Original Article

Mechanical properties and microstructural characterization of a novel 316L austenitic stainless steel coating on A516 Grade 70 carbon steel weld

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ABSTRACT

The aim of this work is to characterize properties and microstructure of AISI 316L stainless steel used as a coating on welding of carbon steel sheets. Two carbon steel plates were set as the metal base and the stainless steel coating was applied on the weld bead. The applied process used was the submerged arc welding (SAW) and tests were carried out for the tensile strength and Vickers hardness, in addition to observation of the microstructure by optical microscopy. The results indicated that the stainless-steel coating applied on the weld bead provided relatively high values of tensile strength. Moreover, the hardness values suggest that the investigated innovative material can be applied in corrosive environments.

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1. Introduction

A large number of metallic materials can be used in the manufacture of industrial equipment and pipes and, among them, the cost-effective carbon steel is the one that has the greatest application in the construction of most equipment such as pressure vessels [1]. Indeed, carbon steels are known as general purpose materials, as they can be used in a variety of applications however they have technical limitations, especially at low temperatures and corrosive environments. By contrast, alloy steels and stainless steels have properties not found in carbon steels, but they are associated with much higher costs in relation to carbon steel, both in its production and also in the assembly and welding operations related to industrial installations [2].

In spite of cost advantage, carbon steels do not resist the condition of corrosion or erosion that generates undesirable contaminant residues. For this reason, carbon steel cannot be directly used where it may cause contamination to the product. In these cases, other alloys or coatings of more resistant materials, metallic or non-metallic, are applied on the carbon steel in order to provide protection at reduced costs. Such is the case of stainless steels [3] that are easily weldable. In particular, austenitic stainless steels are used for construction and anti-corrosion coating of carbon steel equipment and piping. For other stainless steels, such as ferritic and martensitic
their use as structural steel or welded steel is not recommended, except for some ferritic steels with a chromium content of up to 17%, which have acceptable weldability and have a coefficient of expansion close to that of carbon steel [4].

The advantage of a metallic coated material is that the final product combines the superior properties of both coating and base material in terms of mechanical strength, corrosion resistance, low weight, lower cost and thermal and electrical conductivity such combination produces a material which is superior to either one of the two metals [5].

The most common metal coating process is cladding, where the clad materials consist of a plate of metal or alloy, resistant to corrosion as a coating, and protecting another metal, which has a structural function and can be applied by pressure, lamination, welding or explosion [6].

The selection of the welding process for coating is as important as the selection of the alloy. In-service performance requirements are not dictated solely by alloy selection but are strongly influenced by a well-selected welding process. Other technical factors involve process selection, including coating properties and quality as well as the physical characteristics of both parts. The metallurgical properties of the base metal, the shape, and composition of the coating alloy, and the ability of the welder [7] are also other relevant factors in the processing operation.

One of the most important variables that must be observed in the case of the welding associated with a coating of carbon steels with stainless steels is the control of the percentage of dilution. Dilution rates should be controlled and adjusted to ensure final coating quality, such as maintenance of mechanical properties and corrosion resistance, as well as the proper geometry of the weld bead [7,8].

One of the main metallurgical problems found in welds of dissimilar metals is the formation, along the interface of the melting line, regions that can reach hardness higher than 400 HV, which would indicate the presence of martensite and, therefore, of brittle characteristics of the microstructure [9]. As a form of prevention some, studies suggest that the material should be preheated to a temperature of 25 °C or more [8–10]. Thus, this work has the objective of evaluating the mechanical and microstructural properties of the dissimilar coating of AISI 316L stainless steel, on a ASTM A516 Gr carbon steel weld as an innovative structural material.

2. Materials and methods

In this work, two samples of 25 mm thick ASTM A 516-06-70 [11] carbon steel plates, each with 200 mm wide and 500 mm long, were used. These plates were then joined by top weld. The welding position was flat 1G, following the guidelines of the ASME IX standard [2]. Table 1 shows the chemical composition of the steel.

