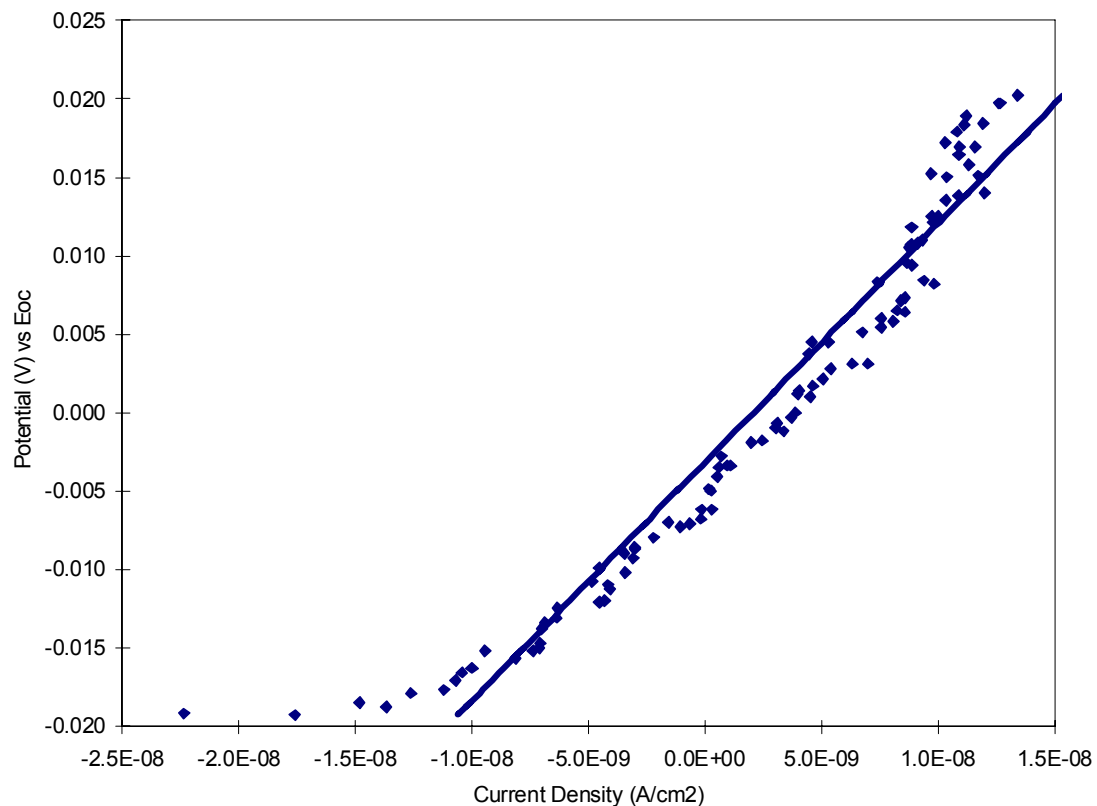


Pstat: PStat3
Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
EOC: -0.342024 V
Area: 96.713 cm²
Electrode: 7.94 gm/cm³, 25.12 g/Equiv
Conditioning: OFF
IR Comp.: OFF

Potntio-Dynamic Scan on Nut and bolt connected,
and submerged in Ohio River Water.

TAFEL RESULTS
Region = -837.5 mV to 400.1 mV
Ecorr = -438.7 mV
Icorr = 4.434E-07 A/cm²
BetaC = 193.3 mV/Decade
BetaA = 423.8 mV/Decade
Rp = 1.300E+05 Ohm cm²
CorrRate = 0.181 mpy

Polarization Resistance
'CERL BOLT 2D83 Linear Pol Scan #29.DTA'



