Effect of cyclic heat treatment process on the pitting corrosion resistance of EN-1.4405 martensitic, EN-1.4404 austenitic, and EN-1.4539 austenitic stainless steels in chloride-sulfate solution

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Abstract
The effect of high temperature variation on the corrosion resistance of EN-1.4405, EN-1.4404, and EN-1.4539 stainless steels in 2 M H₂SO₄/3.5% NaCl solution was studied. Untreated EN 1.4405 exhibited the highest corrosion rate at 4.775 mm/year compared to untreated EN 1.4539 with the lowest corrosion rate (1.043 mm/year). Repetitive heat treatment significantly decreased the corrosion rate of the steels by 54.61%, 27.83%, and 50.28% to 2.167, 1.396, and 0.519 mm/year. EN-1.4539 steel exhibited the shortest metastable pitting activity among the untreated steels due to higher resistance to transient pit formation while heat treated EN-1.4404 and EN-1.4539 steels exhibited double metastable pitting activity. Heat treated EN-1.4405 was unable to passivate after anodic polarization signifying weak corrosion resistance. Pitting current of heat-treated steels was generally higher than the untreated counterparts. Heat treatment extended the passivation range value of EN-1.4405 and EN-1.4539 steels compared to those of the untreated steels. The corrosion potential of heat-treated steels significantly shifted to electronegative values. The optical image of untreated and heat treated EN-1.4404 and EN-1.4539 steels were generally similar while the images for EN-1.4405 significantly contrast each other.

