CORROSION BEHAVIOUR OF DISSIMILAR WELDS BETWEEN MARTENSITIC STAINLESS STEEL AND CARBON STEEL FROM SECONDARY CIRCUIT OF CANDU NPP

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ABSTRACT

Corrosion damages of welds occur in spite of the fact that the proper base metal and filler metal have been correctly selected, industry codes and standards have been followed and welds have been realized with full weld penetration and have proper shape and contour. It is not unusual to find that, although the base metal or alloy is resistant to corrosion in a particular environment, the welded counterpart is not resistant.

In secondary circuit of a Nuclear Power Station there are some components which have dissimilar welds.

Our experiments were performed in chloride environmental on two types of samples: non-welded (420 martensitic steel and 52.2k carbon steel) and dissimilar welds (dissimilar metal welds: joints beetween 420 martensitic steel and 52.2k carbon steel). To evaluate corrosion susceptibility of dissimilar welds was used electrochemical method (potentiodynamic method) and metallography microscopy (microstructural analysis).

The present paper follows the localized corrosion behaviour of dissimilar welds between austenitic stainless steel and carbon steel in solutions containing chloride ions.

We have been evaluated the corrosion rates of samples (welded and non-welded) by electrochemically.

Key words: chloride environmental, 52.2k– 420 dissimilar metal weld

Introduction

Weldments 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, intergranular corrosion, hydrogen cracking, and microbiologically influenced corrosion must be considered when designing welded structures[1].

During welding of stainless steels, local sensitized zones (i.e., regions susceptible to corrosion) often develop. Sensitization is due to the formation of chromium carbide along grain boundaries, resulting in depletion of chromium in the region adjacent to the grain boundary [2-3].

The principal criteria for selecting a stainless steel usually is resistance to corrosion, and white most consideration is given to the corrosion resistance of the base metal, additional consideration should be given to the weld metal and to the base metal immediately adjacent to the weld zone [4]. Welding naturally produces a temperature gradient in the metal being welded, ranging from the melting temperature of the fused weld metal to ambient temperature at some distance from the weld.

Much use has been made of the Schaeffler Diagram (**Figure 1**) for determining whether a specified weld metal composition will contain delta ferrite, and the approximate percentage. Selection of filler metal and the planning of a welding procedure must be done carefully to secure the small, but important amount of delta ferrite.

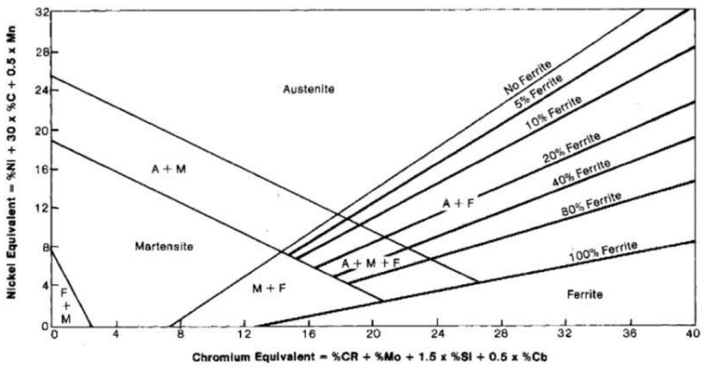


Figure 1 *Schaeffler Constitution Diagram for Stainless Steel Weld Metal [4]*

Martensitic stainless steels, which are identified by AISI 400 Series numbers [4], contain chromium as the principal alloying element In the annealed condition these stainless steels have basically a ferritic microstructure and are magnetic. On heating beyond the critical temperature, the ferrite transforms into austenite. If then rapidly cooled to below the critical temperature, the austenite transforms into martensite. In many respects, the martensitic stainless steels are similar to the quenched and tempered carbon or alloy steels whose mechanical properties can be varied through heat treatment. Whether or not the transformations take place depends upon alloy content, especially the chromium and carbon contents. Other alloying additions may also affect transformation.

The chance of stress-corrosion cracking is another reason for post-weld heat treatment, in the as-welded condition, areas close to the weld contain residual stresses approaching the yield point of the material, it is difficult to predict when an environment will produce stress-corrosion cracking and to decide how much reduction must be made in the magnitude of residual stress to avoid its occurrence. To ensure against this stress-corrosion cracking in welded austenitic stainless steels is to anneal the types which contain regular carbon content, and to stress relieve the stabilized and extra-low-carbon types.

