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Experimental Evaluation of the Corrosion effect of Sensitized Welded and Unwelded AISI 301 in Seawater Environment

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ABSTRACT: Experimental Evaluation of the corrosion effect of Sensitized welded and unwelded AISI 301 in seawater Environment was carried out in this research. The Samples selected werecut into several equal parts and divided into three groups and two of thegroups were welded together in twos while other group remained unwelded. To induce sensitization, the samples were heated and soaked at different soaking times interval of 30minutes,60minutes, 180minutes,300minutes and 600minutes followed by normalizing, annealing and quenching. The samples were then subjected to corrosion test using the Linear Polarization resistance (LPR) technique at 10,15, 20, 25, 30, 35, 40, 45 and 50minutes immersion time periods respectively.Conclusions drawn from the results obtained showed that Corrosion rate of the samples with 30minutes soaking time was lowest at in all the heat treatment cases, the lowest been -2.90mpy which indicates that SS301 has more resistance to corrosion. Also, the welded and annealed sample had better resistance followed by the quenched and lastly the normalized.

Keywords: Corrosion, Sensitization, Stainless steel, Soaking time, Heat treatment, Seawater.

I. INTRODUCTION

Stainless steels contain 13% or higher chromium and because of the large amount of chromium, they are kept free from corrosion. Stainless steels could be Austenitic, ferritic, martensitic or duplex type. The austenitic stainless steels have high corrosion resistance ability because of the high chromium content and also nickel addition in its alloy. Because of this advantage, they are used for example in a wide range of applications due to their excellent mechanical properties, workability, weldability, in addition to superior corrosion resistance.Austenitic stainless steel is widely used in caustic environments [4–9].Also the conducting stainless steel foils have been used as current collector in nanomaterial based electrochemical or energy device research. [1]. When austenitic stainless steel is exposed into corrosive aqueous solution, chromium oxide enriches at the metal- film interface due to the formation of large layer, which is primarily attribute its high corrosion properties.[2-3]. Corrosion of steel increases with decrease in its carbon contents and or alloy elements and accounts to about 85% of all corrosion problems in the whole world. Continued failures of carbon steel as a prime structural material in our annals of engineering technology from mere farm and house to large industrial structures such as railways, road bridges, storage tanks, aircrafts, automobiles and ocean liners as a result of its poor mechanical properties and corrosion resistance have been worrisome to engineers. A lot of money equivalent to several millions of American dollars is spent worldwide annually on researches on the science and methods of negating corrosion of carbon steel, yet the up-to-date efforts and technological sophistication on the subject are far from utopian achievement [4-5].

Welding is one of the most widely used processes to fabricate austenitic stainless steel structures [6-7] ,whereas Intergranular corrosion due to sensitization is one of the most common problems encountered in austenitic stainless steel weldment during welding as well as in service conditions. This is a well-known phenomenon called sensitization that occurs during welding when these steels are subjected to a temperature range of 500^0C to850^0C, chromium reacts with carbon and form chromium carbides and precipitate along the grain boundaries thus giving rise to adjacent region that are depleted in chromium [8]. In the unstabilized steel such as SS304 and SS316, such attack occurs in a narrow band parallel to and at some distance away from the weld and is referred to as Weld decay. Weld decay has been observed to be a reoccurring decimal in sensitized stainless steel structures [9]. This weld decay that

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occurs during welding becomes a cause of concern when these joints are further subjected toa temperature range less than 500^{0}C as usually encountered in nuclear applications where it is observed that the pre-existing carbide nuclei that nucleate during welding tend to grow as exposure time increases [10].Therefore this study tends to evaluate the effect of sensitization heat treatment on the weld decay of stainless steel in acidic environment.

II. MATERIALS AND EXPERIMENTAL DETAILS

The material used for this study SS 301 stainless steel. which is a commercial pure sample and available in the form of pipes . The type 301 stainless steel was purchased from a commercial steel market in YenagoaBayelsa State.The Positive Material Identification (PMI) test of the selected sample was determined at Turret Engineering Limited Port Harcourt using the XRF 7500 positive identification machine. The details of the chemical composition are as shown in Table 1.The PMI Spectrometer (Model X –MET 7000 OXFORD INSTRUMENT SPECTROMETER).