KEYWORDS
chloride, corrosion, passivation, pitting, steel

1 | INTRODUCTION

Stainless steels generally have extensive applications in most industries due to their superior physical, mechanical, economic, physico-chemical, and corrosion resistance properties compared to carbon steels. Corrosion reaction mechanisms influence the chemical properties of stainless steels and subsequently cause significant alterations in their physical and mechanical properties. The corrosion resistance of stainless steels is due to the chemical reaction of Cr with adsorbed
O₂ resulting in the formation of a transparent and inert protective oxide layer on the steel surface. The oxide acts as a barrier layer which separates the steels from their operating environments. This results in significant decrease in the material corrosion rate. Breakdown of the protective oxide due occur in the presence of flaws, nonmetallic inclusions etc. which are responsible for localized corrosion reactions and deterioration on the steel surface. One of the most prevalent forms of localized corrosion is pitting and intergranular corrosion. Intergranular corrosion initiates at the crystallites in stainless steels due to grain boundary degradation of elements and is responsible for corrosion resistance of stainless steels. Segregation of impurities at the grain boundary areas is also another factor responsible for intergranular corrosion. Pitting corrosion occurs in the form of cavities or deep penetrating holes with limited dimensions on stainless steel surfaces. The insidious nature and instantaneous action of pitting corrosion initiation and propagation are major problems in pitting corrosion control. The degree of pitting and intergranular corrosion damage varies with respect to concentration of corrosive anions in aqueous industrial conditions. Alteration of the microstructure of stainless steels significantly improves or decreases their resistance to localized corrosion. Microstructural constituents such as grain size, phases, precipitates, flaws, impurities, and inclusions undergo significant changes under high temperature variation causing significant changes to their crystallographic orientation, phase transformations and more importantly the mechanical, chemical, and surface properties of stainless steels. Stainless steels are used in high temperature environments such as energy conversion plants, glass industry, chemical and petrochemical industry, incineration plants, steam boilers, cement industry, exhaust systems, heat exchangers etc. due to the weak mechanical and electrochemical properties of carbon and low-alloyed steels. The metallurgical and microstructural properties of metallic alloys change with respect to the hours in service. Selection of appropriate steels alloy for high-temperature application is complex due to the very complex nature of corrosion at these temperatures and the lack of standardized testing practices. Research by Loto et al showed that quenching heat treatment process enhances the corrosion resistance of 420 martensitic stainless steel by 60%. The presence of alloying elements such as Cr, Ni, and Mo impart excellent corrosion resistant properties on duplex steel nevertheless when subject to extreme heat treatment processes, several harmful precipitates such as carbides, nitrides, and intermetallic phases forms, resulting in weak resistance to intergranular crack and pit formation on the steel. Chen et al and Isfahany et al studied the effect of heat treatment on the microstructural properties of plastic mold steel in chloride solution and determined the corrosion resistance of the steels increased with austenitizing temperature but decreased after tempering. Choi et al studied the effect of austenitizing temperature on the electrochemical performance of 0.3C-14Cr-3Mo stainless steel in neutral chloride solutions and observed that increase in austenitizing temperature caused a proportionate increase in pitting corrosion of the steel due to precipitation of carbides within the steel matrix. Research by Loto et al showed that quenching heat treatment process enhances the corrosion resistance of 420 martensitic stainless steel by 60%. The presence of alloying elements such as Cr, Ni, and Mo impart excellent corrosion resistant properties on duplex steel nevertheless when subject to extreme heat treatment processes, several harmful precipitates such as carbides, nitrides, and intermetallic phases forms, resulting in weak resistance to intergranular crack and pit formation on the steel. Chen et al and Isfahany et al studied the effect of heat treatment processes on the microstructure, mechanical and corrosion resistance properties of 316 L and 420 steel. Their report shows the process has significant influence on the corrosion resistance of both steels due to changes in the contents of σ and δ phases, precipitation of M7C3 and secondary hardenings. Pezzato et al showed that quenching heat treatment process enhances the corrosion resistance of 420 martensitic stainless steel by 60%. The presence of alloying elements such as Cr, Ni, and Mo impart excellent corrosion resistant properties on duplex steel nevertheless when subject to extreme heat treatment processes, several harmful precipitates such as carbides, nitrides, and intermetallic phases forms, resulting in weak resistance to intergranular crack and pit formation on the steel. Candelaria and Pinedo determined that the corrosion resistance of 420 martensitic stainless steel in sulfate environment is strongly influenced by the austenitizing temperature, internal lattice stresses, and carbide volume fraction. Previous research has focus on the corrosion behavior of work-hardened stainless steels in chloride-sulfate environment. However, the literature study on the effect of high temperature variation within the environment is lacking. This article focuses on the effect of cyclic temperature variation between 1000°C and 37°C on the corrosion resistance of EN-1.4404, EN-1.4405, and EN-1.4539 stainless steels in dilute H₂SO₄/3.5% NaCl solution.

2 | EXPERIMENTAL METHODS

2.1 | Materials and preparation

EN-1.4405 cast martensitic, EN-1.4404 austenitic and EN-1.4539 austenitic stainless steels were obtained from Vienna University of Technology, Austria. Their elemental composition (wt. %), shown in Table 1 was determined with
TABLE 1 Composition (wt.% ) of EN-1.4405, EN-1.4404, and EN-1.4539

| Element symbol | P   | S   | C   | Cr  | Ni  | Mo  | Mn  | Si  | Ti  | Cu  | V   | N   | Fe  |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| % Composition  | 0.04| 0   | 0.06| 17  | 6   | 1.5 | 1   | 0.8 | 0.3 | 0.1 | 0   | 73.21|
| EN-1.4404      | 0.045| 0.03| 0.03| 18  | 13  | 3   | 2   | 1   | 0   | 0   | 0   | 62.9 |
| % Composition  | 0.035| 1   | 0.02| 21  | 23  | 4   | 0.8 | 0.045| 0   | 1.5 | 0   | 0.1  | 48.5 |

