Potentiodynamic corrosion studies on laser beam welded austenitic stainless steel AISI 321

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Potentiodynamic corrosion studies on laser beam welded austenitic stainless steel AISI 321

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Abstract: In this study, the microstructure and corrosion characteristics of laser beam welded austenitic stainless plates has been studied.CO_2 Laser beam produced defect free weldments in AISI 321 with no trace of heat affected zone. The microstructural studies revealed distributed ferrites in the weld zone. Potentio-dynamic polarization studies were carried out on the weldments in 5% NaCl environment in order to understand corrosion current, potential and rate.

1. Introduction

Austenitic stainless steels are general purpose steels, these are a class of alloys with a face-centered-cubic lattice structure, they are highly corrosion resistant and have excellent high-temperature tensile and creep strength. Thus, making austenitic stainless steels one of the most favored materials for structural components. They are mainly used in automatic machinery, power plants and nuclear industries for their high strength, excellent toughness, reduced corrosion resistance, weld-ability, etc. The austenitic stainless steels, 18Cr-8Ni with additional stabilizers such as Ti and Nb to suppress the chromium carbide grain boundary and for better corrosion resistance are widely used in nuclear power plants and also in nuclear waste treatment plants. The composition of the austenitic tainless steel is the deciding factor for the mechanical behavior and the area of application of these materials [1-3].
Among the various utilized stainless steels AISI 321 has superiority in the nuclear facilities due to the presence of Ti which avoids the chromium carbide precipitation inter-granular corrosion at elevated temperatures. Conventional welding processes over the stainless steels results in segregation, depletion of major alloying elements viz titanium and chromium and leads to formation of intermetallics. Another issue is during the solidification of the weld pool from elevated temperature results in altering the microstructure in the weld zone and heat affected zones. The alteration from the original microstructure can drastically affect the strength and corrosion properties of the parent metals. Hence it is important that these issues shall limit the use of conventionally welded joints of AISI 321 in the nuclear reactors, which are critical areas where the lifetime of the welded components plays an important role, as it is necessary that the joints shall not be replaced in their lifetime [3].
Major issue in welding of austenitic stainless steels is, if not done properly or by the book there could be HAZ cracking, since austenitic stainless steels are more sensitive to micro fissuring during

solidification. They are usually formed due to the melting at lower temperatures by eutectic alloys. Primarily ferritic and austenitic will solidify but once ferrites are complete austenitic will rise through the segregation and transformation. Thus making the matrix will rise with a resting smelt of ferrites.
Laser welding of metallic materials is continuously attracting attention by the industry because of its potential benefits on saving material cost (autogenous welding), design flexibility and complexity as well as enhancing product functionality [4]. Laser beam welding is a suitable technique for joining in various industrial applications because of its low heat input, high precision, high controllability and repeatability. This is especially true for electrical applications where sufficient joint strength and electrical conductivity are usually the two main criteria for a successful weld. Joint strength and electrical conductivity can be translated into the design parameters, joint geometry and contact area which is controlled by the heat geometry and contact area which is controlled by the heat transfer respectively between the work pieces [5].
Though there are several other fusion welding processes performed on stainless steel 321, employing laser beam welding shall greatly reduce the changes in the metallurgical properties and thereby the corrosion properties of the Austenitic stainless steel. Hence, this research work aims to perform a Laser Beam welding on the AISI 321, evaluate the macro and microstructures, and perform the potentio - dynamic corrosion studies (TAFEL) to analyze the effect of welding on the corrosion properties.

2. Experimental procedure

Chemical composition of AISI 321 is represented in Table 1. The austenitic stainless steel plates were welded using a CO_2 laser beam welding. The photographs of the as welded AISI 321 are shown in the Fig. 1. Two cross sectional specimens for corrosion studies were cut by EBM to a required dimension of 20 × 10 × 5 mm.

