A Comparative Study of Intergranular Corrosion of AISI 304 Stainless Steel and Chrome-Manganese Austenitic Stainless Steel

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The use of Chrome-Manganese austenitic stainless steel (Cr–Mn ASS) has tremendously increased in past few years in applications like home accessories, office appliances, light poles, etc and it is serving as an alternative to 300 series. But, the study related to sensitization behavior of these steels is scanty. Therefore, this paper aims a systematic comparison on intergranular corrosion of AISI 304 stainless steel and Cr–Mn ASS. The qualitative and quantitative comparison of degree of sensitization of these steels was carried out on the basis of optical microscopy (ASTM standard A-262 practice A test) and electrochemical test (double loop electrochemical potentiokinetic reactivation (DLEPR)) respectively. The isothermal time-temperature-sensitization diagrams were used to compare the effect of heat treatment on sensitization zone of both the steels. The DLEPR results showed that the AISI 304 SS starts to recover from sensitization when ageing time is prolonged beyond 2880 min. (at 700 °C), whereas for Cr–Mn ASS, the degree of sensitization keeps on increasing to a very high value of 60.70% (11520 min.). Chromium depleted zone was identified and compared using Electron Probe Micro-analyzer (EPMA) line scan of both the steels. The depleted region of sensitized Cr–Mn ASS is found to be much wider than that of AISI 304 SS.

KEY WORDS: Chrome-Manganese austenitic stainless steel (Cr–Mn ASS); AISI 304 SS; intergranular corrosion (IGC); TTS diagram; double loop electrochemical potentiokinetic reactivation test; Electron Probe Micro-Analyzer (EPMA) line scan.

1. Introduction

Austenitic stainless steel (ASS) is extensively used as structural material in chemical, petrochemical, fertilizers, power and nuclear industries due to its excellent corrosion resistance, high mechanical strength and good weldability.1–3) This excellent corrosion resistance of ASS is because of the formation of passive film of Cr₂O₃ on the surface, when exposed to aqueous environment.3) The ASS family is primarily divided into two categories - 300-series and 200-series. 300-series (mainly AISI 304 and 316 SS) are the most popular grades of ASS.4,5) Usually, nickel is added in 300-series steel as a major constituent. Addition of nickel stabilizes the austenite structure and improves formability, weldability, toughness and resistance to propagation of corrosion in acidic environment.4,5) But, due to high cost and inadequate supply of Ni in India, the local producers turned to a new grade of stainless steel, “200-series” as a promising alternative to 300-series. 200-series mainly consists of manganese, chromium, nitrogen and small amount of nickel. This series is also known as “Chrome-Manganese Austenitic Stainless Steel (Cr–Mn ASS)”.7) These steels do not have the same level of corrosion resistance, formability and weldability as “300-series”9) but, can replace 300-series ASS in applications such as home accessories, office appliances, light poles, constructions, out-door installations etc., where high corrosion resistance is not primarily required. Apart from this, it is economical as compared to 300-series.4,7,8)

The austenite phase stability with respect to alloying elements viz. Cr, Ni and Mn is explained by Charles.9) The austenite phase is stable even with lower nickel content, but with an increase in manganese percentage. However, this leads to decrease in solubility limit of chromium in the austenite phase. Hence, the chromium content has to be reduced to 15–16 wt% in Cr–Mn ASS to keep the austenite structure intact. This Cr content is lower than 18–20 wt% Cr, which is present in AISI 304 SS. It suggests that, Cr–Mn ASS have lower corrosion resistance and are suitable for a much narrower range of applications than AISI 304 SS.