Table 1: Chemical composition of austenitic stainless-steel type 301

Types	Fe%	Cr%	Ni %	Mn%	Zn%	Ti%	Co%	V%	Cu%	Mo%	Pd%	Au%	W%
301	75.06	16.08	4.49	3.76	-	-	-	-	0.28	-	0.32	-	-

The stainless steel pipe was mounted on a vice and a stainless steel Hack saw was used cut the samples.The sample was cut into Fifteen (45)pieces in rectangular shapes . Before welding, the edges and faces of the samples were cleaned and ground with 600 grit emery paper, rinsed in distilled water and then degreased in Acetone and air dried. Thirty (30) out of the cut sampleswere selected, welded together in twos. The remaining 15 pieces from samples were not welded but kept as received. All welding were done according to the appropriate GAWT welding technique. The welded samples then divided into three (3) groups, A, B, and C. Group A consisting of five samples marked as "Normalized", Group B, consisting five samples marked as "Annealed" and group C consisting of the last five samples marked as "Quenched". Theunwelded samples were also grouped into three groups D, E, and F for Normalized, Annealed and Quenched respectively.

2.1 Heat Treatment

The heat treatment was carried out using the Electric Heat Treatment furnace – Model ESM 9920. The different groups A, B and C of the welded samples and E, F, and G of the unwelded samples were subjected to heat treatment. To induce sensitization, the samples were soaked at 600^{O}C at different soaking time intervals of 30minutes , 60minutes, 180minutes, 300minutes and 600minutes.This was followed by normalizing air.

2.2 Corrosion Rate Determination

The linear polarization resistance technique was the method used in the determination of the corrosion rate. This technique is a reliable electrochemical procedure based on the principles outlined in ASTM G59 Standard Practice for Conducting Potentiodynamic Polarization Resistance Measurement (11).Each of the normalized samples (welded and unwelded) in the different groups were put into different containers that contains 50 ml. of seawater measured into it using a 50ml measuring cylinder. The PLRcorrosion meter was then used to measure the corrosion rate as the probe was inserted into the corrosion medium and the sample.

Fig.1. The probe of the LPR meter connected to the MS1000 meter.

Fig.2. The experimental setup for the corrosion test.

Fig. 3. Shows the welded and sensitized samples in the corrosion media.

III. RESULTS /TABLES AND GRAPHS.

The corrosion rate variation with immersion time for each sample in the different heat treatment processes i.e. (Normalized, Annealed and Quenched) after soaking times of 30mins, 60mins, 180min, 300mins and 600minsare shown in tables 2, 3,4,5,6 and 7and graphical representations as shown in figs 4, 5, 6, 7, 8 and

Table 2. Corrosion Rate variation with Immersion time at different soaking time of unwelded /normalized SS301

Immersion Time(min)	Corrosion rate of unwelded / normalized SS301 at different Soaking Times immersed in seawater				
	30(min)	60(min)	180(min)	300(min)	600(min)
5	0.32	3.54	1.13	1.39	1.18
10	0.46	3.31	1.12	1.18	1.09
15	0.37	3.31	1.34	1.15	1.36
20	2.47	3.41	1.11	1.13	0.86
25	0.79	3.29	1.09	1.12	1.38
30	0.60	3.34	1.16	1.30	1.32
35	0.57	3.36	1.04	1.06	1.27
40	0.21	2.89	0.98	1.05	1.47
45	0.29	3.29	1.04	1.52	1.36
50	0.46	3.33	1.02	0.99	1.17
Average corrosion rate	0.59	3.01	1.0	1.08	1.13

Table 3 . Corrosion Rate variation with Immersion time at different soaking time of welded /normalized SS301

Immersion Time(min)	Corrosion rate of welded / normalized SS301 at different Soaking Times immersed in seawater				
	30(min)	60(min)	180(min)	300(min)	600(min)
5	0.84	2.47	0.61	2.26	2.84
10	-1.43	2.32	0.55	3.72	2.11
15	0.73	2.02	0.68	2.09	4.11
20	0.67	2.37	0.84	3.33	9.32
25	4.13	2.38	0.88	3.09	2.02
30	3.66	2.44	0.68	3.21	0.76

35	3.37	1.42	0.61	3.18	0.83
40	3.20	2.06	0.54	1.36	2.43
45	3.01	4.77	0.56	3.38	0.33
50	3.13	1.46	0.63	1.25	-0.70
Average Corrosion rate	1.94	2.16	0.60	2.44	2.19