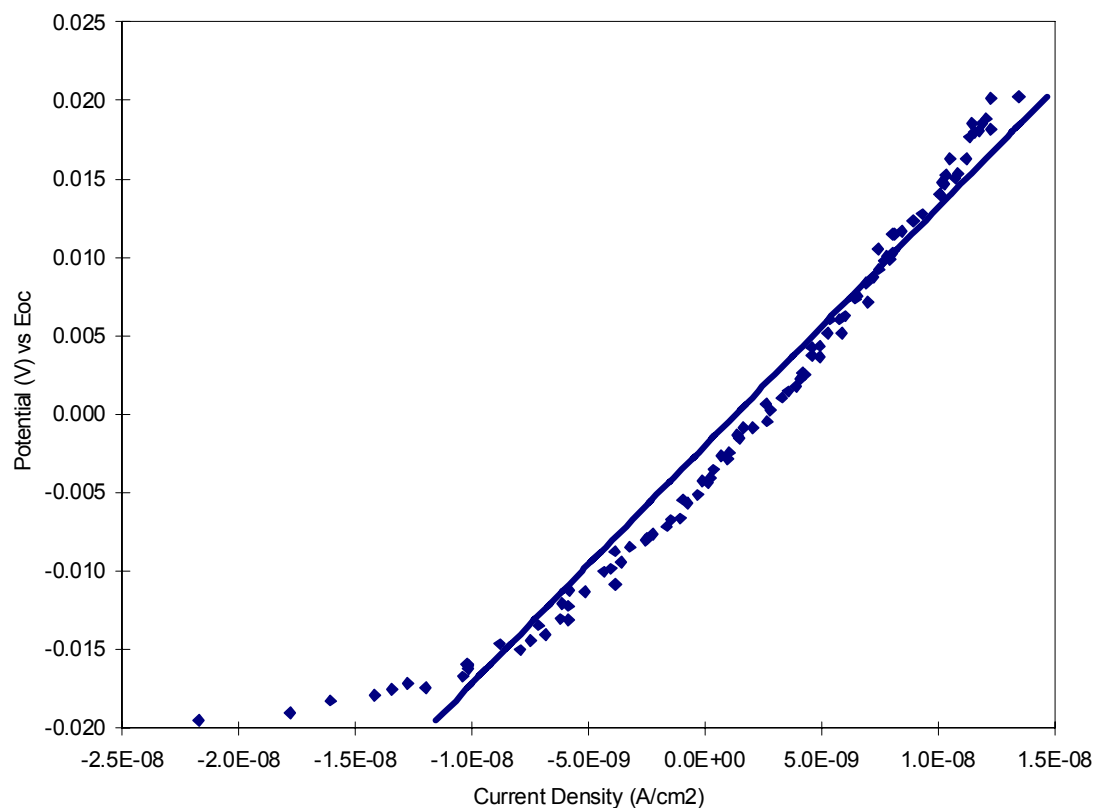
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.138973 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS

Region = -19.2 mV to 20.2 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -142.1 mV
 Icorr = 1.713E-08 A/cm²
 Rp = 1.521E+06 Ohm cm²
 CorrRate = 0.007 mpy

Polarization Resistance
'CERL BOLT 2D83 Linear Pol Scan #30.DTA'