When ASSs are subjected to slow heating or cooling in the temperature range of 450°C–900°C, it undergoes sensitization.9) This phenomenon involves the formation of Cr-rich carbides at the grain boundaries which extracts chromium from the grain boundaries and neighboring matrix, leaving a Cr-depleted zone extending to both sides of the grain boundaries. The Cr-depleted zone is vulnerable to attack, leading to intergranular corrosion (IGC).4,10–12) Carbon

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and chromium are the predominant compositional variables controlling sensitization.\textsuperscript{1,3} 300 series ASS will be more resistant to IGC than Cr–Mn ASS as it contains more amount of chromium. It is known that, by reducing the carbon content, more time is required to initiate sensitization phenomenon.\textsuperscript{1}\textsuperscript{1} The carbon content in Cr–Mn ASS is usually much higher than that of 300 series. The sensitization behavior of 300-series ASS has been extensively studied.\textsuperscript{1,3,10–12} However, studies on the sensitization behavior of 200-series ASS are relatively few.

The major applications of Cr–Mn ASS involve fabrication process like welding, which leads to formation of chromium carbides precipitation in heat affected zone resulting in decrease in corrosion resistance. Hence, the IGC behavior of this steel must be studied carefully before bringing it into application. Taiwade et al.\textsuperscript{13} have reported that Cr–Mn ASS gets sensitized during welding and they have also discussed briefly the IGC behavior of Cr–Mn ASS. Shankar Rao et al.\textsuperscript{14} have laid the foundation of the electrochemical corrosion behavior of 200 series in 1 M H\textsubscript{2}SO\textsubscript{4}. They also emphasized that the number of research works on the corrosion behavior of 200 series is still limited compared to that of 300 series stainless steel, but the demand of 200 series in replacement of 300 series is increasing worldwide, particularly in India and China. At present, the 200 series stainless steel account for more than 10% of the total stainless steel production.\textsuperscript{14,15} This has been the motivation for the present study. This research work may be called as the stepping stone towards the contribution of generating the valuable electrochemical data of Cr–Mn ASS. In this study, the effect of sensitization on IGC has been compared for AISI 304 SS and Cr–Mn ASS. ASTM standard A-262 Practice A and E test were used to investigate the intergranular corrosion behavior of both the steels in relation to the influence on microstructure produced by different heat treatments. Degree of Sensitization (DOS) was compared using double loop electrochemical potentiokinetic reactivation (DLEPR) test. Chromium depleted zone was identified and compared using Electron Probe Micro-analyzer (EPMA) line scan in both the steels.

2. Experimental Work

The AISI 304 SS and Cr–Mn ASS were procured from local market in the form of sheet. The chemical composition (as determined by optical emission spectrometer) is given in Table 1.

Samples for ASTM standard A-262 Practice A, Practice E and Electrochemical tests were cut from the sheets by wire-cut electrical discharge machine to avoid heating zone during cutting operation. Samples for ASTM standard A-262 Practice E were 70 mm × 10 mm × 3 mm in size and for other tests they were 10 mm × 10 mm × 3 mm. All the samples were solution annealed at a temperature of 1 050°C for 1 hour, followed by water quenching.\textsuperscript{11} The solution annealed samples were then subjected to isothermal ageing treatment at temperatures of 550, 600, 650, 700, 750, 800 and 850°C (±1°C) for various durations (5 min. to 11 520 min.) followed by air cooling.

The sample preparation for size 10 mm × 10 mm × 3 mm is described as follows. The samples were joined with a brass stud (8 mm Φ) using silver paste for electrical connections. The stud was connected to brass wire (3 mm Φ) via M3 threads. The assembly was then mounted in cold setting resin, leaving one of the surface of sample open for testing. The open surface of samples were polished on emery papers (180, 240, 400 and 600 grit), and then on velvet cloth smeared with 0.75 μ alumina (Al\textsubscript{2}O\textsubscript{3}) slurry. The samples were then ultrasonically cleaned in distilled water prior to each test.