Table 1. Chemical composition, atomic weight of the base materials

	C	**Mn**	**P**	**S**	**Si**	**Cr**	**Ni**	**Mo**	**Cu**	**V**	**Ti**	**Fe**	**ρ**	**Eq. At. Wt.**
Wt %	0.04	1.36	0.026	0.002	0.64	17.35	9.19	0.63	0.37	0.11	0.28	69.5		
At.wt.	12.0	54.9	30.9	32.0	28.0	51.9	58.6	98.9	63.54	50.9	47.8	55.9	**8.0**	**585.3**

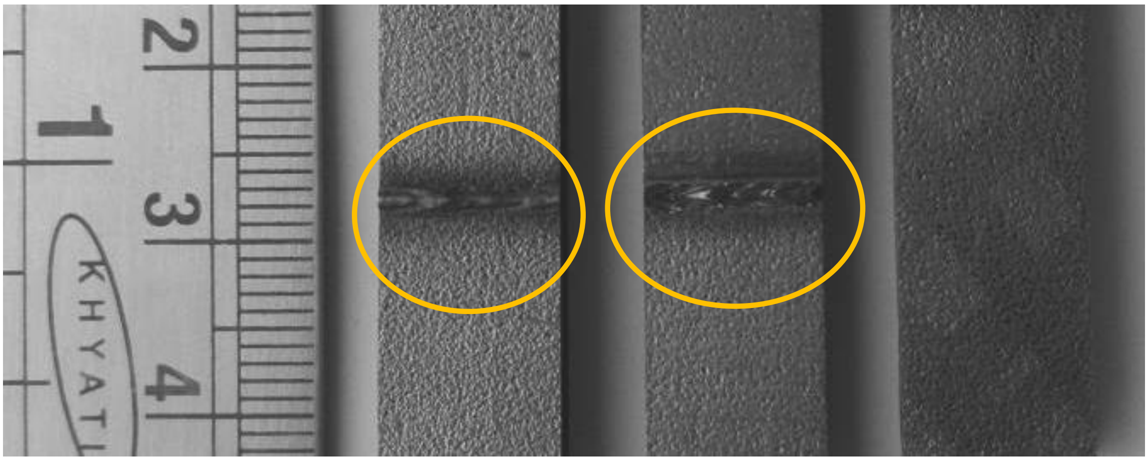


Figure 1. Photograph showing the unwedded and welded samples of 25 mm x 10 mm x 5 mm.

2.1. Macro and Micro structural Examination.

For macro and microstructural analysis samples two samples were cold mounted, and were prepared for observing microstructure using SiC emery sheets from grade 400 to 2000 and disc polished using alumina slurry. The etchant used is a combination of hydrochloric acid (HCL), nitric acid (HNO_3), and Acetic acid (CH_3COOH) mixed in 3:2:2 ratios. The samples were etched by gently swabbing the acid mixture on the surface using cotton. After etching the samples were washed under slow running water to prevent over etching. The macro structural examination across a section of the weldment done and is represented in Fig. 2**.** Microstructural Examination of the weld cross section is examined with an Inverted type Carl Zeiss Microscope and the microstructure at the weld zone and the base material is represented in the Fig. 3**.**

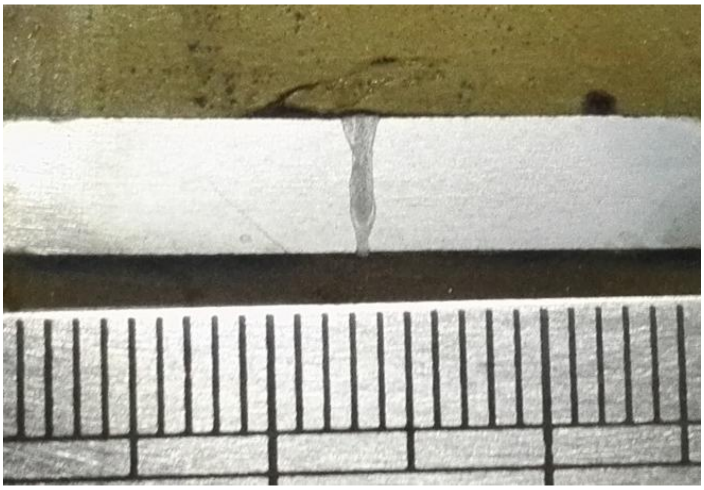


Figure 2. Macrostructure of laser welded austenitic stainless steel showing narrow weld bead.

