Investigation of the Corrosion Behaviour of Welded Area of Austenitic Stainless Steels under Stress

Yehia Youssef, Walaa El Bestawy, Mootaz Ghazy, Mohamed Shehadeh, and Ibrahim Hassan

***Abstract*—The corrosion behavior of austenitic stainless steel was investigated under both static and dynamic conditions. In this study, corrosion behavior of welded and unwelded austenitic stainless steels, SS304, SS310, SS316 were investigated using three different stirring speeds; 100, 200, 350 rpm and were subjected to two different corrosive environments; seawater (3.5% NaCl), and acidic ferric chloride ($FeCl_3$). The rate of corrosion was measured using spectrophotometry. The microstructure was examined using optical microscopy. Experimental results indicated that the highest corrosion rate was observed in acidic ferric chloride, 8.56 mg. $min^{-1}.cm^{-2}$ for SS304 at 350 rpm speed (high mechanical stress condition), compared to seawater under the same conditions, 7.96×10^{-4} mg. $min^{-1}.cm^{-2}$. Welded stainless steel area were highly sensitive to the corrosive environment as a result of the increasing thermal stresses in both the weld zone and the heat affected zone (HAZ). Also, the corrosion rate was found to increase with increasing the stirring speed due to its effect on the mass transfer and mechanical stresses.**

***Index Terms*—Corrosion rate, seawater, austenitic stainless steel, corrosion behavior, welded stainless steel.**

I. INTRODUCTION

In recent years, stainless steels have been widely used in the metal working industry especially in the construction sector. Austenitic stainless steels are characterized by their relatively high corrosion resistance and excellent properties which play an important role in many industrial and domestic applications. Welding is often used in the manufacturing of engineering components which may cause the microstructure and mechanical properties of the welded zones to be different from the base metal [1], [2]. The base of various stainless-steel alloys is the binary Fe-Cr system, the properties of which are modified by the addition of several major alloying elements such as Ni, Mo and Mn as well as minor ones such as C and N. The alloy systems mostly used in austenitic stainless steels are the Fe-Cr-Ni alloys which are susceptible to localized corrosion attacks of which many problems are caused by sensitization leading to premature failure (e.g. [3]-[6]).

Austenitic stainless steels have many applications and uses in industrial fields but are usually subjected to failures resulting from their exposure to various corrosive environments [2], [7]-[10]. In order to understand the causes of these failures, the behavior of stainless steel in different corrosive environments needs to be studied carefully; not only under static working conditions but also when subjected to dynamic loads. Previous investigations for welded and unwelded austenitic stainless steels used specific environments in their methods, without studying the effect of applied stresses [1], [5]-[7], [11]-[13]. The present study investigates the corrosion behavior of austenitic stainless steel in different corrosive media. Furthermore, stresses have been applied by undergoing different stirring speeds in order to promote pitting and stress corrosion cracking to understand the effect of welding and dynamic loads on the corrosion behavior. The main objectives of this study are therefore to evaluate the corrosion rate using spectrophotometry for the three types of austenitic stainless steels after being exposed to stresses, initiated using different stirring speeds, in two different corrosive media; seawater (3.5% NaCl solution) and acidified ferric chloride solution. Evaluation of the corrosion rate and corrosion behavior of the three types of austenitic stainless steels is performed for welded and unwelded specimens. Microscopic examination of the three types of austenitic stainless steels is done for the welded and unwelded specimens to correlate the results obtained to the microstructure observed.

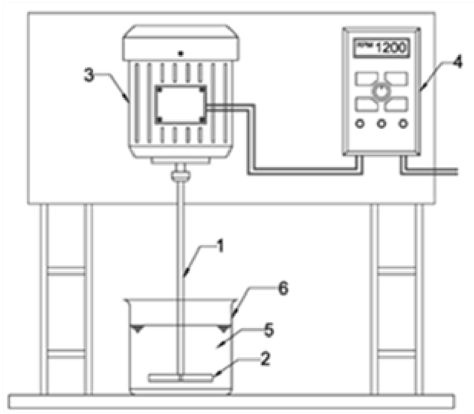

Fig. 1. Schematic of experimental setup, **1**: Stirring Shaft, **2**: Impeller, **3**: Drive Motor, **4**: Speed Control Unit, **5**: Corrosive Electrolyte Solution and **6**: Glass Container.

II. EXPERIMENTAL METHODS

The corrosion behavior of welded stainless steel 300 series for different grades; SS304, SS310, SS316, is investigated when the specimens were under stress; and exposed to different corrosive environments; namely, seawater (NaCl 3.5%), and acidic ferric chloride solution. The specimens were then tested in the as-received, polished and etched conditions. A number of specimens; three welded and three

Manuscript received May 15, 2018; revised August 17, 2018.