PhenomWorld scanning electron microscope (Model No. MVE0224651193) located at the Materials Characterization Laboratory in Department of Mechanical Engineering, Covenant University, Ota, Nigeria. The untreated stainless steel specimens (UN-1.4405, UN-1.4404, and UN-1.4539) and their heat-treated counterparts (HT-1.4405, HT-1.4404, and HT-1.4539) were machined and subsequently embedded in Versocit acrylic mounts with exposed surface areas of 1 cm². The exposed surface of the steels underwent metallographic preparation with coarse silicon carbide papers (120, 240, 320, 600, 800, 1000, 1500, 2000, 2500, and 3000 grits) and polished with 6 μm diamond-polishing solution. The polished surfaces were degreased with distilled H₂O and acetone. 800 mL of 0.05 M H₂SO₄ solution at 3.5% NaCl concentration was prepared from analar grade reagent of the acid (98% purity) and recrystallized NaCl.

2.2 | Heat treatment

A second set of machined stainless steel specimens underwent repetitive heat treatment process in a muffle furnace where the specimens were heated to 1000°C (to partially simulate exhaust system temperature), kept at the temperature for about 30 minutes, cooled to room temperature and the process repeated a couple of times. The temperature was maintained with a regulator at an accuracy of ±10°C and linked to a thermocouple (K-Type) to achieve the required temperature.

2.3 | Potentiodynamic polarization test

Electrochemical test of EN-1.4405, EN-1.4404, and EN-1.4539 was done with Digi-Ivy potentiostat at 30°C ambient temperature to study the corrosion polarization behavior of the steel specimens. The potentiostat setup consists of working electrodes (versocit embedded EN-1.4405, EN-1.4404, and EN-1.4539), Ag/AgCl reference electrode and Pt wire counter electrode. The electrodes were submerged in 200 mL of the acid chloride solution within a transparent cell and linked to Digi-Ivy 2311 potentiostat interfaced with a computer. Polarization curves were plotted at scan rate of 0.0015 V/s from −1.5 V to +1.5 V. Corrosion current density (A/cm²) and corrosion potential (V) were determined from the curves by Tafel extrapolation method. Corrosion rate \( C_R \) (mm/year) was calculated from the formula below:\(^3\)

\[
C_R = \frac{0.00327 \times C_D \times E_Q}{D},
\]

where \( E_Q \) is the equivalent weight (g) of stainless steel, 0.00327 is a corrosion rate constant, and \( D \) is the steel's density (g).

2.4 | Optical microscopy and open circuit potential measurement

Open circuit potential measurement was performed at step potential of 0.1 V/s for 9000 seconds in 200 mL of 2 M H₂SO₄/3.5% NaCl concentration with Ag/AgCl reference electrode and resin mounted steel working electrode connected.
to Digi-Ivy 2311 potentiostat and computer system. Morphological characterization of the surface of untreated and heat treated steel specimens was done before and after corrosion test with Omax trinocular metallurgical microscope for comparative analysis and assessment of the extent of surface deterioration.

