Data on the comparative assessment of corrosion resistance of 2101 duplex and 410 martensitic stainless steel for application in petrochemical crude distillation system

Roland T Loto
Department of Mechanical Engineering, Covenant University, Ogun state, Nigeria
Email: tolu.loto@gmail.com

Abstract: The corrosion resistance of 2101 lean duplex stainless steel and 410 martensitic stainless steel were studied and compared in 1M – 6M H₂SO₄ solution by coupon measurement for application in extreme process environments. Data obtained showed 2101 duplex steel is significantly more resistant to corrosion at lower concentrations (1M and 2 M H₂SO₄ solution) of the acid solution with final corrosion rate values of 0.000010 mm/y and 0.00028 mm/y compared to the values obtained for 410 martensitic steel at 0.0019 mm/y and 0.0738 mm/y. H₂SO₄ concentration at 4M - 6M narrowed the margin between the corrosion rates of both steel with final values of 0.0235 mm/y, 0.0326 mm/y and 0.0459 mm/y for 2101 duplex steel, and 0.0479 mm/y, 0.0482 mm/y and 0.0511 mm/y for 410 martensitic steel which signifies the corrosion resistance of both steels are comparable and generally similar at higher concentrations of SO₄²⁻ anions. Statistical analysis through analysis of variance shows H₂SO₄ concentration strongly influence the corrosion rate value of both steel compared to exposure time which has limited influence.

1. INTRODUCTION

Stainless steels are corrosion-resistant ferrous alloys prone to localized corrosion such as pitting in the presence of chloride and/or other aggressive anions [1-3]. The petrochemical industry coupled with its difficult production operations experiences huge corrosion of its plants and structure made of stainless steels [4, 5]. The major causes of corrosion in the oil industry are sulphates, chlorides, CO₂, NH₃, HCl and H₂. HCl is produced by the hydrolysis of CaCl₂ and MgCl₂ salts at temperatures of 121°C and the decomposition of organic chloride compounds [6-10]. Duplex stainless steels are the steels developed with high strength and chloride stress corrosion cracking resistance in aggressive environments [11, 12]. Martensitic stainless steels are general-purpose steels containing chromium, which provide good corrosion resistance properties. Both steels are good candidates for application in petrochemical industries [13]. Comparative assessment of their corrosion resistance in aggressive environment is important for documentation purpose to ensure proper material selection. This article aims to study and compare the corrosion resistance of 2101 duplex and 410 martensitic stainless steel in specific concentrations of H₂SO₄ solution for application in extreme process environments.

2. MATERIAL AND METHODS

2101 duplex stainless steel (ST2101) and 410 martensitic stainless steels (ST410) purchased from the Steel Works, Owode, Nigeria has a cylindrical dimension of 17mm and 7 mm diameter respectively. Both steels were machined into 6 test specimens each for both steels. The steels were cut and sectioned until the average length of the duplex steel (ST2101) is 7 mm while the martensitic steel...
(ST410) is 10 mm. The two exposed ends of the steel rod specimens were grinded with SiC abrasive papers to partially smoothen the surface. Weighed specimens of both steels were immersed in 200ml of 1, 2, 3, 4, 5 & 6M H2SO4 solution for 312 h. The steel specimens were weighed every 24 h with using Ohaus analytical weighing balance. Tabulated results of ST2101 and ST410 weight loss and corrosion rate at each concentration of H2SO4 are shown from Tables 1 to 4. Corrosion rate was calculated from the equation below;

\[ R = \frac{87.6W}{DAT} \]

(W is the weight loss in grams, D is the density in g/cm², A is the area in cm², and T is the time of exposure in hours. W was calculated from the difference between the initial weight of the steel (kept constant for 312 h) and every final weight taken at 24 h interval for 312 h.

