CORROSION RESISTANCE OF LASER WELDED JOINTS OF TP347HFG AND VM12-SHC STAINLESS STEELS

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Abstract: The CO2 laser welding technique was suggested as a method of joining dissimilar materials. The corrosion resistance at high temperatures of the joint of TP347HFG and VM12-SHC stainless steel was investigated. The stainless steel was butt welded. Materials were examined by the thermogravimetric method. The surface and microstructure of the sample were observed in a scanning electron microscope (SEM). The results showed the substantial intermixing of both substrates within the fusion zone. The thermogravimetric data indicate that at high temperatures and air condition the joint and the stainless steel undergo chemical corrosion. The joint has acquired medium resistance for chemical corrosion in relation to both steels.

KEYWORDS: LASER WELDING; JOINT, AUSTENITIC, MARTENSITIC, CROSS-SECTION, THERMOGRAVIMETRIC ANALYSIS, CHEMICAL CORROSION

1. Introduction

Stainless steels are Fe-Cr-Ni alloys which are widely applied in various industrial sectors such as marine, chemical, desalination and petrochemical industries. Austenitic and martensitic stainless steels are most widely used to produce modern energetic devices. They can work at high and low temperatures [1-5]. These steels are usually used for a wide range of applications such as steam generators, pressure vessels, mixer blades, cutting tools and offshore platforms for oil extraction [6]. The joining of dissimilar materials is one of the most challenging tasks facing modern manufactures. Dissimilar metal joints are widely used in various industrial applications for both technical and economic reasons. Stainless steels are seldom welded because of their high hardenability and susceptibility to hydrogen induced cold cracking. Austenitic and martensitic stainless steels with their chromium and carbon contents are resistant to various environmental conditions. Moreover, nickel and molybdenum content provides the elevated-temperature strength through the formation of stable carbide both metals [7]. The laser welding technique was suggested as a modern method of joining two metals of different properties. Laser welding is a high energy density process and well-known for its deep penetration, high speed, small heat-affected zone, fine welding seam quality, low heat input per unit volume [8]. A butt joint is one of the most common laser welded materials used to produce tubes and tailor welded blanks. It is of profit to all welding, but even more important to laser welding. Unfortunately, in the case of dissimilar materials the butt joint is subject to chemical and electrochemical corrosion at high temperatures or in an aggressive environment, particularly in the presence of chloride ions [9-16].

The present paper deals with the corrosion resistance of the CO2 laser welded joint of TP347HFG (austenitic) and VM12-SHC (martensitic) stainless steels. The samples were examined using a thermogravimetric analyzer (TGA) in air atmosphere. The surface and microstructures were observed by a scanning electron microscope (SEM).

2. Experimental

2.1. Materials

The materials of TP347HFG and of VM12-SHC stainless steels were designed for the laser welding. Samples for welding were prepared by cutting to the size of 150×200×5 mm from the base material.

2.2. CO2 laser welding system

The CO2 laser welding system was used for the melting of two stainless steels. A TRUMPF LASERCELL 1005 (TLC 1005) with 6 kW power made it possible to produce short and long series of different materials at low costs and in a short time.

The welding velocity was 160 mm/min in X-direction for the trial tests to perform a successful welding. The laser beam was positioned at the joint (and moved) 2 mm in relation to the surface of a sample. Helium gas at the pressure of 200 Pa and speed of 18 L/min was used as a shield gas to protect the heated surface against oxidation.

2.3. Laser welded joint

The materials were butt welded. The full joint penetration was applied. The joint was initially examined in an optical microscope. The cross-section of the weld fillet was observed to determine the geometry, depth of penetration and cracks in the heat-affected zone (HAZ) as well as in the welded zone (WZ) of the joint. Moreover, no special heat treatment was carried out after laser welding.

2.4. Thermogravimetric measurements

Thermogravimetric measurements were carried out on an NETZSCH STA Jupiter 449 thermogravimetric analyzer (TGA). The sample in the furnace was heated up from 25 to 1380 °C with the heating rate of 5 °C min-1. A analyzer was applied for the thermal analysis of TP347HFG or VM12-SHC stainless steels, and the joint of both steels.

2.5. Additional measuring instruments

The cross-section of the surface and microstructure of a sample was observed in a scanning electron microscope (SEM), Joel, type JSM-5400.

To evaluate the mechanical properties, microhardness values were determined along the cross-section by the Vickers (HV) method using a Microtech MX3 tester under of 0.4 N load.

3. Results and discussion

3.1. Thermogravimetric measurements and kinetic studies

The thermogravimetry curves for TP347HFG, VM12-SHC stainless steels and the joint are presented in Figure 1.

Fig. 1. Thermogravimetry curves for stainless steel and joint: (a) TP347HFG, (b) joint, and (c) VM12-SHC. Heating rate of 5 °C min-1.
The weight gain of samples were observed after the achievement of the critical temperature conversion in which the increase of the mass of a sample achieved the value of 0.1% in relation to the mass of the initial specimen. Table 1. TP347HFG was the most resistant to oxidation whereas VM12-SHC stainless steel was the least resistant to it. It is noteworthy that the critical temperature conversion for the joint was placed between both stainless steels. Moreover, Table 1 contains the weight gain of samples after the measurement.