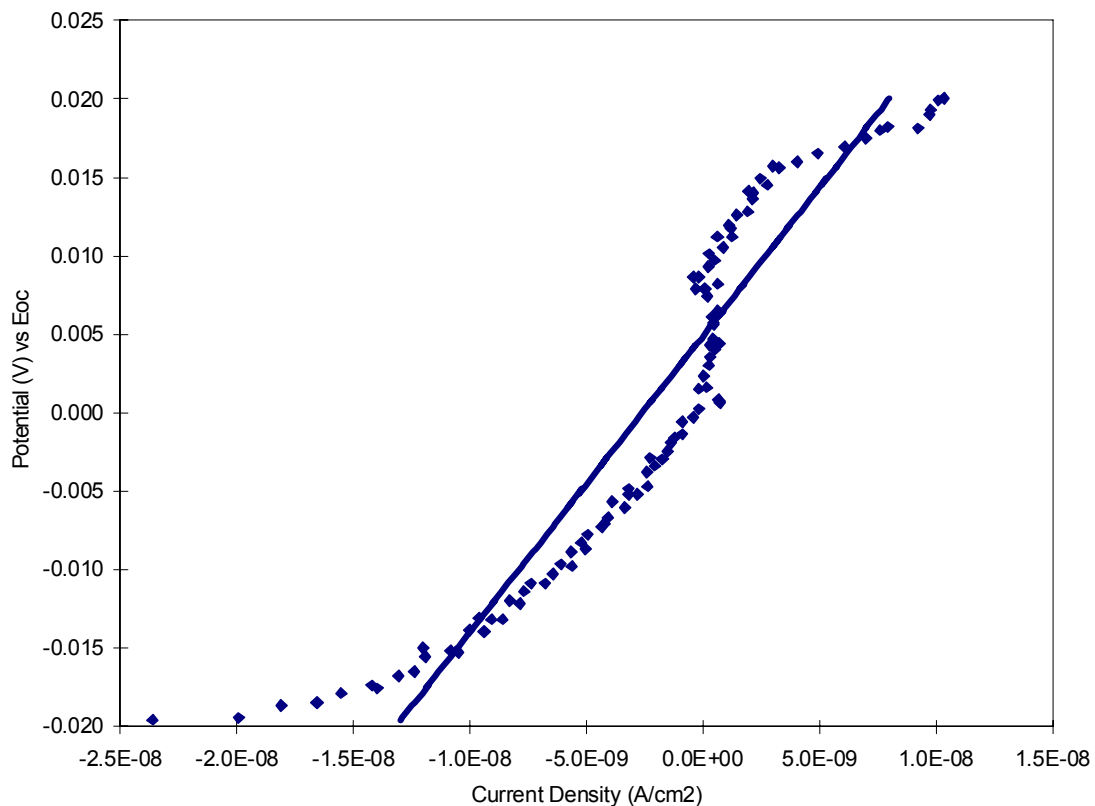


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.138303 V
Area: 46.82 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
Region = -19.5 mV to 20.3 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -140.3 mV
Icorr = 1.718E-08 A/cm²
Rp = 1.517E+06 Ohm cm²
CorrRate = 0.007 mpy

Polarization Resistance
'CERL BOLT 2D83 Linear Pol Scan #31.DTA'

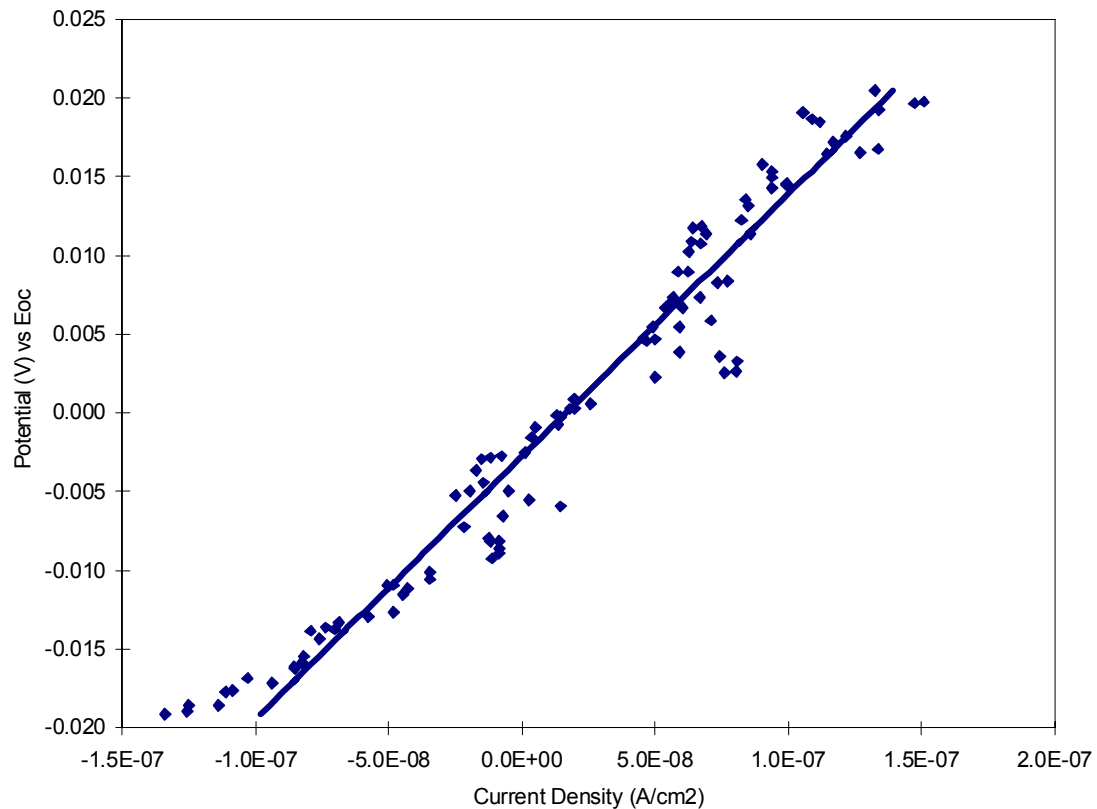


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.150173 V
 Area: 46.82 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Bolt (5 total this size) submerged in Ohio River Water.