3. RESULTS AND DISCUSSION

3.1 Coupon measurement

Tables 1 and 2 shows the weight loss values of ST2101 and ST410 steels while Tables 3 and 4 shows their corrosion rate values. Corrosion rate data for ST2101 were significantly lower compared to the values obtained for ST410 at 1-2M H2SO4 solution throughout the exposure hours. Values of 0.000019 mm/y and 0.00337 mm/y (1 M and 2 M H2SO4 concentration) were obtained for ST2101 at 24 h compared to 0.0128 mm/y and 0.0480 mm/y for ST410. The values progressed to 0.00008 mm/y and 0.00049 mm/y at 168 h for ST2101, and 0.0019 mm/y and 0.0738 mm/y for ST410. At 312 h the optimum values for ST2101 are 0.000010 mm/y and 0.0028 mm/y while the corresponding values for ST410 are 0.0019 mm/y and 0.0738 mm/y. At 3 M H2SO4, the corrosion rate values for ST2101 were still visibly lower than values obtained for ST410, though the extent of variation has significantly narrowed. The values at 24 h for both steels are 0.0115 mm/y and 0.0950 mm/y. At 168 h the values are 0.0150 mm/y and 0.0935 mm/y, while at 312 the corresponding values are 0.0149 mm/y and 0.0503 mm/y. These values show ST2101 is still more corrosion resistant to the electrochemical actions of SO4^- ions though at a significantly lower degree. However, at higher H2SO4 concentration (4-6M H2SO4 solution), the differences in corrosion rate value for ST2101 and ST410 has narrowed further for which they are comparable. This signifies that ST2101 and ST410 have generally similar corrosion resistance at high concentrations of H2SO4. The corrosion rate of ST2101 at 24 h are 0.0267 mm/y, 0.0596 mm/y and 0.1206 mm/y. Comparing these values to the values obtained for ST410 (0.1769 mm/y, 0.2703 mm/y and 0.3714 mm/y), ST2101 is visibly more corrosion resistant. However, at 312 h the corrosion rate values of ST2101 at 4 M to 6 M H2SO4 (0.0235 mm/y, 0.0326 mm/y and 0.0459 mm/y) are comparable to the values obtained for ST410 (0.0479 mm/y, 0.0482 mm/y and 0.0511 mm/y).

### Table 1. Data on weight loss of ST2101 from 1-6M H2SO4 solution

| Exp. Time (h) | HCl Conc. (M) | 1M     | 2M     | 3M     | 4M     | 5M     | 6M     |
|--------------|-------------|--------|--------|--------|--------|--------|--------|
| 24           |             | 0.0004 | 0.0692 | 0.2360 | 0.5476 | 1.2247 | 2.4774 |
| 48           |             | 0.0006 | 0.0693 | 0.4559 | 1.0626 | 2.3151 | 4.0829 |
| 72           |             | 0.0008 | 0.0694 | 0.8351 | 1.8221 | 3.4940 | 5.9869 |
| 96           |             | 0.0009 | 0.0695 | 1.1271 | 2.3772 | 4.3605 | 7.1079 |
| 120          |             | 0.0010 | 0.0697 | 1.4688 | 2.7262 | 4.8196 | 7.9612 |
| 144          |             | 0.0011 | 0.0698 | 1.7705 | 3.3151 | 5.5428 | 8.6623 |
| 168          |             | 0.0012 | 0.0699 | 2.1563 | 3.5680 | 6.3373 | 9.5185 |
| 192          |             | 0.0013 | 0.0700 | 2.4088 | 4.2080 | 6.7429 | 10.0611|
| 216          |             | 0.0014 | 0.0701 | 2.8189 | 4.6410 | 7.3436 | 10.6909|
| 240          |             | 0.0015 | 0.0702 | 3.0540 | 5.1371 | 7.8740 | 11.3489|
Table 2. Data on weight loss of ST410 from 1-6M H₂SO₄ solution