A Potentiostat (Solartron-1285) was used for ASTM standard A-262 Practice A test. In Practice A, the samples were electrolytically etched in 10 wt% oxalic acid solution with current density of 1 A/cm\textsuperscript{2} for 90 second.\textsuperscript{12,16} The samples were then observed under optical microscope (Zeiss Axiolab). For Practice E test, the samples were exposed in boiling solution of 16% H\textsubscript{2}SO\textsubscript{4} + 100 gl –1 CuSO\textsubscript{4} (in presence of Cu turnings) for 24 hours, and then bent through 180° over a mandrel (3 mm Φ).\textsuperscript{15} The bent samples were examined under low magnification (20×) to observe cracks. Cracks appeared on those samples which suffered from IGC. These results indicated which set of conditions of thermal ageing caused IGC. The information obtained from both the tests was then used to construct time temperature sensitization (TTS) diagram.\textsuperscript{17} The TTS diagrams were constructed using software “ORIGIN PRO 8”.

Double loop Electrochemical Potentiokinetic Reactivation (DLEPR) test was performed in a solution consisting of 0.5 M H\textsubscript{2}SO\textsubscript{4} + 0.01 M NH\textsubscript{4}SCN at room temperature (27°C). It was carried out using a Potentiostat (Solartron-1285), in conventional three-electrode electrochemical cell, with platinum electrode as counter electrode, saturated calomel electrode (SCE) as the reference electrode and sample as the

<table>
<thead>
<tr>
<th>Elements</th>
<th>C</th>
<th>Cr</th>
<th>Ni</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 304 SS</td>
<td>0.054</td>
<td>20.011</td>
<td>7.972</td>
<td>1.110</td>
<td>0.510</td>
<td>0.028</td>
<td>0.006</td>
</tr>
<tr>
<td>Cr–Mn ASS</td>
<td>0.110</td>
<td>15.861</td>
<td>0.309</td>
<td>9.601</td>
<td>0.434</td>
<td>0.038</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Fig. 1. EPMA line scan performed at various locations near grain boundaries using JEOL 8 600 M Electron Probe Micro-analyzer.
working electrode. Before exposing the sample, the test solution was de-aerated using dry (oxygen free) nitrogen gas for 1 hour. All the DLEPR experiments were initiated after attaining nearly steady-state open circuit potential (about 45 min). The tests were performed at scan rate of 6 V/h and the potential range was from –500 mV (SCE) to +300 mV. This gives the forward scan. The scanning direction was then reversed, and the potential was then reduced back to –500 mV to obtain reverse scan. The peak activation current density (\( I_a \)) and the peak reactivation current density (\( I_r \)) were measured during forward and reverse scans, respectively. The % DOS was then computed as the ratio of \( (I_r/I_a) \times 100 \).18,19

EPMA line scans of two samples each from both the steels was performed in conjunction with SEM using JEOL 8 600 M Electron Probe Micro analyzer. The line scan determines the chemical composition of the alloying elements across the grain boundaries. Figure 1 shows the EPMA line scan performed at various locations near the grain boundaries. The locations of scans, shown in Fig. 1 are of Cr–Mn ASS sample heat treated at 700°C for 120 min. The image shows five line scans. Each line scan was performed for a set of 25 data points. Similar line scan was also performed for solution annealed AISI 304 SS and Cr–Mn ASS, AISI 304 SS samples heat treated at 700°C for 120 min.

3. Results and Discussion

Figures 2(a) and 2(b) shows the optical micrographs of solution annealed AISI 304 SS and Cr–Mn ASS after etching as per ASTM standard A-262 Practice A test. It is observed that both the steels have single phase austenitic structure and no traces of carbides are found.

Fig. 2. Optical micrographs of solution annealed sample as per ASTM standard A-262 Practice A test for a) AISI 304 SS b) Cr-Mn ASS.

Fig. 3. Optical micrographs as per ASTM standard A-262 Practice A test for AISI 304 SS samples heat treated at 700°C for a) 15 min b) 120 min c) 360 min d) 720 min e) 1 440 min f) 2 880 min g) 5 760 min h) 11 520 min.

Fig. 4. Optical micrographs as per ASTM standard A-262 Practice A test for Cr–Mn ASS samples heat treated at 700°C for a) 15 min b) 120 min c) 360 min d) 720 min e) 1 440 min f) 2 880 min g) 5 760 min h) 11 520 min.
3.1. Qualitative Comparison

The microstructures of heat treated samples for both the steels after the ASTM standard A-262 Practice A test were classified as:16)

1) Step structure: Steps only between grains, no ditches at grain boundaries.
2) Dual structure: Some ditches at grain boundaries in addition to steps, but no single grain completely surrounded by ditches.
3) Ditch structure: One or more grain completely surrounded by ditches.