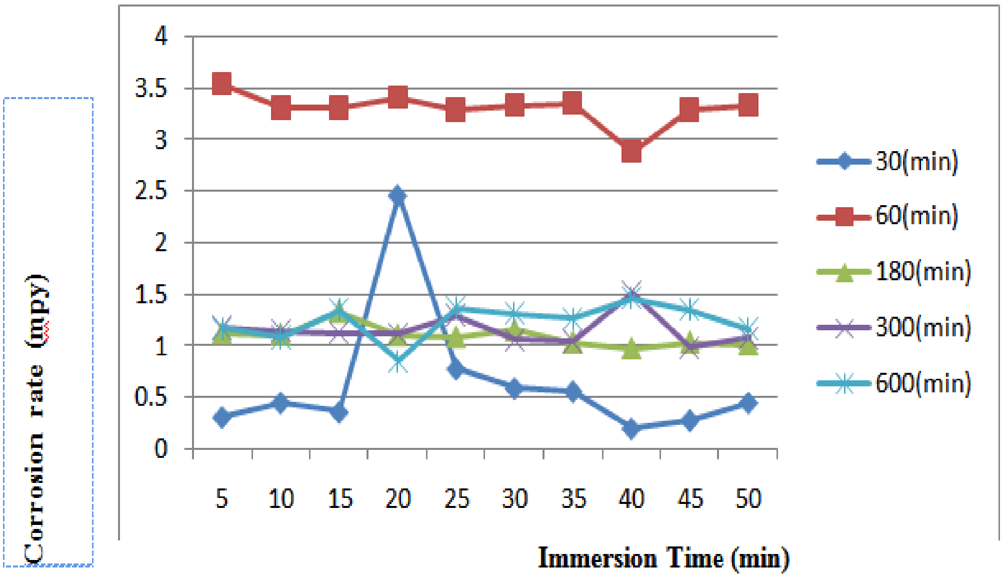

Fig4. Graphical presentation of Corrosion rate variation with Immersion time of unwelded / normalized SS301 at different soaking times in seawater

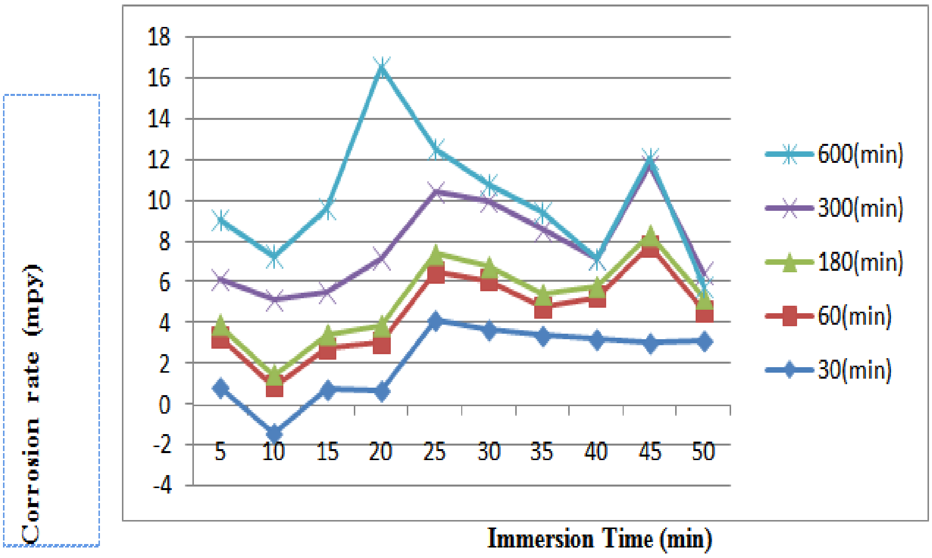

Fig5. Graphical presentation of Corrosion rate variation with Immersion time of welded / normalized SS301 at different soaking times in seawater

Table 4.Corrosion Rate variation with Immersion time at different soaking time of unwelded /annealed SS301

