MULTI-SCALE CHARACTERIZATIONS (SEM/DRX/EBSD) OF ELECTRIC ARC WELDED OF AN INDUSTRIAL LOW CARBON STEEL

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Abstract

The aim of this work is to highlight various expertise characterizations used in electric arc welded field of an industrial low carbon steel plate, the proposed steel with the chemical composition of %C 0.19 Wt, %Si 0.25 Wt, %Mn 0.40 Wt, %P 0.025 Wt, %S 0.015 Wt, %Al 0.09 Wt, %Mo 0.009 Wt, %Nb 0.05 Wt and %Ti 0.03 Wt. The plates with thickness of 2.6 mm, it is called BS2 and it used in the gas storage manufacture. The electric submerged arc is the welding process used to assembling parts.

This steel is manufacturing by various processes which are responsible for deformations such as mechanical deep stamping and thermal deformation such as welding and annealing.

Note that in this working part, the behavior of thermal deformation that is invested by the proposed characterizations. Essentially the electric arc welding like many other processes causes a noticeable disturbance of the mechanical parameters, as well as micro-structural and also textural character.

The mechanicals properties evolution is reflected by different microstructure and represented by scanning electron microscopy (SEM) and electrons back scattered diffractions (EBSD) characterizations on different specimens which showing clearly the different areas affected by the welding process. And in order to know the main phases in the welding regions, X-ray diffraction (XRD) has been used micro hardness test and tensile test were also performed.

Keywords: Industrial Steel - Characterization - Electric Arc Welding.

1. INTRODUCTION:

Electric arc welding is a classic welding process, which has many advantages in joining of low carbon steel. The shielded metal arc welding under solid flow technique is most adopted in the industrial sector, especially in the field of gas storage assembling.

A uniform microstructure with appropriate volume ratio, geometry and aspect ratio of martensite islands are often assigned suitable for mechanical properties assessments [1]. Dual phase steels are preferred in the automotive industry due to their low density and high load bearing capacity [2]. Dual phase steels mostly have low yield strength, but on the contrary have high strain hardening rates during deformation [3].

The welding operation affects locally the crystallographic texture of the heat affected zone (HAZ) [4]. The heat affected zone, has a great influence on the properties of welded joints since it can alter the microstructure and residual stresses. At high heat input, coarse grains appear in the HAZ which results in lower hardness values in this zone. High heat input and low cooling rates produced fine austenite grains, resulting in the formation of fine grained polygonal ferrites at ambient temperature [4].

In the welding of low-carbon steels, it has been shown that the grain-coarsened (GCZ) and heat affected (HAZ) zones are very critical since embrittlement is concentrated these areas [5]. The weakest mechanical properties are still at HAZ, where inter-granular mode is dominant during fracturing of the material. [5]. Depending on the equivalent carbon content and cooling rate, generally grain boundary ferrite (GBF),
Widmanstatten ferrite (WF), acicular ferrite (AF) and some martensite together with minor amount of retained austenite and dissociated pearlite phases can be seen in the welded metal [6,10-12]. Some occasional formation of bainite in the microstructure has also been reported [12]. However, the decrease in strength associated with the lowering of Carbon Equivalent Value (CEV) needs to be compensated through other strengthening mechanisms such as grain refinement, precipitation strengthening, dislocation strengthening and second phase strengthening. The steel composition and processing schedule need to be optimized accordingly [13].

Nucleation of AF on the other hand is mostly spotted on non-metallic inclusions [14, 15], where they promote strength and toughness of the material [6]. On the contrary, the presence of GBF is detrimental to the toughness [16] where a brittle mode of fracture is mostly found to be related to the amount of WF that forms in the weld metal [6, 17].

In low carbon steels, the embrittlement in the heat affected GCZ (i.e., at peak temperatures above AC3) is primarily associated with the undesired harmful coarse microstructures of GBF and WF that may form after welding [18].

Depending on weld thermal cycle, the metallurgical changes due to the welding way range from over tempering, is resulting in loss of strength, hardness and toughness, to the deformation of undesirable microstructure causing hardening and embrittlement [19].

Moreover, the brittle fracture observable in GCZ is mostly attributed to prior grain size of austenite and formation of non-tempered martensite after fast cooling rates [20]. On the other hand, when maximum temperature reaches between the AC1 and AC3 lines (in the intercritical HAZ), pearlite grains in the original ferrite–pearlite structure before welding will first transform into austenite on heating and further to relatively small grains of ferrite-pearlite, upper bainite, auto-tempered martensite or high carbon martensite on subsequent cooling [21]. Since carbon content of austenite in intercritical HAZ is generally greater than its usual composition [6-5], austenite easily transforms into martensite [22-24]. Alloying elements also increase the hardenability of the steel even at slow cooling rates. Thus, low fracture toughness of the welded metal is associated with the amount of martensite and sometimes of bainite formed in HAZ. Microstructure of low carbon bainite is very similar to that of AF and it is therefore very difficult to identify these phases. It is reported that the presence of AF in HAZ is a benefit [6, 25], however to enhance the toughness considerably, normalization treatment seems to be practically adequate [6]. It has been clarified that during welding of ferritic–pearlitic steels, formation of spherical carbides in HAZ inhibits normal grain growth and therefore improves the toughness of the material [26]. There are several studies of the increase the strength of low carbon steels particularly after welding. Thus, it has been practically recommended to anneal 1020 steel at 650 °C right after the welding operation [27]. After welding, the occurrences of retained tensile stresses in HAZ are also very critical and may deteriorate toughness and fatigue of the material in service. It is therefore a practice to relieve residual stresses in HAZ by appropriate annealing at about 600 °C [6, 28].

