STUDY OF CORROSION BEHAVIOUR OF SOME DISSIMILAR WELDS FROM CANDU NPP PRIMARY CIRCUIT

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Abstract

One of the most important issues, in the case of dissimilar welds, is the evaluation of proper filler materials for welds between Inconel alloys and carbon steels. Inconel 600 alloy and some carbon steel alloys are widely used for high temperature applications in power and nuclear industries, which are often joined by TIG (Tungsten Inert Gas). The current work was carried out to characterize welding of 52.2k carbon steel to Inconel 600 alloy autoclaved under primary circuit conditions. The electrochemical tests (corrosion potential vs time behaviour, potentiodynamic method) were performed in treated demineralized water with LiOH on two types of samples: dissimilar metal welds using Inconel 82 and dissimilar metal welds using Inconel 52, respectively. By using two methods (Tafel slope and polarisation resistance) the corrosion rates of samples were evaluated. In conclusion, Inconel 52 filler material offered the best corrosion resistance for the joint between Inconel 600 and 52.2k carbon steel.

Keywords: *Inconel 600, 52.2k carbon steel, Inconel 82 and Inconel 52 fillers, corrosion*

Introduction

Welds can experience all the classical forms of corrosion, but they are particularly susceptible to those affected by variations in microstructure and composition. Specifically, galvanic corrosion, pitting, stress corrosion cracking (SCC), intergranular corrosion, hydrogen cracking, and microbiologically influenced corrosion must be considered when designing welded structures [1].

Dissimilar metal welds between Inconel 600 (In 600) and carbon steel alloys are present in the outlet feeders of some CANDU Nuclear Power Plant. There is an acknowledged risk that Stress Corrosion Cracking (SCC) may initiate in these welds due to exposure to primary coolant at outlet temperatures, and due to residual stresses from welding. It is known that the weld root does not retain the nominal composition of the Inconel 82 filler metal. Dilution of the carbon steel into the weld root region increases iron content and reduces chromium content. Relatively high Cr content is a key factor controlling resistance to SCC.

To date, no assessments of the relative risk of cracking in these welds have considered the weld root dilution factor. This approach had to be taken because no data is available to quantify the relative risk of crack initiation as a function of chromium concentration in the weld root material. Crack growth rate data is available which indicates that loss of chromium does increase cracking rates but the effect on crack initiation remains unknown. It is desirable to quantify any relative loss of SCC resistance to support life cycle management as the welds in some units are to remain in service for another many years. In addition to the concern over dissimilar metal welds from some CANDU units currently in service, after the units' refurbishment, the replacement of dissimilar metal welds will be between Inconel 690 and carbon steel with an Inconel 52 (I52) filler metal. Inconel 690 and I52 have significantly higher chromium contents than Inconel 600 and I52. In the absence of any loss of Cr via weld root dilution, the replacement welds are expected to be highly resistant to SCC, but weld dilution cannot be avoided. It will be useful to compare the relative resistance of the I52 weld roots (with representative dilution) with the original Inconel 82 (I82) weld root material in order to evaluate the reason of the material changes.

The welding is performed manually with the operator holding the electrode at an angle, with the end just far enough away from the base metal to maintain an arc (as shown in Fig.1). As the metal melts off at the end of the rod, the operator moves the electrode closer to the work as well as moving it along the joint.

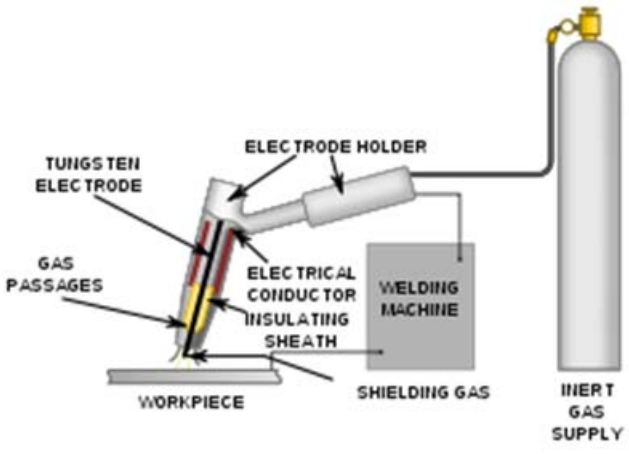


Fig.1. General representation of gas tungsten arc welding process (GTAW) [2]

Experimental aspects

Material and testing solutions

Mechanical characteristics of of Inconel alloys and 52.2k carbon steel are presented in Table 1. The constants means: $R_{P0.2}$ - resistance to flow; R_m - resistance to rupture; $A_{0.5}$ - elongation. Both materials chemical composition is specified in Table 2.

