
CORROSION BEHAVIOUR OF DISSIMILAR WELDS BETWEEN FERRITIC- MARTENSITIC STAINLESS STEEL AND AUSTENITIC STAINLESS STEEL FROM SECONDARY CIRCUIT OF CANDU NPP

L. POPA, M. FULGER, M. TUNARU L. VELCIU, M. LAZAR

*Institute for Nuclear Research Pitesti, POBox78, 1 Câmpului Street,
Mioveni 115400, ROMANIA
laurentiu.popa@nuclear.ro*

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.

In secondary circuit of a Nuclear Power Station there are some components which have dissimilar welds. The principal criteria for selecting a stainless steel usually is resistance to corrosion, and while 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.

Our experiments were performed in chloride environment on two types of samples: non-welded (410 or W 1.4006 ferritic-martensitic steel and 304L or W 1.4307 austenitic stainless steel) and dissimilar welds (dissimilar metal welds: joints between 410 ferritic-martensitic and 304L austenitic stainless steel). To evaluate corrosion susceptibility of dissimilar welds was used electrochemical method (potentiodynamic method) and optic microscopy (microstructural analysis).

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

It was evaluated the corrosion rates of samples (welded and non-welded) by electrochemical methods.

Key words: dissimilar metal weld, 410 ferritic-martensitic, 304L austenitic stainless steel, chloride ions solutions, corrosion rate

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 while 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.

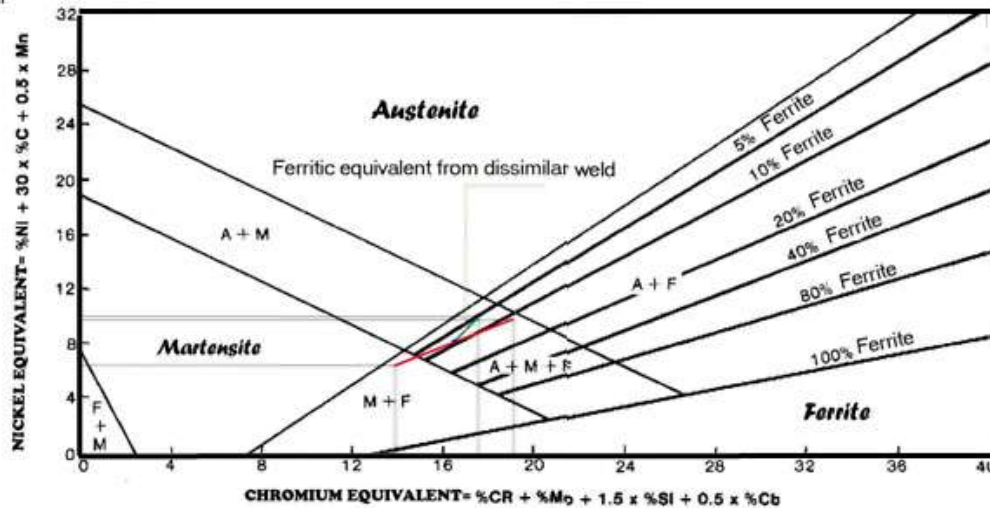


Fig. 1. Schaeffler Constitution Diagram for Stainless Steel Weld Metal [4]

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.

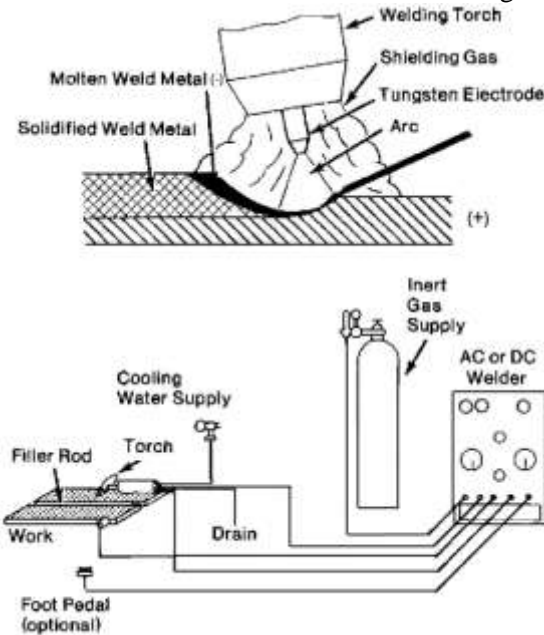


Fig.2. General representation of fusion welding process (GTAW) [4]

