Correlated macrostructural parameters of weld and weld current in the SMAW of small pipes†

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Abstract

The present research investigated the effect of increased weld current on the apparent discontinuities, macrostructure, and hardness in the shielded metal arc welding of pipes. Thin, small pipes were butt welded, and the section view of the weld was observed using an optical microscope equipped with an image analyzer. Vickers hardness measurements were also made. The results indicated that the area of the melting zone and the width of the weld at the midpoint of pipe thickness were the appropriate parameters for assessing the weld current. In contrast, the lengths of the columnar grain zone and hardness values were not correlated with the current levels. A moderate current level caused the mechanical properties of the melting zone to become closer to those of the parent metal.

Keywords: Welding; Steel pipe; Hardness; Macrostructure; Melting zone

1. Introduction

Welding is a common fabrication process for developing pipelines, particularly those for transporting fuel gases. These flammable products are distributed in welded pipes, which should be fabricated based on the Standard Welding Procedure Specifications (SWPS) [1-3]. API standard 1104 [1] is the most common SWPS employed in the petroleum industry, particularly where the shielded metal arc welding (SMAW) process is used for pipe connection. This standard focuses on welding large size pipes (e.g., over 2 in). In some countries, natural gases are used in houses as a source of energy for heating and cooking. The gases are distributed by spreading thin, small welded pipes in populated areas. However, the API standard 1104 [1] and other related standards [2, 3] do not thoroughly discuss the welding process of these pipes, particularly the safety guideline for spreading the flammable pipes in populated areas. Investigations on a weld with appropriate mechanical properties and macrostructure free of discontinuities in thin, small pipes is a potential novel research.

In a sound weld, the formation of discontinuities such as incomplete fusion and lack of penetration due to insufficient thermal energy should be controlled. Literature also reveals that high energy sources can cause high temperature gradients, which possibly increases defects such as excess penetration and undercutting. These emerging discontinuities and defects in welds can be mainly attributed to inappropriate sources of thermal energy in the welding process [4-6].

The energy of a heat source is controlled by the current density, voltage, and weld speed [2-6]. Using a higher current density with constant speed in a welding process has become a favorable method among welders because more melted metals are obtained and the operation is faster. This method may raise safety concerns, particularly in thin, small pipes. Inspectors usually control weld beads after each weld operation only by direct observation of weld appearance. This method may not provide enough information about the actual current level or other process variables maintained during weld operation.

Macrostructural and microstructural analyses of a weld may lead to a better understanding of process parameters employed by welders during welding [6-11]. The macrostructural analysis of a weld section combined with visual observations may provide sufficient information for inspectors to check precisely the welds. In the present research, appropriate macrostructural parameters were investigated.

Hardness is correlated with the mechanical strength [12], and this correlation may be used in estimating other mechanical properties, to prevent brittle fractures for instance. When hardness resulting from the treatment of a given material by a given process is established, a rapid and simple means of inspection control for the process is also afforded [13]. Therefore, in the present research, the effect of current density on
hardness compared with the parent metal in the welding of pipes was also discussed.

2. Experimental procedure

Samples 100 mm in length were prepared by cutting a steel pipe with 20.6 mm inside diameter and 3 mm thickness (¾ inch pipes). This size of small steel pipes is the most frequently used in distributing natural gases inside houses. Table 1 provides the chemical composition of this type of steel pipe, which approximately meets the API 5L grade A25 standard. Three sets of samples were welded by manual SMAW at ~60 A (low current), ~80 A (moderate current), and ~100 A (high current). An AWS E6010 type of electrode 2.5 mm in diameter was employed in the welding process, and the weld groove design of weld was square. To assure the repeatability of results, three samples were welded at each run (current status). After welding, the specimens were longitudinally sectioned, ground, and polished. The defects and discontinuities in the samples were visually investigated. The macrostructures of the samples were characterized using an optical microscope equipped with an image analyzer. Hardness was tested by the Vickers method (15.625 kgf) across the midpoint thickness of the pipe in a space of 1 mm.

3. Results and discussion

As aforementioned in Section 1 (Introduction), a sound weld can be characterized by visual inspection, macrostructural analysis, and hardness assessment. The present research aimed to investigate the correlation between these factors and the current level as an important controllable parameter in the weld process.

3.1 Visual inspection

Figs. 1 and 2 show the typical micrographs of samples welded at various current densities. Incomplete fusion was more visible in the samples prepared at the low current level, whereas burn outs and spatters were more apparent in the samples prepared at high current levels. At high currents, a higher heat level is produced and the superheated melted metal disintegrates. The disintegration is caused by the increased spatters produced by the arc pressure. At low current levels, the heat is not sufficient and the cold melted metal cannot properly fill the gaps between the jointed pipes because of its high viscosity.