The testing solutions used in our experiments were demineralized water threated with LiOH (pH 10.5).

Table 1. Mechanical characteristics of Inconel 600 alloy and 52.2k carbon steel alloys

Material type	$R_{P0.2}$ (daN/mm^2)	R_m (daN mm^2)	$A_{0.5}$ (%)
Inconel 600	240	550	30
52.2k carbon steel	429	589	23

Table 2. Chemical composition of Inconel and 52.2k carbon steel alloys

Elements	52.2k Carbon Steel	filler metals		Inconel 600 (%) [3]
		Inconel 82 (%)	Inconel 52 (%)	
C	0.17	0.026	0.024	Max 0.15
Si	0.45	0.11	0.14	Max 0.5
Mn	1.55	2.96	0.24	Max 1
Fe	bal.	1.24	8.6	6-10
Cr	-	20.0	29.30	14-17
Ti		0.3	0.38	-
Al		-	0.39	-
Nb+Ta		2.6	-	-
Ni	-	72.5	60.80	72 min (Nickel with Cobalt)
Cu		0.13	0.001	Max 0.5
Sn				Max 0.015
S	0.019	0.0005	0.001	-
P	0.018	0.003	0.004	-

Joint of dissimilar steels by welding

When two different metals/alloys are joined together, it is termed as dissimilar metal welding. A dissimilar metal welding contains a weld deposit with a chemical composition different by several percent from the composition of either of two different metals that has been welded together.

The dissimilar welds between 52.2k carbon steel and In 600 (see Fig.2) were made by gas tungsten arc welding GTAW, equivalent to tungsten inert gas or TIG welding, using different filler metals: Inconel 82 (a) and Inconel 52 (b), respectively, at Institute for Nuclear Research Pitesti.

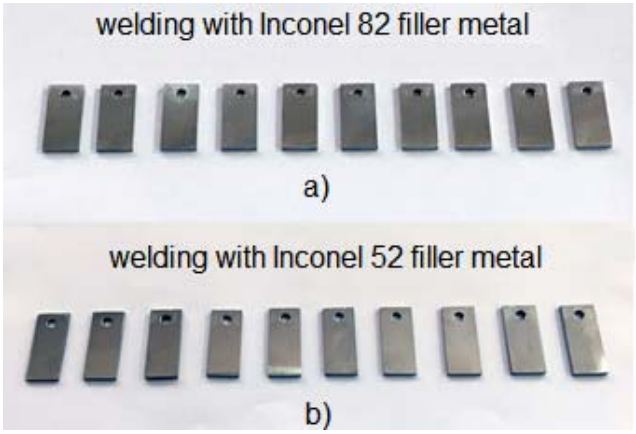


Fig.2. The aspect of dissimilar metal welds (between In 600 /52.2k carbon steel) with different filler metals, namely, Inconel 82 (a) and Inconel 52 (b), respectively

The apparatus

The evaluation of corrosion behaviour of dissimilar welds between ferritic-martensitic steel steel and austenitic stainless steel in presence LiOH solutions, was done by using corrosion tests performed by potentiodynamic polarization at temperature room $(25\pm5)^0$C with a scan rate of 1mV/s using an electrochemical system Princeton Applied Research Model 2273 (presented in Fig.3) constituted from a potentiostat interfaced with a Dell computer. Also, surface samples were examined by optical microscopy using an Olympus GX 71 microscope.



Fig.3. Electrochemical potentiostat-galvanostat system (Princeton Applied Research 2273)

Results and discussions

Corrosion potential/time behaviour of autoclaved samples in LiOH solution

The 52.2k carbon steel/In 600 specimens welding with Inconel 52 filler metal shown a typical behaviour of that associated with a freshly passivated sample surface (as can be seen in Fig. 4).