3 | RESULTS AND DISCUSSION

3.1 | Potentiodynamic polarization studies

Potentiodynamic polarization plots of untreated and heat treated EN-1.4405, EN-1.4404, and EN-1.4539 stainless steels from 2 M H₂SO₄/3.5% NaCl solution are shown in Figures 1 and 2. Figure 1 shows the polarization plots of the untreated steels while Figure 2 shows the polarization plots of the heat treated steels. UN-1.4405 exhibited the highest corrosion rate value at 4.775 mm/year which corresponds to corrosion current density of 4.44 × 10⁻⁴ A/cm² and polarization resistance of 57.82 Ω among the untreated steels. UN-1.4539 had the lowest corrosion rate at 1.043 mm/year signifying greater corrosion resistance in the presence of Cl⁻ and SO₄²⁻ anions. Observation of the corrosion potential values of the steels show trends that agrees with the corrosion rate results. The corrosion potential of UN-1.4405, UN-1.4404, and UN-1.4539 at −0.311 V, −0.283 V and −0.216 V shows increased tendency to anodic values with respect to the steels. This trend is associated with formation of the protective oxide (resulting from the chemical combination of Cr and O₂) on the steels at varying degrees synonymous with the corrosion resistance. The cathodic portions of the polarization plots in Figure 1 shows UN-1.4405, UN-1.4404, and UN-1.4539 steels underwent similar H₂ evolution and O₂ reduction reactions. These cathodic reaction processes are under activation control though between −0.334 V and −0.216 V decrease in cathodic slope of UN-1.4539 steel occurred as a result of resistance to cathodic reaction processes earlier mentioned. The difference in the anodic portion of the polarization plots attest to the variation in corrosion resistance of the steels. Cyclic heat treatment significantly enhanced the corrosion resistance of the untreated steels. The corrosion rate values of HT-1.4405, HT-1.4404, and HT-1.4539 steels decreased by 54.61%, 27.83%, and 50.28% to 2.167, 1.396, and 0.519 mm/year. While the cathodic polarization of HT-1.4404 and HT-1.4539 steels remained under activation control similar to their untreated counterparts, the cathodic slope of HT-1.4405 decreased compared to UN-1.4405 due to decrease in reduction corrosion reactions. Heat treatment caused significant changes in the microstructure and metallurgical properties of UN-1.4405.

**FIGURE 1** Potentiodynamic polarization data of untreated EN-1.4404, EN-1.4405, and EN-1.4539 stainless steels in 2 M H₂SO₄/3.5% NaCl (n = 1)

**FIGURE 2** Potentiodynamic polarization data of heat-treated EN-1.4404, EN-1.4405, and EN-1.4539 stainless steels in 2 M H₂SO₄/3.5% NaCl (n = 1)
which hindered the H₂ evolution and O₂ reduction reactions on its surface. The corrosion potential of the heat treated steels (HT-1.4405, HT-1.4404, and HT-1.4539) shifted to −0.362 V, −0.269 V, and −0.235 V. HT-1.4405 and HT-1.4539 exhibited cathodic shift due to reasons earlier stated while HT-1.4404 shifted in the anodic direction due to decrease in the dominant oxidation reaction mechanisms on its surface (Table 2).

### 3.2 Passivation and pitting resistance studies

Table 3 shows the potentiostatic data (metastable pitting, stable pitting, and passivation range) for the localized corrosion resistance of untreated and heat treated EN-1.4405, EN-1.4404, and EN-1.4539 stainless steels in 2 M H₂SO₄/3.5%

**Table 2** Potentiodynamic polarization data of EN-1.4404, EN-1.4405, and EN-1.4539 stainless steels in 2 M H₂SO₄/3.5% NaCl before and after heat treatment (n = 1)

| Untreated Steels         | Corrosion Rate (mm/year) | Corrosion Current Density (A/cm²) | Corrosion Potential (V) | Polarization Resistance, Rp (Ω) | Cathodic Tafel Slope, Bc (V/dec) | Anodic Tafel Slope, Ba (V/dec) |
|--------------------------|--------------------------|----------------------------------|-------------------------|---------------------------------|----------------------------------|---------------------------------|
| UN-1.4405                | 4.775                    | 4.44E-04                         | −0.311                  | 57.82                           | −8.814                           | 3.272                           |
| UN-1.4404                | 1.934                    | 1.80E-04                         | −0.283                  | 142.8                           | −8.458                           | 1.232                           |
| UN-1.4539                | 1.043                    | 9.96E-05                         | −0.216                  | 258.0                           | −4.732                           | −3.893                          |

| Heat-treated Steels      | Corrosion Rate (mm/year) | Corrosion Current Density (A/cm²) | Corrosion Potential (V) | Polarization Resistance, Rp (Ω) | Cathodic Tafel Slope, Bc (V/dec) | Anodic Tafel Slope, Ba (V/dec) | % Change in Corrosion Rate |
|--------------------------|--------------------------|----------------------------------|-------------------------|---------------------------------|----------------------------------|---------------------------------|----------------------------|
| HT-1.4405                | 2.167                    | 2.02E-04                         | −0.362                  | 127.4                           | −5.995                           | 6.687                           | 54.61                      |
| HT-1.4404                | 1.396                    | 1.30E-04                         | −0.269                  | 198.7                           | −5.794                           | 1.094                           | 27.83                      |
| HT-1.4539                | 0.519                    | 4.95E-04                         | −0.235                  | 518.9                           | −8.231                           | 7.117                           | 50.28                      |