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 1. Chemical composition of 410 (W1.4021) ferritic-martensitic steel and 304L austenitic stainless steel (W 1.4307)

steel type	elements (% wt)							
	C	Mn	P _{max.}	S _{max.}	Si	Ni	Cr	Others
410 ferritic-martensitic steel (W 1.4006)	0.21	0.56	0.019	0.026	0.410	-	12.18	Balance
304L austenitic stainless steel (W 1.4307)	0.023	1.64	0.031	0.002	0.039	8.10	18.20	Balance

The testing solutions used in our experiments were 6% FeCl₃

Table 2. 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} (%)
410 ferritic-martensitic steel (W 1.4006)	84.2	94.3	19.5
304L austenitic stainless steel (W 1.4307)	35.7	62.0	60

Where constants means:

$R_{p0.2}$ (N/mm²) - resistance to flow;

R_m (N/mm²) - 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 410 ferritic-martensitic stainless steel (W 1.4006) and 304L austenitic stainless steel (W 1.4307) (figure 3) were made manual electric welding using ER 308L filler metal (18/10 austenitic structure: 18% Cr, 10% Ni) at Institute for Nuclear Research Pitesti.

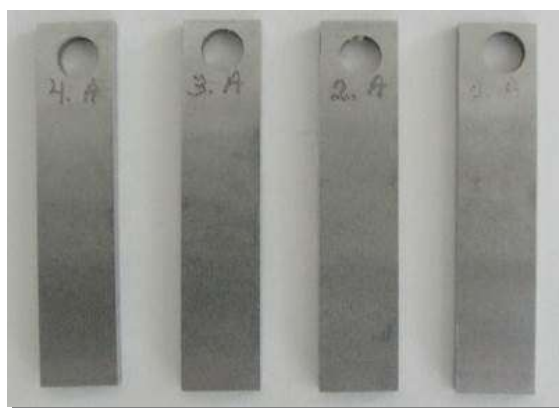


Fig. 3. The aspect of dissimilar welds between 410 ferritic-martensitic steel (W 1.4006) and 304L austenitic stainless steel (W 1.4307)

- *The apparatus*

The evaluation of localized corrosion behaviour of dissimilar welds between ferritic-martensitic steel and austenitic stainless steel in presence of 6% FeCl₃ solution, was performed by corrosion tests by potentiodynamic polarization at temperature room (25±5)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 optical microscopy using an Olympus GX 71 microscope.

Results and discussions

- *The evaluation of localized corrosion behaviour of 410 ferritic-martensitic steel (W 1.4006) and 304L austenitic stainless steel (W 1.4307) in 6% FeCl₃ solution*

The potentiodynamic measurements (PD) in 6% FeCl₃ solution, respectively, were performed at (25±5)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_{OCF}) to anodic range [(+1000 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 be seen the corrosion behaviour of 410 ferritic-martensitic steel, 304L austenitic stainless steel and 410- 304L welded samples, respectively, in 6% FeCl_3 solution at $(25\pm 5)^\circ\text{C}$.

Experimentally was detected a different behaviour at electrochemical polarization (figure 4) of two types of steels in 6% FeCl_3 solutions. From these figure resulted that Cl^- anions confer a higher susceptibility to corrosion of 410 ferritic-martensitic steel (PD FM PR. 1) than 304L austenitic stainless steel (PD W1.4307) in 6% FeCl_3 solution.

From figure 5 was determined follow:

- in presence of Cl^- anion, the PD curves corresponding to 304L austenitic stainless steel samples (curve PD W1.4307) show that these alloys passivated easier than in the case 410 ferritic-martensitic steel (PD FM PR. 1) and 304L– 410 dissimilar welds samples (curve PD WELD);

- in presence of Cl^- anion, the PD curves corresponding to 304L– 410 dissimilar welds samples have not passive range and show a higher passive current density (curve PD WELD from figure 5) than 304L austenitic stainless steel samples (curve PD W1.4307).