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Table 1. Chemical composition of welded pipes (wt%).

Fig. 1. Comparison of penetration in the weld roots of samples welded at currents of (a) ~60A; (b) ~80A; (c) ~100A.

Fig. 2. Burn outs and spatters on samples welded at a high current (~100A).
3.2 Macrostructure parameters correlated with the weld current

Fig. 3 presents a typical macrostructure micrograph. The weld zone structure can be clearly distinguished from the base metal. By apparent observation of the melted zone, it can be identified as a columnar grain and equiaxed grain zones. Fig. 4 compares the micrographs of samples welded at various current levels. Increased current density led to changes in the melting zone area. Hence, the total melting zone area and length of columnar grains were examined to control the current during the welding process. Table 2 presents the melting zone areas (“A” parameter) and columnar grain lengths (“B” parameter) obtained using an image analyzer. Any increase in current level led to a considerable increase in the value of parameter “A”. This finding indicated the correlation between the current level and parameter “A”. On the other hand, the current did not significantly affects parameter “B”. Therefore, no correlation existed between the length of columnar grains and the weld current.

Any increase in parameter “A” can clearly be attributed to the net heat input, which may be obtained from both increased current levels and/or decreased weld speed. The current level can be confidently increased by introducing parameter “C”, which was examined correspondingly. This parameter identifies half of the weld width at the midpoint of pipe thickness, as shown in Fig. 3. Table 2 also presents the measurement results of this parameter from which the correlation between the proportionality of parameter “C” and the current levels can be inferred. The correlation indicated that a high current density extended the width of the melting zone in the midline of pipe thickness, and that the solid-liquid interface stood farther from the weld axis.

Table 2. Melting zone areas (A), columnar grain lengths (B), and half the weld width at the midpoint of pipe thickness (C) for pipes welded by various currents, I.

<table>
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<tr>
<th>I (A)</th>
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<th>80</th>
<th>100</th>
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<tr>
<td>A (mm²)</td>
<td>12.25</td>
<td>17.78</td>
<td>27.53</td>
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<tr>
<td>B (mm)</td>
<td>2.11</td>
<td>2.43</td>
<td>2.40</td>
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<tr>
<td>C (mm)</td>
<td>1.30</td>
<td>2.22</td>
<td>2.90</td>
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Fig. 3. Welded pipe macrostructure details.

Fig. 4. Optical micrographs of the macrostructure of samples welded at (a) ~60A; (b) ~80A; and (c) ~100A.
3.3 Weld current and hardness correlation

Hardness was measured for regions lying from the base metal to the weld zone. The average of three hardness trials in the base metal far from the weld (i.e., 30 mm distance from the weld axes) was assessed. An average of 144 HV for the base metal was detected. Fig. 5 shows a typical pattern of hardness against the distance from the weld axes. The hardness had a minimum value in the HAZ region, and increased to the maximum stage at the melting zone. Similar patterns were observed for other current levels, but the minimum and maximum values were different.

The minimum values of hardness as a function of the weld current were investigated. A drop in hardness, which is defined as the difference between the minimum hardness and the hardness of the parent metal, was studied with the current level (Fig. 6). The decline in hardness was ~11 HV at low current, ~35 HV at moderate current, and ~29 HV at high current.

Fig. 7 shows the values obtained for the difference between the maximum and parent metal hardness at various current levels. At moderate current, the maximum weld hardness was closest to the parent metal hardness. This result may be accounted for by the suggestion that this current level was the optimum current level in the welding this size of pipes. Other current levels caused seriously increased hardness, which may increase the risk for brittle fractures.

Figs. 6 and 7 show that hardness was not correlated with current levels. Hence, hardness measurement was not an applicable method for controlling the weld current. However, hardness measurements in the melting zone can be used to identify the optimum current level for the welding process.

4. Conclusions

High weld currents are favorable for welders, and the effects of changing the weld current on apparent discontinuities, macrostructure parameters, and hardness patterns were studied. The parameters correlated with the weld current were also investigated. The following conclusions were drawn:

(1) Visual inspections showed that incomplete fusion is more apparent when welding at low currents, whereas burn outs and spatters were observed at high currents.

(2) Macrostructural analysis revealed that the melting zone area and weld width at the midpoint of the pipe thickness were the appropriate parameters for assessing the weld current. These parameters can be used by weld inspectors to control the performance of welders based on a reasonable welding procedure specification.

(3) Macrostructure and hardness analyses indicated that the lengths of columnar grain zones and hardness values were not correlated with the current levels.

(4) At moderate current levels, the maximum weld hardness was closest to the hardness of the parent metal.

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References


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