Fused Line Study of 17-4PH Stainless Steel Deposited with Co-Based Alloy

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To improve the surface performance, precipitation hardening martensitic stainless steel 17-4PH is deposited with Co-based alloy stellite12 by plasma-transferred arc welding (PTAW). The microstructure and microhardness of the fused line between base metal and coating were characterized by optical microscope (OM), scanning electron microscope (SEM), transmission electron microscope (TEM) and hardness tester. The results show that the interface between weld coating and base metal is favorable without pore and crack. The microstructure of the fused line is composed of martensite and austenite, without precipitates.

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1. Introduction

Martensitic precipitation-hardened stainless steels, which have excellent properties, such as corrosion resistance, high strength, high anti-fatigue and good weldability, have been used in a variety of applications, for instance oil field valve parts, chemical process equipment, aircraft fittings, fasteners, pump shafts and so on. However, severe service conditions (evolved gases, fast flows, sequential impacts, high temperature and erosion) in some fields restrict the wide application of martensitic precipitation-hardened stainless steels, because of their poor tribological properties. So, it is necessary to improve the surface qualities, such as surface hardness and wear resistance in order to get satisfactory performance under severe conditions.¹⁻⁵

There are many kinds of surface engineering technologies that can be applied to achieve surface strengthening,⁶⁻⁷ for example argon tungsten-arc welding, electrode welding, submerged arc welding, plasma arc welding and so on. But, among these, plasma transferred arc welding (PTAW) is the best choice. With PTAW, the fused interface formed between base metal and coating is metallurgical bonding. In addition, there is a reduction in the dilution between base metal and coating. Last but not least, it not only can reduce cost, but also can improve productivity. Co-base alloys with good wear resistance and excellent corrosion resistance are regarded as candidate materials for surface hardening of 17-4PH stainless steel. A few studies have reported on base metal and coating of 17-4PH deposited with Co-based alloy by welding,⁶⁻¹⁰ but a report on fused interface is rare. This paper will present research on fused interface of 17-4PH deposited with stellite12.

2. Experimental Procedure

The shaft sleeve of precipitation hardening martensitic stainless steel 17-4PH was deposited with Co-based alloy stellite12 by PTAW. Thickness of the coating is about 4.5 mm. The chemical composition of 17-4PH and stellite12 alloy is respectively shown in Tables 1 and 2. The PTAW process parameters were presented in Table 3. The shaft sleeve, which was deposited with Co-based alloy, was cut into 15 × 15 × 15 mm samples.

The microstructure of fused interface was observed by optical microscope (OM), scanning electron microscope equipped with energy dispersive spectroscopy (SEM-EDS) and transmission electron microscope (TEM); the distribution of main elements was analyzed by EPMA; the hardness was measured by microhardness tester.

3. Results and Discussions

Figure 1 is an OM image of the interface between stellite12 coating and 17-4PH. The figure shows that there is no pore and crack in the fused area and the interface is favorable with a relatively homogeneous structure. The fused line was melted during PTAW procedure forming a metallurgical combination, which had a fine mechanical capability because the interface of coating and substrate belongs to
metallurgical bonding. The columnar dendrites grew epitaxially from the substrate in the [001] direction. It then grew in a direction perpendicular to the weld interface into the molten pool.

Figure 2 shows the element distribution of the cross-section, where left side is the coating and right side is the substrate. It shows that there is a great difference in the content of the major element (Fe, Co, Ni and Cr) on both sides of the fused line. Low dilution was achieved when appropriate shielding and critical parameters were maintained. The composition and properties of coating are strongly influenced by the dilution obtained. Control of dilution is of great importance in hardfacing, where low dilution is normally desirable.

The hardness value of the base metal is generally between 270 and 300 HV and the average is 288.7 HV. Figure 3 shows the hardness value of the fused area on the base of the OM image. The average hardness value on the fused line is 274.9 HV, which is lower than that of the base metal (358.2 HV). The microstructure in the fused line may also be different accordingly.

Figure 4 shows a SEM photograph of the fused line, which was electrolytically etched in 10% aqueous sodium hydroxide solution. The thickness of fused line is about 5 µm. In PTAW process, transferred arc melts the feeding powder and, locally, the surface of the substrate so that the entire amount of powder and only a thin film of the substrate surface under the arc melts. The EDS was used to acquire the chemical composition at different positions shown in Fig. 5 and the values are shown in Table 4. The position of 2 is in the fused line. The main chemical composition of this position is similar to that of the base metal, but, Cu and Nb disappear and a small quantity of Co appears nearby.
Figure 6 shows the TEM micrograph and corresponding diffraction patterns of the fused line and Table 5 is the value of d of the corresponding diffraction patterns. From which, the fused line could be assuredly confirmed to be composed of bcc matrix and fcc austenite. The TEM photograph and corresponding diffraction patterns of the base metal are shown in Fig. 7. By comparison, differences between fused line and base metal are rather obvious. Firstly, austenite is one phase in the microstructure of the fused line, but no austenite is observed in the base metal; Secondly, there are no precipitates in the microstructure of fused line, but the precipitates, such as Cr7C3, are observed in the base metal. The main chemical composition of fused line is about the same as that of base metal (Table 4 and Fig. 5), however the microhardness of fused line is relatively lower than that of base metal (Fig. 3), which is mainly because of the appearance of soft austenite and the vanishing of precipitation hardening phase (Figs. 6 and 7) during the PTAW and cooling process.

Fused line here is essentially the transition zone where both substrate and feeding powder are melted during PTAW procedure. Among various types of coating approaches, the most important difference lies in the weld dilution rates. The dilution of Co-based alloy by iron causes increased toughness, reduced hardness and corrosion resistance in many corrosive environments. It also causes reduced wear resistance because of increase in cobalt lattice stacking fault energy. Therefore, the application of an inter-layer is usually suggested to minimize the dilution. As for samples tested in this study, the fused line area is rather limited and homogeneous. As the result, inter-layer will no longer be necessary and coating without inter-layer will result in better efficiency.

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<tr>
<th>Table 4</th>
<th>Chemical composition measured by EDS (mass%).</th>
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<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Base metal</td>
<td>0.04</td>
</tr>
<tr>
<td>HAZ</td>
<td>0.05</td>
</tr>
<tr>
<td>1</td>
<td>0.04</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
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<td>5</td>
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<table>
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<tr>
<th>Table 5</th>
<th>D values of diffraction patterns in Fig. 6.</th>
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<tr>
<td>d (nm)</td>
<td>0.209</td>
</tr>
<tr>
<td>Fe (bcc)</td>
<td>0.203</td>
</tr>
<tr>
<td>Fe (fcc)</td>
<td>0.211</td>
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Fig. 6 TEM micrographs and corresponding diffraction patterns of fused line.

Fig. 7 TEM micrographs and corresponding diffraction patterns of 17-4PH; (a) Fe (bcc), (b) corresponding diffraction patterns of (a), (c) Cr7C3 and Fe (bcc), (d) corresponding diffraction patterns of (c).
4. Conclusion

The aim of this work is to study the microstructure and properties of fused line between 17-4PH substrate metal and stellite12 coating. On the basis of test results above, we can reach the following conclusions:

(1) The fused line between coating and base metal is about 5 µm and the diffusion of elements is not excessive in the fused area.

(2) The microstructure of the fused line is composed of martensite and austenite without precipitates.

Acknowledgements

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