The PD curves (Figures 4-5) corresponding to systems both types of steels samples/ 6% FeCl_3 solution present the following characteristics:

- the values of R_p (Table 3) in the case of 304L austenitic stainless steel samples are greater than those corresponding to the other samples and consequently;
- the values of i_{corr} , respectively, v_{corr} corresponding to 410 ferritic-martensitic steel are greater than those corresponding to welded samples and 304L austenitic stainless steel samples, respectively;
- in exchange, the values of i_{pass} are smaller in the case of unwelded 304L austenitic stainless steel samples than those corresponding to welded samples and 410 ferritic-martensitic steel samples, respectively;
- the results presented in figures 4, 5 confirm that 304L– 410 dissimilar welds samples had the greatest corrosion resistance.

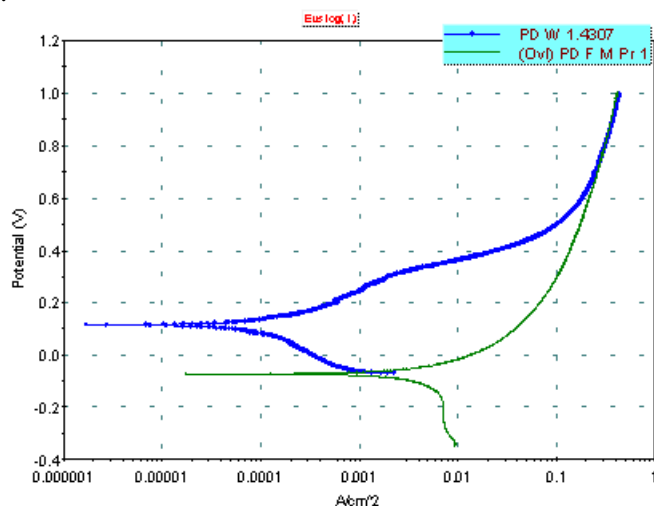


Fig. 4 The PD curves corresponding to the systems: 410 ferritic-martensitic steel (PD FM PR. 1)/6% FeCl_3 solution and 304L austenitic stainless steel /6% FeCl_3 solution (PD W1.4307), respectively

It was followed the corrosion behaviour of 304L– 410 dissimilar welds by potentiodynamic method in 6% FeCl_3 solution at $(25\pm 5)^\circ\text{C}$ comparatively with 304L austenitic stainless steel and 410 ferritic-martensitic steel (figure 5).

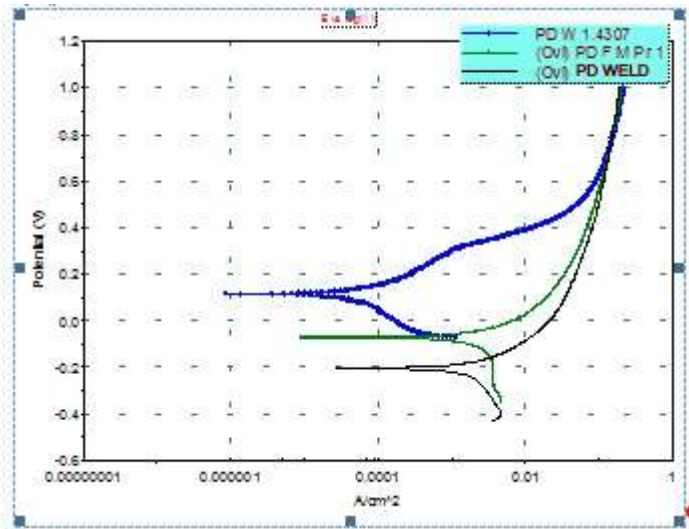


Figure 5 The PD curves corresponding to the follow systems: 410 ferritic-martensitic steel (PD FM PR. 1) /6% FeCl₃ solution, 304L austenitic stainless steel /6% FeCl₃ solution (PD W1.4307) and 304L–410 dissimilar welds/ 6% FeCl₃ solution (PD WELD), respectively

It resulted that the susceptibility at localized corrosion of 304L– 410 dissimilar welds is higher than 304L austenitic stainless steel and 410 ferritic-martensitic steel alloys in 6% FeCl₃ solution.