Immersion Time (min)	Corrosion rate of unwelded / annealed SS301 at different soaking Times immersed in seawater				
	30(min)	60(min)	180(min)	300(min)	600(min)
5	-2.90	1.32	0.77	1.28	1.29
10	-0.28	1.09	0.90	1.05	1.42
15	0.75	1.14	2.34	1.15	1.14
20	0.15	1.14	1.51	1.44	1.29
25	0.20	0.91	1.42	1.18	1.16
30	-0.05	1.04	1.84	1.36	1.02
35	0.02	1.10	1.80	1.61	1.16
40	0.73	0.96	2.59	1.47	1.39
45	0.47	1.05	1.72	1.53	1.20
50	0.83	1.16	1.82	1.59	1.00
Average Corrosion rate	-0.01	0.99	1.52	1.24	1.10

Table 5.Corrosion Rate variation with Immersion time at different soaking time of welded /annealed SS301

Immersion Time(min)	Corrosion rate of welded / annealed SS301 at different soaking times immersed in seawater				
	30(min)	60(min)	180(min)	300(min)	600(min)
5	3.20	2.61	2.55	1.60	6.46
10	2.69	2.55	2.31	3.33	0.29
15	2.67	6.04	2.34	3.19	5.96
20	2.76	2.40	2.11	1.46	0.37
25	2.86	2.23	2.23	2.89	0.57
30	2.69	2.13	2.09	3.10	0.81
35	2.67	2.46	1.76	0.85	0.26
40	2.56	2.33	2.28	2.25	0.26
45	2.61	1.07	2.21	1.70	0.46
50	2.58	2.15	2.40	0,50	0,72
Average corrosion rate	2.48	2.36	2.03	1.90	1.47

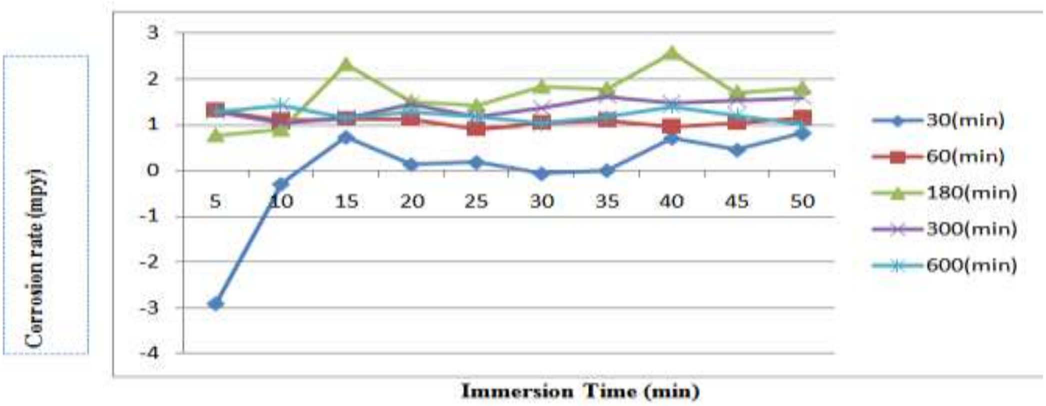

Fig6.Graphical presentation of Corrosion rate variation with Immersion time of unwelded / annealed.SS301 at different soaking times in seawater.

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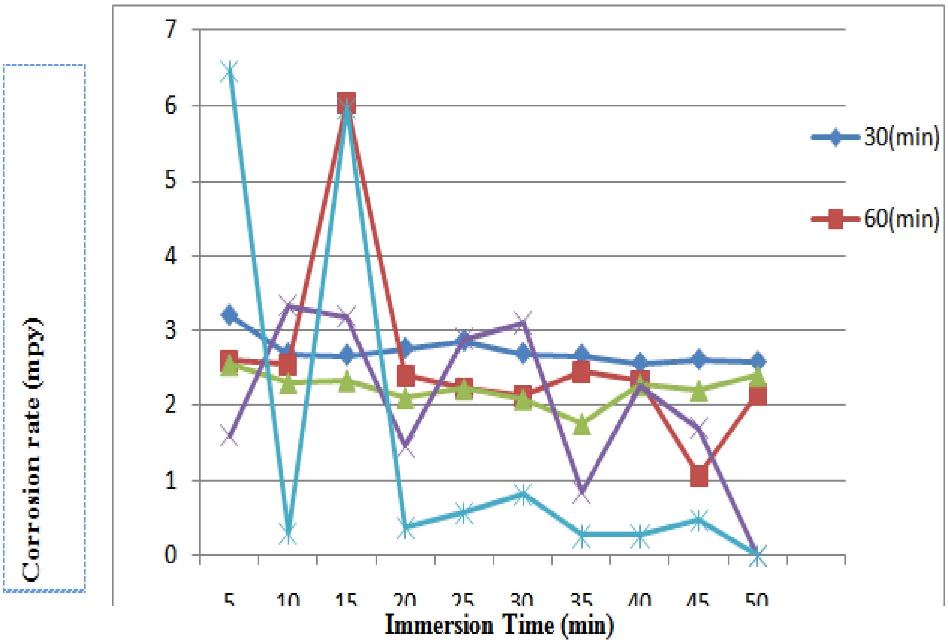