POLRES RESULTS
 Region = -19.6 mV to 20.0 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -145.2 mV
 Icorr = 1.379E-08 A/cm²
 Rp = 1.889E+06 Ohm cm²
 CorrRate = 0.006 mpy

Polarization Resistance
'CERL NUT 2D83 Linear Pol Scan #5.DTA



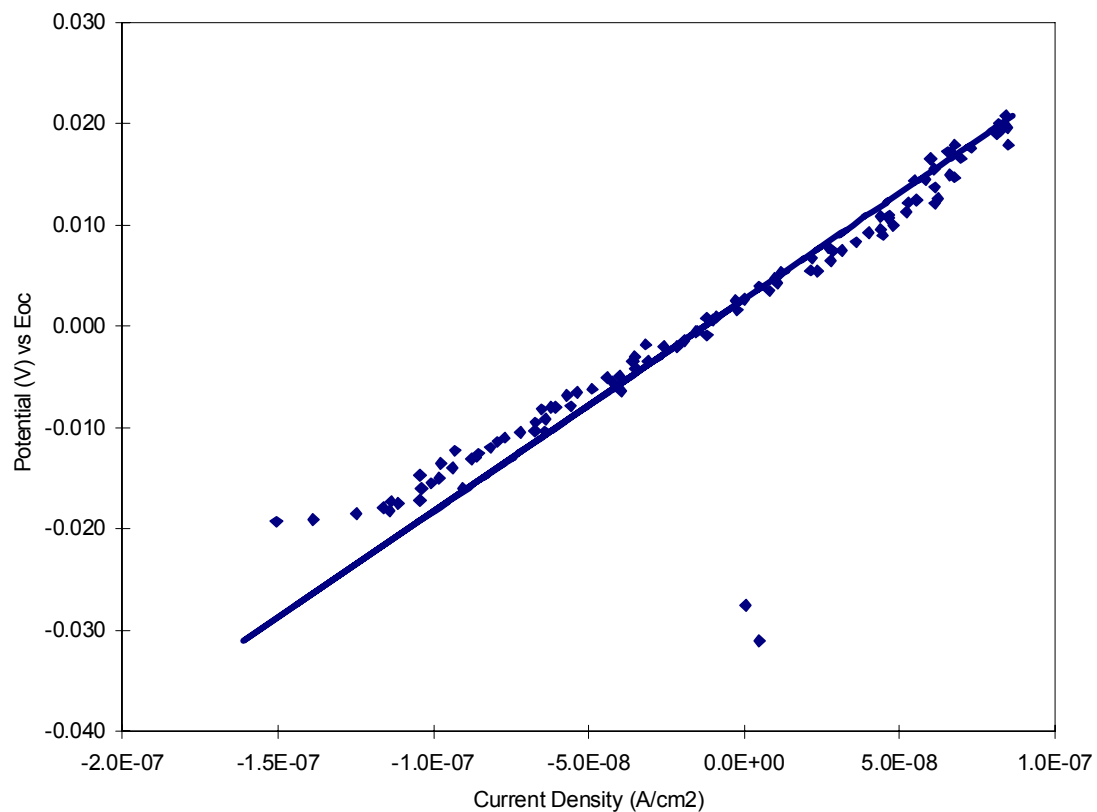
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.304896 V
Area: 65.318 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS

Region = -19.2 mV to 20.4 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -307.7 mV
Icorr = 1.564E-07 A/cm²
Rp = 1.666E+05 Ohm cm²
CorrRate = 0.064 mpy

Polarization Resistance
'CERL NUT 2D83 Linear Pol Scan #6.DTA'