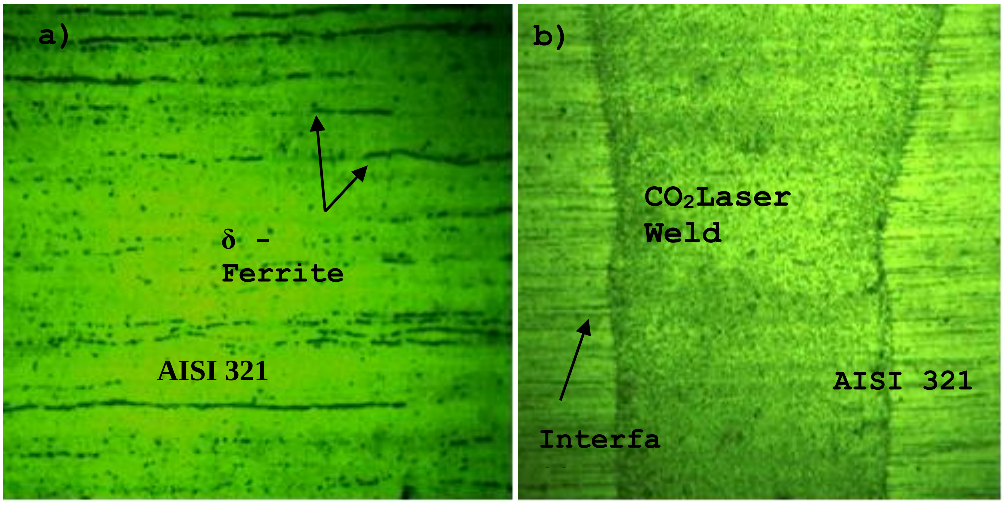


Figure 3. Observed microstructure of a) Base material AISI 321 b) Interface between laser beam weld and the HAZ.

2.2. Potentiodynamic studies

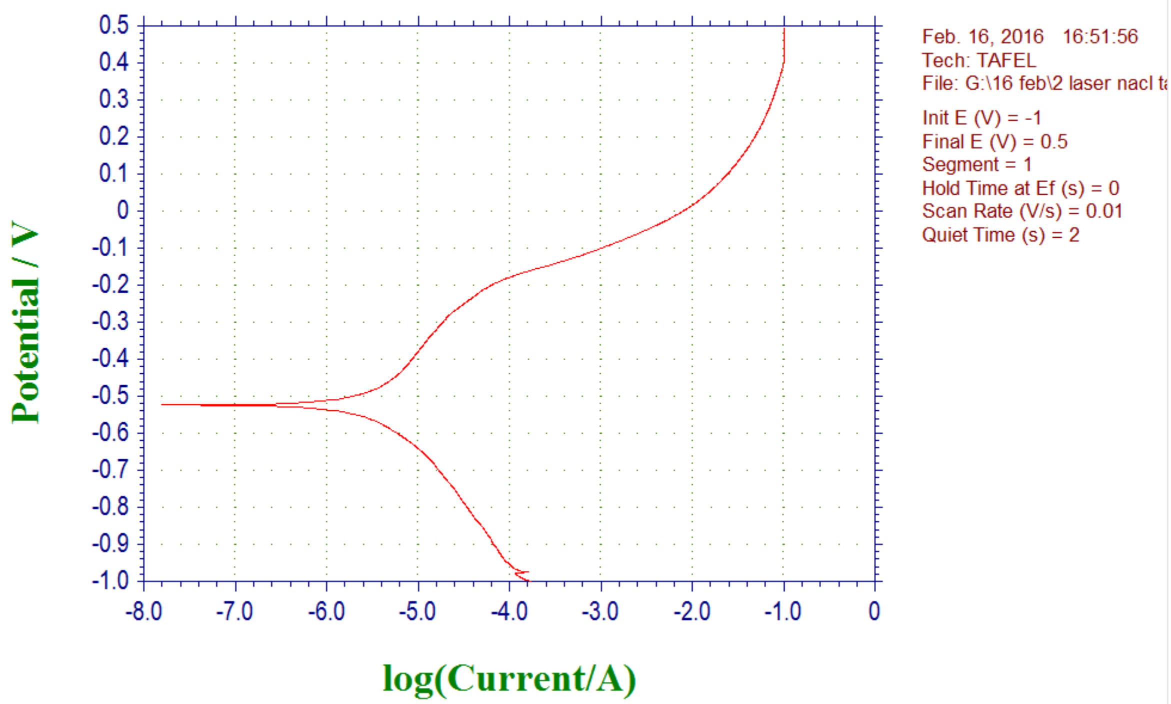
Potentiodynamic corrosion studies were conducted at ambient temperatures with of an electrochemical corrosion analyzer of Make CH Instruments. The samples are analyzed in 5N NaCl solution since the austenitic stainless steel is more susceptible in the chloride environment. In this experiment a 3 electrodes setup, the weldment is used as a working electrode, a platinum electrode is used as the counter electrode and a saturated calomel electrode via capillary probe as a reference electrode. Both the base material and the laser weldment were tested. The laser weld bead and the adjoining area (2mm×10mm) are exposed to the solution while testing and thus the total area that is exposed is for the experiment 20 mm. The working electrode was dipped in the corrosive environment for 15 min to obtain an open circuit potential (OCP). Then the Potentiodynamic polarization curves result was obtained by changing the electrode potential to anodic from the Cathodic direction. The TAFEL plots were then extrapolated to find the corresponding corrosion potential $\mathbf{E_{Corr}}$ and the corrosion current I_{Corr} as shown in the **Table 2** Mils per year (mpy) was obtained [6].

