# Sensitization Condition of Alloy 182 Welds Joined by Stainless Steel 304 and Low Alloy Steel SA 508

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## 1. Introduction

The non-destructive examination (NDE) helps to prevent failure in reactor components through detection of degradation before the degradation challenges the structural integrity of nuclear reactor components. In order to evaluate the performance of NDE, it is necessary to mass-produce mock-up specimens easily and economically. One of the techniques for artificial crack formation is making materials be weak to corrosion through sensitization [1, 2]. Sensitization heat treatment makes intergranular cracking by forming chromium carbide causing chromium depletion along grain boundary that is directly related to corrosion resistance [3]. In this paper, sensitization condition of dissimilar metal welds (DMWs) with Alloy 182 joined by stainless steel 304 and low alloy steel SA 508 grade 3 class 1 was defined. The materials have been used in surgeline nozzle in old nuclear power plants which needs steady monitoring using NDE based on cracking experience in Wolf Creek, Farley 2, and so forth [4].

## 2. Experimental Results

### *2.1 Materials*

The V groove SMAW 182 welding was performed between two base metal plates. The chemical composition and material properties are shown in Table 1 and Table 2. All specimens having 1cm$^2$ surface area with 3mm thickness were produced from bottom part of V groove welds.

### *2.2 Sensitization Heat Treatment*

The specimens were heat treated for the range from 400°C and 700°C which is well known as a sensitized condition of austenitic steel [5, 6]. The heat treatment (HT) conditions are shown in Table 3.

### *2.3 Modified Huey Test*

The modified Huey tests were performed in boiling 25% Nitric acid for 24 hours, because Ni base Alloy is too sensitized to analyze degree of sensitization (DOS) through general Huey test [7].

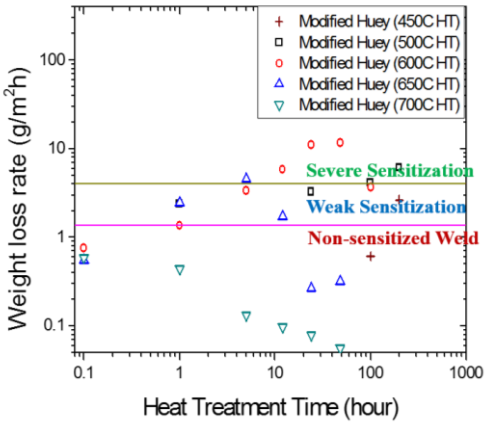


Fig. 1. Weight loss rate of sensitized specimens after modified Huey tests.

Table1: Chemical Composition of Alloy 182 Welds Joined by Stainless Steel 304 and Low Alloy Steel SA 508 Gr.3 Cl.1

| Ni | Ti | Si | Mo | Nb | C | Mn | Fe | Cr | P | S |
|---|---|---|---|---|---|---|---|---|---|---|
| Bal. | 0.39 | 0.58 | 0.58 | 1.59 | 0.057 | 6.67 | 8.83 | 14.7 | 0.011 | 0.005 |

Table2: Mechanical Properties of Alloy 182 Welds Joined by Stainless Steel 304 and Low Alloy Steel SA 508 Gr.3 Cl.1

| | Modulus (GPa) | Yield Strength (MPa) | Tensile Strength (MPa) | Tensile strain at Break (%) |
|---|---|---|---|---|
| DMW Alloy 182 | 168.97 | 378.74 | 659.60 | 16.73 |
| Type 304 stainless steel | 147.02 | 348.14 | 504.89 | 11.5 |
| SA 508 Gr.3 Cl.1 | 249.05 | 471.19 | 615.21 | 9.15 |

Table3: Sensitization Heat Treatment Conditions

| Temperature (°C) | 450 | 500 | 600 | 650 | 700 | | | |
|---|---|---|---|---|---|---|---|---|
| Time (hours) | 0.1 | 1 | 5 | 10 | 24 | 48 | 100 | 200 |

Fig. 1 shows weight loss rate of sensitized specimens versus HT time. The weight loss rate of sensitized specimens at lower temperature such as 450°C HT and 500°C HT increases as HT time increases. On the other hand, in cases of sensitized specimens at the mid temperature such as 600°C HT and 650°C HT, the weight loss rate stops increasing at a specific HT time, which means chromium replenish occurs if the specimens are heat treated for a specific time. The most sensitized condition is HT at 600°C for 48hours.