**Table 3** Potentiostatic data for the corrosion resistance of untreated and heat-treated 1.4405, 1.4404, and 1.4539 stainless steels in 2 M H₂SO₄/3.5% NaCl solution (n = 1)

| Untreated Steel          | Metastable Pitting Potential (V) | Metastable Pitting Current (A) | Passivation Potential (V) | Passivation Current (A) | Pitting Potential (V) | Pitting Current (A) | Passivation Range (V) |
|--------------------------|----------------------------------|-------------------------------|---------------------------|-------------------------|----------------------|---------------------|-----------------------|
| UN-1.4405                | −0.156                           | 7.95E-03                       | 0.035                     | 1.03E-05                | 1.014                | 1.40E-04           | 0.979                 |
| UN-1.4404                | −0.177                           | 5.05E-03                       | 0.010                     | 2.90E-05                | 1.001                | 8.05E-05           | 0.991                 |
| UN-1.4539                | −0.157                           | 8.45E-04                       | 0.030                     | 9.49E-06                | 1.011                | 1.33E-04           | 0.981                 |

| Heat-treated Steel       | Metastable Pitting Potential (V) | Passivation Potential (V) | Passivation Current (A) | Pitting Potential (V) | Pitting Current (A) | Passivation Range (V) |
|--------------------------|----------------------------------|---------------------------|-------------------------|----------------------|---------------------|-----------------------|
| HT-1.4405                |                                  |                            |                         |                      |                     |                      |
| HT-1.4404                | −0.179                           | 3.80E-03                    | −0.115                  | 1.43E-02              | 1.014               | 4.77E-04           | 1.129                 |
| HT-1.4539                | −0.159                           | 6.90E-04                    | −0.093                  | 2.40E-04              | 1.008               | 1.42E-04           | 1.101                 |
NaCl solution. Metastable pits are transient corrosion pits which form below the potentials for stable pit propagation and eventually disappear due to passivation.\textsuperscript{39} The metastable pitting portion of the polarization plots for untreated stainless steels are shown in Figure 3A. UN-1.4539 exhibited the shortest metastable pitting activity among the untreated steels following anodic polarization due to higher resistance of the steel to transient pit formation. Metastable pits initiated at $-0.156 \text{ V} \left(7.95 \times 10^{-3} \text{ A}\right)$ and ceased at $0.035 \text{ V} \left(1.03 \times 10^{-5} \text{ A}\right)$ after onset of passivation on the steel surface. Passivation of the steel and the extent to which it sustains its passivity (corrosion resistance) is shown in the passivation range values in Table 3.\textsuperscript{40} The metastable plot of UN-1.4405 was the widest due to relatively weak resistance to transient pit formation. The plot extended from $7.95 \times 10^{-3}$ to $1.03 \times 10^{-5}$ A. Figure 3B shows the metastable pitting activity of the heat treated steels. HT-1.4405 was unable to passivate after anodic polarization as a result of changes in the microstructural configuration of the steel which significantly altered its ability to withstand localized corrosion reactions despite improved general corrosion resistance. HT-1.4404 and HT-1.4539 steels exhibited double metastable pitting activity as a result of passivation, breakdown and repassivation of the steel surfaces. The metastable pitting activity initiated at $-0.179$ and $-0.159 \text{ V}$, and stopped at $-0.115$ and $-0.093 \text{ V}$ due to passivation as earlier mentioned. The stable pitting portion of the polarization plots for the untreated and heat treated steels are shown in Figure 4A,B which are associated with pitting potential. Pitting potential refers to the electrochemical potential above which corrosion pit initiates and propagates on the steel surface.\textsuperscript{40} The transpassive region of the stable pitting plot of UN-1.4404 (Figure 4A) indicates unstable passivation indicated by visible potential transients before breakdown of the protective oxide. This phenomenon also occurred on the plot for UN-1.4539 though at a lesser degree. The pitting potential of the untreated steels are closely similar at 1.014, 1.001, and 1.011 V. However, observation of the pitting current value shows UN-1.4404 and UN-1.4539 steels are more resistant to stable pit formation due to the higher pitting current values. The pitting current of the heat treated steels are generally higher than the untreated steels signifying increased pitting resistance. Comparison of the passivation range of the untreated and heat treated steels shows heat treatment extended the passivation range value of UN-1.4404 and UN-1.4539 steels at 0.991 and 0.981 to 1.129 and 1.101 V (HT-1.4404 and HT-1.4539).
3.3 | Open circuit potential measurement