In order to compare both the steels qualitatively, the effect of ageing time and temperature on microstructural behavior of both the steels was studied with the help of ASTM standard A-262 Practice A test. Figures 3(a)–3(h) and 4(a)–4(h) shows the optical micrographs of heat treated AISI 304 SS and Cr–Mn ASS respectively at 700°C for various durations. In Figs. 3(a) and 4(a), partial attack or precipitation of carbides is observed and hence they were classified as “dual” structure. It means that, at 700°C, ageing time of 15 min. is not sufficient for carbides to precipitate completely in both the steels. In Figs. 3(b)–3(h) and 4(b)–4(h), it can be seen that the chromium carbide is precipitated along all the grain boundaries and hence they were classified as “ditch” structure. From Figs. 3(a)–3(f) and 4(a)–4(f), it is observed that the carbide precipitation along the grain boundaries increased with ageing time. From Figs. 3(g) and 3(h), when the ageing time further increases to 5 760 min. and 11 520 min., the intensity of carbide precipitation has decreased in AISI 304 SS, whereas from Figs. 4(g) and 4(h), the intensity of carbide precipitation has further increased in Cr–Mn ASS.

Figures 5(a)–5(f) and 6(a)–6(f) shows the optical micrographs of AISI 304 SS and Cr–Mn ASS respectively, which were heat treated in the temperature range of 600–850°C for constant ageing time of 1 hour. AISI 304 SS shows a “step” structure (Fig. 5(a)), when heat treated at 600°C for 1 hour. A “dual” structure (Fig. 5(b)) was observed at 650°C and at this temperature, precipitation of carbides has initiated. The carbide precipitation attack has further increased up to 750°C. Figures 5(c) and 5(d) shows “ditch” structure. At 800°C (Fig. 5(e)), few traces of carbides were observed. But, when the temperature was increased beyond 800°C, no traces of carbide precipitation were observed and a “step” structure can be seen in Fig. 5(f). Cr–Mn ASS shows fully ditch structure (Figs. 6(a)–6(f)) for all temperatures from 600–850°C, when aged 1 hour. Figures 6(d) and 6(e) representing the micrographs of heat treated at 750°C and 800°C respectively, indicates more rigorous attack as compared to other micrographs. Therefore, it can be concluded that the duration of 1 hour is insufficient for susceptibility to IGC at temperatures of 600, 800 and 850°C in case of AISI 304 SS, whereas this duration is favorable for IGC in Cr–Mn ASS for the given range of temperatures.

ASTM standard A-262 Practice E test was performed on those samples which showed “dual” and “ditch” structures. This test was conducted for the confirmation of susceptibility to IGC of AISI 304 SS and Cr–Mn ASS. The samples which showed cracks (fissures) on the surface after bend test were considered for the construction of TTS diagram. TTS diagrams for AISI 304 SS and Cr–Mn ASS were constructed and presented in Figs. 7(a) and 7(b) respectively. Critical cooling rate (CCR), above which there is no risk of sensitization was evaluated using method described in literature.17) Nose temperature is the temperature at which

![Fig. 5. Optical micrographs as per ASTM standard A-262 Practice A test for AISI 304 SS samples heat treated for 60 min at a) 600°C b) 650°C c) 700°C d) 750°C e) 800°C f) 850°C.](image)

![Fig. 6. Optical micrographs as per ASTM standard A262 Practice A test for Cr–Mn ASS samples heat treated for 60 min at a) 600°C b) 650°C c) 700°C d) 750°C e) 800°C f) 850°C.](image)
minimum time is required for sensitization. Temperature range for sensitization that is $T_H$ (higher limit) and $T_L$ (lower limit), temperature at nose, minimum time required for sensitization ($t_{min}$), CCR and the position of the TTS are reported in Table 2.