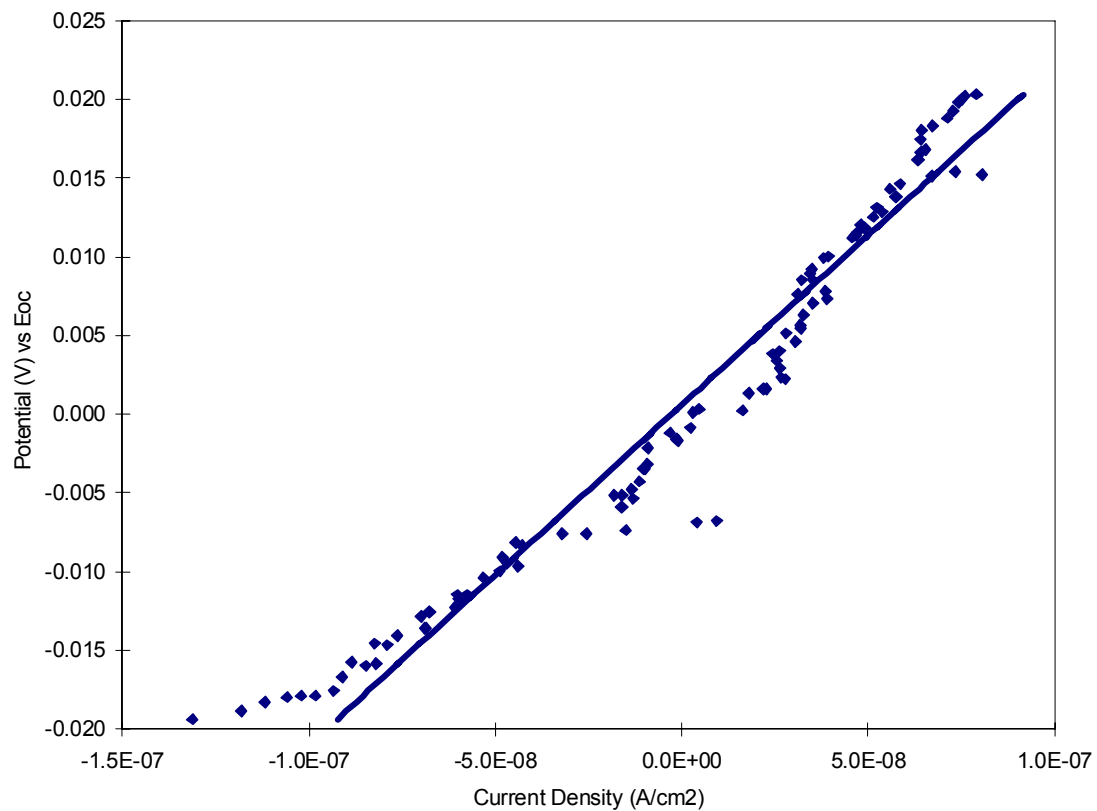


Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.317132 V
 Area: 65.318 cm2
 Electrode: 7.94 gm/cm3, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
 Region = -19.3 mV to 20.8 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -314.5 mV
 Icorr = 1.243E-07 A/cm2
 Rp = 2.096E+05 Ohm cm2
 CorrRate = 0.051 mpy

Polarization Resistance
'CERL NUT 2D83 Linear Pol Scan #7.DTA

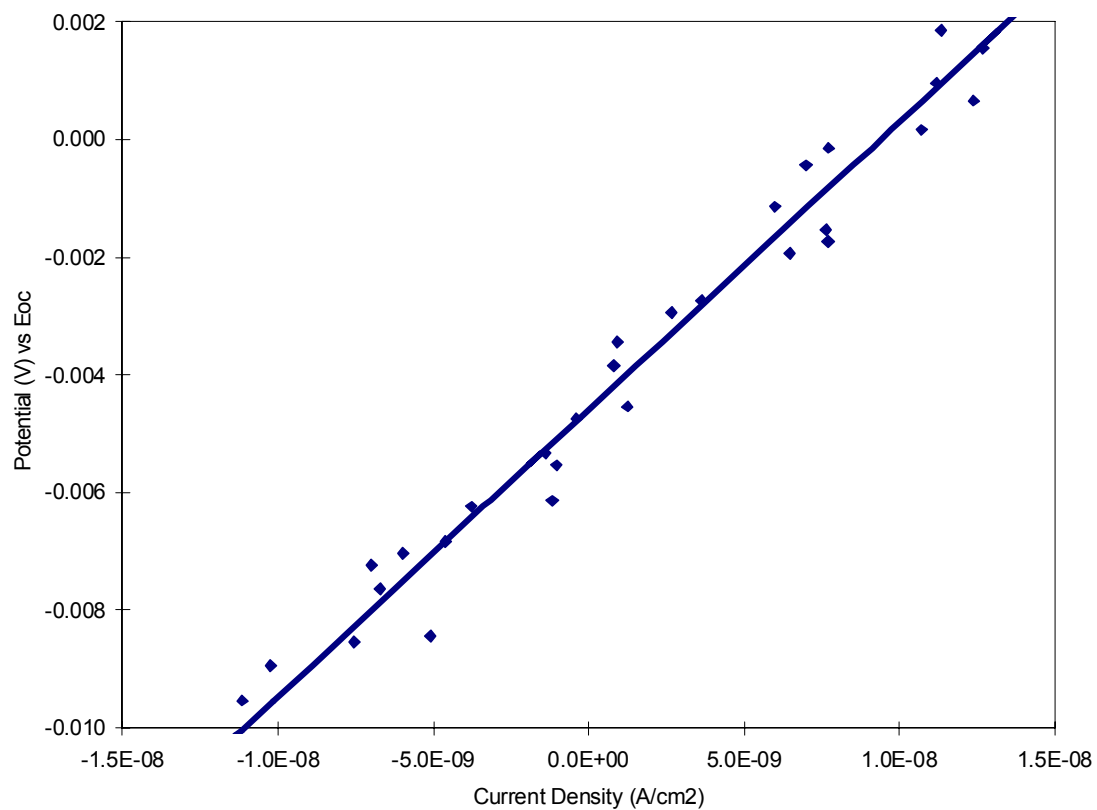


Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.315064 V
Area: 65.318 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Smaller Nut (5 total this size) in Ohio River Water

