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Experimental Investigation on the Microstructure and Mechanical Properties of Arc Welded Structural Steel Plate EN10025

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***Abstract*— *Structural alloy steel is widely used in engineering application due to its mechanical properties. The fabrication technique employed to weld carbon steel plays a crucial factor in the performance of the welded parts when put into service. In this study, a process of Arc welding on steel EN10025 which fabricated in Libya; in Musrata steel factory was performed to estimate how the mechanical properties and microstructure affected in different specific places after welding. The Rockwell Hardness testing have been carried out for the welded samples. The microstructural investigation was also carried out for the weld metal (WM), the heat-affected zones (HAZ) and the base metal (BM). The test results were analyzed. It is shown that the microstructure results shows large variations in grain size and geometry between the welding zones. The distribution of hardness in all zones was determined. It has been noticed that the hardness value of weld metal rise to around 18% regarding to the base metal value. The main value of the RHc hardness of weld metal was 54 HRc, while the mean value of base metal was 44.5 HRc. Charpy v-notch tests showed a variation in results, however the highest absorbed energy was at weld metal.*

***Keywords*— *Weldability, Microstructure, Hardness, Phase, Constituents.*

I. INTRODUCTION

Welding is a fabrication process whereby two or more parts are fused together by means of heat, pressure or both forming a join as the parts cool. Generally, welding is the preferred joining method and most common steels are weldable. The phase transformation and mechanical properties after the welding process of many steels have been discussed [1, 2]. References [3-5] have discussed the mechanism of the grains growth during the welding of steels. Observations in the welded joints indicate the presence of very large grains near the fusion line and these are oriented along the directions of the heat flow. Regarding the welding of low carbon steels, it has been shown that the grain- coarsened zone and heat affected zone are very critical since embitterment is concentrated in these areas. It is also known that the microstructures and mechanical properties of welded steel are effected by chemical composition. For example, presence of carbon exhibit good welding ability. Several studies have been conducted to better understand the welding prosecco of structural steel. One of these paper in this field of work is prepared by Rajko KejzÏar et al [6]. They stated that the chemical composition of the welds and surfacing welds, which essentially affects their quality, is mostly dependent on the degree of penetration.

TABLE 1. Chemical composition of the base metal

C%	Mn%	Si%	P%	S%	Fe
0.22 max	1.60 max	0.05 max	0.05 max	0.05 max	Bal

Christopher N Mbah et al [7] also investigated the mechanical properties and The chemical constituents and the microstructure of welded joints. They observed that the base metal has better hardness and impact strength compared to the welded joints. Weldability of *reinforcing steel* and compatibility of *welding procedures* need to be considered and closely supervised when manual arc welding of *reinforcing* is required. Libyan local market use many different types of sheet metal to maintenance of some industrial facilities, specifically, metal reinforcement of steel structure warehouse using welding processes. One of the most important of these types is structural steel plate EN10025, which fabricated in Libya; in Musrata steel factory. In this study, a process of Arc welding on structural steel plate EN10025 was carried out to determine how the mechanical properties and microstructure affected in different specific places.

II. EXPERIMENTAL WORK

The base metal used in this study is structural steel EN10025 which fabricated in Libya; in Musrata steel factory where available in the Libyan markets. It is suitable for welding, bolted connections and riveting. It is typically used in the construction of steel warehousing, tools and cutters. The main chemical composition of the base metal given in Table 1.

The work specimen was cut into 180 mm x 50 mm x 8 mm as shown in figure (1). It was cleaned with a steel wire brush and compressed air before they were welded. The welding process was carried out using AC arc welding machine BX1-500 with the parameters of (120 A) current and (30 V) voltage, E6013 - Q3.25. One run in a welding position (right method) was utilized in producing the butt joint as shown in figure (1).

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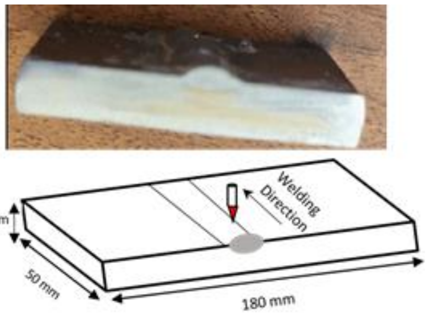

Fig. 1. Typical sample appearance after the welding process morphology analysis

In this work, the microstructural analysis of the weldment has been studied by a light optical microscope (M 100/229).

Microstructure images were analysed using MountainsMap 9 software to evaluate the shape, distribution and appearance of the grains, of welding metal (WM), heat affected zone (HAZ) and the base metal (BM). MountainsMap is a software platform created by Digital Surf Company compatible with most surface imaging, analysis and metrology instruments. It is designed to receive a rich choice of options and provide profile curves and many filtering selections. Microstructures characteristics such as thickness, porosity, pore size, surface roughness and defects.

