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Investigation of mechanical properties of low carbon steel weldments for different welding processes

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Abstract Welding process is one of the joining methods of metals. It can be applied in the solid and fusion states. In the fusion state welding, the amount of the heat generated highly affects the quality of weldments from the mechanical properties point of view. To study this effect, three different fusion welding techniques were used to weld low carbon steel samples: Shield Metal Arc Welding (SMAW), Metal Inert Gas Welding (MIG), and Oxy Acetylene Welding (OAW). The mechanical properties of the welded joints were evaluated using mechanical tests such as tensile strength, hardness , and impact toughness. The results showed that MIG weldments have the best mechanical properties among the other welding techniques ,the reason is due to the amount of heat in the welding region in the (MIG) method is much less compared with other welding methods, which makes the size of the heat-affected zone (HAZ) less and thus obtaining smaller grains size in this area, which leads to an improvement mechanical characteristics of the welds.

Keywords:. (Low carbon steel; Mechanical properties; MIG welding; Mild steel; OAW; SMAW).

1 Introduction

1.1 Low carbon steels: Plenty of engineering applications adopt plain carbon steels as engineering materials for designing different parts of these applications. Plain carbon steel is an alloy consists of iron as the main metal and carbon percent not exceeding 1.5 % by weight, and some other elements such as manganese, copper, silicon. In addition to a small percentage of impurities such as sulfur and phosphorous [1-2]. Low carbon steels is a category of plain carbon steel categories which contains a percent of carbon up to 0.3 %, and characterized by high ductility and medium strength. Having such desirable mechanical properties, low carbon steels are used in many manufacturing processes such as drawing, rolling as well as welding processes [3]. Depending on the carbon content, low carbon steels are classified into two sub-categories:

- Dead mild steel with carbon content between (0.1 - 0.15 %). Dead mild steel has a good ductility; it is used in the manufacture of chains, car bodies, and rivets,
- Mild steel with carbon content between (0.15 – 0.3 % C). Mild steel is stronger than dead mild steel; it is used in forging processes, manufacturing of machine parts and structures [4-5].

1.2 Welding Processes: Welding process is known as the process of joining metals or alloys using heat or pressure or both of them. The outcome is a permanent joint that cannot be dismantled without damaging the two connected parts [6]. Welding methods can be categorized as: solid-state welding, fusion welding.

Two metallic parts are melted to create a welding joint in the fusion welding with or without the adding of a filler metal. Some examples of the fusion welding: electric arc welding, tin welding, gas welding… etc. In the solid state welding, the connection is made as a result of using pressure alone or using heat and pressure together. The temperature in this case is below the melting temperature of the welded metals. Some examples of the solid state welding: electrical resistance welding, friction welding, friction stir welding, explosive welding… etc. [6-7].

1.3 Weldability and welding of low carbon steel: Weldability is the ability of material to be welded; it is considered as an indicator of the ability of welded materials to maintain the same mechanical properties after welding processes compared to the base metal [7].

Low carbon steel has a good weldability. In general, the higher the carbon content the lower the weldability. Low

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carbon content renders the possibility of the martensite phase formation in the HAZ extremely low. Therefore, many of the low carbon steels are easy to weld [5-8].

Many of fusion and solid state welding techniques can be used to joint mechanical parts that are made from low carbon steel. Fusion welding such as: Shielded Metal Arc Welding (SMAW), Metal Inert Gas (MIG) welding, tungsten inert gas welding, and gas welding are commonly used for welding low carbon steels [9].

1.4 Literature Review: Many researchers have studied welding methods and welding factors that are assumed to affect the microstructure and mechanical properties of low carbon steel wedding joints. Bahman and Alialhosseini [10] studied the effects of welding parameters of metal active gas welding on the mechanical properties (hardness, yield stress, and ultimate strength) of low carbon steel plates (0.2 wt. % C). They found that increasing the welding current and voltage with decreasing the welding speed resulted in decreasing the mechanical properties of the weldments. Boumerzoug et al. [11] investigated the SMAW parameters in mild steel weldments (0.19 % C).They claimed that the microstructure of the nugget zone differs from the HAZ, and the maximum hardness values present at the center of the weldments. .Cico et al. [12] performed a study on the effect of welding parameters of manual arc welding and gas metal on the microstructure of mild steel weldments (0.17 % C) . Their results proved the effect of welding parameters on the grain size of the weldments. Another study by Talabi et al. [13] on the effect of SMAW parameters (current, voltage, and welding speed) on the mechanical properties of (0.08 wt. % C) low carbon steel plate reached that increasing the voltage and current of the welding decreased the values of yield strength, ultimate strength, and impact energy and increased the hardness at the welding zone. Also, Ogbunnaoffor et al. [14] studied the effect of SMAW parameters (electrode, current, voltage) on the tensile strength of low carbon steel plate (0.15 wt. % C). They concluded that the values of mechanical properties (yield and ultimate strength) were lower than the case in the base metal. On the other side better percent of elongation was obtained in the weldments if compared with the base metal. Al-Saraireh [15] did experimental investigation on low carbon steel weldments (0.25 % C). He studied the effect of the welding current and voltage on the mechanical properties (hardness, impact toughness. yield stress, and ultimate strength). His conclusions were that increasing the welding current caused increasing in the grain size in the welding zone and reduced the mechanical properties of the welding joints.