The time-temperature sensitization (TTS) diagram was developed based on the results, as shown in Fig. 2. The DOS is divided to three parts by defining weight loss rate criteria: non-sensitization, weak sensitization, and severe sensitization.

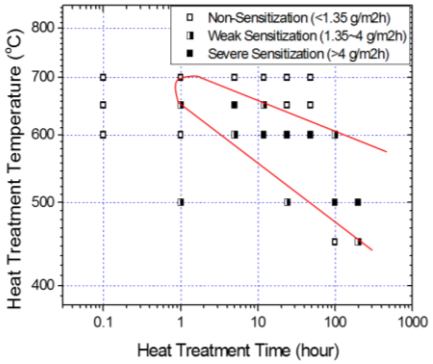


Fig. 2. Time-temperature sensitization diagram of Alloy 182 welds

Fig. 3 and Fig. 4, respectively, show the surface morphology of specimens heat treated at 600°C after modified Huey test by using optical microstructure (OM) and scanning electron microscope (SEM). The specimen heat treated 48 hours shows the most sensitized surface morphology with dendritic microstructure through OM micrographs. The SEM micrographs also show the surface of a specimen heat treated for 48 hours indicate severe intergranular corrosion accompanied with interdendritic corrosion comparing with other conditions.

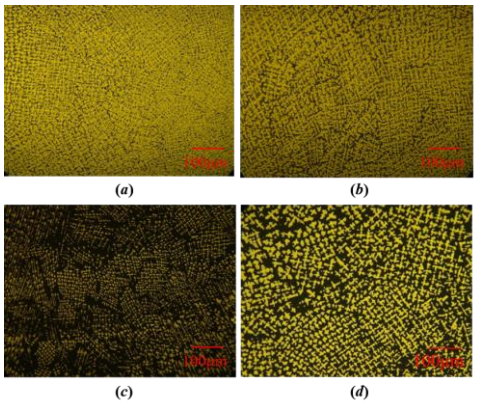


Fig. 3. Surface morphology of Alloy 182 welds heat treated at 600°C for (*a*) 0.1hour, (*b*) 1hour, (*c*) 48hours, and (*d*) 100hours after modified Huey test through OM

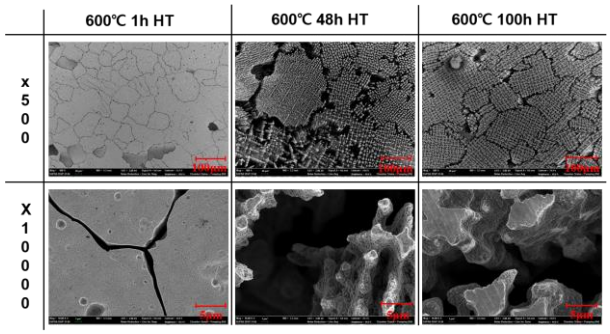


Fig. 4. Surface morphology of Alloy 182 welds heat treated at 600°C after modified Huey test through SEM

### *2.4 Modified DL-EPR Test*

The modified double loop electrochemical potentiokinetic reactivation (DL-EPR) tests were performed in 0.01M sulfuric acid and 0.0001M KSCN with 0.5mV/s scan rate according to technical report [7] in order to verify the previous modified Huey test results. The experimental cell consisted of SCE reference electrode, Pt counter electrode and nitrogen gas to remove dissolved oxygen, as shown in Fig. 5. The DL-EPR test results using the specimens heat treated at 600°C are shown in Fig. 6.

