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EFFECTS OF BEVEL ANGLE AND HEAT INPUT ON TENSILE PROPERTY AND MICROSTRUCTURES OF MILD STEEL WELDMENTS

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Abstract: The effect of bevel angles and welding heat input on tensile property and microstructures of mild steel weldments was carried out. In this study, a pair each of 150 x 50 x 10 mm mild steel specimen with bevel angles of 30^{o}, 45^{o}, 60^{o} and 90^{o}, were manually welded with electric arc welding process. The welded specimens were machined with lathe machine to standard test samples' specification. The weldments and the Heat Affected Zone (HAZ) parts of the welded samples were subjected to microstructural analysis and followed by tensile test. Results showed that the heat input for optimum tensile property at 60^{o} bevel angle is 1361 kJ/mm while at 45^{o} bevel angle has the maximum tensile strength of 410.92 MPa) at yield; maximum ductility; and maximum ultimate tensile strength for as–welded sample. The microstructure has finest grain at 45^{o} bevel angle sample as compared with the as–received base metal sample.
Keywords: Tensile, heat input rate, bevel angle, weldment, electric arc welding

1. INTRODUCTION

Welding is a fabrication process used to join materials, usually metals or thermoplastic by the application of heat, and sometimes pressure [1; 2]. It is usually the most economical way to join components in terms of material usage and fabrication costs, although, it is known to create high temperature gradients around the weld [3;4]. Welding is extensively used in some of these sectors: automobile industry, aircraft machine frames, structural work, tanks, machine repair work, ship-building, pipe-line fabrication in thermal power plants and refineries, oil and gas industries, sugar and cement processing industries, quarries industry, and fabrication of metal structures [5]. The mechanical property such as tensile strength is of great importance to be considered for any fabrication to be carried out, while previous work reported the hardness property of weldments due to bevel angle variation [6]. However, other factor heat input needs to be looked into since a lot of heat is generated during the cause of welding. Apurv and Vijaykumar discussed the effect of heat input on tensile strength, micro-hardness and microstructure of austenitic 202 grade stainless steel weldments. Shielded metal arc welding was employed to weld the austenitic 202 grade stainless steel using 308L stainless steel solid electrode as the filler material. Tensile strength of austenitic stainless steel decreases with increase in welding parameters [7]. A study on tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel showed deteriorate strength because of carbon precipitation and loss of chromium which leads to increase in porosity which affects the quality of joint. The tensile strength of the welded test samples vary from 394 to 459 MPa depending on the welding condition. All the specimens broke in the weld region and percentage of elongation measured across the weldment using an extensometer showed ductility ranging from 4.9% to 6.6% [8; 9].

It has been observed that the joints made by TIG welding have better mechanical properties as compared to SMAW weldments [10]. In the work done by Rakesh and Satish, the microstructure, hardness and tensile strength of weld specimen were investigated in the study. The selected three input parameters were varied at three levels using Taguchi's methodology, which consist three input parameters. Root gap has greatest effect on tensile strength followed by welding current and arc voltage. Arc voltage has greatest effect on hardness followed by root gap and welding current. Microstructure of weld metal consists of fine grains of ferrite and pearlite [11].

The effect of heat input on the mechanical properties of low-carbon steel was studied using two welding processes: Oxy-Acetylene Welding (OAW) and Shielded Metal Arc Welding (SMAW). It was discovered that the tensile strength and hardness reduce with the increase in heat input into the weld. However, the impact strength of the weldment increases with the increase in heat input. Besides it was also discovered that V-grooved edge preparation has better mechanical properties as compared with straight edge preparation under the same conditions. Microstructural examinations conducted revealed that the cooling rate in different media has significant effect on the microstructure of the weldment. Pearlite and ferrite were observed in the microstructure, but the proportion of ferrite to pearlite varied under different conditions [12; 13].

During welding, applied heat and the subsequent cooling-rate influences the mechanical parameters of weldments to some extent [14]. The effect of bevel angle and heat input on hardness property and microstructure of mild steel weldments has been considered [6]. Now, this investigation is carried out to determine the tensile properties for optimum performance of the mild steel weldment as any failure can result in catastrophe in the industries. With a view to achieving this, the tensile and microstructure tests have been carried out to obtain the required information about the effects of bevel angles, heat input rate on the weld zone and Heat Affected Zone (HAZ) for mild steel weldments.