The upper temperature limit ($T_H$) for Cr–Mn ASS is 905°C and for AISI 304 SS, it is 778°C. The lower temperature limit ($T_L$) for Cr–Mn ASS is 531°C and for AISI 304 SS, it is 568°C. The temperature range of TTS ($T_H$–$T_L$) for Cr–Mn ASS is 374°C whereas for AISI 304 SS, it is 210°C. The temperature range for Cr–Mn ASS is significantly larger than that of AISI 304 SS. This implies that the Cr–Mn ASS is susceptible to IGC for wide range of temperatures, whereas AISI 304 SS is susceptible for lesser range of temperatures. The TTS curve for Cr–Mn ASS (Fig. 7(b)) is shifted towards left as compared to that for AISI 304 SS. The position of TTS influences the nose temperature and corresponding minimum time required for sensitization. Nose temperature for Cr–Mn ASS is found to be 725°C and that for AISI 304 SS is 719°C. Minimum time required for sensitization ($t_{min}$) at nose temperature is 8.16 min. in case of Cr–Mn ASS and 17.80 min. for AISI 304 SS. This indicates that the time taken for Cr–Mn ASS for sensitization is nearly half of the time taken by AISI 304 SS. CCR for Cr–Mn ASS is estimated to be 23.62°C/min. and for AISI 304 SS, it is 6.41°C/min. The CCR for Cr–Mn ASS is higher than AISI 304 SS. Therefore, faster cooling rates have to be adapted to avoid sensitization in case of Cr–Mn ASS. In other words higher the value of CCR, more is the susceptibility of the material towards sensitization and hence IGC.

### 3.2. Quantitative Comparison

#### 3.2.1. DLEPR Test

Figures 8(a) and 8(b) shows the DLEPR curves for solution annealed AISI 304 SS and Cr–Mn ASS respectively. The activation peak current density ($I_a$), reactivation peak current density ($I_r$) and % DOS are reported in Table 3. The $I_r$ value for Cr–Mn ASS is nearly one order magnitude higher than that of AISI 304 SS. The development of the reactivation peak current density can be attributed to metal dissolution during reverse scan. This means that the passive film formed on the surface of Cr–Mn ASS has lower corrosion resistance as compared to AISI 304 SS. A ratio of maximum current generated in the DLEPR test ($I_r/I_a$) is used as a measure for the “degree of sensitization (DOS)” .

The % DOS of solution annealed Cr–Mn ASS shows exceptionally high

### Table 2. Results obtained from TTS diagram.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$T_H$ (°C)</th>
<th>$T_L$ (°C)</th>
<th>Nose Temp. (°C)</th>
<th>Sensitization time at nose ($t_{min}$)</th>
<th>CCR (°C/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 304 SS</td>
<td>778</td>
<td>568</td>
<td>719</td>
<td>17.80</td>
<td>6.41</td>
</tr>
<tr>
<td>Cr–Mn ASS</td>
<td>905</td>
<td>531</td>
<td>725</td>
<td>8.16</td>
<td>23.62</td>
</tr>
</tbody>
</table>