2. EXPERIMENTAL PROCEDURES:

The studied material steel is the BS2 commercial steel transformed mechanically and thermally by SNS BAG (Batna-Algeria) Company specialized in gas storage manufacturing.

Chemical composition of base and filler metal for gas storage cylinders is given in Tables 1 and 2, respectively. Samples of the gas storage cylinders were submitted to deep stamping under pressure value equal 200 MPa. They were then arc welded. Steel electrodes were used to deposit the welds using the shielded metal arc welding process.
Table 1 Chemical composition of Base Metal (MB)

<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>Mo</th>
<th>Nb</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>0.19</td>
<td>0.25</td>
<td>0.4</td>
<td>0.025</td>
<td>0.015</td>
<td>0.09</td>
<td>0.009</td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 2 Chemical composition of Filler Metal

<table>
<thead>
<tr>
<th></th>
<th>C %</th>
<th>Mn %</th>
<th>Si %</th>
<th>S %</th>
<th>P %</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>0.06 - 0.12</td>
<td>0.40 - 0.60</td>
<td>0.01</td>
<td>0.025</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Different techniques have been used for this investigation: Scanning Electron Microscopy (SEM) observations of the metal in as received form, after deep stamping welding and annealing were made along of different specimens in order of deformation course for the manufacturing product.

To evaluate the mechanical properties evolution of this steel, Micro-hardness and tensile tests measurement evolution were performed. Specimens were prepared for Electron Back Scattered Diffraction (EBSD) analysis in the standard manner. A Zeiss 940 SEM with a tungsten filament was used. The SEM device is coupled with the automatic OIMTM (Orientation Imaging Microscopy) software, from the TSL Company. X-Ray Diffraction (XRD) was used to determine the main phases in welded steel by using CuKα radiation.

The analysis in the welded joint was performed for samples cut from the HAZ which is the critical area which is symmetric region of the welded zone Figure 1 presents different analyzed zones of welded sample.

![Part of filler metal](image)

**Fig. 1** Different Analyzed zones of welded sample

### 3. RESULTS AND DISCUSSIONS

#### 3.1 Evolution of mechanical properties

![Micro hardness curve values after arc welding and after annealing](image)

**Fig. 2** Micro hardness curve values after arc welding and after annealing of BS2 steel
Micro hardness annealing values in Figure 2 shows a form of parameters restoration relatively of values observed after welded process if we consider the micro-hardness value of BS2 steel at as received state equal 180 Hv (value confirmed by characterization and obtained in BS2 commercial delivering certificate). This type of result has already been met in low carbon steel [29–31].

Micro hardness measurements “Figure 2” show an increase in the hardness of the welded joint region steel. This increase is very strong in the middle part of the Fusion Zone and then tends to stabilize by browsing the HAZ towards the BM.

![Graph showing hardness measurements](image)

**Fig. 3** Tensils Tests of BS2 steel (behavior steel along its path manufacture)

![SEM microstructures of BS2 steel](image)

**Fig. 4** SEM microstructures of BS2 steel (a: base metal in as received state, b: after deep stamping, c: after electric arc welding in fusion zone d: after annealing at 910 °C for 05 min in fusion zone)
SEM pictures in Figure 4b shows elongated grains along the stamping axis due to important pressure of deep stamping load.

3.2 Evolution of micro structural properties.

![Graph showing grain size fraction evolution of metal before and after deep stamping](image)

**Fig. 5** Grain size fraction evolution of metal before and after deep stamping

The EBSD characterizations of Base metal and deep stamping Metal shows that the grain size depends on the level of deformation, the finer grains are obtained after deep stamping process Figure 5.

![EBSD maps showing grain orientations](image)

**Fig. 6** EBSD map–distribution of directions <hkl>/z superimposed to the Kikuchi pattern quality factor at 1000 µm from weld joint axis (transition zone)

By using EBSD observation a fusion line is determined. We observed clearly micro structural difference between Fusion Zone metal zone and HAZ. This transition zone is characterized by bands of coarse grains, where each band of grain has quite the same orientation. In this coarse-grained zone, it seems that the grains tend to grow along a certain preferred crystallographic directions [31].
In order to know the main phases in the welded joints (Weld metal + HAZ), X Ray Diffraction was applied in this region from three ferrite peaks observed in this spectrum: the bcc (110), bcc (200) and bcc (111), we conclude a presence only of ferrite phase. [32].

4 CONCLUSION

This work is a contribution study of the effect of shielded metal arc welding on industrial low carbon steel.

By using these various characterizations we conclude:

- The microstructures in different zones are determined from the base metal to the weld metal and the microstructure of the middle of weld zone is completely different from the heat-affected zone.
- The tensile curves profile of Base Metal and annealing Metal (post-welding- heat treatments) are similar and also the fracture occurs in the same zone. So tensile properties are similar.
- The grain size depends on the level of deformation, the finer grains are obtained after deep stamping process.
- The proposed annealing heat treatment stabilized the mechanical properties of welded joint after welding process.
REFERENCE