The open circuit potential plots for untreated and heat treated EN-1.4405, EN-1.4404, and EN-1.4539 stainless steels are shown in Figure 5A,B. The plots show the thermodynamic stability of the steel surfaces in the presence of Cl\(^-\) and SO\(_4^{2-}\) anions and their relative tendency to corrode. The plots on Figure 5A shows UN-1.4539 steel displayed the lowest tendency to corrode compared to UN-1.4405 and UN-1.4404. UN-1.4539 plot initiated at \(-0.258\) V (0 seconds) and sharply progressed to \(-0.221\) V at 1800 seconds. Beyond this point the plot was relatively stable to 2197.42 seconds at corrosion potential of \(-0.222\) V due to stability of the protective film. It must be noted that positive shift in corrosion potential results from growth of the protective oxide film with respect to time. At 2197.42 seconds an instantaneous rise in corrosion potential was observed from \(-0.222\) to \(-0.208\) V after which progressive shift of corrosion potential to positive values was gradual, nevertheless indicates increased resistance of UN-1.4539 steel to localized deterioration. UN-1.4405 showed the highest tendency to corrode. Its open circuit potential plot is the most electronegative due to the nature and metallurgical composition of its passive film. The relative position of its plot attests to the fact that its passive film is quite weaker then UN-1.4539 and UN-1.4404 steel. The plot of UN-1.4405 initiated at \(-0.310\) V (0 s) and visibly progressed to \(-0.284\) V at 1355.81 seconds. Beyond this point the plot shifted to electronegative values till 4398.23 seconds at \(-0.288\) V due to increased tendency to corrosion. This results from possible weakening of the passive film or formation of complexes between Cl\(^-\), SO\(_4^{2-}\), and the constituents of the protective oxide.

The open circuit potential plots of the heat-treated steels generally shifted to electronegative values as a result of the effect of repetitive heat treatment processes undergone by the steels. Potentiodynamic polarization studies show heat treatment increases the corrosion resistance of the steels. However, in the absence of applied potentials the thermodynamic tendency of the steel to corrode increased as shown in the plots. The plots of HT-1.4405, HT-1.4404, and HT-1.4539 initiated at \(-0.397\), \(-0.326\), and \(-0.290\) V (0 seconds) compared to initiation value of their untreated counterparts (\(-0.310\), \(-0.295\), and \(-0.258\) V). At 9000 seconds, the corrosion potential values of the heat treated steels are \(-0.369\), \(-0.274\), and \(-0.236\) V while the value for the untreated steels are \(-0.285\), \(-0.242\), and \(-0.202\) V. The final corrosion potential difference between the heat-treated and untreated steels are 84, 32, and 34 V. The larger difference for 1.4405 steel attest to its weaker corrosion resistance compared to the other steels. Though the plot configuration of the heat treated steels is generally similar to the untreated steels, minimal potential transients appeared on the plot for HT-1.4405 steel due to breakdown/repassivation occurrences on the steel surface.