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 (**Figure 2**). As the metal melts off the end of the rod. the operator moves the electrode closer to the work as well as moving it along the joint.

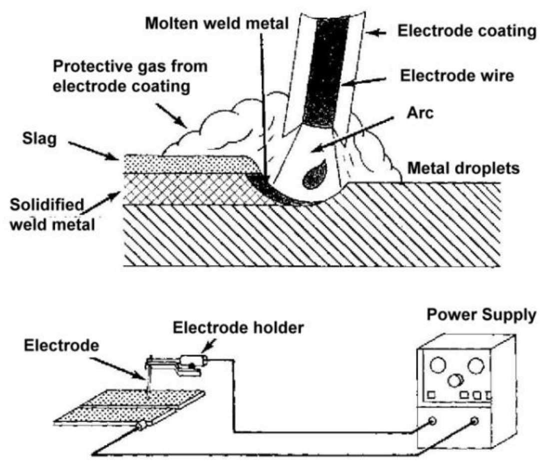


Figure 1 *Arc Zone In Shielded Metal Arc Welding [4]*

Experimental

Material and testing solutions

Chemical composition of stainless steel alloys, are given in the **Table 1**. Mechanical characteristics of both stainless steels are presented in **Table 2**.

Table ***3*** *Chemical composition of 420 (W1.4021) martensitic stainless steel and 52.2k carbon steel (% wt)*

steel type	elements (% wt)							
	C	Mn	$P_{max.}$	$S_{max.}$	Si	Ni	Cr	Others
420 (W 1.4021)	0.35	0.94	0.003	0.03	max. 0.6	0.23	13.12	1.01
52.2k carbon steel	0.17	1.55	0.018	0.019	0.45	-	-	-

The testing solutions used in our experiments were 2 mg/l Cl^- concentration (from NaCl reagent).

Table ***4*** *Mechanical characteristics of 420 martensitic stainless steel and 52.2k carbon steel*

Type of steel	$R_{P0.2}$(daN/mm^2)	R_m(daN mm^2)	$A_{0.5}$ (%)
420 martensitic steel	45	75	16
52.2k carbon steel	429	58.9	23

where constants means:

$R_{P0.2}$(N/mm^2) - resistance to flow;
R_m (N/mm^2) - resistance to rupture;
$A_{0.5}$ (%)-elongation

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 welds between of 420 martensitic stainless steels and 52.2k carbon steel (**Figure 3**) were made manual electric welding using ER 316L filler metal (19/12 austenitic structure: 19% Cr, 12% Ni) at Institute for Nuclear Research Pitesti.

Figure 2 *The aspect of dissimilar welds between 52.2k carbon steel and 420 martensitic stainless steels*

The apparatus

The evaluation of localized corrosion behaviour of dissimilar welds between martensitic stainless steel and carbon steel in presence of 2 mg/l Cl^- solution, was performed by corrosion tests by potentiodynamic polarization at temperature room $(25\pm5)^0C$ with a scan rate of 1mV/s using an electrochemical system Princeton Applied Research Model 2273 constituted from a potentiostat interfaced with a Dell computer. Also, surface samples were examined by metallographic microscopy using an Olympus GX 71 microscope.

Results and discussions

The evaluation of localized corrosion behaviour of dissimilar welds between 420 martensitic stainless steel and 52.2k carbon steel in presence of 2mg/l Cl^- solution

The potentiodynamic measurements (PD) in 2mg/l Cl^- solution, respectively, were performed at $(25\pm5)^0C$ using the potentiostat-galvanostat (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 [(+1600 mV) vs. reference electrode potential] using a scan rate of 1mV/s simultaneously with the measurement of the current from cell.

In **Figures 4 and 5** can bee seen the corrosion behaviour of 420 martensitic stainless steel, 52.2k carbon steel and 420- 52.2k welded samples, respectively, in 2mg/l Cl^- solution at $(25\pm5)^0C$.

Experimentally was detected a different behaviour at electrochemical polarization (**figure 4**) of two types of steels in 2mg/l Cl^- solutions. From these figure resulted that Cl^- anions confer a higher susceptibility to corrosion of 52.2k carbon steel (PD 2_2014).than 420 martensitic stainless steel (PD 1_2014) in 2 mg/l Cl^- solution.

