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EFFECTS OF WELDING PARAMETERS ON CHARACTERIZATION AND MECHANICAL PROPERTIES OF STEEL 37 WELDMENTS

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ABSTRACT

Effects of welding parameters on the characterization and mechanical properties of steel 37 weldments were investigated on a single V-shaped groove weld joint. These parameters are; type of electrode, welding current, welding speed, and type of used arc welding and plate thickness. Radiography, metallography and mechanical testing were carried out for the steel 37 weldments.

Results indicated that as the heat input increased, the welding current and plate thickness increased but the welding speed decreased. The grains of the base metal, heat affected zoon (HAZ), root and cap were changed in size and phases in these locations. Radiography showed that no defects were found. The average hardness values were 173 HB at base metal, 175 HB at the HAZ, 180 HB at the cap and 133 HB at the root, respectively. Yield strength, ultimate tensile strength and elongation of the welded steel 37 were in the range between 374 and 425 MPa, between 542 and 606 MPa and in the range between 34.6 and 37.5 %, respectively. Such values tend to increase with increasing the current and heat input and decreasing the plate thickness. The chemical and mechanical properties of the welded electrodes proved to influence the efficiency of the welding process. The best welding results were obtained with current 75 A at the root, 130 A at the cap and welding speed of 1.3 mm/s in the root and 2 mm/s in the cap.

***Keywords**:* Steel 37 - Weldments- Welding variables- Hardness -Tensile strength- Elongation.

1. Introduction

Welding process is used to join hundreds of various commercial alloys in many various shapes by heat or pressure or both. Many welded products could even be made, e.g., nuclear power plants, jet aircraft, pressure vessels, ships, boilers, pipelines…etc. [1-3]. Many problems associated with the welding process can be avoided by properly considering properties and process requirements. Identifying the specific process needs to understand a large number of options available, a variety of possible joint configurations, and the many variables that must be defined for each process [4]. Welding processes can be divided into two major kinds, fusion welding- the widely used method in this process is arc welding- and pressure welding. There are different types of arc welding: flux-cored arc

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welding (FCAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW), shielded metal arc welding (SMAW) and submerged arc welding (SAW) [5]. The type of arc welding depends mostly on the material to be welded.

SMAW process -also known as manual metal arc welding- is used to examine optimum welding current (WI) which is the most important parameter in the arc welding process. WI controls the electrode burn-off rate, the depth of fusion and geometry of the weldment [1, 4].

While increasing the welding speed (Ws) and maintaining constant welding voltage (W_V) and WI will reduce the width of the bead and also increase penetration until an optimum speed is reached at which penetration will be maximum. Increasing the speed beyond this optimum will result in decreasing penetration [5, 6]. If the Ws decrease beyond a certain point, the penetration also will decrease due to the pressure of the large amount of weld pool beneath the electrode, which will cushion the arc penetration force [7].

So using the control system in arc welding can remove many of the guess work that workers often use to determine welding factors for a particular task [4]. Heat input (HI) of the welding played an important role in the microstructure of the joints. However, more attention should be given to the effect of HI of the welding on the properties of the area heat affected zone (HAZ), as the weakest area, rather than the base metal (BM) welding [3, 8, and 9].

The main objective of this work was to investigate the effects of welding parameters on the characterization and mechanical properties of steel 37 in single V shaped groove weldments.

2. Experimental work

2.1. Materials

Steel 37 and many kinds of electrodes were applied during the welding process. The chemical analysis and mechanical properties of steel 37 (base metal) are listed in Table 1 [3, 10]. This kind of steel 37 based on carbon percentage means that is suitable for producing bars, plates and structural shapes.

Table 1.
Chemical analysis and mechanical properties of steel 37

Chemical analysis		Mechanical properties	
Carbon, %	0.2	Yield strength, MPa	235
Silicon, %	0.15	Ultimate tensile strength, MPa	360
Manganese, %	0.56	Brinell hardness, BH	110
Phosphorus, %	0.05	Elongation at break, %	25

For the welding process, the applied electrodes in this work are E6010, E7018 and E70S-3. The chemical analysis and mechanical properties for these electrodes are shown in Tables 2, 3.E6010 electrode has deeper penetration, so it used in root welding**,** while E7018 electrode has shallower penetration, so it used in weld metal and cap.