3.4 | Optical microscopy studies

Optical images of EN-1.4405, EN-1.4404, and EN-1.4539 stainless steels before and after corrosion tests are shown from Figures 6A to 8C. Figure 6A to C shows the optical images of UN-1.4405, UN-1.4404, and UN-1.4539 stainless steels before corrosion. Figure 7A to C shows the optical images of UN-1.4405, UN-1.4404, and UN-1.4539 stainless steels after corrosion while Figure 8A to C shows the optical images of HT-1.4405, HT-1.4404, and HT-1.4539 stainless steels after corrosion. The optical image of UN-1.4405 after corrosion (Figure 7A) sharply contrasts its uncorroded counterpart (Figure 6A). Deep contoured grain boundaries are clearly visible on Figure 7A with a minor pitted surface. The morphology of UN-1.4404 (Figure 7B) appears less corroded with larger grain sizes and thinner grain boundary. This observation
**FIGURE 6** Morphology of (A) UN-1.4405, (B) UN-1.4404, and (C) UN-1.4539 stainless steels before corrosion.

**FIGURE 7** Morphology of (A) UN-1.4405, (B) UN-1.4404, and (C) UN-1.4539 after corrosion in 2 M H$_2$SO$_4$/3.5% NaCl solution.

**FIGURE 8** Morphology of (A) HT-1.4405, (B) HT-1.4404, and (C) HT-1.4539 after corrosion in 2 M H$_2$SO$_4$/3.5% NaCl solution.
is due to its microstructural constituent which differs from UN-1.4405 steel. Grain boundaries also appeared on the morphol
ogy of UN-1.4539 steel though larger than the ones on Figure 7A, it is significantly smaller than the ones in Figure 7C. Evidences of shallow corrosion pits are also visible. However, the morphologies on Figure 7A to C show the steels are resistant to pitting corrosion, but somewhat more vulnerable to intergranular corrosion with UN-1.4405 (Figure 7A) being the most prone it. Heat treatment had no significant effect on the morphological configuration of HT-1.4404 and HT-1.4539 steel (Figure 8A,B). Their morphology remained generally the same. However, the morphology of HT-1.4405 was significantly influenced by changes in its microstructure resulting in badly corroded morphology and corrosion pits. This morphology aligns with the absence of passivation region on its polarization plot (Figure 1) due to collapse of its protective oxide. Comparing the morphologies of EN-1.4405 steel (Figures 7A and 8A), observation shows deterioration of Figure 7A is due to localized corrosion along the grain boundary while the deterioration in Figure 8A is due to the combination of general and localized corrosion.

4 | CONCLUSION

Cyclic high temperature variation of EN-1.4405, EN-1.4404, and EN-1.4539 stainless steels significantly improved their general and localized corrosion resistance in dilute chloride/sulfate solution. The pitting current of the heat-treated steels were generally higher than the untreated steels signifying increased pitting resistance. The passive film characteristics of EN-1.4405 and EN-1.4539 were strengthened after heat treatment compared to their untreated counterparts. Untreated and heat treated EN-1.4405 exhibited the lowest corrosion resistance compared to EN-1.4539 with the highest resistance. The corrosion potential of the steels varied anodically with respect to their corrosion rate values. Among the untreated steels, EN-1.4539 steel exhibited the highest resistance to metastable pitting. Heat treated EN-1.4404 and EN-1.4539 steels exhibited double metastable pitting activity while heat treated EN-1.4405 was unable to passivate after anodic polarization. The open circuit potential measurement showed the higher tendency of heat treated steels to corrode with EN-1.4539 being comparatively more resistant to corrosion than the other steels.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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