POLRES RESULTS
Region = -19.4 mV to 20.3 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -314.5 mV
Icorr = 1.207E-07 A/cm²
Rp = 2.158E+05 Ohm cm²
CorrRate = 0.049 mpy

Polarization Resistance
'CERL Nut-Bolt 2D83 Linear Pol Scan #38.DTA'



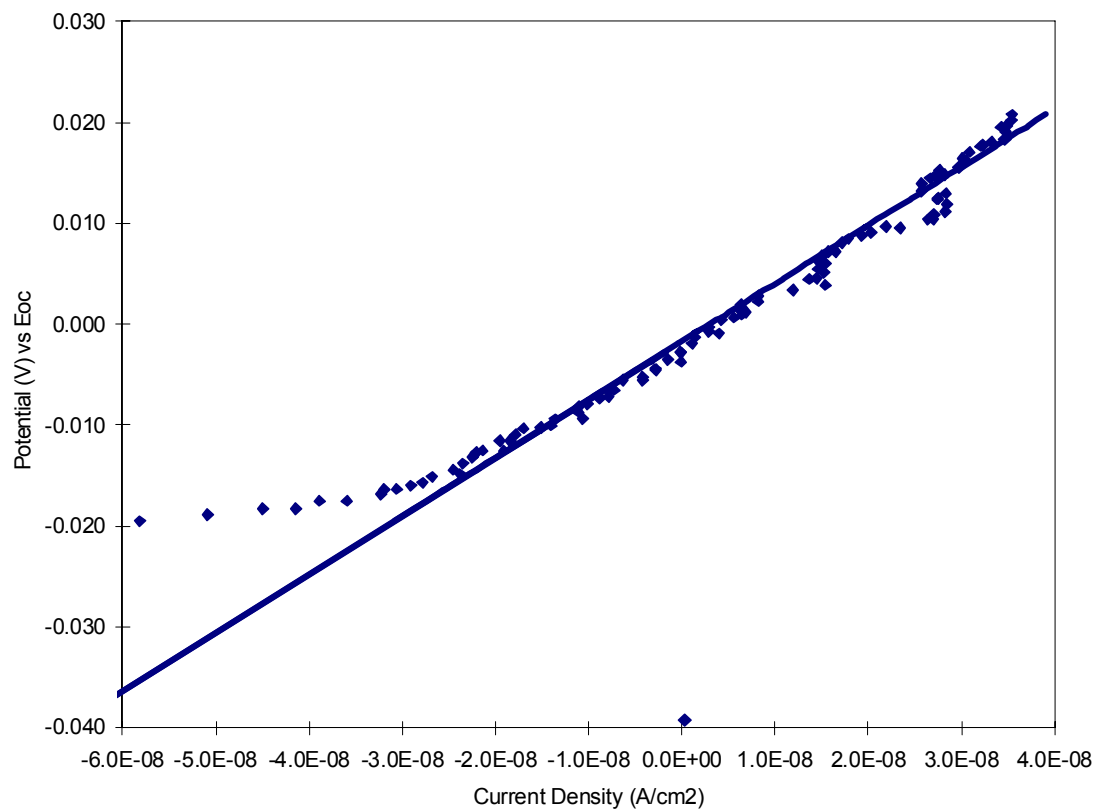
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.281514 V
 Area: 112.138 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
 together -Nut 75% Bare Metal

POLRES RESULTS

Region = -9.5 mV to 0.2 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -286.1 mV
 Icorr = 5.333E-08 A/cm²
 Rp = 4.886E+05 Ohm cm²
 CorrRate = 0.022 mpy

Polarization Resistance
'CERL Nut-Bolt 2D83 Linear Pol Scan #39.DTA'