Table 2.
Typical chemical analysis for various electrodes

Elements,% / Kind of electrode and its used	Carbon	Silicon	Manganese	Molybdenum
E6010, (root weld)	0.1- 0.12	0.14-0.3	0.5-0.51	-
E7018(weld metal and cap) in SMAW weld process	0.08	0.35	0.8	0.45
E 70S-3, (GMAW weld process)	0.006 – 0.15	0.45 – 0.75	0.9-0.4	P=0.025, Cu=0.5

Table 3.
Typical mechanical properties for the used electrodes

Property / Kind of electrode	Yield strength , MPa	Ultimate tensile strength, MPa	Elongation at break, %
E6010	$\geq$ 390	470 – 540	-
E7018	$\geq$ 480	$\geq$ 560	26
E 70S-3	$\geq$483	400	22

2.2. Experimental procedures

Many plates with dimensions 150x100x10 mm of steel 37 were prepared to weld with a single V groove butt joint as shown in Figure 1. Two welding technologies (SMAW and GTAW) were used. Joints were made according to the procedural stipulations indicated in applicable code, and may consists of multiple passes as specified on welding procedure specification (WPS) [11]. Manual welding can be carried out using either direct current (DC) or alternating current (AC). With DC WI either positive or negative polarity can be used, so the WI is flowing in one direction. AC WI flows from negative to positive, and in two directional. Power sources for manual welding are either transformer (which transforms the main AC to AC that suitable for welding). In this work, the Miller 9040255, Dig Blue 600 DX apparatus was used.

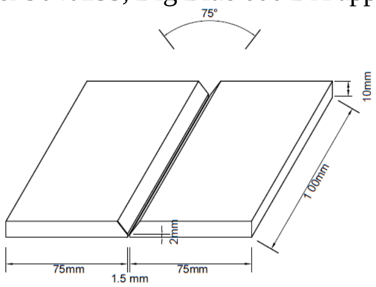


Fig. 1. Sketch of weld edge preparation

2.3. Preparation of the samples for inspection and testing

Weldments were prepared after finishing the welding process to make macro and micro examination. Suitable specimens were prepared with dimensions of 30mm diameter and 20mm thickness. Acidic solution (3 % HNO_3 + 97 % Alcohol (C_2 H_5OH) was prepared to appear the microstructure. The microstructure examinations were carried out by polarized reflected light microscope (Model-OLYMPUS BX51, Japan) supplied with a digital camera (Leica DM500) and four objective lenses of various magnifications. The radiographic test was performed using Iridium 192 to investigate the presence of any internal defects, such as lack of penetration.

The X-rays inspection was used to photo the species & revealed the surface and sub-surface defects and this work was carried out by the X-Ray equipment. X-rays used in the industrial radiography of welds generally have photon energies in the range 30 kV up to 20 MV. The produced weldments were subjected to a series of tests to evaluate some of the mechanical properties such as Brinell hardness (BH) and tensile strength. The BH has been done by using HB test and the specimens for this test were polished [12].Tensile strength test was performed to characterize weld strength by determining Yield strength (YS) and Ultimate tensile strength (UTS) using a universal testing machine on (VH-F1000 kN) SHIMADZU micro-computer controlled electronic, made in Japan, with strain rate 5x10-3 s^{-1} and the specimens were prepared according to ASTM standard test method (the standard width is 10 mm and the gage length is 60 mm) [12].

3. Results and discussion

3.1. The parameters affecting the welding process

Several sets of welding variables were studied for a specific characterization or as a result of the obtained experimental values. These variables include WI, W_V, Ws, electrode kind, HI and plate thickness (Pt) were studied in this work.