From **Figure 5** was determined follow:

- in presence of Cl^- anion, the PD curves corresponding to 420 martensitic stainless steel (curve PD 1_2014) samples show that these alloys passivated easier than in the case 52.2k carbon steel (curve PD 2_2014) and 52.2k– 420 dissimilar welds samples (curve PD 3_2014);
- in presence of Cl^- anion, the PD curves corresponding to 52.2k– 420 dissimilar welds samples have not passive range and show a higher passive current density (curve PD 3_2014 from **Figure 5**) than 420 martensitic stainless steel alloy (curve PD 1_2014);

The PD curves (**Figures 4-5**) corresponding to systems both types of steels samples/ 2mg/l Cl^- solution present the following characteristics:

- the values of R_p (**Table 3**) in the case of 52.2k carbon steel samples are greater than those corresponding to the other samples and consequently;
- the values of i_{corr}, respectively, v_{corr} corresponding to 52.2k carbon steel are greater than those corresponding to welded samples and 420 martensitic stainless steel samples;
- in exchange, the values of ipass are smaller in the case of unwelded 420 martensitic stainless steel samples than those corresponding to welded samples and 52.2k carbon steel samples, respectively;
- the results presented in **Figures 4, 5** confirm that 420 martensitic stainless steel samples had the greatest corrosion resistance.

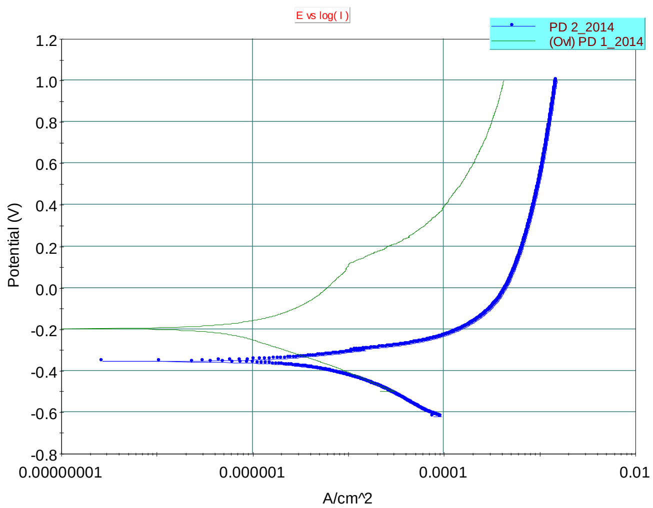


Figure 4 *The PD curves corresponding to the systems: 420 martensitic stainless steel (PD 1_2014) /2 mg/l Cl^- solution and 52.2k carbon steel /2 mg/l Cl^- solution (PD 2_2014), respectively*

It was followed the corrosion behaviour of 52.2k– 420 dissimilar welds by potentiodynamic method in 2 mg/l Cl^- solution at $(25\pm5)^0$C comparatively with 420 martensitic stainless steel and 52.2k carbon steel (**Figure 5**).

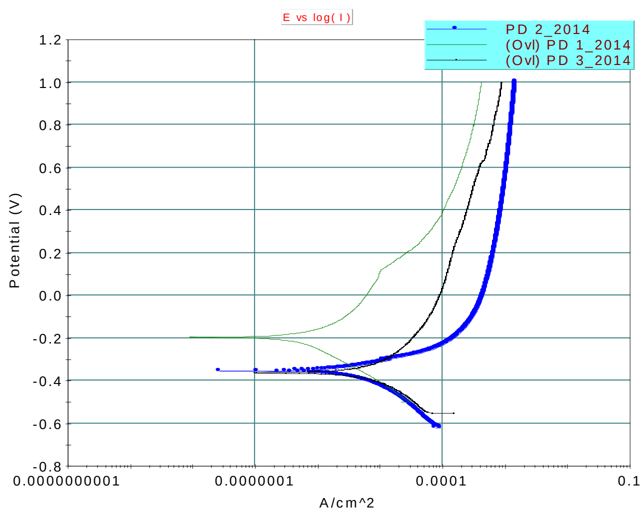


Figure 5 *The PD curves corresponding to the follow systems: 420 martensitic stainless steel (PD 1_2014) /2 mg/l Cl^- solution, 52.2k carbon steel /2 mg/l Cl^- solution (PD 2_2014) and 52.2k– 420 dissimilar welds/ 2mg/l Cl^- solution (PD 3_2014), respectively*

It resulted that the susceptibility at localized corrosion of 52.2k carbon steel is higher than 420 martensitic stainless steel and 52.2k– 420 dissimilar welds alloys in presence 2 mg/l Cl^-.

