Microstructural, Micro-hardness and Sensitization Evaluation in HAZ of Type 316L Stainless Steel Joint with Narrow Gap Welds

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1. Introduction

Several components and pipes of nuclear power plants, are joined by Narrow Gap Welding (NGW) process for less cost and time [1]. In nuclear power plants 316L stainless steels are commonly used material for their metallurgical stability, high corrosion resistance, and good creep and ductility properties at elevated temperatures. Welding zone considered as the weakest and failure initiation source of the components. For safety and economy of nuclear power plants accurate and dependable structural integrity assessment of main components like pressure vessels and piping are need as it joined by different welding process. In similar and dissimilar metal weld it has been observed [1,2] that weld microstructure cause the variation of mechanical properties through the thickness direction. In the Heat Affected Zone (HAZ) relative to the fusion line face a unique thermal experience during welding. Because of maximum temperature and cooling rate of these two zones have its own corrosion susceptibility. In this study 316L Stainless steel welds were prepared by automated NGW technique, Micro-hardness measurement of HAZ, weld fusion zone and base metal were evaluated in three different regions- Top, Middle and Bottom; as well as their microstructure were evaluated. Degree of Sensitization (DOS) of HAZ, weld zone and base metal were evaluated through Double Loop Electrochemical Potentiokinetic Reactivation (DL-EPR) technique.

2. Methods and Results

2.1 Welding materials and sample preparation

Type 316L stainless steel was used for the base metal and 308L for the welding wire. Chemical compositions of both metals are shown in Table1. Welding thickness was 76 mm. Detailed welding procedure was discussed in reference [1].

The weld blocks were cut at the same position for Microstructural observation and Micro-hardness measurement in the Top, Middle and Bottom region as shown in fig.1.

Elements	316L	308L
C	0.018	0.027
Cr	16.4	21.09
Ni	10.08	10.22
Mo	2.04	0.111
Mn	1.50	1.94
Si	0.38	0.531
P	0.029	0.029
S	0.025	0.007
Nb+Ta	-	0.121
N	-	0.017

Table-1 Chemical composition of base metal and weldments (wt%)

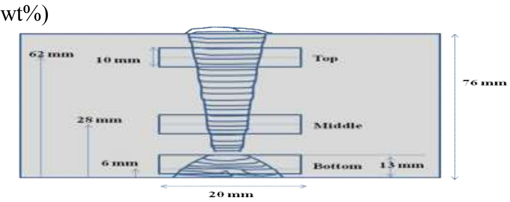

Fig.1 Schematics of narrow gap weld and sample collection region

For the EPR test, samples were collected from the weld block at the same locations as shown in Fig.1. Each extraction step was carried by classify the characteristic microstructures (BM, HAZ, and WM) through an optical microscopic analysis. The HAZ region was the region between the fusion line and the metal base. The collected HAZ sample surface was parallel to the fusion line.

The electrochemical testing samples were mounted in epoxy cold resin to avoid the presence of crevices after the electric contact. The exposed area was 0.28 cm^2. Before the polarization measurements, the Specimen were prepared according to ASTM G108-94(2010)[3].

2.2 Experimental Procedure

The microstructure was observed using optical microscope. Vickers Micro-hardness profiles across the weld-HAZ-base metal interface were obtained at a constant load of 100g. For DL-EPR test a conventional electrochemical cell composed of a graphite counter electrode and a saturated calomel reference electrode (SCE) are connected to a GAMRY potentiostat. DL-EPR polarization curves were obtained in two steps: First, the working electrode was subjected to open circuit conditions, until a steady state potential (E_{corr}) was reached. It takes 3 minutes to reach steady state value. Then, an anodic potentiodynamic sweeping rate of 1.67 mV /s, from -500 mV/E_{corr} to +300 mV_{SCE}, was imposed. At +300 mV, the potential scanning was reversed back to -500 mV/E_{corr}. The test results were expressed in the current densities ratio, i_r/i_a, which was the DOS. i_r means reactivation current density (maximum current density for reactivating the grain boundaries in the reverse scan), and i_a is the activation current density (maximum current density for entire surface in the anodic scan).

2.3 Results

Micro-hardness values in HAZ were increase from the weld and base area but the variation was very little. This is because, the phase structure of 316L and 308L were not transformed by temperature variation during welding process. The HAZ area was approximately 1 to 1.5 mm width in both sides for three regions.

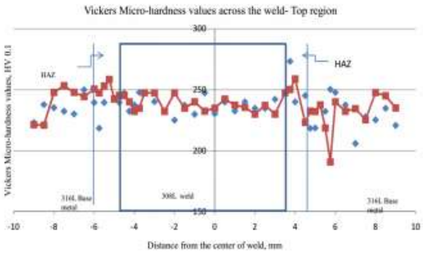

Fig.2 Vickers micro-hardness values in top weld region

In DL-EPR test, as shown in Fig.3 three polarization curves for base, HAZ and weld zone show similar behavior. Table-2 shows that weld 308L was higher degree of sensitization compare to base and HAZ. Comparing with base metal 316L, the weld 308L was higher carbon content than base metal, which results higher Cr-carbide precipitation. However, there is a formation of δ-ferrite phase in the weld that was estimated about 17FN and measured in the finished weld was 12FN. This ferrite is higher than optimal values (3 to 8) for preventing a continuous carbide network. This high δ-ferrite could contribute to form continuous network of carbides and which increased the DOS in the weld. A much lower DOS is obtained in HAZ when comparing with the base metal, because of chromium carbide precipitates possibly re-dissolute at the HAZ specific zones. This process occurred due to high temperature gradients in the HAZ, which is the cause to precipitate dissolution[4]. Moreover, a reduced time of formation of Cr-carbide precipitation could also contributes for low DOS in the HAZ.

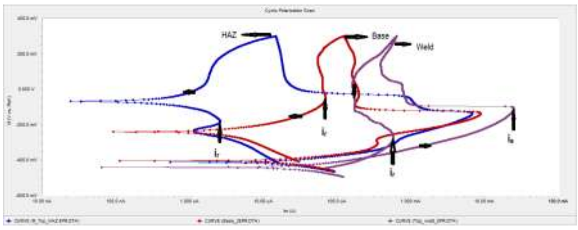

Fig.3 Top region DL-EPR measurements in base, HAZ & weld

Sample	Average DOS [(i_r/i_a)*100] (%)		
	Top	Middle	Bottom
HAZ	0.051	0.111	0.04
Weld	3.24	2.26	
Base	0.525		

Table2- Summary of degree of sensitization

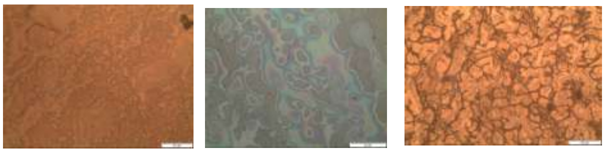

Fig.4 Microstructure after EPR test in base(a),HAZ(b) &Weld(c) by order

Microstructures of HAZ, weld and base region were observed after DL-EPR test by optical microscope. Fig.4 showed the dissolution of Cr-depleted regions in the HAZ and corrosive attack in the weld.

3. Conclusions

From Micro-hardness measurement HAZ zone was found approximately 1-1.5 mm in NGW and DL-EPR test confirmed that 316L NGW HAZ was not susceptible to sensitization as DOS <1% according to sensitization criteria based on reference [5].

REFERENCES

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