Fig7. Graphical presentation of Corrosion rate variation with Immersion time of welded / annealed.SS301 at different soaking times in seawater.

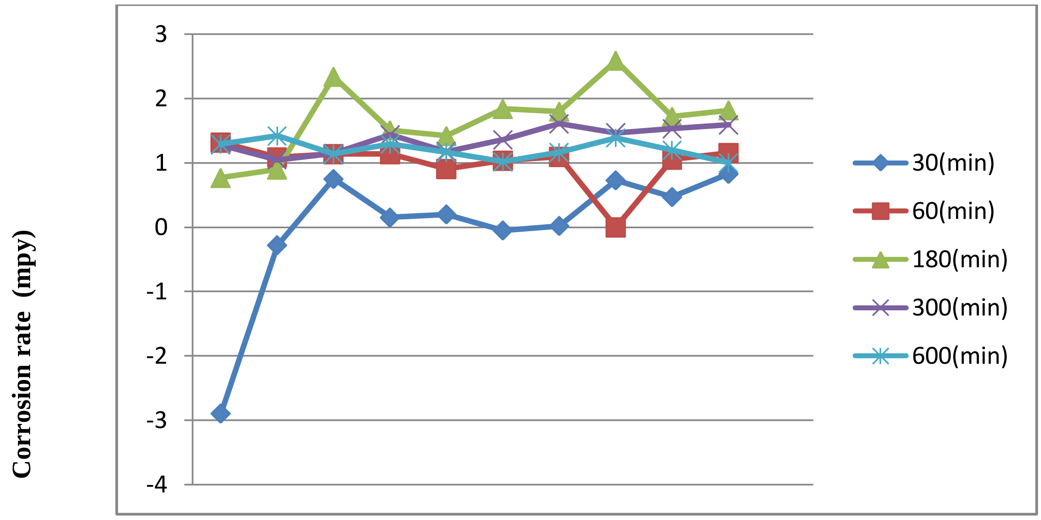
Table 6.Corrosion Rate variation with Immersion time at different soaking time of unwelded /quenched SS301

Immersion Time(min)	Corrosion rate of annealed / unwelded SS301 at different Soaking Times				
	30(min)	60(min)	180(min)	300(min)	600(min)
5	-2.90	1.32	0.77	1.28	1.29
10	-0.28	1.09	0.90	1.05	1.42
15	0.75	1.14	2.34	1.15	1.14
20	0.15	1.14	1.51	1.44	1.29
25	0.20	0.91	1.42	1.18	1.16
30	-0.05	1.04	1.84	1.36	1.02
35	0.02	1.10	1.80	1.61	1.16
40	0.73	o.90	2.59	1.47	1.39
45	0.47	1.05	1.72	1.53	1.20
50	0.83	1.16	1.82	1.59	1.00
Average corrosion rate	-0.01	0.99	1.52	1.24	1.1

Table7.Corrosion Rate variation with Immersion time at different soaking time of unwelded /quenched SS301