Table 3 Electrochemical parameters from Tafel slopes and polarization resistance corresponding to systems containing welded or unwelded stainless steel samples exposed in 6% FeCl₃ solution

Exp. Code	solution	Electrochem. parameters from Tafel slopes (β_c, β_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 Ω/cm^2)	i_{corr} ($\mu A/cm^2$)	v_{corr} (mm/year)
PD FM PR.1 (410)	6% FeCl ₃	-75.9	268	118	$3.6 \cdot 10^3$	$2.1 \cdot 10^1$	-74	6.8	$3.2 \cdot 10^3$	$1.8 \cdot 10^1$
PD W1.4307 (304L)		111.9	102	75	$6.3 \cdot 10^1$	$3.7 \cdot 10^{-1}$	115	250	$8.7 \cdot 10^1$	$5.1 \cdot 10^{-1}$
PD WELD (304L– 410)		-204.4	41.4	61.6	$7.9 \cdot 10^3$	$4.6 \cdot 10^1$	-205	7.3	$2.9 \cdot 10^3$	$1.8 \cdot 10^1$

- *The examination of surfaces of welded coupons by optic microscopy*

To obtain further information we perform the polishing of samples of two different steels weld (DMW), initially analyzed by metallography method after attack in 10% oxalic acid to highlight the new structure. We have observed that:



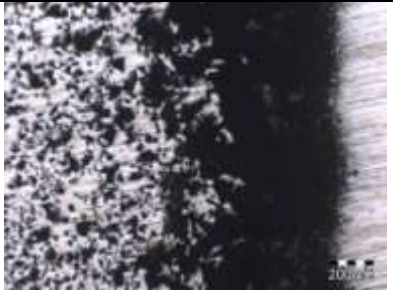
- passed from ferritic-martensitic structure of W1.4006/ 410 ferritic-martensitic steel to heat affected zone (HAZ) is observed an increase ferritic percent;
- in (W1.4006- W1.4307)/ (304L– 410) welded joint appear dendrites due thermal cycles.

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:

- 410 ferritic-martensitic stainless steel and 304L austenitic stainless steel, respectively, in FeCl₃ media show pitting corrosion resulting different size and density pits.
- the (W1.4006- W1.4307) welded joint to W1.4006 ferritic-martensitic stainless steel from dissimilar metal welding has a higher susceptibility at localized corrosion in FeCl₃ solution comparatively with the others counterpart of weld;

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

The high concentration of Ni from ER 308L filler metal (18/10 austenitic structure: 18% Cr, 10% Ni) gives a good behaviour of HAZ and intergranular corrosion does not occur due to the buffer zone with assume the internal stresses induced by the welding process. Ni releases the tension from area so that it doesn't reaches the critical crack initiation.

<p>Type of steel / Experiment code</p>	 <p>The aspect of DMW (304L austenitic stainless steel - 410 ferritic-martensitic stainless steel) after testing in solution FeCl₃ by potentiodynamic measurements (PD WELD)</p>	
<p>Micrographies of surface (304L austenitic stainless steel - 410 ferritic-martensitic stainless steel)</p>	<p>before polishing</p>	<p>after polishing</p>
<p>Weld nugged of DMW sample to 410 (x50)</p>		