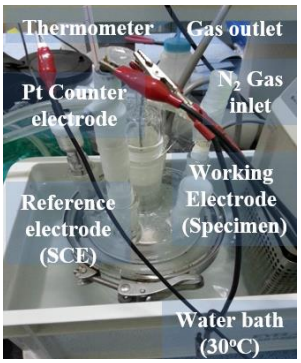


Fig. 5. Photograph of modified DL-EPR cell

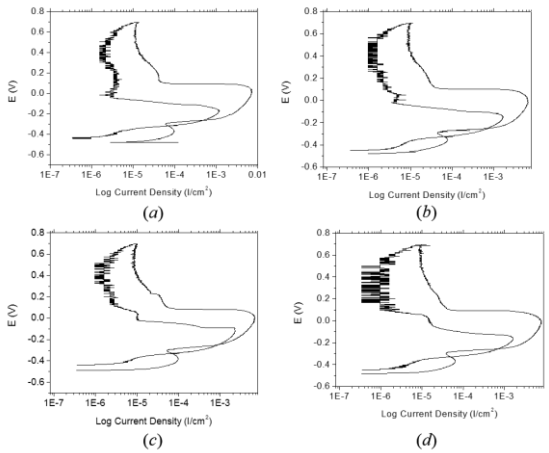


Fig. 6. Modified DL-EPR results using heat treated specimens at 600°C for (*a*) 1hour, (*b*) 24hours, (*c*) 48hours, and (*d*) 100hours

The HT for 48hours shows highest peak-current density ratio, $I_r/I_a$ (where $I_r$ is the maximum current density obtained in the reversed reactivation scan and $I_a$ is the critical passivation current density obtained in the forward scan), which is used to estimate the DOS, as shown in Table 4. Fig. 7 shows a comparison between modified Huey test results and modified DL-EPR test results with two different axes. They show a good agreement.

Table4: DOS through modified DL-EPR tests

| HT time at 600°C (hours) | 1 | 24 | 48 | 100 |
|---|---|---|---|---|
| DOS(%) ($I_r/I_a$ x 100) | 16.22 | 24.63 | 34.13 | 20.15 |

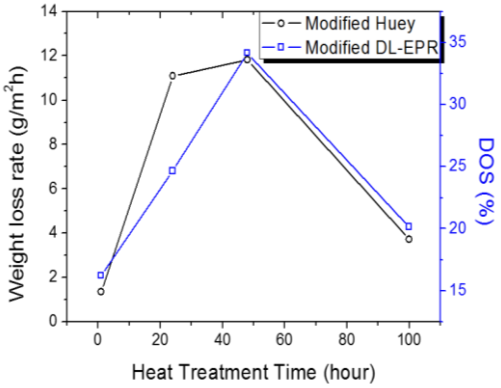


Fig. 7. A comparison between modified Huey test results and modified DL-EPR test results

Fig. 8 shows surface morphology after modified DL-EPR test using specimens heat treated at 600°C through SEM micrographs. The surface of a specimen sensitized for 48 hours shows continuous intergranular corrosion, while the surface of specimens sensitized for 1 hour and 100 hours shows discontinuous intergranular corrosion.

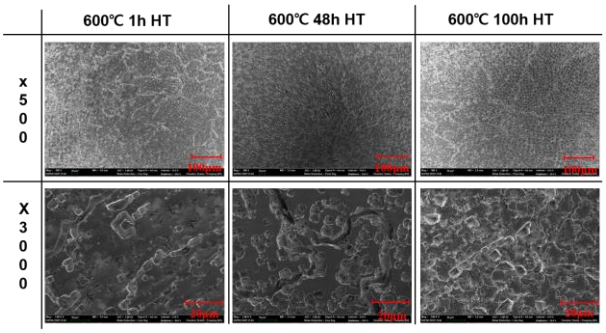


Fig. 8. Surface morphology of Alloy 182 welds heat treated at 600°C after modified DL-EPR test through SEM

## 3. Conclusions

The sensitization heat treatment at 600°C for 48hours is decided to the most sensitized condition for Ni base Alloy 182 welds joined by stainless steel 304 and low alloy steel SA 508 Gr.3 Cl.1 through modified Huey test and modified DL-EPR test. Two tests have a good agreement. The surface morphology of specimens after modified Huey test shows a sharp and deep intergranular attack, which means the more chromium is depleted, the more specimen is corroded. On the other hand, the surface morphology of specimens after modified DL-EPR test shows a wide and shallow attack which means uniform corrosion occurs if Cr depletion is less than the critical content.

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