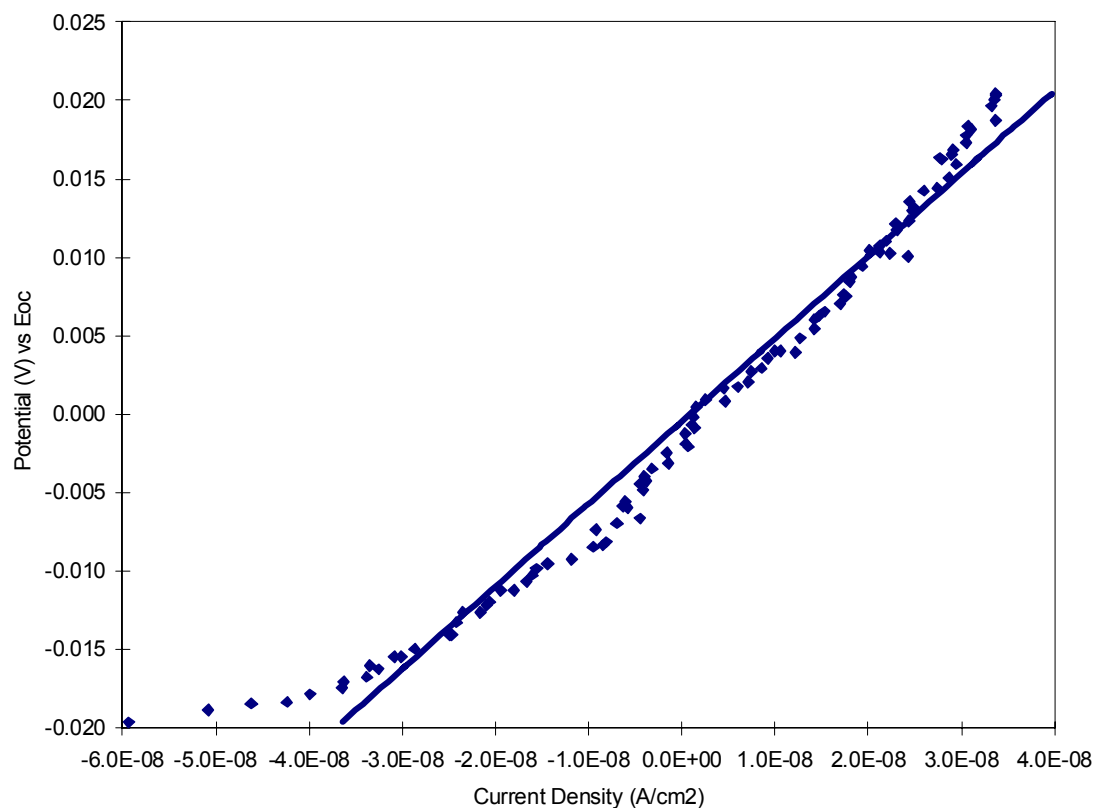
Pstat: PStat3
Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
EOC: -0.288427 V
Area: 112.138 cm²
Electrode: 7.94 gm/cm³, 25.12 g/equiv
Conditioning: OFF
IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
together -Nut 75% Bare Metal

POLRES RESULTS

Region = -19.5 mV to 20.8 mV
BetaC = 120.0 mV/Decade
BetaA = 120.0 mV/Decade
Ecorr = -290.1 mV
Icorr = 4.518E-08 A/cm²
Rp = 5.767E+05 Ohm cm²
CorrRate = 0.018 mpy

Polarization Resistance
'CERL Nut-Bolt 2D83 Linear Pol Scan #40.DTA'