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doi: 10.18178/ijcea.2018.9.4.713

unwelded grades of austenitic stainless steels were examined. The impeller arms were perpendicularly arc welded to a stainless-steel rod. Also, the same dimension of unwelded impeller arms were fitted to the rod perpendicularly. The impeller arms were covered with epoxy except at the welded area to be tested in order to study the effect of welding. The welded and unwelded stainless steel samples were exposed to two different aqueous solutions while stirring at 3 different rotational speeds. Etching was carried out in a glyceregia solution, consisting of HCl, glycerol, HNO_3 with a ratio of 3: 2:1 for microstructural examination. The experimental apparatus is as illustrated in Fig. 1.

The impeller rotating rod was all protected except for the area connecting the blades to the rod which was the area available for the corrosion test

III. Results and Discussion

The corrosion rate was calculated from the iron weight loss over the period of time and the exposed surface area of the rotating impeller rod. The corrosion rate was calculated using the following expression [14], [15]:

$$CR = \frac{W_L}{A \times t} \quad , \qquad (1)$$

where; CR is the corrosion rate ($mg.min^{-1}.cm^{-2}$), W_L is the iron weight loss (mg), A is the exposed area of SS rod (cm^2), and t is the time (min).

Typical results of the corrosion rate as a function of time for welded and unwelded steel grades in NaCl solution are as shown in Figs 2 to 4. Fig. 5 shows the effect of stirring speed on the corrosion rate for all welded and unwelded grades in NaCl solution. The highest rate of corrosion was obtained for the SS304 at the highest rate of stirring, 350 rpm in the welded condition (4.42×10^{-4} $mg.min^{-1}.cm^{-2}$). This represents the highly sensitive case for the corrosion behavior in NaCl solution. On the other hand, the lowest corrosion rate was obtained in the unwelded SS316 sample (0.44×10^{-4} $mg.min^{-1}.cm^{-2}$).

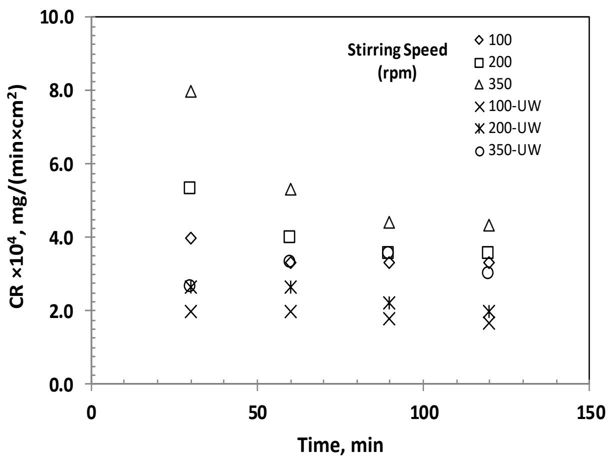

Fig. 2. Corrosion rate of welded and unwelded SS304 steel in NaCl solution at different stirring speeds.

It was clear also that all welded specimens exhibited an increased corrosion rate compared to the unwelded conditions.

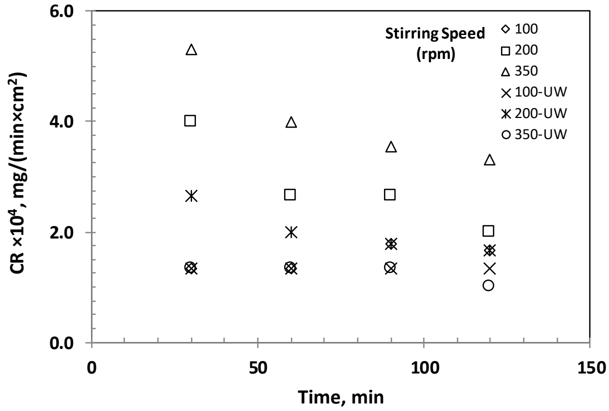

Fig. 3. Corrosion rate of welded and unwelded SS310 steel in NaCl solution at different stirring speeds.