| Exp. Time (h) | 1M  | 2M  | 3M  | 4M  | 5M  | 6M  |
|--------------|-----|-----|-----|-----|-----|-----|
| 24           | 0.0544 | 0.2048 | 0.405 | 0.7542 | 1.1521 | 1.5811 |
| 48           | 0.0547 | 0.5027 | 0.9127 | 1.4625 | 2.0099 | 2.6760 |
| 72           | 0.0548 | 0.9113 | 1.4802 | 2.1471 | 2.6715 | 2.8271 |
| 96           | 0.0554 | 1.2109 | 1.8443 | 2.4745 | 2.6715 | 2.8271 |
| 120          | 0.0557 | 1.514 | 2.1872 | 2.4894 | 2.6715 | 2.8271 |
| 144          | 0.0564 | 1.7403 | 2.4206 | 2.4929 | 2.6715 | 2.8271 |
| 168          | 0.0567 | 2.2026 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |
| 192          | 0.0574 | 2.4621 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |
| 216          | 0.0581 | 2.5739 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |
| 240          | 0.0587 | 2.7865 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |
| 264          | 0.0594 | 2.7865 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |
| 288          | 0.0624 | 2.7865 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |
| 312          | 0.0624 | 2.7865 | 2.7884 | 2.6547 | 2.6715 | 2.8271 |

Table 3. Data on corrosion rate of ST2101 from 1-6M H₂SO₄ solution

| Exp. Time (h) | 1M  | 2M  | 3M  | 4M  | 5M  | 6M  |
|--------------|-----|-----|-----|-----|-----|-----|
| 24           | 0.00019 | 0.00337 | 0.0115 | 0.0267 | 0.0596 | 0.1206 |
| 48           | 0.00015 | 0.00169 | 0.0111 | 0.0259 | 0.0564 | 0.0994 |
| 72           | 0.00013 | 0.00113 | 0.0136 | 0.0296 | 0.0567 | 0.0972 |
| 96           | 0.00011 | 0.00085 | 0.0137 | 0.0289 | 0.0531 | 0.0865 |
| 120          | 0.00010 | 0.00068 | 0.0143 | 0.0265 | 0.0469 | 0.0775 |
| 144          | 0.00009 | 0.00057 | 0.0144 | 0.0269 | 0.0450 | 0.0703 |
| 168          | 0.00008 | 0.00049 | 0.0150 | 0.0248 | 0.0441 | 0.0662 |
| 192          | 0.00008 | 0.00043 | 0.0147 | 0.0256 | 0.0410 | 0.0612 |
| 216          | 0.00008 | 0.00038 | 0.0153 | 0.0251 | 0.0397 | 0.0578 |
| 240          | 0.00007 | 0.00034 | 0.0149 | 0.0250 | 0.0383 | 0.0553 |
| 264          | 0.00008 | 0.00032 | 0.0149 | 0.0243 | 0.0355 | 0.0518 |
| 288          | 0.00009 | 0.00030 | 0.0148 | 0.0239 | 0.0343 | 0.0485 |
| 312          | 0.00010 | 0.00028 | 0.0149 | 0.0235 | 0.0326 | 0.0459 |

Table 4. Data on corrosion rate of ST410 from 1-6M H₂SO₄ solution

| Exp. Time (h) | 1M  | 2M  | 3M  | 4M  | 5M  | 6M  |
|--------------|-----|-----|-----|-----|-----|-----|
| 24           | 0.0128 | 0.0480 | 0.0950 | 0.1769 | 0.2703 | 0.3714 |
| 48           | 0.0064 | 0.0590 | 0.1071 | 0.1716 | 0.2358 | 0.3143 |
| 72           | 0.0043 | 0.0713 | 0.1158 | 0.1679 | 0.2089 | 0.2214 |
| 96           | 0.0032 | 0.0710 | 0.1082 | 0.1451 | 0.1567 | 0.1660 |
| 120          | 0.0026 | 0.0710 | 0.1026 | 0.1168 | 0.1254 | 0.1328 |
| 144          | 0.0022 | 0.0681 | 0.0947 | 0.0975 | 0.1045 | 0.1107 |
| 168          | 0.0019 | 0.0738 | 0.0935 | 0.0890 | 0.0895 | 0.0949 |
| 192          | 0.0016 | 0.0690 | 0.0818 | 0.0779 | 0.0783 | 0.0830 |
3.2 Statistical analysis