The process for joining the plates was performed by submerged arc welding (SAW) and the weld bead received a coat of AISI 316L stainless steel, deposited by electroslag.

After the welding step, tensile and hardness tests were performed. The tensile test was performed according to ASTM-A 370 [12] and the test specimens were tested in a VEB WPM 100 Mp, 1974 model universal hydraulic test machine with scale up to 40 Ton. The hardness analyzed was Vickers, following the guidelines in ASTM E 92 [13]. For hardness measurement in the cross-section, the specimen was prepared according to ASTM E 340 [14]. The tests were performed at room temperature (25 °C) using a load of 10 kgf, with a loading time of 10-15 s. It was also used, as reference for evaluation, the standard PETROBRAS N-133 Revision J [15] and the required value was ≤248 HV.

The samples for metallographic analysis were initially cut, polished emery paper and cleaned with ethyl alcohol. Subsequently, they were polished with a diamond paste of 3, 2.5 and 1 μm and ethyl alcohol was used as a lubricant. The Murakami solution was used as a reagent to reveal and color the surface making it possible to observe the microstructure that was observed under a Zeiss optical microscope.

3. Results and discussion

Table 2 shows the results obtained by traction in the samples. The tensile strength limit values for SA-516-70 steel found in this study are above the minimum values required by ASME which is 49.45 kg/mm². In addition, the tests showed that the fracture in the specimens displays ductile appearance and occurred in the weld bead.

Maintaining strength limits with values above the required minimum indicates that there was little or no influence of the dilution between the coating and the carbon steel addition metal. According to Smith [16], depending on the exact composition of the bonded materials, a range of microstructures may be formed in the diluted zone. Moreover, there may be a potential to form a martensitic phase whose hardness can be defined by the melt carbon content from the base metal. The martensite is associated with high hardness, but at the same time to the brittleness of the material. Values very close to or below the minimum resistance limit could indicate the presence of this phase.

Also, according to Smith [16], from the mechanical point of view for applications at room temperature, the interface zone between the dissimilar metals is not of great concern. The tensile strength is high, so there are no common defects in this region.

The results of the Vickers hardness tests are presented in Table 3.

One should note that the Vickers hardness values obtained were below 248 HV, the minimum required by NACE MR0175 norm [17]. According to this norm, Vickers hardness values above 248HV indicate that the steel is susceptible to stress corrosion. The values found in this study, below the indicated value, suggest that this innovative carbon steel coated with AISI 316L stainless steel can be used in corrosive environments such as acidic atmosphere or even salty water.

Fig. 1 shows the variation of the hardness values found along the cross-section.

It is possible to verify that the highest hardness values are found in the heat affected zone (HAZ), mainly near the upper face. This region is where the formed fusion puddle is larger and is also receiving coating on the weld bead. In the vicinity of both faces, the lowest values were found in the center of
Table 1 – Chemical composition of carbon steel ASTM A 516-06-70.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>Cu</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Cr</th>
<th>Ni</th>
<th>Sn</th>
<th>N</th>
<th>As</th>
<th>Others a</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by weight</td>
<td>0.22</td>
<td>0.18</td>
<td>0.99</td>
<td>0.018</td>
<td>0.008</td>
<td>0.039</td>
<td>0.02</td>
<td>0.08</td>
<td>0.002</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.002</td>
<td>0.0055</td>
<td>0.002</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

a Traces.

Table 2 – Tensile test on welded samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Width (mm)</th>
<th>Thickness (mm)</th>
<th>Area (mm²)</th>
<th>Maximum load (kgf)</th>
<th>The tensile strength (kgf/mm²)</th>
<th>Fracture</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.70</td>
<td>25.10</td>
<td>469.37</td>
<td>28.000</td>
<td>59.65</td>
<td>Ductile</td>
<td>Weld bead</td>
</tr>
<tr>
<td>2</td>
<td>18.70</td>
<td>25.10</td>
<td>741.88</td>
<td>28.400</td>
<td>60.18</td>
<td>Ductile</td>
<td>Weld bead</td>
</tr>
</tbody>
</table>

Table 3 – Hardness Vickers.