The corrosion potential variation in time was observed in LiOH aerated solutions at 25^0C (pH 10.5) for welded components in follow systems: autoclaved in primary conditions 52.2k -In 600 samples welding with Inconel 82 filler metal (Ecorr I82 56Z) and with Inconel 52 filler metal (Ecorr I52 56Z) and non-autoclaved 52.2k -In 600 samples (Ecorr 2_2017 for welding with I82, Ecorr 3_2017 for welding with I52), respectively.

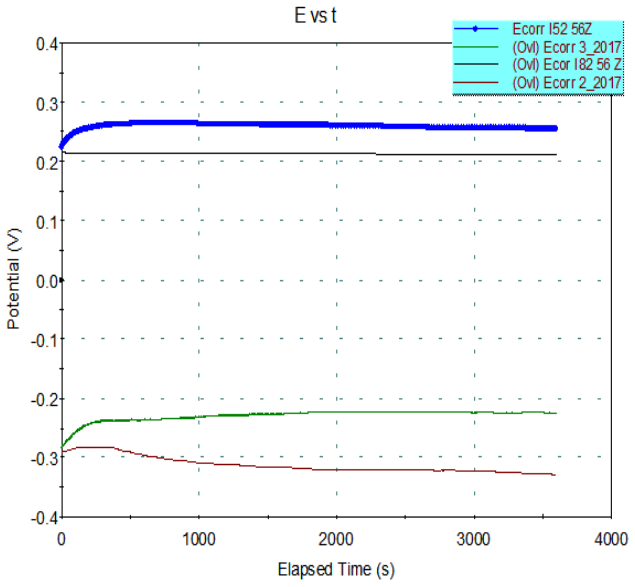


Fig.4 Variation of corrosion potential in time

Thus, the potential decreases because of decreasing passivation of the surface, reaching eventually a constant value (+255 mV vs. SCE) after an hour, but it is more positive than non-autoclaved samples (- 220 mV vs. SCE).

On the other hand, the corrosion potential/time behaviour of autoclaved 52.2k carbon steel/In 600 specimens welding with Inconel 82 filler metal is decreasing to approximately (+210 mV vs. SCE) comparatively to the components welding with Inconel 52 filler metal (+255 mV vs. SCE). The corrosion potential/time curves observed for welded specimens with I52 filler metal (–220 mV vs. SCE) markedly differ from those corresponding to specimens welding with Inconel 82 filler metal (-330 mV vs. SCE). On welded autoclaved specimens, however, the potential remained positive. The difference between the steady-state potentials corresponding to different types of welded specimens was in the range (+45 ÷ +110) mV vs. SCE. These results show that corrosion potential/time curves represent a relatively simple means to detect the onset of corrosion on welded components.

The corrosion behaviour of dissimilar welds between Inconel 600 and 52.2k carbon steel alloys autoclaved in primary conditions

The potentiodynamic measurements (PD) in LiOH solution, were performed at the temperature (25 ± 5)^{0}C using the potentiostat-galvanostat system (PAR model 2273). They consisted in the scanning of the potential from cathodic range (-250 mV vs. open circuit potential-E_{OCP}) to anodic range (+400 mV vs. reference electrode potential) using a scan rate of 1mV/s simultaneously with the measurement of the current from cell. The PD curves corresponding to systems both types of 52.2k carbon steel/ In 600 dissimilar welds / LiOH solution (pH 10.5) were obtained and are presented in Fig.5.

In presence of LiOH solution were determined:
- the PD curves corresponding to 52.2k carbon steel -In600 welding with Inconel 52 filler metal (curve PD I52_56Z) show that these alloys passivated easier than in the case 52.2k carbon steel-In 600 welding with Inconel 82 filler metal (PD I82 56 Z);
- the PD curves corresponding to welded autoclaved samples (curves PD I82 56 Z and PD I52 56 Z) have passive range at lower passive current density than welded samples (curves PD2_2017 and PD3_2017).

