Optimizing Tensile Strength and Corrosion Resistance of API 5LX52 Steel Pipe after Repair Using MMAW

Keyvan Seyedi Niaki, Mohammad Karim Kheradmand Vojdan, Seyed Ebrahim Vahdat

Abstract
In the present study, the effect of multiple repairs on the microstructure and, thus, strength and corrosion resistance of API 5LX52 steel is investigated using manual metal arc welding (MMAW). To this end, four sets of specimens were utilized for the tensile and corrosion tests: control, once-, twice- and three-time-repaired specimens. The result showed that strength was decreased by repeating the repair. Also, the corrosion resistance of the twice-repaired specimen was higher than that of other repaired specimens. Therefore, considering maximum tensile strength and corrosion resistance, the use of micro-alloy electrodes with twice repair is recommended to achieve the best result.

Keywords: Manual metal arc welding; Micro-alloy; Corrosion

1. Introduction
The API 5LX52 pipe is one of the most frequently used pipes in the oil, gas and petrochemical industry and is used for transferring oil products. This steel is a low-carbon micro-alloy, the microstructure of which is optimized using thermodynamic procedures. The above-mentioned process results in the development of strong sediments with various sizes and morphologies, which could eventually enhance strength and corrosion resistance [1]. In oil product transfer engineering, oil and gas pipeline fatigue is an important challenge that results in a decrease in strength and an increase in corrosion rate in the parts of the pipes. Pipeline fatigue must be resolved through the repair or replacement of the pipe. Pipeline replacement is highly time-consuming and costly [2]. Therefore, repair is usually performed.

The age hardening procedure at 250°C on X52 carbon steel pipe changes the fracture type from brittle to ductile in welding metal and weld-affected zone. It also increases grain size. The effect of this procedure increases strength up to 500 hrs, but decreases it afterwards. The increase in strength is attributed to the precipitation hardening phenomenon and the decrease in strength shows the increase in precipitation particle size [3-4]. Yield strength and hardness are decreased in the A36 low-carbon steel repaired using butt fusion TIG welding. This change in properties is attributed to the increase in grain size and the area of weld-affected zone [5].

The results of multi-pass welding on an API 5LX70 steel pipe demonstrate that tensile residual stress is created in the center of welding metal along the circumference of the pipe’s outer surface. Maximum stress equals 60% of welding yield strength. Thus, tensile strength and impact resistance are decreased, which is attributed to microstructure changes [6-7].

For X52 seamless carbon pipes which are repaired for multiple times using manual metal arc welding (MMAW), a decrease is reported in corrosion resistance (especially between the base metal and heat-affected zone), yield strength, tensile strength and malleability, which is ascribed to microstructure changes [8].

The above-mentioned studies have pointed to a decrease in API 5LX52 pipe properties after repair, which is attributed to microstructures in all the cases. Although repairing the pipe is faster and less costly, there is no precise evaluation of property change in the API 5L X52 steel after the repair because its relationship with microstructures is not yet clear. The main aim of the present study is to determine and then evaluate the...
relationship between microstructures and tensile strength and corrosion resistance in the pipe after multiple repairs.

Materials and Method

An API 5LX52 steel seam pipe with 16” in diameter produced through sub-powder welding was prepared from the 6th district warehouse of gas transfer operations. This pipe is currently used in high-pressure gas transfer pipelines. The mentioned steel is a low-carbon micro-alloy with high strength. The chemical composition was determined through light scattering spectrometry using the equipment of Applied Research Laboratories (Switzerland) according to the ASTM E415 [9]. The results are presented in Table 1.

Table 1 Chemical composition of St37

<table>
<thead>
<tr>
<th>Element</th>
<th>Fe</th>
<th>C</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Mn</th>
<th>Ni</th>
<th>Nb</th>
<th>Al</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>0.16</td>
<td>0.30</td>
<td>0.001</td>
<td>0.013</td>
<td>1.09</td>
<td>0.02</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

The pipe was repaired through MMAW using a Pars 630 welding machine (Iran) with the maximum capacity of 400 A according to the API 1104 [10]. The electrode types used in this study were E6010 (3.25 mm in diameter) for the root pass and E7010 (4 mm in diameter) for the other passes, and their chemical compositions based on the ASME SEC II [11] are listed in Table 2.

Table 2 Chemical composition Wt% of E7010 and E6010 electrodes

<table>
<thead>
<tr>
<th>Electrode</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>E6010</td>
<td>0.20</td>
<td>1.20</td>
<td>1.00</td>
<td>-----</td>
<td>0.30</td>
<td>0.20</td>
<td>0.30</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>E7010</td>
<td>≤0.12</td>
<td>≤0.6</td>
<td>≤0.4</td>
<td>≤0.03</td>
<td>-----</td>
<td>0.4-0.65</td>
<td>----</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussion

The metallographic specimens were prepared according to the ASTM E3 [15]. In Figs. 1 and 2, the light and dark phases are pearlite and ferrite (background), respectively.