The values of these variables were selected within their respective ranges to maintain variability of the variable values and to explore a large range of the welding variables to cover all possible situations as shown below:-

- W_V value was taken 24 V during the welding process. While the WI values were changed from 55 to 85 A at the root and from 110 to 140 A at the weld metal and cap.
- Various plates' thicknesses (6, 10, 15 and 20 mm) were used.
- Ws is defined as the rate of travel of the electrode along the seam. Ws were changed from 0.9 to 2 mm/s in the root and from 1.3 to 4 mm/s in the weld metal and cap.
- HI was calculated according to Eq. (1) [13, 14].

$$\mathrm{HI} = \frac{\mathrm{V\,X\,I}}{\mathrm{Ws}} \ , \mathrm{J/mm} \tag{1}$$

- Welding time (Wt) was varied during welding of all specimens. Ws was calculated for each welded specimen according to Eq. (2) [14].

$$\mathrm{Ws} \ = \frac{\textbf{Travel of electrode}}{\mathrm{W}_t} \ , \mathrm{mm/s} \tag{2}$$

3.3.1. Effect of welding current

The effect of WI on the HI is shown in Figure 2. HI increases significantly with an increase of WI in the root, filling and cap. This results agreed with the results said that as the WI increases, weld penetration and HI increase and verse as WI decreases, weld penetration and HI decrease. WI is the greatest factor affecting the degree of the weld penetration [9, 15].

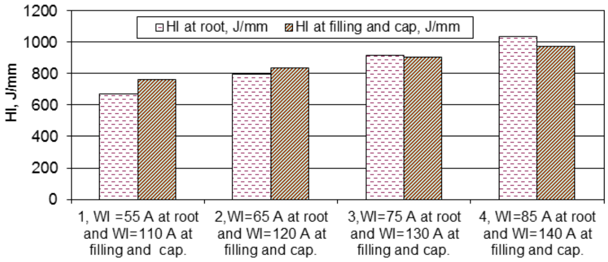


Fig. 2. Effect of welding current on heat input (HI)

3.3.2. Effect of welding speed

The relation between Ws and HI for welded steel at 130 ampere in the cap and filling regions is shown in Figure 3. HI is inversely proportional to the Ws. Therefore, when the Ws decreases the HI increases. This result also achieved in the other studied of WI's in the root, filling and cap regions. So, Ws needs to be adjusted within limits to control the depth of penetration and weld size [13].

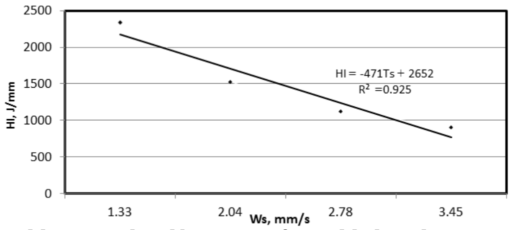


Fig. 3. Relation between welding speed and heat input for welded steel at 130 A in the cap and filling regions.

3.3.3. Effect of plate thickness on heat input

The relation between plates welded using SMAW process at various thicknesses (6, 10, 15 and 20 mm) and HI is shown in Figure 4 at the following conditions (WI= 65 A at the root, WI=125 A at the cap, W_V=24 V and Ws= 2.5 mm/s). The results illustrated that when the Pt increases the HI increases.

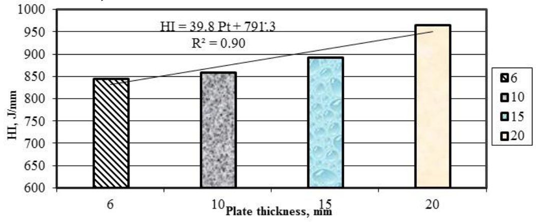


Fig. 4. Effect of HI on plate's thickness at constant WI

3.3.4. Effects of changing the kind of welding process on heat input

In this group, kind of process welding was changed from SMAW to GTAW at the same conditions of current and Ws as shown in Table 4. In this group the Ws at 1.9 mm/s., W_V (24 V), and WI 60-65 A in the root and 120-130 Ain the cap. HI increases when GTAW process was used as compared with the SMAW process at constant values of the following parameters WI, W_V and Ws.