Rockwell C scale hardness measurement (HRC) was measured under a load of 150 Kg over cross sections on vertical (the welding centreline) and horizontal lines 2 mm distance between each indentation on the sample taken from each welded specimen using ERNST AT-130 (figure (2). The locations of the points of hardness test are shown in figure (3).

Fig. 2. Rockwell Hardness Testing

The Charpy impact tests were carried out using BROOKS MAT20 machine with standard Charpy V notch specimens. Charpy-V sub-sized specimens were used has a dimension of (10 × 8 × 55 mm). Notch locations of the impact test specimens were extracted from the WM, HAZ and BM. The notches were placed at the weld metal (WM), then after 2 mm each for HAZ and BM according to [8].

Fig. 3. Locations of test points of the hardness test samples. Base metal (BM), heat affected zone (HAZ), weld metal WM)

III. RESULTS AND DISCUSSION

3.1. Microstructures

Surface optical microscope images were analysed using MountainsMap 9 software to analyse the variation and distribution of grains in the three different area. MountainsMap is a software platform created by digital surf company compatible with most surface imaging, analysis and metrology instruments. It is designed to receive a rich choice of options and provide profile curves and many filtering selections.

Figure. 4 shows the optical images of microstructures of various regions of the structural steel arc welded. A comparison of images indicates that the differences in microstructure are easily to distinguishable, which can be identified. Each region has its own different microstructure, and consequently possesses different mechanical properties.

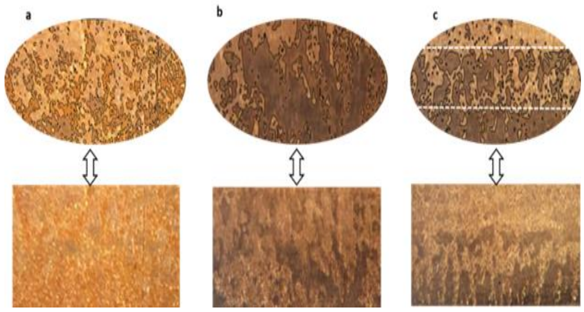

Fig. 4. optical images of microstructures of various regions of the structural steel arc welded. (a) base metal (BM), (b) weld metal (WM), (c) heat affected zone (HAZ).

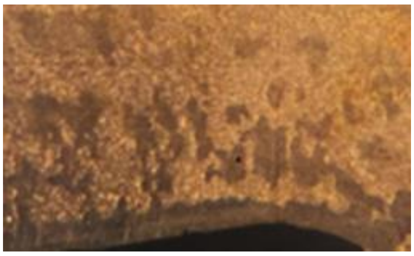

Fig. 5. Variation and defects in Microstructure of HAZ due to temperature difference.

The *optical microscope image* of specimen (base metal) is composed of ferrite and small regions of pearlite (α-Fe + Fe3C) at grain boundary edges and corners as shown in Fig. 4-a. The macro segregation phenomenon, which appear in the micrograph is called banding. This is due to the presence of high percentage of Mn (0.4-0.5%) [9]. This appears to be consistent with the results of Emin *et al* [10-12]. Also, ref [13] stated that the micrograph revealed dark and bright regions which probably indicate the presence of bands of pearlite and ferrite respectively. As a result of using an optical microscope, the (MountainsMap 9) software contributed to clarifying the images. This software allows quite accurate determination of boundary lines gains and other statistics by converting the grey scale image to a binary image. Depending on the temperature reached, the heat affected zone can be divided in to number of sub-regions depending on the material being welded. The image in figure 4-C, shows different grains shapes determined by the welding conditions such as thermal cycle, prior thermal and mechanical history and more importantly the chemical composition of the material. As can be seen in figure 2-c, the grain coarsened region of the HAZ is the region adjacent to the fusion line, where delta phase can be present at the higher temperature in this range. However, Tanka [14] expected high temperature phase is austenite. The final transformation product of this region is determined by many factors such as percentage of carbon and temperature transformation. Cold crack is the most structure defect in this region. It is results from the structure embrittlement [15]. Moreover, the microstructure results shows large variations in grain size and geometry between the welding zones due to temperature gradient as shown in figure (4&5). The black spot in the microscopy represents the inclusion, while the variation at surface in heat affected zone due to slag. These are the basic defects observed in the microscopic analysis of HAZ. This is consistent with the results reported by T. Tadavi *et al* [16]. The image in figure 4-c at the nearest region to HAZ shows the elongated ferrite grains, this results due to direction of heat flow. It is showed that large grains are exist near the fusion line and they are oriented along the direction of large heat flow as shown in figure 6. Such observation was also consistent with the results of K.E. Esterling and Michio Inagaki [17, 18]. In other hand, figure 4-b shows that the weld metal is totally different from the other zones, because it is characterized by pseudo-grains and a microstructural inhomogeneity which is a result of the fastest cooling rates.