![Figure 1 FESEM image of phase A](image1)

![Figure 2 FESEM image of phase B](image2)

The metallographic specimens were prepared according to the ASTM E3 [15]. In Figs. 1 and 2, the light and dark phases are pearlite and ferrite (background), respectively.

Based on energy dispersive spectroscopy (EDS), A and B particles in Figs. 3-6 are the transfer-carbides because they contain 10.94-19.32 A% of carbon.
Grain size was measured according to the ASTM E112 [16] and the contents of ferrite and pearlite were calculated according to ASTM E 883 [17], as presented in Table 3.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Corrosion rate</th>
<th>Grain size</th>
<th>Ferrite content</th>
<th>Pearlite content</th>
<th>Tensile strength</th>
<th>Yield strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>13.15 mpy</td>
<td>11.4 μm</td>
<td>70 V%</td>
<td>30 V%</td>
<td>558 MPa</td>
<td>465 MPa</td>
</tr>
<tr>
<td>1 repair</td>
<td>14.28 mpy</td>
<td>11.8 μm</td>
<td>63 V%</td>
<td>37 V%</td>
<td>552 MPa</td>
<td>417 MPa</td>
</tr>
<tr>
<td>2 repairs</td>
<td>4.256 mpy</td>
<td>11.2 μm</td>
<td>68 V%</td>
<td>32 V%</td>
<td>550 MPa</td>
<td>425 MPa</td>
</tr>
<tr>
<td>3 repairs</td>
<td>28.52 mpy</td>
<td>11.9 μm</td>
<td>75 V%</td>
<td>25 V%</td>
<td>541 MPa</td>
<td>413 MPa</td>
</tr>
</tbody>
</table>

Based on Table 3, the content increase in pearlite after the first repair (from 30 to 37 V%) could be attributed to the fast cooling in the welding metal. However, the content of pearlite in a ferrite background decreased from 37 to 25 V% from the once- to the three-time-repaired specimen. The reason is that the heat entering in different welding passes from the once- to three-time-repaired specimens increased the time, for which the piece was maintained at grain-growth temperature. Thus, there was enough time for the expansion of grains and decrease of grain size value. The germination of the new phase in the melt occurred at the grain boundary. The total grain boundary length decreased; therefore, the content of pearlite had a decreasing trend with the increase in the repair times.

Strength must increase with the increase in the amount of pearlite and decrease in grain size [18-19]. For instance, based on Table 3, the amount of pearlite was less (25 V%) and its grain size was larger (11.9 μm) in the three-time-repaired specimen. Consequently, its yield strength (413 MPa) and tensile strength (541 MPa) were less than other specimens. The twice-repaired specimen had less yield strength (425 MPa) and tensile strength (550 MPa) than the control. Nevertheless, in this specimen, the amounts of pearlite (32 V%) and grain size (11.2 μm) were less than those of the control (30 V% and 11.4 μm, respectively).

As a result, there was no significant correlation between the amount of pearlite or grain size, on the one hand, and yield and...
tensile strength, on the other hand. To facilitate the comparisons, the above-mentioned variables are compared in Fig. 7. We must look for another variable to find a significant correlation. Therefore, the available alloy elements and their total amount in the welding metal are listed for all the specimens in Table 4.

According to ASTM G3 and ASTM G1 [13-14], the results of the corrosion test in the control and repaired specimens are listed in Table 3 and shown in Fig. 8 for the comparison.

Based on Figs. 8, the decreasing trends in the final strength and yield strengths of the specimens were similar. We expected the strength trend to be decreasing with repeating the repair. Nevertheless, the yield strength of the twice-repaired specimen was slightly (less than 2%) more than that of the once-repaired specimen, the reason for which is ascribed to the error of the tensile test equipment (allowed up to 3%).

The corrosion rates of the specimens are compared in Fig. 8. It was increased compared with the control one with once- and twice-repair. Nevertheless, it was decreased in the twice-repaired specimen (at least 3 times) compared with the other specimens.

The MMAW procedure at ambient temperature and in laboratory conditions created thermal residual stress in the welding piece. Therefore, high-energy points increased corrosion rate. However, the thermal residual stress may be adjusted in the twice-repaired piece, which needs further reason to confirm.

Based on Fig. 8, the total amount of alloy elements, i.e. copper, nickel, molybdenum, chromium, vanadium and niobium, which increased corrosion resistance was higher in the twice-repaired specimen compared to the others. In addition, yield strength and tensile strength were highest in the twice-repaired specimen compared to other repaired specimens since the total amount of alloy elements was the highest. According to Table 2, these elements were resulted from the electrodes.
Conclusion

The present study was aimed to investigate the effects of multiple welding using MMAW on tensile strength and corrosion resistance in an API 5LX 52 steel pipe in order to repair oil and gas transfer pipelines. To this end, four sets (four specimens each) were utilized. The findings suggested that in addition to tensile strength, corrosion resistance was higher (at least 3 times) in the twice-repaired specimen than other repaired ones because the amount of alloy elements was maximized with twice repair. Therefore, considering maximum tensile strength and corrosion resistance, the use of micro-alloy electrodes with twice repair is recommended to achieve the best result.

References