<table>
<thead>
<tr>
<th>Region</th>
<th>Point</th>
<th>Hardness (HV)</th>
<th>Point</th>
<th>Hardness (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base material</td>
<td>1</td>
<td>192</td>
<td>12</td>
<td>206</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>219</td>
<td>13</td>
<td>208</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>219</td>
<td>14</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>212</td>
<td>15</td>
<td>208</td>
</tr>
<tr>
<td>Welding material</td>
<td>5</td>
<td>185</td>
<td>16</td>
<td>201</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>175</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>187</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAZ</td>
<td>8</td>
<td>191</td>
<td>17</td>
<td>208</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>199</td>
<td>18</td>
<td>212</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>212</td>
<td>19</td>
<td>199</td>
</tr>
<tr>
<td>Base material</td>
<td>11</td>
<td>190</td>
<td>20</td>
<td>204</td>
</tr>
</tbody>
</table>

The weld metal, and for the base metal, the values found near the bottom face are larger than those of the top face.

According to Modenesi [18], the higher hardness levels found in ZAC can be justified by the increase in the hardenability of the coarse-grained region, due to the increase in the austenitic grain size. This region is characterized by a microstructure rich in acicular constituents such as bainite and martensite. Thus, the ZAC tends to be the most problematic region, being able to present high hardness, loss of tenacity and to be a common place for the formation of cracks. These problems are common for steels with higher carbon content since they present high hardenability, high hardness, and high martensite brittleness; and for bonded steels, which have high hardenability.
Fig. 2 – Micrograph obtained by optical microscopy. (a) Molten zone of AISI 316L stainless steel, 800× magnification and (b) Molten zone of AISI 316L stainless steel showing the formation of delta ferrite, increase of 800×.

Fig. 2 shows the micrographs obtained by optical microscopy of the coating material on the weld bead.

The micrographs revealed a microstructure of austenitic matrix and delta ferrite in the interdendritic spaces. In addition, the micrographs have shown that the molten zone of the coating material has a structure consisting of delta ferrite, with different morphologies, inside an austenite matrix. The morphologies of the delta ferrite comprise regions of acicular, vermicular ferrite and grain boundary ferrite (Fig. 2a).

The ferrite delta distributed in the austenitic matrix presents distinct morphologies according to its formation during the cooling rate after the soldering process [18,19].

Fig. 2(b) shows an austenitic matrix and the dark-colored dispersed phase, found with different morphologies, corresponding to the delta ferrite formed in the molten zone after welding.

The delta ferrite is beneficial to austenitic stainless steels, minimizing the dissolution of chromium and preventing the unwanted intergranular corrosion in this type of steel.

Thus, the study on the mechanical and microstructural characteristics of the innovative ASTM A516 Gr 70 carbon steel coated with AISI 316L steel welded by the SAW process revealed that the welding process did not negatively influence the tensile strength so little in the hardness of the base metal, indicating that the process of welding by electrodes can be applied in several industrial sectors, such as the manufacture of pressure vessels.

4. Conclusion

- The analysis of the mechanical and microstructural characteristics of the dissimilar metal, a coating of AISI 316L stainless steel on the face of ASTM A516 Gr. 70 carbon steel welded by the SAW process, revealed an innovative material.
- The application of metallic coatings of dissimilar materials on base metals in carbon steel by the electroslag welding process proves to be advantageous, not only because of the lower cost and high productivity but also because of its characteristic of providing low dilution rates, without impairing properties of interest to metallurgical industries.
- The tensile test demonstrated that the mechanical strength properties were maintained, even with the addition of dissimilar material to the base metal.
- Results of Vickers hardness tests showed low values along the cross section that indicate the absence of martensite.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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