Hamd et al. [16] did a research work for studying the reflection of the heat generated during MIG welding on the microstructure and the properties (hardness and impact toughness) of low carbon steel weldments (0.148 % C). They reached that increasing the welding current caused a formation of coarse grains in the welding nugget and heat affected zones and reduced both of impact toughness and hardness of the weldments. Fathi et al. [17] made a comparison between the properties (tensile strength, impact energy, and micro hardness) of mild steel weldments (0.136 % C) using shielded metal arc welding and oxy-acetylene welding techniques. The SMAW weldments had a better micro hardness and impact toughness compared to OAW weldments, while the OAW weldments had a better tensile strength.

Mohanta and Senapat [18] investigated the depth of welding penetration of low carbon steel joints (0.19 wt. % C) welded by manual metal arc welding technique. They summarized their findings as: the depth of penetration increased when the welding speed decreased to an optimum value before started to decrease beyond this value, Whereas Ali and Kh. [19] welded (0.2% C) steel using SMAW and GTAW techniques. They concluded that the heat entering during welding process have significant effect on the HAZ and mechanical properties of the weldments , and it is decreased when welding speed increased.

The current practical work aims to study the effect of three types of fusion welding (SMAW, OAW, MIG welding) on the mechanical properties (hardness, tensile strength, and impact resistance) of circular-section joints of mild steel with carbon percent of 0.244 % C to optimize the properties of the weldments based on the outcomes of the traditional mechanical tests

2 Martial and Methods

Low carbon steel rod was selected as a base metal in this work for its softness and Weldability. The chemical composition of the rod was inserted in Table 1. ARUN Polyspek analyzer (England) was used to analyze the chemical composition of the rod. Then, a small piece of the rod was prepared and etched in Nital for metallography test. Figure 1 shows the microstructure of the rod which represents the typical two phases of a hypo eutectoid steel: ferrite and pearlite. Based on the estimated phase percentages in Figure 1, the carbon content was roughly estimated as 0.25 -0.3 % .

Table 1 Chemical composition of the base metal

%C	%Mn	%Si	%S	%P	%Ni	%Cr	%Mo
0.244	1.460	0.336	0.014	<0.002	0.016	0.204	0.002
%Al	%Cu	%B	%Co	%Sn	%Nb	%Ti	%Fe
0.064	0.06	0.048	0.059	0.084	0.002	0.007	Bal.

Fig. 1 Microstructure of the base metal with estimated (0.25-0.3%C) ,(X160).

There was two stages of the experimental work: welding the preparations using different, previously-selected welding techniques, and preparing of the welded samples for mechanical tests.

2.1 Welding Techniques : After joints preparation (Double V- grove) ,three fusion welding butt joints techniques were used to weld samples of 100 mm in length and 12 mm in diameter: SMAW, MIG welding, and OAW. Tables 2, 3, and 4 show the specification and parameters of the welding techniques.

Table 2 SMAW parameters

Welding Machine	Welding Current	Welding Electrode
Tazaka model:300s	125 A	EWC 235010IN GCO 3.5

Table 3 MIG welding parameters

Welding Machine	Welding Current	Welding Electrode
Tazaka model:300s	119 A	Weld 70 S-6

Table 4 OAW parameters

Welding Machine	Welding Flame	Welding Electrode
Oxy-acetylene equipment	Neutral	Coating of the SMAW electrode (flux)

Fig. 2 (Top to bottom) SMAW, MIG, and OAW joints

2.2 Mechanical Tests

2.2.1 Tensile test :

Tensile tests for the base metal and the weldments were carried out on QUALITEST model: G7-7001-LS100 tensile machine (Made in USA). The testing parameters were: room temperature and 5 mm/minute strain rate.