Table 3 *Electrochemical parameters from Tafel slopes and polarization resistance corresponding to systems containing welded or unwelded stainless steel samples exposed in 2 mg/l Cl^- solution*

Exp. Code	Cl^- anion conc.	**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} (μA/cm^2)	v_{corr} (mm/year)	E(I=0) (mV)	R_p (KΩ/cm^2)	i_{corr} (μA/cm^2)	v_{corr} (mm/year)
PD 1_2014 (420 martensitic stainless steel)	2 mg/l Cl^-	-196	323	323	1.54	7.25 10^{-3}	-197.5	32.86	0.66	3.1 10^{-3}
PD 2_2014 (52.2k carbon steel)		-354	212	107.6	5.27	4.12 10^{-2}	-369.4	2.69	8.8	6.3 10^{-2}
PD 3_2014 (dissimilar metal weld)		-363	89	94.65	3.26	1.19 10^{-2}	-351.81	4.35	4.99	1.83 10^{-2}

The examination of surfaces of welded coupons by metallographic microscopy

The exploring of stainless steels samples, after consecutive polishing, does relieved some modifications of the surface aspect of steels. From **Figure 6** we observed the following aspects:

- the 52.2k carbon steel from dissimilar metal welding has a higher susceptibility at localized corrosion in 2mg/l Cl^- solution comparatively with the other counterpart of weld;
- in 2 mg/l Cl^- media in weld root for 52.2k carbon steel and the weld HAZ we observed cumulative effect of localized corrosion on a pre-existing defect (inclusions, pores).

The high concentration of Ni from ER 316L filler metal (19/12 austenitic structure: 19% Cr, 12% Ni) gives a good behaviour of heat affected zone (HAZ) and intergranular corrosion does not occur due to the buffer zone with assume the internal stresses induced by the welding process. Even where we meet chromium carbides more or less finely dispersed high concentrations of Ni release the tension from area so that it doesn't reaches the critical crack initiation.

To obtain further information we perform the polishing of samples of two different steels weld (DMW), initially analyzed by metallography method and then were tested in 2mg/l Cl^- solutions attacked in oxalic acid to highlight the new structure.

We have observed that:

- the low concentration of 2mg/l Cl^- on the side of welded 52.2k carbon steel is observed to a range of possible attack initiated by a defect type inclusion;
- the 420 martensitic stainless steel material shows good corrosion behavior at 2mg/l Cl^- comparatively with 52.2k carbon steel.
- 52.2k carbon steel in 2mg/l Cl^- solution has high susceptibility at localized corrosion resulting different size and density pits.

The exploring of stainless steels samples, after consecutive polishing, does relieved some modifications of microstructure or the surface aspect of dissimilar metal welding (DMW).

It observed that 52.2k carbon steel are more susceptible at pitting corrosion comparatively with the other steels.