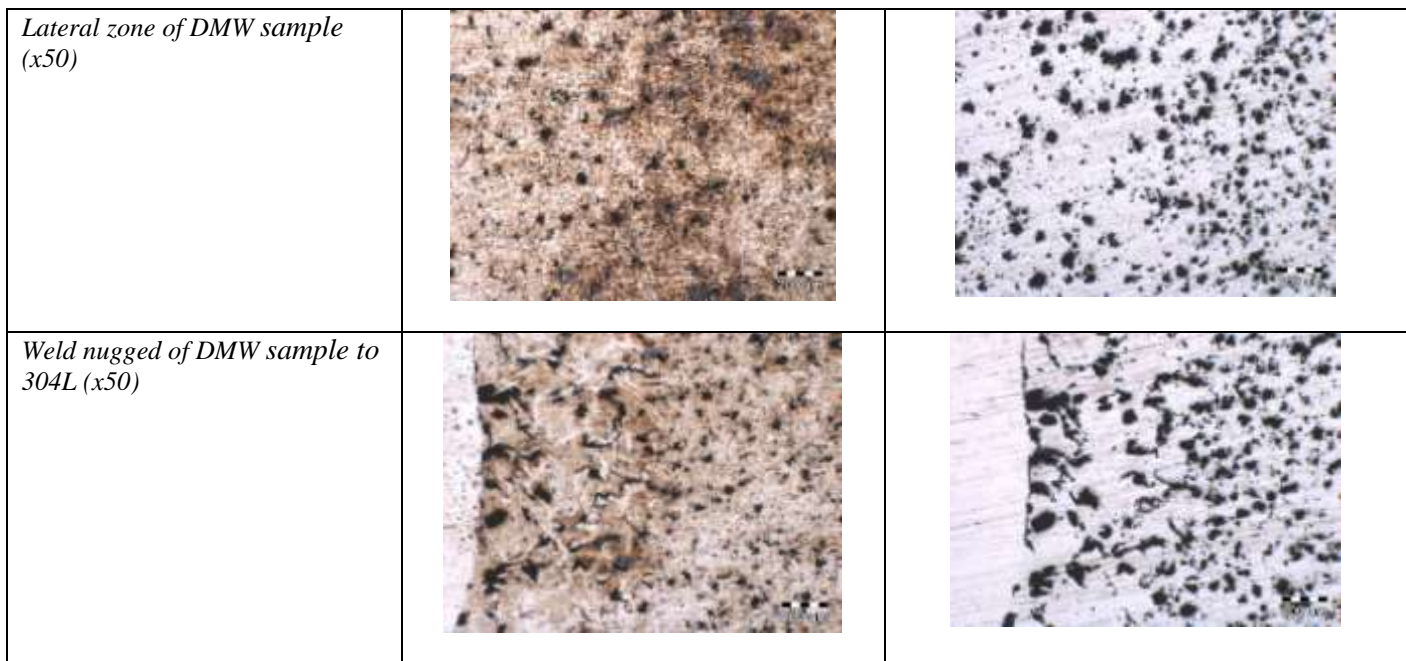


Fig. 6 Micrographies (x50) from 304L– 410 welded joint of post-tested samples in $FeCl_3$ solution

Conclusions

- To made the experiments corresponding to this paper, were used the samples from the following alloys types:
 - unwelded alloys (410 ferritic martensitic stainless steel and 304L austenitic stainless steel) and
 - dissimilar welds between 410 ferritic martensitic stainless steel and 304L austenitic stainless steel.
- 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.
- As result of these the potentiodynamic tests we ascertained that:
 - the 304L– 410 dissimilar welds samples immersed in Cl^- media, presented greater values of passivation current density and a without passive range than 410 ferritic-martensitic steel samples tested in the same solutions.
 - the Cl^- ions have a more influence on heat affected zone (HAZ) to W1.4006 ferritic-martensitic steel counterpart of dissimilar metal weld.
- The effect of Cl^- anions on 410 ferritic martensitic stainless steel counterpart of (304L– 410) welded sample is more pronounced, increasing its susceptibility at localized attack (pitting corrosion) of dissimilar metal welds comparatively with the 304L austenitic stainless steel alloy.
- The values of the corrosion current intensity, i_{corr} , and of the corrosion rate, v_{corr} , corresponding to 410 ferritic-martensitic steel alloy and (304L– 410) welded samples are greater than those corresponding to the 304L austenitic stainless steel alloy;
- The examination of surfaces of tested coupons in presence of Cl^- anions was made by optic microscopy and as result of images analysis it observed that 410 ferritic-martensitic steel alloy are higher susceptibility pitting corrosion of in $FeCl_3$ solution at $(25 \pm 5)^\circ C$ than the other counterpart of weld.

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