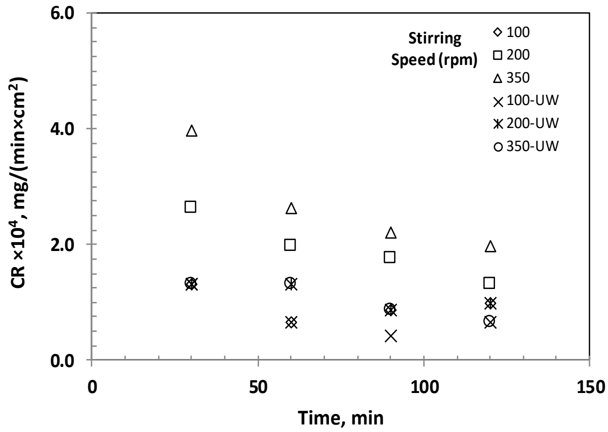

Fig. 4. Corrosion rate of welded and unwelded SS316 steel in NaCl solution at different stirring speeds.

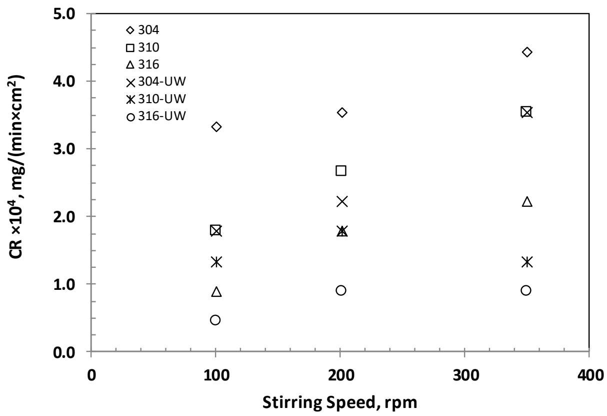

Fig. 5. Effect of stirring speed on corrosion rate for all welded and unwelded stainless steel grades in NaCl solution after 90 min.

Similarly, typical results of the corrosion rate as a function of time for welded and unwelded specimens in acidified ferric chloride solution are as shown in Figs 6 to 8. Fig. 9 shows the effect of stirring speed on the rate of corrosion for all welded and unwelded grades in acidified $FeCl_3$ solution. It was clear that welded SS304 steel exhibited the highest corrosion rate (3.80 $mg.min^{-1}.cm^{-2}$). This result is approximately four orders of magnitude higher than the case of the NaCl solution. The lowest corrosion rate was again obtained for the unwelded SS316 steel (0.21 $mg/min^{-1}.cm^{-2}$). This effect is expected because of the presence of the chloride ions which have a special damaging effect on passive layer on the stainless-steel surface [13].

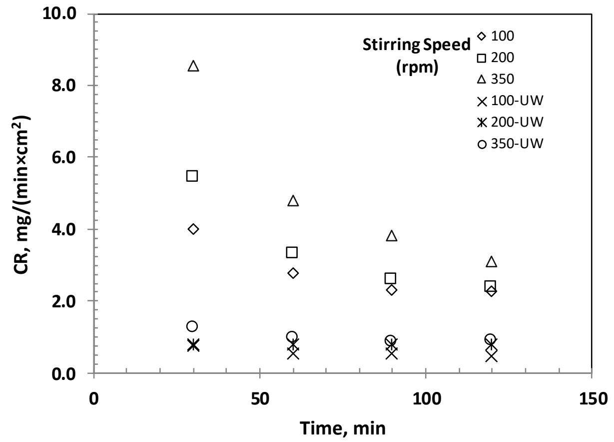

Fig. 6. Corrosion rate of welded and unwelded SS304 steel in acidified ferric chloride solution at different stirring speeds.

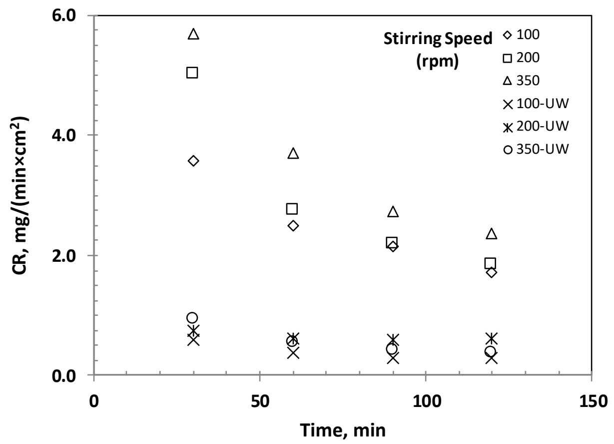

Fig. 7. Corrosion rate of welded and unwelded SS310 steel in acidified ferric chloride solution at different stirring speeds.