### Table 3. Data obtained from DLEPR curves.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Time (min.)</th>
<th>$I_r$ (Amp/cm²)</th>
<th>$I_a$ (Amp/cm²)</th>
<th>% DOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Annealed AISI 304 SS</td>
<td>-</td>
<td>0.0001</td>
<td>0.0770</td>
<td>0.17</td>
</tr>
<tr>
<td>5</td>
<td>0.0002</td>
<td>0.0781</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.0005</td>
<td>0.0704</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.0013</td>
<td>0.0686</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.0017</td>
<td>0.0683</td>
<td>2.71</td>
<td></td>
</tr>
<tr>
<td>Solution Annealed AISI 304 SS + Heat treated at 700°C for</td>
<td>120</td>
<td>0.0023</td>
<td>0.0599</td>
<td>3.94</td>
</tr>
<tr>
<td>240</td>
<td>0.0082</td>
<td>0.0667</td>
<td>12.38</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td>0.0100</td>
<td>0.0537</td>
<td>18.62</td>
<td></td>
</tr>
<tr>
<td>720</td>
<td>0.0199</td>
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<tr>
<td>1440</td>
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<tr>
<td>2880</td>
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<td>34.49</td>
<td></td>
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<tr>
<td>5760</td>
<td>0.0172</td>
<td>0.0631</td>
<td>27.32</td>
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<tr>
<td>11520</td>
<td>0.0123</td>
<td>0.0710</td>
<td>17.34</td>
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<tr>
<td>Solution Annealed Cr–Mn ASS + Heat treated at 700°C for</td>
<td>-</td>
<td>0.0017</td>
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<td>60</td>
<td>0.0056</td>
<td>0.0628</td>
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</tr>
<tr>
<td>Solution Annealed Cr–Mn ASS + Heat treated at 700°C for</td>
<td>120</td>
<td>0.0071</td>
<td>0.0600</td>
<td>11.77</td>
</tr>
<tr>
<td>240</td>
<td>0.0073</td>
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<tr>
<td>360</td>
<td>0.0086</td>
<td>0.0549</td>
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<tr>
<td>720</td>
<td>0.0109</td>
<td>0.0550</td>
<td>19.77</td>
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<tr>
<td>1440</td>
<td>0.0123</td>
<td>0.0463</td>
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<td>2880</td>
<td>0.0152</td>
<td>0.0540</td>
<td>28.07</td>
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<tr>
<td>5760</td>
<td>0.0166</td>
<td>0.0520</td>
<td>31.68</td>
<td></td>
</tr>
<tr>
<td>11520</td>
<td>0.0179</td>
<td>0.0460</td>
<td>60.70</td>
<td></td>
</tr>
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</table>
value of 2.92, whereas for AISI 304 SS, it is 0.17%. But, from Figs. 2(a) and 2(b), it can be seen that both the steels when solution annealed have single phase austenitic structure. The exceptionally high value of % DOS in Cr–Mn ASS may be due to the less amount of % Cr present in this steel.

In order to see the effect of ageing time quantitatively on IGC of both the steels, the DLEPR test was performed for samples heat treated at 700°C for various ageing time. The

![DLEPR curves for solution annealed sample of: a) AISI 304 SS b) Cr–Mn ASS.](image)

![DLEPR curves of AISI 304 SS at 700°C for a) 30 min b) 120 min c) 360 min d) 720 min e) 1440 min f) 2880 min g) 5760 min h) 11520 min.](image)
DLEPR test results are collectively reported in Table 3. And, DLEPR curves of few samples of AISI 304 SS and Cr–Mn ASS are shown in Figs. 9(a)–9(h) and 10(a)–10(h) respectively.

Using the results of DLEPR tests, the relation between $I_r$ and % DOS with respect to ageing time is established and presented in Figs. 11 and 12 respectively for both the steels. From graphs in Figs. 11 and 12, it can be seen that the $I_r$ values of samples of AISI 304 SS and Cr–Mn ASS heat treated at 700°C for 15 min. are 0.0005 and 0.0043 A/cm$^2$, whereas the % DOS values are 0.78 and 7.65 respectively. This indicates that the Cr–Mn ASS is more prone to sensitization than AISI 304 SS for 15 ageing time. Similar relation can be found for ageing time of 5, 30, 120 and 240 min.

The $I_r$ values of samples of AISI 304 SS and Cr–Mn ASS heat treated at 700°C for 720 min are 0.0199 and 0.0109 A/cm$^2$, whereas the % DOS values are 26.90 and 19.77 respectively. This indicates that during reactivation, the metal dissolution in case of AISI 304 SS is more as compared to Cr–Mn ASS. In other words, it can be said that the protective passive film which forms over chromium depleted areas is more easily dissolved in AISI 304 SS. Hence, the AISI 304 SS is more susceptible to IGC for ageing time of 720 min. Similar metal dissolution behaviour can be seen for ageing time of 360, 1 440 and 2 880 min. This behaviour was further cross-checked using EPMA line scan for samples heat treated at 700°C for 1 440 min (see Fig. 13). It is evident that the depletion of Cr (in wt%) at the grain boundaries was higher for AISI 304 SS as compared to Cr–Mn ASS. Hence, the higher DOS is obtained for AISI 304 SS.