Three specimens for each test were machined according to the ASTM Standard (E8/E8M 16a).

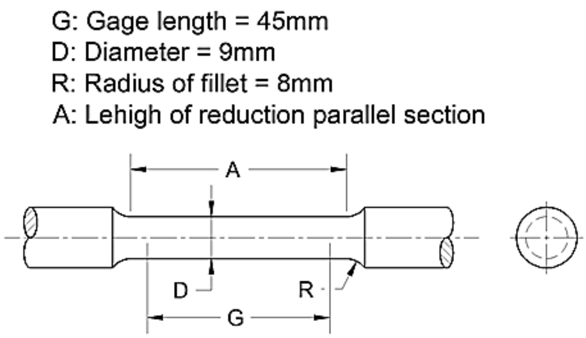

Fig. **3** ASTM Standard (E8/E8M 16a)

Fig. 4 Dog bone specimens of the base metal

Fig. 5 QUALITEST model G7-7001-LS100 tensile test machine (capacity : 100 Ton.)

2.2.2 Impact Test

The impact test for the base metal and the weldments was carried out on Pendulum Impact Tester BROOKS model: MAT21/IT3U (Made in England). Three specimens for each test were machined in accordance with to the ASTM Standard (E23–7a).

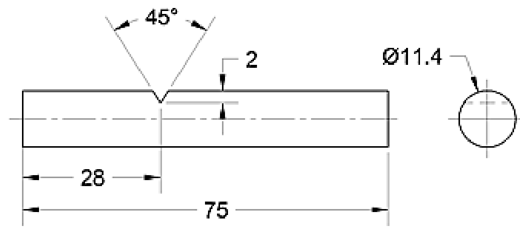

Fig. 6 ASTM Standard (E23-7a)

Fig. 7 Notched specimens of the base metal and welded joints

2.2.3 Hardness Test

The hardness test for the base metal and the weldments was performed on BROOKS Hardness Tester model: MAT24/CRBV (Made in England). Three specimens for each test were subjected to 100 Kgf compression load using an indenter of steel ball and diameter of 1/16 inch in diameter (HRB).

3 Results and Discussion

The heat generated during the welding process highly affects the mechanical and metallurgical properties of the welding zone. The relatively high temperature generates during the welding causes to coarsen the grains in the Nugget Zone (NZ) and the Heat Affected Zone (HAZ) which results in a significant drop in the mechanical properties of the NZ [15- 16].

3.1 Tensile test:

Figure 8 shows the results of the tensile test represented by the values of the ultimate tensile stress (MPa) of the base metal and the weldments. Three weldments of each welding technique were machined into dog bone-shaped specimens (Figure 3) and tested. MIG weldments had the best tensile strength (544.899 Mpa) with joint efficiency (85.573%) compared with other weldments. As the joint efficiency was defined is the ratio between the welded joint tensile strength and the tensile strength of the parent metal [20] , while OA weldments showed the lowest tensile strength which did not exceed (17%) of strength of the base metal.

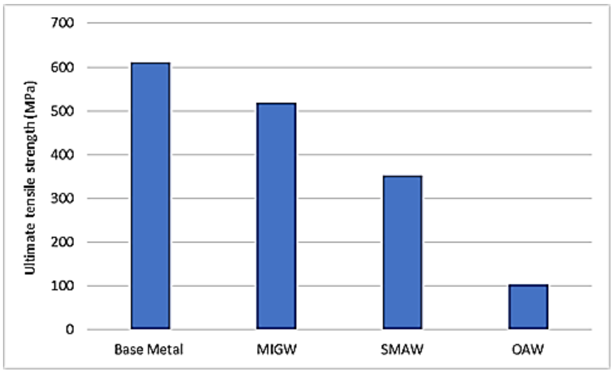

Fig. 8 Tensile strength results

3.2 Impact test:

The results of the impact test were represented in Figure 9. SMA weldments and MIG weldments showed very close values regarding the impact strength comparing with OA weldments. In the OAW, the high amount of heat that inputs the NZ causes excess plasticization and growth in the size of the grains which leads to decrease the impact strength in the welding zone .