Table 4.
HI of two processes of welding with at constant WI, Wv and Ws

Kind of process	Ws, mm/s	WI, I	Pt, mm	HI, J/mm
GTAW	1.9	$60\text{-}65_{root}$ $120\text{-}130_{cap}$	10	1394
SMAW				1104

3.2. Macrostructure examination

A schematic illustration of bead penetration measurement is shown in Figure 5 and measurement of the width equals 12 mm, size of weld metal equals 11mm, depth of penetration equals 1.5 mm and width of root equals 2 mm.

Fig. 5. Macrostructure of the welded metal

3.3. Microstructure results

The microstructure of the BM, HAZ, root and cap is shown in Figure 6(A-D). The grains of the BM are coarse pearlite and Alpha ferrite as shown in Figure 6A. Alpha ferrite and pearlite form by the slow cooling of austenite, with the associated rejection of carbon by diffusion.

Alpha ferrite and pearlite can begin within a temperature range of 900°C to 723°C, and 1150°C to 723°C, depending on the composition of the alloy [8]. Its characteristics by high ductility and low hardness. But, the grains at HAZ are decreased in size as shown in Figure 6B. Because, the HAZ was heated above A1 (lower critical temperature i.e. 723 ^{o}C) with moderate cooling leads to some of recrystallization causes an internal stress and dislocations. This needs to make partial annealing to remove the dislocation and relief the stresses. Figure 6C at the root, indicates the metal was melted and moderate cooled so there is a few of internal stress and dislocations. The grains at the cap as shown in Figure 6D are a mixture from martensite and bainite that is originated from the overheating caused by welding operation then fast cooling. The cooling rates of bainite was slower than the martensite formation and faster than the ferrite and pearlite formation [3]. Its characteristics by low ductility and high hardness. So annealing after welding or the welds leave to cool in air was recommended.

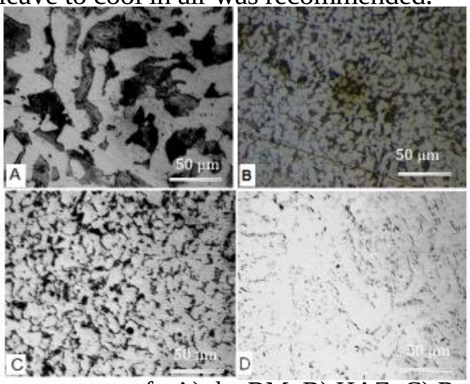
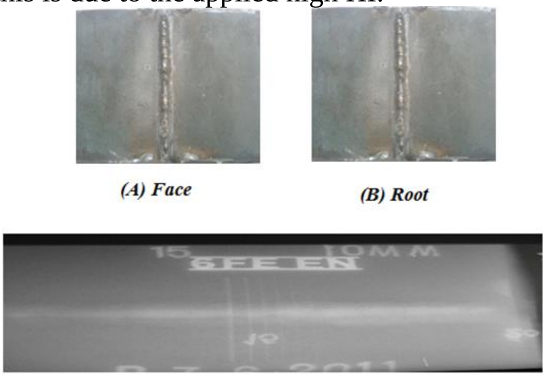


Fig. 6. Microstructure of A) the BM, B) HAZ, C) Root and D) Cap

3.4. Radiographic results

The visual appearance of the face, root weld and photos of radiographic films are shown in Figure 7(A-C). It was found that weldment had the best weld quality with no observed defects, and this is due to the applied high HI.



(C) Radiography

Fig. 7. Weld piece at WI= 110 A at cap, Ws (at face) = 0.9 mm/s and Ws (at root) = 1.3 mm/s.

3.5. Mechanical Properties

3.5.1. Brinell hardness

In order to additionally analyze and confirm weld characteristic changes due to the welding process with various parameters, BH measurements were performed on the welded samples. BH results were processed in 19 points as shown in Figure 8. In general, the BH of this specimen is in the range of 101 to 198 HB. The regions of BH measurements were divided into five regions include BM, HAZ, thermo-mechanical affected zone (TMAZ), cap and root. At BM the average value of BH was found 173 HB. At HAZ the average BH value was 175 HB, while the average BH of the cap and root were 180 and 133 HB, respectively. At TMAZ the average value of BH was found 160 HB. The BH value in the BM in each side of the specimen was observed to be nearly compatible constant throughout the material, but the results of all sides' show incompatibility throughout the material. The difference in these results may be due to using the manual welding.