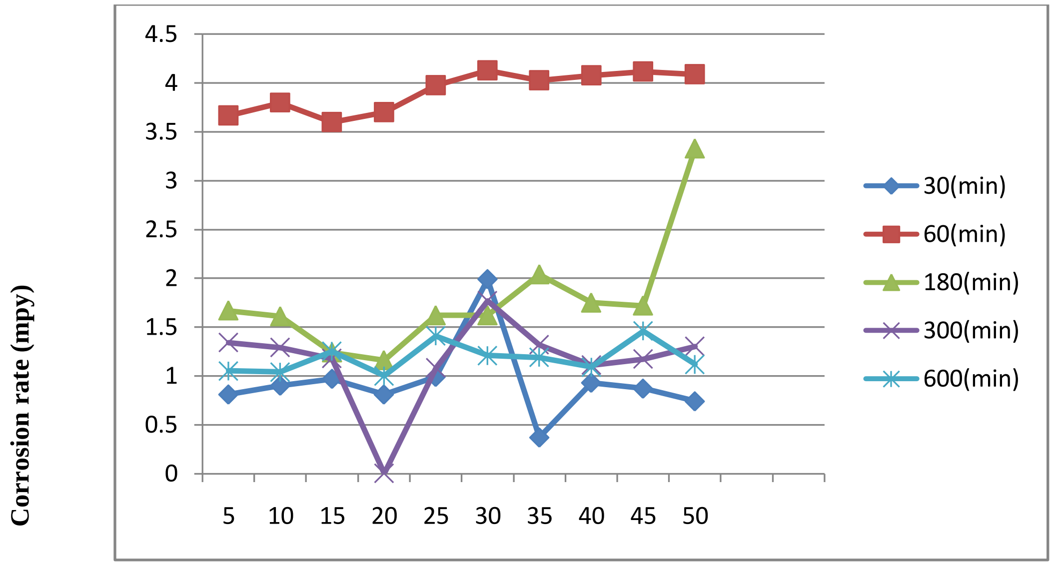
Immersion Time(min)	Corrosion rate of quenched / unwelded SS301 at different Soaking Times				
	30(min)	60(min)	180(min)	300(min)	600(min)
5	0.81	3.67	1.67	1.34	1.05
10	0.90	3.80	1.61	1.29	1.04
15	0.97	3.60	1.24	1.18	1.25
20	0.81	3.70	1.16	0,96	1.00
25	0.99	3.98	1.62	1.08	1.41

30	1.99	4.13	1.62	1.77	1.21
35	0.37	4.03	2.04	1.32	1.19
40	0.93	4.08	1.75	1.11	1.09
45	0.87	4.12	1.72	1.17	1.46
50	0.74	4.09	3.33	1.30	1.12
Average corrosion rate	0.85	3.56	1.61	1.14	1.o7



Immersion Time(min)

Fig8.Graphical presentation of Corrosion rate variation with Immersion time of unwelded / quenched. SS301 at different soaking times in seawater



Immersion Time (mins)

Fig 9. Graphical presentation of Corrosion rate variation with Immersion time of welded / quenched. SS301 at different soaking times in seawater

IV. DISCUSSION

1. From the results of the corrosion variation with immersion time of the unwelded/ normalized samples at the different soaking times are as shown in tables 2and figures 4 respectively. It can be observed that within the first 15 minutes of immersion time, the sample that had been soaked for 30minutes, had the lowest corrosion rate and then increased drastically up to about 2.5 mpy and then reduced immediately for the rest of the immersion period thus becoming the lowest in corrosion rate for the unwelded samples.
2. For the welded/ normalized samples, the samples with 30minutes soaking time had the lowest corrosion rate at -1.43mpy at 10minutes immersion time. This was followed by the sample that was soaked at 60minutes then 180minutes, 300minutes and lastly 600minutes soaking time.
3. For the unwelded /annealed samples, the corrosion rate of the samples were almost uniform except for te sample that was soaked for 30 minutes where the corrosion rate decreased from the onset and was -2.98mpy at 5minutes immersion time. This sample was however had the lowest corrosion rate follow by the sample at 60minutes soaking time, then 300minutes soaking time, 600minutes soaking time and lastly the sample at 180minutes soaking time which had its corrosion rate of 2.59mpy.
4. It was different for the welded and annealed samples where the corrosion rate was lowest for the sample soaked at 600minutes soaking time between 20minutes and 50minutes immersion period the least been 0.26mpy at 35minutes and40minutes immersion time.
5. The quench and unwelded samples displayed a different pattern, where the sample at 180minutes soaking time had the lowest corrosion rate, the lowest been -2.90mpy at 5minutes immersion time, The corrosion rate of this sample continued to slide downward and lowest throughout the 50minutes immersion period followed by the samples soaked at 60minutes, 300minutes,600minutes and lastly 180 soaking time.
6. The trend was different for the samples that were welded and quenched. The samples soaked at 300minutes soaking time had the lowest corrosion rate of 0.96mpy at 15minutes immersion time interval. However, at the end of 50minutes immersion time, the sample soaked at 30minutes soaking time had the lowest corrosion rate of 0.74

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