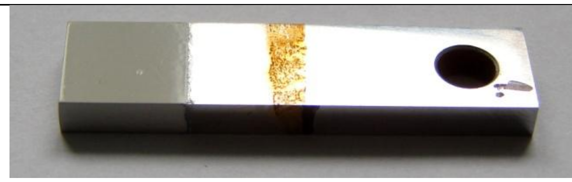
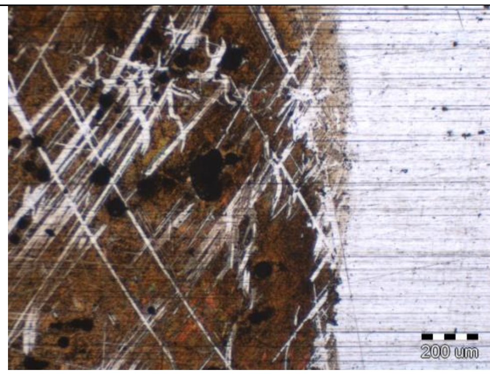
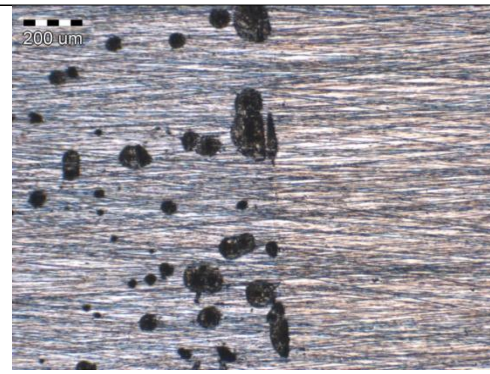
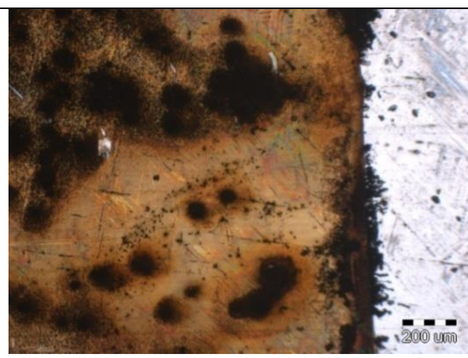
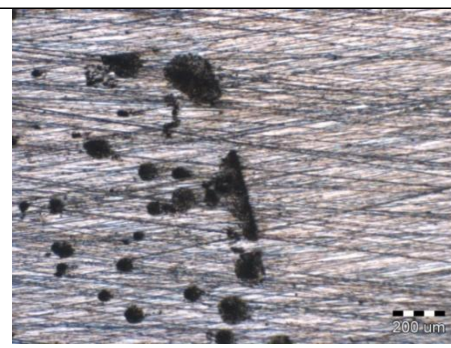
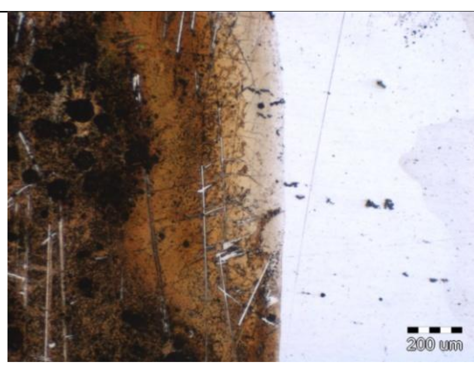
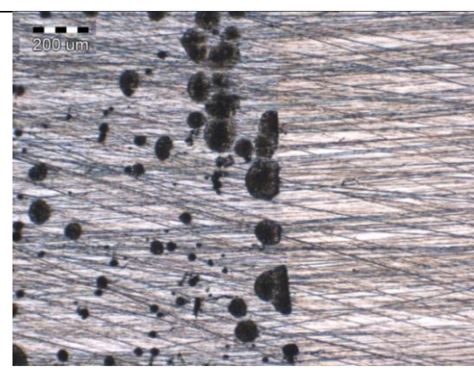
Type of steel / Experiment code	 *The aspect of DMW (52.2k carbon steel - 420 martensitic stainless steel) after testing in solution 2mg/l Cl$^-$ by potentiodynamic measurements (PD 3_2014)*	
Micrographies of surface (52.2k carbon steel - 420 martensitic stainless steel)	*before polishing*	*after polishing*
Weld nugged of of DMW sample (x50)		
Lateral zone of DMW sample (x50)		
Root of DMW sample (x50)		

Figure 6 *Micrographies (x50)from 52.2k– 420 welded joint of post-tested samples in 2mg/l Cl$^-$ solution*

Conclusions

1. To made the experiments corresponding to this paper, were used the samples from the following alloys types:
   a) unwelded alloys (420 martensitic stainless steel and 52.2k carbon steel) and
   b) dissimilar welds between 420 martensitic stainless steel and 52.2k carbon steel.

2. To characterize the localized corrosion of welded/ unwelded stainless steel alloys in chloride solution some corrosion tests have been executed. To evaluate their corrosion susceptibility two methods were used: the potentiodynamic polarization and metallographic microscopy method.

3. As result of these the potentiodynamic tests we ascertained that:

a) the 52.2k carbon steel samples immersed in Cl^- media, presented greater values of passivation current density and a without passive range than 420 martensitic stainless steel samples tested in the same solutions, that undergone a quicker passivation.

b) the Cl^- have a more influence on carbon steel counterpart (52.2k carbon steell) of dissimilar metal weld (52.2k– 420).

4. The effect of Cl^- anions 52.2k carbon steel counterpart of dissimilar metal welded (52.2k– 420) is more pronounced, increasing its susceptibility at localized attack (pitting corrosion) of dissimilar metal welds (52.2k– 420) comparatively with the 420 martensitic stainless steel alloy.

5. The examination of surfaces of tested coupons in presence of Cl^- anions was made by metallographic microscopy and as result of images analysis it observed that 52.2k carbon steel alloy are higher susceptibility pitting corrosion of in 2 mg/l Cl^- solution at $(25\pm5)^0$C than the other counterpart of weld.

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