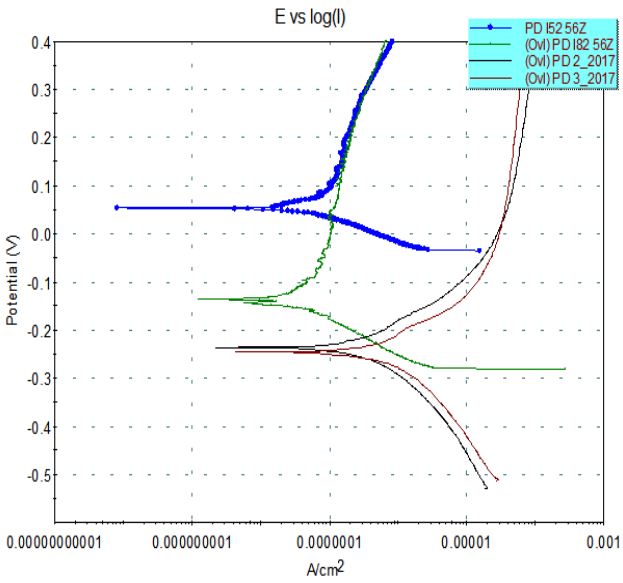


Fig.5. The PD curves for considered systems

The PD curves present the following characteristics:
- the values of R_p (given in Table 3) in the case of welded autoclaved samples are greater than those corresponding to the other samples and consequently;
- the values of i_{corr}, and v_{corr}, respectively, corresponding welded autoclaved samples are lower than those corresponding to welded samples;
- in exchange, the values of i_{pass} are smaller in the case of welded autoclaved samples than those corresponding to welded samples;
- the results presented in Fig. 4 confirm that welded samples with I52 filler metal had the greatest corrosion resistance.

Table 3. Electrochemical parameters (pH 10.5) from Tafel slopes and polarization resistance corresponding to non-autoclaved and autoclaved samples tested in LiOH solution (pH 10.5)

Experiment Code	Electrochem. parameters from Tafel slopes ($ß_c$, $ß_a$)					Electrochem. parameters from polarization resistance R_p			
	E(I=0) (mV)	β_c (mV)	β_a (mV)	i_{corr} ($\mu A/cm^2$)	v_{corr} (mm/year)	E(I=0) (mV)	R_p ($K\Omega/cm^2$)	i_{corr} ($\mu A/cm^2$)	v_{corr} (mm/year)
PD 3, Pr. 28, 52.2k-In 600 samples, I 52 filler metal	- 246	44	51	1.6×10^{-1}	3.40×10^{-4}	-237	62.7	3.40×10^{-1}	1.40×10^{-3}
PD 2, Pr. 13, 52.2k-In 600 samples, I 82 filler metal	-237	111	112	3.5×10^{-1}	1.43×10^{-3}	-236.8	59.54	3.65×10^{-1}	1.5×10^{-3}
PD I52 56 Z, 56 days autoclaved samples	56	24	32	1.76×10^{-2}	3.70×10^{-5}	59	435	4.9×10^{-2}	0.14×10^{-5}
PD I82 56 Z, 56 days autoclaved samples	-136	46	63	2.2×10^{-2}	6.8×10^{-5}	59	435	4.9×10^{-2}	0.70×10^{-5}

The examination of surfaces of welded coupons by optic microscopy

To obtain further information we perform the polishing of samples of two dissimilar metal welds (DMW), initially analyzed by metallography method after attack in 10% oxalic acid and 6V, 10-15 s (according to R13a from [4]), to highlight the new structure.

From Figs. 6 and 7, respectively, the following aspects can be observed:

- the weld joint between In 600 and 52.2k carbon steel presents columnar grain specific melting (dendritic structure) due thermic cycles;
- in heat affected zone (HAZ), we observed an enhanced feritic percent; HAZ has dendritic structure, in both case (I82 and I52 filler metals), specific high temperature;
- there is no semnificativ migration of chromium (some scattered points); without chromium carbide there is no major danger for cracks;
- in both metal welds (using I82 and I52 filler metals), from border to center, it forms a lattice of columnar grain and echiaxial grain (a mix zone);
- in heat affected zone (HAZ), according to literature data [5], we observed that appers Widmanstatten structure by superheating, relative fragile;
- passed from ferritic-perlitic structure of 52.2k carbon steel to heat affected zone (HAZ) is observed an increase ferritic percent;
- in In 600- OL 52.2k welded joint appear dendrites due thermal cicles.