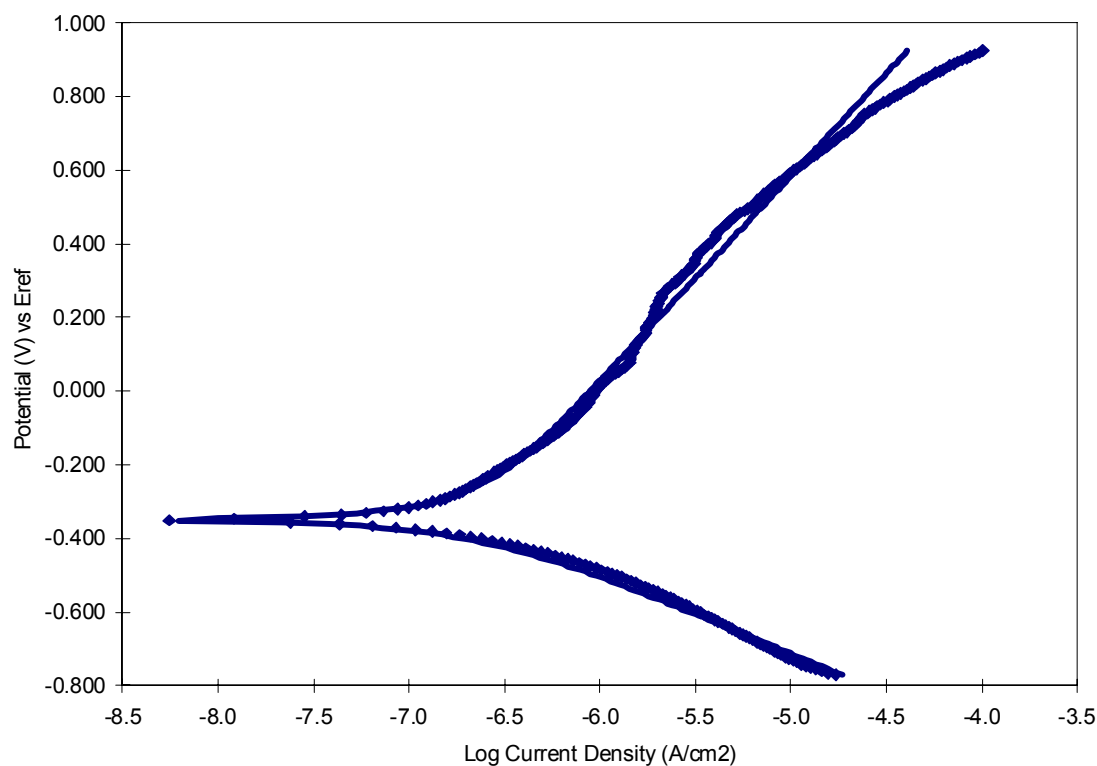
Pstat: PStat3
 Scan: -0.02 V to 0.02 V, 0.2 mV/s, 2 s/pt
 EOC: -0.289691 V
 Area: 112.138 cm²
 Electrode: 7.94 gm/cm³, 25.12 g/equiv
 Conditioning: OFF
 IR Comp.: OFF

Lin Polarization Scan of Bolt and Nut Coupled
 together -Nut 75% Bare Metal

POLRES RESULTS

Region = -19.7 mV to 20.3 mV
 BetaC = 120.0 mV/Decade
 BetaA = 120.0 mV/Decade
 Ecorr = -290.1 mV
 Icorr = 4.948E-08 A/cm²
 Rp = 5.267E+05 Ohm cm²
 CorrRate = 0.020 mpy

Potentiodynamic Scan
'CERL POTDYN Scan on Bolt-Nut Combo #2D83
Scan#5.DTA'



Pstat: PStat3
Scan: -0.5 V to 1.2 V, 5 mV/s, 1 s/pt
EOC: -0.276761 V
Area: 112.138 cm²
Electrode: 7.94 gm/cm³, 25.12 g/Equiv
Conditioning: OFF
IR Comp.: OFF

Potntio-Dynamic Scan on Nut and bolt connected,
and submerged in Ohio River Water.

TAFEL RESULTS
Region = -771.1 mV to 918.1 mV
Ecorr = -349.9 mV
Icorr = 2.106E-07 A/cm²
BetaC = 216.6 mV/Decade
BetaA = 557.4 mV/Decade
Rp = 3.217E+05 Ohm cm²
CorrRate = 0.086 mpy

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				5c. PROGRAM ELEMENT NUMBER	
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14. ABSTRACT During rehabilitation of the roller gates at the R.C. Byrd Locks and Dam, Gallipolis, OH, the U.S. Army Engineer District, Huntington found some of the bolts had failed. Analysis by the Construction Engineering Research Laboratory found the primary cause of failure to be temper embrittlement. The microstructure of the bolt revealed a brittle fracture, with the fracture mode being intergranular. The presence of chlorides also accelerated the galvanic corrosion that occurred between the bolt and nut. The temper embrittled bolts have approximately 10 times higher corrosion rate immersed in Ohio River water than the non-temper embrittled bolts. The non-temper embrittled bolts should have a 40 to 50 year service life expectancy, assuming the Ohio River water chemistry does not change significantly. The suggested material replacement is a martensitic age-hardenable stainless steel combining the very good corrosion resistance characteristics of Type 304 stainless steel and the moderate strength characteristics of Type 410 stainless steel. Either ARMCO 17-4 PH stainless steel or Carpenter Custom 450 stainless steel is recommended for use in aqueous environments where high strength and corrosion resistance is required.					
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