The $I_r$ and % DOS values are increasing for both the steels with respect to ageing time till 2 880 min. When the ageing time is increased beyond 2 880 min, the $I_r$ value and % DOS for AISI 304 SS goes on decreasing. This means

![Fig. 10. DLEPR curves of Cr–Mn ASS at 700°C for a) 30 min b) 120 min c) 360 min d) 720 min e) 1 440 min f) 2 880 min g) 5 760 min h) 11 520 min.](image-url)
that, the suffered AISI 304 SS starts to recover from sensi-
tization when the ageing time is prolonged. This recovery
in the micrographs shown in Fig. 3(h). But,
Cr–Mn ASS did not indicate any such behavior for prolonged
of Cr–Mn ASS is ≈20% and ≈16% respectively. This is
also evident from the EPMA line scan and it can be seen in
chromium concentration profile shown in Fig. 13. No
depleted region was identified in solution annealed AISI
304 SS and Cr–Mn ASS. The figure also indicates that,
there is depleted region in the heat treated samples of both
the steels. The depleted region for heat treated Cr–Mn ASS
is much wider than that of heat treated AISI 304 SS. The
minimum Cr-concentration in the depleted region for AISI
304 SS heat treated for 120 min, 1 440 min and 5 760 min
are ≈14, 11.3 and 12 wt% respectively. Since, the minimum
Cr-concentration for 5 760 min is higher than 1 440 min, its
% DOS value was found to be lower (see Table 3). The min-
imum Cr concentration in the depleted region for Cr–Mn
ASS heat treated for 120 min, 1 440 min and 5 760 min are
≈9.5, 8 and 6 wt% respectively. Since, the minimum Cr con-
centration value decreases continuously, the passive film
will be weaker with increase in ageing time. Hence, the %
DOS for Cr–Mn ASS do not decrease even if ageing time
is increased beyond 2 880 min, whereas for AISI 304 SS, the
% DOS decreases, which was observed due to healing.

4. Conclusions

(1) Intergranular corrosion of AISI 304 SS and Cr–Mn
ASS was systematically compared with the help of qualita-
tive and quantitative tests.
(2) From optical micrographs and DLEPR results, it can
be concluded that the AISI 304 SS starts to recover from
sensitization, whereas Cr–Mn ASS did not show any such
behavior for the ageing time till 11 520 min at 700°C.
(3) The duration of 1 hour was insufficient for suscep-
tibility to IGC at temperatures of 600, 800 and 850°C
in case of AISI 304 SS, whereas this duration is favorable for
IGC in Cr–Mn ASS at 600–850°C.
(4) From TTS diagrams, it can be concluded that Cr–
Mn ASS is prone to IGC for wider range of temperatures
and shorter time as compared to AISI 304 SS.
(5) EPMA line scan revealed that, no depleted region
was identified in solution annealed AISI 304 SS and Cr–Mn
ASS. The depleted region for heat treated Cr–Mn ASS is
much wider than that of heat treated AISI 304 SS.
(6) The % DOS for Cr–Mn ASS do not decrease even if ageing time
is increased beyond 2 880 min, whereas for
AISI 304 SS, the % DOS decreases, which was observed
due to healing.
(7) The overall conclusion of this comparative study is
that, the Cr–Mn ASS is more prone to IGC than AISI 304
SS for identical heat treatments. This poor sensitization
behaviour of Cr–Mn ASS is due to its high carbon and low
chromium content.
(8) The objective of this paper, which was to contribute
towards the literature development of sensitization behavior
of Cr–Mn ASS, which at present is scanty, has been
achieved.
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