Table 1. Critical temperature conversion, weight gain of stainless steel and joint.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Critical temperature conversion (°C)</th>
<th>Weight gain sample (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP347HFG</td>
<td>1145</td>
<td>20.01</td>
</tr>
<tr>
<td>Joint</td>
<td>1101</td>
<td>41.71</td>
</tr>
<tr>
<td>VM12-SHC</td>
<td>1049</td>
<td>62.69</td>
</tr>
</tbody>
</table>

The largest increase in mass was registered for VM12-SHC, but the smallest for TP347HFG stainless steel. However, for the joint a medium increase in the mass of the sample was observed.

Kinetic studies, based on the change of mass, were obtained by the TG curve analysis. The corrosion rate of materials was calculated from the following equation:

\[ k = \frac{\Delta m}{A t} \]  

where \( \Delta m \) is the change mass of sample, \( A \) is the surface area of the test specimen, and \( t \) is the time of measurement. The corrosion rate was expressed in mg cm\(^{-2}\) h\(^{-1}\).

The corrosion rate of samples were calculated on basis of Equation (1). The results are shown in Figure 2. The corrosion rate of samples increased with increase of temperature. The joint achieved the medium values of corrosion rate in comparison with both steels.

The thermogravimetric process in the atmosphere of air depends on the oxidation of the sample surface. The process of forming an oxide layer on the surface of the clean metal begins from the adsorption of oxygen:

\[ 4 \text{Fe} + 3 \text{O}_2 \rightarrow 2 \text{Fe}_2\text{O}_3. \]  (2)

The product of the iron corrosion (reaction (2)) at high-temperature has a stratified structure. The spatial structure of layers of oxide is of ion character. The process of forming a layer of oxide on the metal depends on the diffusion of Fe\(^{2+}\) through the layer in the direction of the gas phase (from pithy diffusion). Moreover, the diffusion ions of oxide from the layer in the direction of the metallic basis (to pithy diffusion) is also possible [17]. The tight and suitable thick of the oxide layer should effectively protect the metal against the significant progress of the corrosion process. The high temperature (higher than 1300 °C) causes the dissociation pressure of the oxide layer according to the equation:

\[ 6 \text{Fe}_2\text{O}_3(s) \leftrightarrow 4 \text{Fe}_3\text{O}_4(s) + \text{O}_2(g). \]  (3)

The compositions of scales for multiple alloys are usually varied.

In the case of TP347HFG and VM12-SHC stainless steels the compiled composition concerns the scale of the joint because it contains oxides of chrome, nickel, or cobalt.

Figure 3 shows the images of the joint, TP347HFG and VM12-SHC stainless steels after thermogravimetric measurements. It can be seen that on the surface of TP347HFG the compact, uniform and hard oxide layer was formed, which protects the steel prior to high-temperature corrosion.

3.2. Microhardness profiles and microstructures

The microhardness profiles of the specimen were analyzed using the Vickers method. The results are presented in Figure 4.
In the heat-affected zone an increase in microhardness of both steels was observed. The maximum hardness value is located in the weld zone (about 580 HV0.4). The hardness of the joint increased about twice as much in comparison to the hardness of steels. The HV value indicates that the joint is fragile, and has low strength on hitting in relation to stainless steels. In this case special heat treatment should be applied after laser welding.

The scanning electron microscope images of the microstructure of the sample is shown in Figure 5.

![Fig. 4. Vickers microhardness profile along the cross-section in specimen.](image1)

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The scanning electron microscope images of the microstructure of the sample is shown in Figure 5.

![Fig. 5. Scanning electron microscope images of microstructure: a) TP347HFG, b) joint, and c) VM12-SHC stainless steel. Magnification 1000×.](image2)

The characteristic austenitic microstructure (Fig. 5a) is observed for TP347HFG as well as the martensitic microstructure (Fig. 5c) for VM12-SHC stainless steel. Moreover, observations revealed a fine grained microstructure, and basically dendritic in the weld zone (Fig. 5b). The material which possesses dendritic microstructure is usually very hard. However, this type of microstructure is a result of high cooling rates typical of the laser welding process.

4. Conclusions

1. The CO₂ laser welding technique was suggested as a method of joining dissimilar materials.
2. The thermogravimetric data indicate that at high temperature under air conditions the joint and stainless steels undergo chemical corrosion. The product of the corrosion of iron, Fe₂O₃, has a stratified structure at high-temperature.
3. The joint has the medium resistance to chemical corrosion in relation to both steels, and the chemical composition of the joint is different in comparison to both steels.
4. The weld zone revealed a fine microstructure and was basically dendritic, due to the high cooling rate which is characteristic of the laser welding process.
5. The value of Vickers microhardness indicates that the joint is fragile, and has low strength on hitting in relation to stainless steels.

References