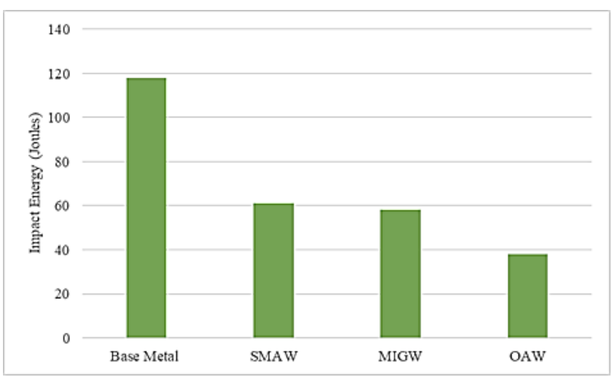

Fig. 9 Impact strength results

3.3 Hardness test:

The hardness measurements (HRB) for the base metal and the weldments were made on BROOKS Hardness Tester. For the base metal, the average HRB value was 88 as shown in table 5. For the weldments, the hardness was measured along each sample starting from the NZ and towards the right and the left with a step size of 2 mm as shown in Figure 10. MIG weldments gave the largest HRB values in the NZ. This can be attributed to the low amount of the heat the inputs in the MIG welding which has the effect of narrowing the HAZ and softening its grains. Hence, the hardness values improves. In the HAZ and the base metal zone the hardiness values of the MIG weldments were very close to those of the SMA and OA weldments. SMA and OA weldments showed close behavior along the three zones. In general the hardness values increase in the welding zone, then decrease in the HAZ. These results are in agreement with Sumardiyanto and Susilowati [21].

Table 5 Base metal hardness test result

Test type	Load (Kgf.)	Indenter	Hardness (average)
Rockwell – scale B	100	Steel ball 1/16 "	88

4 Conclusions

During this work, the mechanical properties of the welding zone was investigated using destructive and non-destructive inspections at room temperature to evaluate (tensile strength, hardness, and impact toughness) of the welded joints. Depending on the local market, three different fusion welding techniques were adopted. There was a difference in the mechanical properties between the three welding techniques. This difference was made by the amount of the heat input which differs in each of the welding techniques. MIG weldments showed the best mechanical properties of the welding zone comparing with the weldments by SMAW and OAW. Among all of the mechanical properties that were evaluated in this work, the biggest drop was in the impact strength of the weldments by the three welding techniques. There was about 50% decrease in the impact strength of the best weldments if compared with the impact strength of the base metal, whereas the MIG weldments have best joint efficiency (85.573%) compared to joint efficiency of SMAW (61.495%) and OAW (16.989 %) .

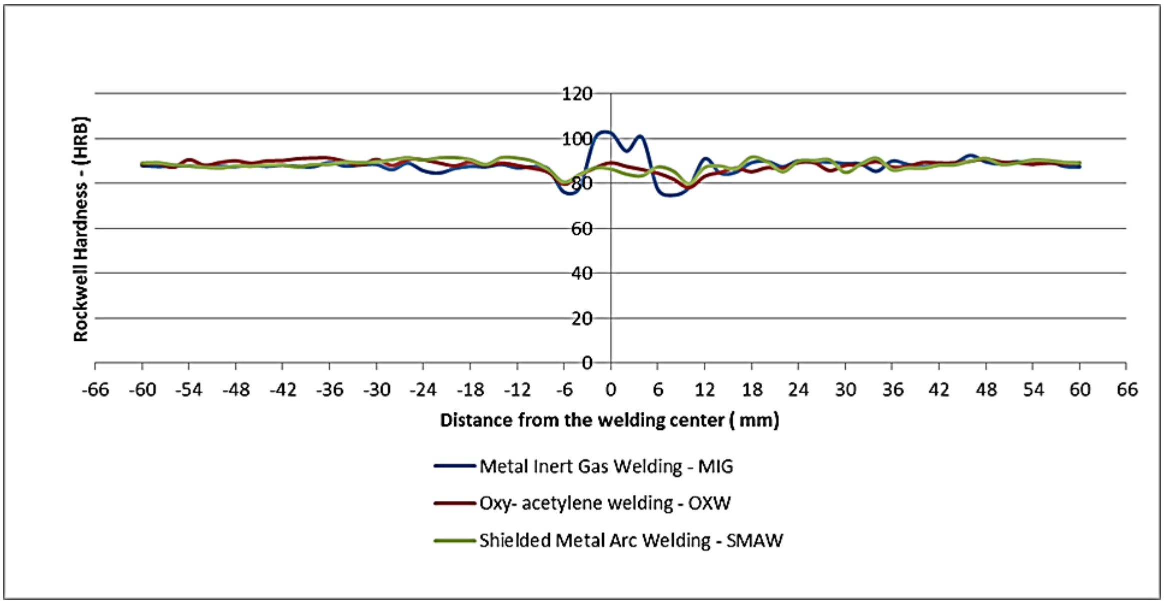

Fig. 10 Rockwell hardness values for the weldments

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