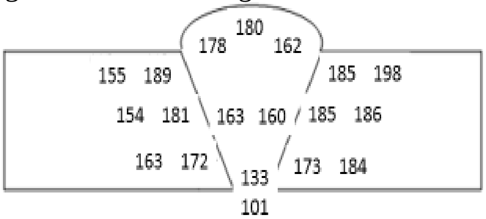


Fig. 8. The BH results on steel welded specimen.

3.5.2. Tensile strength

Steel 37 with various plate thicknesses (6, 10 and 15 mm) were successfully welded at all given welding conditions. The tensile properties for six tested specimens are shown in Table 5and Figure 9. YS of welded steel was ranged between 374 and 425 MPa with an average value of 401 MPa. UTS of the welded steel 37 was ranged between 542 and 606 MPa with an average value of 562 MPa. El of the welded steel was ranged between 34.6 and 37.5 % with an average value of 35.7 %. YS and UTS of the welded steel 37 tend to increase with an increase of WI and HI, and with decreasing the Pt. The UTS has been maximum at WI of 130 ampere in comparison with welded steel 37 at 110 and 120 A. With increasing the WI to 140 A, the UTS still constant and recorded the same value of 130 A (588 MPa). The maximum value of UTS was obtained when Ws was 1.3 in the root and 2 in the cap mm/s. Based on the published mechanical data of steel 37 and electrodes [10], it can be observed that the UTS, YS and EL properties of the welded joints are better if compared with properties the base metal(BM). These improved results may be due to the welding was carried out with suitable electrodes (E7018) that has higher mechanical properties than the BM. This result means that the strength of the welded steel 37 is stronger than the BM.

Table 5.
Tensile properties and welding conditions of various steel 37 welded specimens

No. of specimen	Thickness, mm	Welding conditions		YS, MPa 0.2%	UTS, MPa	EL, %
13	10	HI in root, J/mm	1016	387	569	34.6
		HI in filling &cap	1320			
		WI, A	55 in root 110 in cap			
		Ws, mm/s	1.3 in the root, 2 in cap			
		Wt, s	77 in the root, 55 in cap			
11	10	HI in the root J/mm	796	400	542	35.1
		HI in the filling &cap	835			
		WI , A	65 in the root 120 in cap			
		Ws, mm/s	1.96 in the root, 3.45 in cap			
		Wt, s	51 in the root, 29 in cap			
16	10	HI in the root, J/mm	1116	421	588	37.5
		HI in filling &cap	1248			
		WI , A	75 in the root 130 in cap			
		Ws, mm/s	1.6 in the root, 2.5 in cap			
		Wt, s	62 in the root, 40 in cap			

Table 5. (Cont.)

3	10	HI in the root, J/mm	1571	399	588	35.5
		HI in the filling &cap	1680			
		WI, A	85 in the root 140 in cap			
		Ws, mm/s	1.3 in the root, 2 in cap			
		Wt, s	77 in the root, 50 in cap			
17	6	HI in the root, J/mm	1108	425	606	35.5
		HI in filling &cap	1152			
		WI , A	60 in the root 120 in cap			
		Ws, mm/s	1.3 in the root, 2.5 in cap			
		Wt, s	77 in the root, 40 in cap			
19	15	HI in the root, J/mm	1386	374	478	35.9
		HI in the filling &cap	1560			
		WI , A	75 in the root 130 in cap			
		Ws, mm/s	1.3 in the root, 2 in cap			
		Wt, s	77 in the root, 50 in cap			

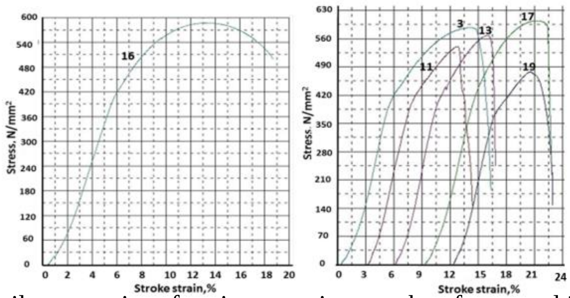


Fig. 9. Tensile properties of various specimens taken from steel 37 weldments.