Figure 4. Photograph showing the hydrogen evolution at the working electrode during the TAFEL studies

3. Results and discussion

The visual examination of the laser welded plates has shown no weld defects. It is clearly visible from the macro structural studies that LBW is free from sub surface imperfections. Also, the weld bead width is found to be very narrow, ranging from 0.5 at the weld root and 1 mm at the cap resulting in a full penetration joint.

On observing the optical micro structure images, it suggests that the base metal has an austenitic grain structure, the principal attribute of austenitic stainless steels is their corrosion resistance but also excellent properties in extreme temperature range, and the weld region has delta ferrite structure this is because, during welding the temperature reached in the weld produces microstructural transformations. Presence of delta ferrites up-to a maximum of 7% is preferred as it decreases the cracking susceptibility of weld material and improves the cracking resistance [6-11]. The weld bead is very narrow in the case of the LBW ranging from min 0.5 mm in the root region to maximum of 1 mm in the cap region. This when welded in the conventional welding with a filler wire shall have produced a wider weld bead [12,13]. Also, there is no trace of heat affected zone adjacent to the weld interface.



The corrosion potential and corrosion current for the LBW was found to be 524 mV and $3.717e^{-006}$ respectively.

Figure 5. Tafel plots for the laser beam welded AISI 321.

The corrosion rate is calculated from the equation (1) from the corrosion current (I_{Corr}),the density and equivalent atomic weight of the base material AISI 321. for the laser beam weldments is found to be $1.21732\ e^{-5}$ mpy.

$$\text{Corrosion rate CR} = \frac{Icorr.k.EqWt}{dA} \quad (1)$$

Where

Icorr	-	Corrosion current (A)
k	-	Constant
Eq_{Wt}	-	equivalent atomic weight of the material (g)
D	-	density of the material (g/cm^3)
A	-	exposed specimen area during corrosion (cm^2)

Table 2. Cumulative table representing corrosion current density (I_{corr}), corrosion potential (E_{corr}) and corrosion rate

Material	I Corr A (µA)	E corr mV	Corrosion Rate (mpy)
AISI 321 laser weldment	$3.717e^{-006}$	-524	0.4462

4. Conclusion

- Laser weld beam has produced defect free welds in AISI 321, with a very narrow weld bead.
- Cross sectional microstructural studies revealed the absence of heat affected zone when employing the laser welding.
- Fine delta-ferrites are observed in the weld zone of the laser weldments.
- The corrosion rate for the laser welded AISI 321 is found to be 1.21732 e^{-5} mpy which is a meagre amount showing the laser beam weld has minimal effect with respect to corrosion in 5% NaCl Solution.

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