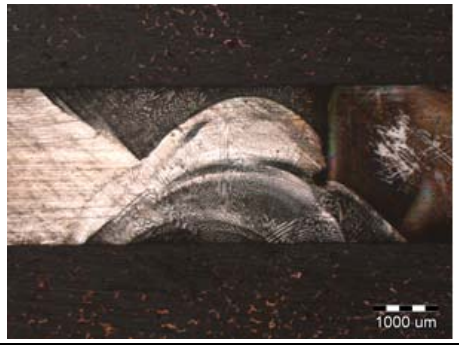
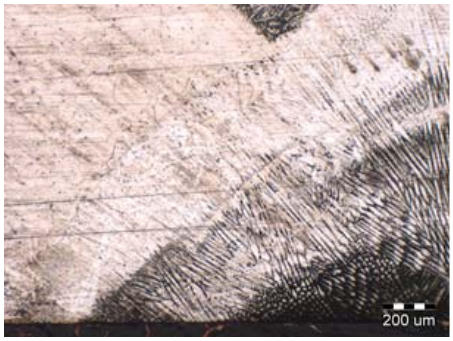
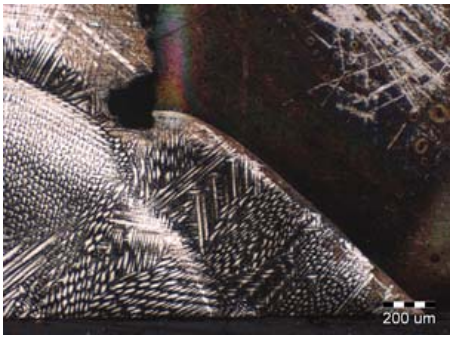
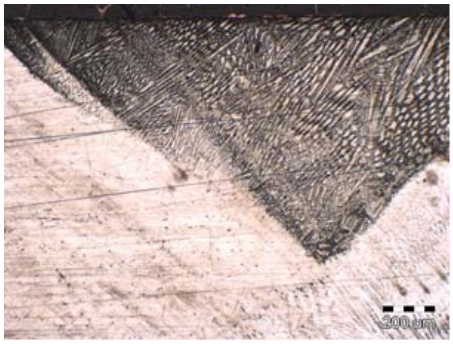
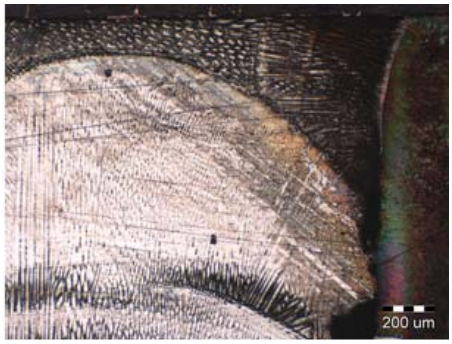
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</td></tr>
<tr><td rowspan="4">weld top (lateral zone)</td><td>x 15
</td><td>x 25
</td></tr>
<tr><td rowspan="3">Microstructures of welded joint
welding top</td><td rowspan="2">
DMW, I82 filler metal _to In 600 (x50)</td><td rowspan="2">
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<tr><td>
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DMW, I82 filler metal _
to In 600 _two cover layers (x50)</td><td>
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Fig.6. Micrographies of welded joint (after attack with 10% oxalic acid) between In600 and 52.2k carbon steel using I82 filler metal