Statistical data of the mean and standard deviation for ST2101 and ST410 corrosion rate values in 1 – 6 M H$_2$SO$_4$ solution for 312 h are shown in Table 5. The mean corrosion rate values of ST2101 are generally lower than the values obtained for ST410. The corrosion rate values of both alloys increased with increase in H$_2$SO$_4$ concentration. The standard deviation shows the amount of variation among the corrosion rate values varies with exposure time.

| ST2101 | H$_2$SO$_4$ Conc. (M) | 1M | 2M | 3M | 4M | 5M | 6M |
|--------|----------------------|----|----|----|----|----|----|
|        | SD                   | 0.0000026 | 0.00019 | 0.00056 | 0.0017 | 0.0063 | 0.013 |
|        | Mean                 | 0.0000088 | 0.00046 | 0.015 | 0.025 | 0.041 | 0.062 |
| ST410  | H$_2$SO$_4$ Conc. (M) | 1M | 2M | 3M | 4M | 5M | 6M |
|        | SD                   | 0.00063 | 0.0066 | 0.021 | 0.031 | 0.035 | 0.037 |
|        | Mean                 | 0.00019 | 0.067 | 0.078 | 0.081 | 0.084 | 0.089 |

Statistical data from analysis of variance (ANOVA) gave insight on the statistical influence of H$_2$SO$_4$ concentration and exposure time on the corrosion rate values of ST2101 and ST410 alloys. Table 6 shows the statistical relevance factor, theoretical significance factor and mean square ratio for the sources of variation (H$_2$SO$_4$ concentration and exposure time). The statistical relevance factor depicts the statistical influence of the variables in percentage format. The means square ratio is the statistical value which must be greater than the theoretical significance factor for statistical relevance factor to be relevant. Observation of Table 6 shows H$_2$SO$_4$ concentration strongly influenced the corrosion rate values of ST2101 at 93.90% compared to 2.04 % for exposure time. The corresponding value for ST410 are 59.44% and 26.98% where the influence of exposure time is more prevalent. Comparing the values of mean square ratio for both alloys, observation shows they are greater than the theoretical significance factor making them statistically relevance and influential on the resulting corrosion rate values.

| Source of Variation | Sum of Squares | Degree of Freedom | Mean Square | Mean Square Ratio (F) | Theoretical Significance Factor | Statistical Relevance Factor, F (%) |
|---------------------|---------------|------------------|-------------|-----------------------|---------------------------------|----------------------------------|
| H$_2$SO$_4$ Conc.   | 0.0296        | 5                | 0.005921    | 208.40                | 2.42                            | 93.90                            |
| Exposure Time       | 0.0006        | 9                | 0.000072    | 2.52                  | 2.15                            | 2.04                            |
| Residual            | 0.0013        | 45               | 0.000028    |                       |                                 |                                  |
| Total               | 0.0315        | 59               |             |                       |                                 |                                  |

| Source of Variation | Sum of Squares | Degree of Freedom | Mean Square | Mean Square Ratio (F) | Theoretical Significance Factor | Statistical Relevance Factor, F (%) |
|---------------------|---------------|------------------|-------------|-----------------------|---------------------------------|----------------------------------|
| H$_2$SO$_4$ Conc.   | 0.0538        | 5                | 0.01077     | 39.40                 | 2.42                            | 59.44                            |
| Exposure Time       | 0.0244        | 9                | 0.00272     | 9.94                  | 2.15                            | 26.98                            |
| Residual            | 0.0123        | 45               | 0.00027     |                       |                                 |                                  |
| Total               | 0.0906        | 59               |             |                       |                                 |                                  |
4. CONCLUSION

Comparative study of the corrosion resistance of 2101 lean duplex and 410 martensitic stainless steels was performed by coupon measurement in 1-6 M H$_2$SO$_4$ solutions for application in petrochemical crude distillation overhead systems. Data obtained show that 2101 duplex steel has significantly lower corrosion rate values than 410 steel from 1-2 M H$_2$SO$_4$ concentrations. At 4-6 M H$_2$SO$_4$ concentrations the corrosion rates of both steels were comparable though 2101 proves to be more corrosion resistant.

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