4. Conclusions

- Heat input was proportional inversely with welding speed, and proportional directly with current, plate thickness and efficiency of the welding process (GMAW was greater heat input than SMAW).
- The chemical composition and mechanical properties of the welded electrodes influence the efficiency of the welding process especially the tensile strength properties.
- The hardness of the welded steel 37 was in the range 101 to 198 HB. The hardness of the cap was higher than the root. Fine pearlite was formed at the HAZ with high hardness. These results are agreed with the microstructure findings.
- The average yield strength, ultimate tensile strength and elongation of the welded steel 37 were 401, 562 MPa and 35.7%, respectively, and tend to increase with increasing the current, and decreasing the plate thickness. UTS have been maximum at welding current of 130A as compared with the welded specimens carried out at 110 and 120 A.

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Nomenclature

Nomenclature		Nomenclature	
A	Current, Ampere	MV	Mega volt
A1	Lower critical temperature	PAW	Plasma arc welding
AC	Alternative current	Pt	Plate thickness, mm
ASTM	American society for testing and materials	SAW	Submerged arc welding
BH	Brinell hardness	SM	Shielded metal
BM	Base metal	SMAW	Shielded metal arc welding
DC	Direct current, Ampere	TMAZ	Thermo-mechanical affected zone
EL	Elongation, %	UTS	Ultimate tensile strength, MPa
FCAW	Flux-cored arc welding	V	Volt
GT	Gas tungsten	WPS	Welding procedure specification
GTAW	Gas tungsten arc welding	Ws	Welding speed, mm/sec
HAZ	Heat affected zone	W_t	Welding time, s
HI	Heat input, J/mm	Wv	Welding voltage, V
MPa	Mega Pascale	YS	Yield strength, MPa

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فحص تأثير متغيرات اللحام علي التوصيف والخواص الميكانيكية للصلب 37

الملخص:

فى هذا البحث تم فحص تأثير متغيرات اللحام علي التوصيف والخواص الميكانيكية لوصلات ملحومة بأخدود مفرد على شكل حرف V للصلب 37. إشتملت المتغيرات التى تم دراستها على نوعين من أنواع اللحام بالقوس الكهربائى وأقطاب كهربائية مختلفة، تيار وسرعة اللحام وسمك الوصلة الملحومة. وقد تم إختبارالبنية العيانية (الماكروسكوبية) والبنية المجهرية والتصوير الإشعاعي والصلادة وقوة الشد والإستطالة للوصلات الملحومة للصلب 37.

أوضحت النتائج أن الحرارة الداخلة تزداد مع زيادة تيار اللحام، وزيادة سمك وصلة اللحام وإنخفاض سرعة اللحام. كما حدث تغير لكل من الحجم والأطوار في مناطق المعدن الأصلي وفي نطاق المنطقة المتأثرة حراريا والجذر والقمة بالوصلة الملحومة. أظهرت نتائج التصوير الإشعاعي التي أجريت علي الوصلات الملحومة التى تم فحصها عدم وجود أى عيوب بها. كانت قيمة الصلادة للمعدن الأصلي للصلب 37 هى 173 بمقياس برنيل للصلادة بينما كانت القيمة فى المناطق المختلفة من الوصلة الملحومة 175، 180، 133 بمقياس برنيل للصلادة فى المنطقة المتاثرة حراريا وفي منطقة القمة وفي منطقة الجذر علي الترتيب. وتراوحت إجهاد الخضوع وإجهاد الشد والإستطالة للوصلات الملحومة للصلب 37 بين 374-425ميجا باسكال، 542 - 606 ميجا باسكال و 34.6 - 37.5 % علي الترتيب، وكانت تلك القيم تزداد مع زيادة التيار والحرارة الداخلة ونقص سمك الوصلة الملحومة.

الكلمات الدالة: الصلب 37 – الوصلات الملحومة – متغيرات اللحام- الصلابة- قوة الشد- الاستطاله.