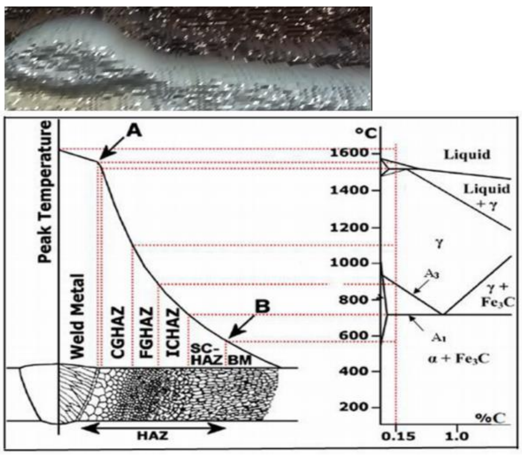

Fig. 6. A schematic diagram of the various sub-regions of the HAZ approximately corresponding to the alloy Co (0.15wt% C) indicate on the Fe-Fe_3C phase diagram reference [17].

It appears that this zone contains mainly ferrite and some colonies of pearlite.

3.2. Hardness

To provide a simple conceptual picture of mechanical properties of structural steel plate EN10025 and associated effects after welding, the hardness and impact toughness were estimated. The hardness values and its distribution in the weld metal, heat affected zone and base metal were observed and presented in figure 7.

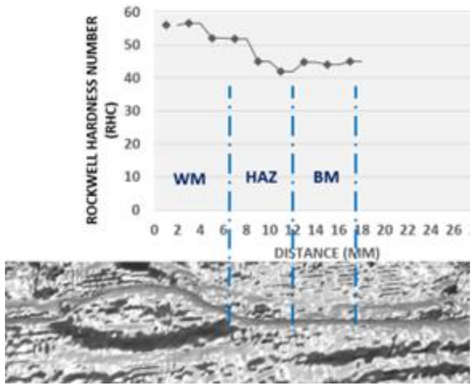

Fig. 7. The distribution of hardness values in weld metal

From the above results, it has been noticed that the hardness value of weld metal rise to around 18% regarding to the base metal value. The main value of the RHC hardness of weld metal was 54 HRc, while the mean value of base metal was 44.5 HRc. This is due to of recrystallization condition and cooling rate. Furthermore, at the base metal zone, there was no heat affect occurred and material compositions also has significant influence in the changes of hardness. In other hand, the hardness of HAZ is fairly close to the base metal, where the grain coarsening occurred at the HAZ interface, the hardness values were decreased.

3.3. Notch impact toughness test

Toughness is defined as the capacity of a material to absorb energy by deforming plastically before fracture. The integrity of a welded structure may be limited by the fracture toughness of the HAZ since it represents the crack resistance of HAZ in industrial applications [8]. The tests were performed at room temperature (~28°C). The results of CVN tests are listed in Table 2.

The Charpy results showed variable and low values in both the base metal and HAZ.

The sample which tested at weld metal contributed the highest impact toughness values of 61 J following with base metal with impact toughness of 52 J and heat affected zone of 47 J. This appears to be consistent with the results of [7]. As can be seen from results with high heat inputs, some reduction in impact toughness in heat affected zone can be observed compared to the results at weld metal, while in base metal are the impact toughness values fairly near the heat affected zone. These differences in toughness are eventually related with the fact that, even at relative low heat input welds and due to the higher ferrite content attributed to the lower heat input during the welding process.

TABLE 2. The impact test results of three locations; (1). Weld Metal (WM) (2). Heat Affected Zone and (3). Base Metal (BM)

Sp. NO	T ºC	Weldment location	Indvisual CVN (J)	Mean CVN
1	~28°C	WM	64	61
2			61	
3			58	
4		HAZ	49	47
5			46	
6			46	
7		BM	53	52
8			51	
9			52	

IV. CONCLUSION

- The study investigated the variations occurred after welding process on the microstructure and mechanical properties of structural steel EN100025 prepared using shielded metal arc-welding process.
- The microstructures in different zones are estimated from the base metal to the weld metal. The *image* of specimen (base metal) is composed of ferrite and small regions of pearlite (α-Fe + Fe3C) at grain boundary edges and corners.
- It has been concluded that the hardness value of weld metal rise to around 18% regarding to the base metal value.

The Charpy results showed variable and low values in both the base metal and HAZ.

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