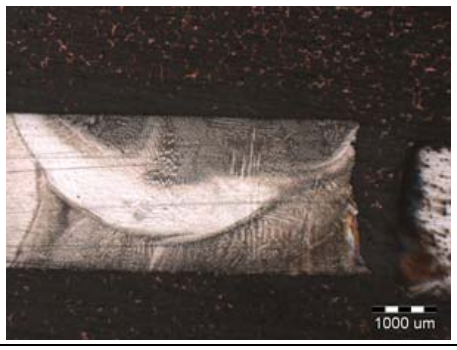
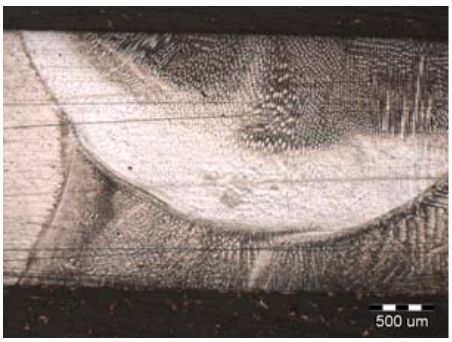
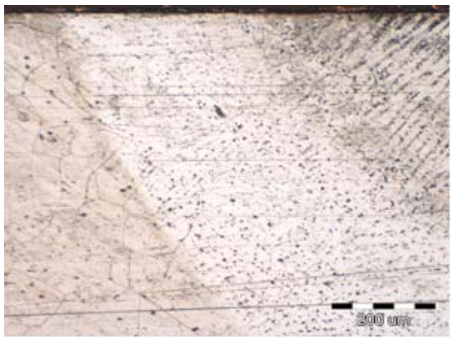
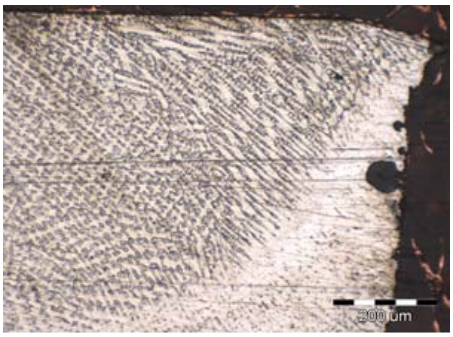
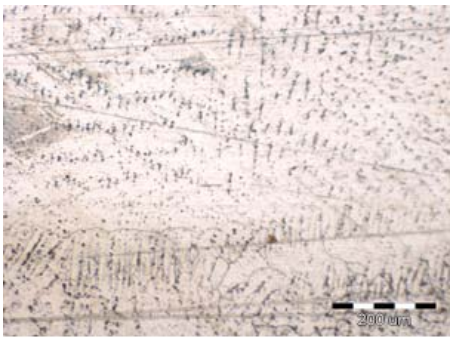
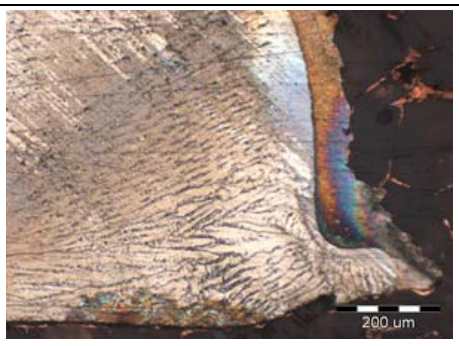
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Fig.7. Micrographies of welded joint (after attack with 10% oxalic acid) between In600 and 52.2k carbon steel using I52 filler metal

Conclusions

In order to perform the experiments proposed in this study, samples from the following alloys types were used:

a) dissimilar welds between Inconel 600 and 52.2k carbon steel alloys using I82 and I52 filler metals, respectively, and

b) 56 days welded autoclaved samples.

To characterize the corrosion resistance of dissimilar welds between In 600 and 52.2k carbon in LiOH solution some corrosion tests have been performed. To evaluate their corrosion susceptibility, the variation of corrosion potential vs. time, the potentiodynamic polarization and metallographic analyses were used.

Based on the electrochemical tests (corrosion potential/ time behaviour) results, it can be ascertained that: the susceptibility at localized corrosion of the 56 days autoclaved samples welding with Inconel 82 filler metal is higher than that corresponding to 56 days autoclaved samples welding with Inconel 52 filler metal, and lower than the susceptibility of the welded samples in LiOH aerated solutions at 25^0C (pH 10.5).

The effect of OH^- anions on autoclaved samples welding with I82 filler metal between 52.2k carbon steel - In 600 is more pronounced, increasing its susceptibility at localized attack of dissimilar metal welds comparatively with that on autoclaved samples welding with I52 filler metal.

The values of the corrosion current intensity, i_{corr}, and the corrosion rate, v_{corr}, corresponding to 52.2k - In 600 welded samples are greater than those corresponding to welded autoclaved samples.

The corrosion susceptibility of tested coupons in presence of OH^- anions was evaluated by both electrochemical methods, and as result of tests it was observed that higher Cr content of I52 filler metal enhances corrosion resistance of dissimilar metal welds.

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