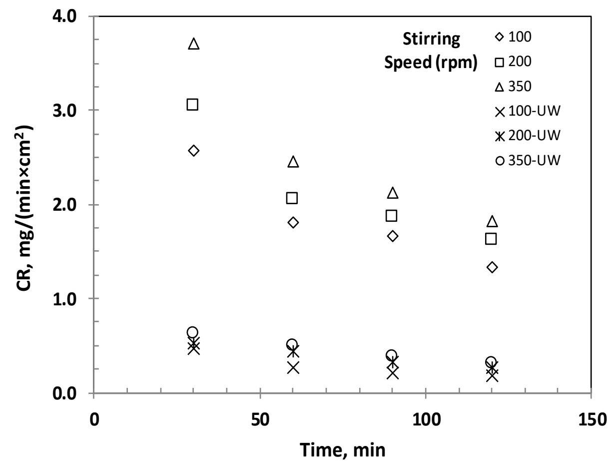

Fig. 8. Corrosion rate of welded and unwelded SS316 steel in acidified ferric chloride solution at different stirring speeds.

Corrosion micro-pits could be clearly observed in the microstructural examination of welded SS304 steel, see Fig. 10. However, the case of SS310 and SS316 did not show the same effect (see Fig. 11).

The acidic ferric chloride is a highly aggressive corrosive environment since it is a strongly oxidizing solution. Therefore, the rate of corrosion is expected to increase significantly. This is clearly shown in Figs 6-9. For this reason, as shown in micrograph Fig. 10, a clear damage is taking place in the stainless-steel structure.

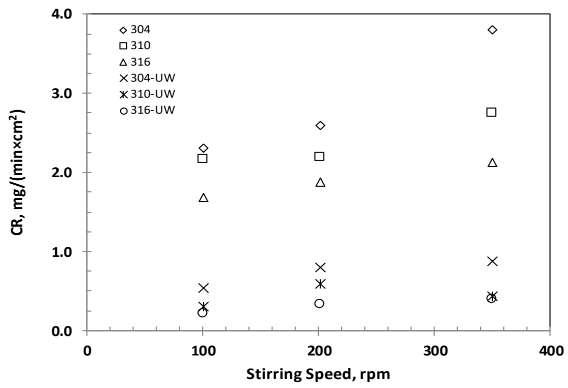

Fig. 9. Corrosion rate for all welded and unwelded grades in acidified ferric chloride solution at different stirring speeds after 90 min.

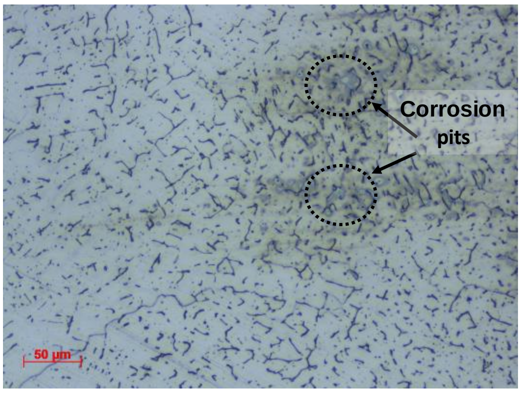

Fig. 10. Optical micrograph of welded SS304 steel in acidified ferric chloride solution after 90 min.

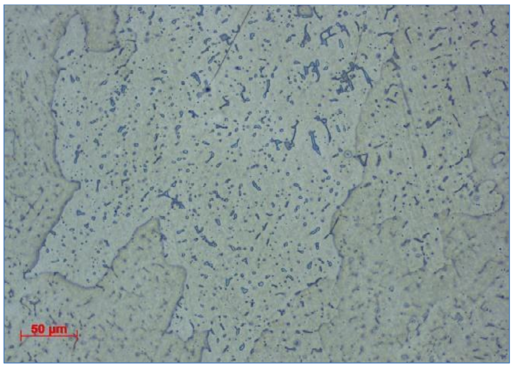

Fig. 11. Microscopic examination of welded SS310 in NaCl solution after 90 min.

The corrosion rate as a function of the stirring and stirring speed show a similar effect. The seawater (NaCl) solution has a similar effect due to the presence of the chloride ions. However, the rate is shifted to a much higher value (orders of magnitude higher corrosion rate) because of the damaging effect of the acidified $FeCl_3$ solution which accelerates the rate of corrosion significantly.

IV. Conclusion

Corrosion rate for all studied corrosive media decreases with time till it reaches a plateau due to the fact that a steady state condition is reached for the corrosion reaction. The highest corrosion rate was observed in acidic ferric chloride while, the seawater has a special effect due to the presence of Cl^- ions. Increasing the forced convection effect in solution by increasing the stirring speed results in an accelerated mass transfer rate and a resulting increase in the rate of corrosion and this is observed in all cases. Welded stainless steel are highly sensitive to the corrosive environment. As a result of increasing the thermal stresses in both the weld zone and the heat affected zone (HAZ).

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