2. MATERIALS AND EQUIPMENT.

The mild steel plate of thickness 10 mm was procured locally and the chemical properties was analysed using EDXRF Spectrophotometer (EDX3600B). Four samples each having the edge preparation at varying bevel angles 30°, 45°, 60°, 90° and a pair as-received were made from the mild steel plates. Each sample consists of two plates having the size 150 mm lengths by 50 mm width before welding. The composition of the base metal is given Table 1.

Table 1: Chemical Composition of Mild Steel

Element	C	Al	Si	P	S	Ti	V	Cr
Content	0.0099	0.1671	0.1795	0.0249	0.0000	0.6115	0.0164	0.0365

Mn	Fe	Ni	Cu	W	As	Mo	Sn
0.4769	98.3978	0.0600	0.0064	0.0077	0.0060	0.0000	0.0094

The following equipment were used for the research: EDXRF Spectrophotometer (EDX3600B) machine for XRF of the base metal, Electric Arc Welding Machine for the welding of the plates samples, Milling machine, Optical Metallurgical Microscope (Nicon Eclipse ME600) having 100x magnification for the microstructures of the samples and Instron 3369 cap 50KN tensile machine for tensile strength test.

3. METHODOLOGY

— Welding Procedure

All the samples were welded manually with electric arc welding machine using MS electrodes at varying currents. Each run was de-slagged by conventional method prior to successive welding runs. The samples were allowed to cool in air. The welding current and arc voltage were taken while time of weld was taken by stop watch. The number of runs for each of the weldments was noted.

— Machining of the Samples

Test samples were milled from the welded specimens in pairs having dimension 50 mm lengths by 40 mm width by 8 mm thickness and 90 mm length by 18 mm width by 5 mm thickness respectively according to the specification (EMDI, Akure) as presented in Figure 1.

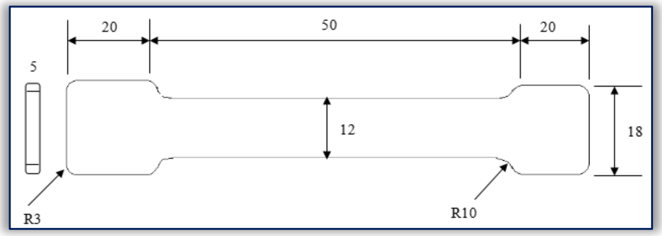

Figure 1: Tensile Strength Sample Schematic Drawing

Figure 2: Machined (milled) tensile and microstructures tests samples

—Tensile Test

Tensile strength was performed on the tensile specimen using Instron tensile machine. The samples preparation, testing procedure and determination of the tensile strength and tensile modulus were in accordance with ASTM D638 as shown in Figure 2 (ASTM International, 2010).

—Microstructures of the welded metal

There was proper study of the metallurgical structure of the weld zone as well as heat affected zone (HAZ) of all the samples. The samples were ground to remove rough surfaces. These were molded with a plastic for proper holding; the surfaces were polished and cleaned by emery paper to remove dirt and finally etched (the weld zone and heat affected zone (HAZ) of all the samples were dipped in 2% Nital agent for etching and finally dried by using blower). The microstructures of weld zone and heat affected zone (HAZ) of all the samples were carried out using Optical Metallurgical Microscope (Nicon Eclipse ME600) having 100x magnification [15].

4. RESULTS AND DISCUSSIONS

The average heat input is shown in Table 1 and the tensile strength in Table 2.

Table 1: Average Heat Input Rate

Sample	Average Heat input rate, H. (kJ/mm)	Percentage Heat Input Rate (%)
Bevel Angle 30°	13.08	25.00
Bevel Angle 45°	13.49	26.00
Bevel Angle 60°	13.61	27.00
Bevel Angle 90°	11.38	22.00

Table 2: Tensile Strength Results for the Various Tests Samples

	30° BV	45° BV	60° BV	90° BV	BM
Area (mm^2)	600	600	600	600	600
Length (mm)	50.00	50.00	50.00	50.00	50.00
Width (mm)	12.00	12.00	12.00	12.00	12.00
Modulus (Automatic)(MPa)	3475.85	3332.71	3189.20	3442.47	2659.56
Energy at Yield (J)	462.21	495.10	360.94	480.98	217.18
Load at Yield (N)	23475.70	24654.93	19100.22	23751.48	15214.63
Tensile Strain at Yield (mm/mm)	0.49	0.51	0.46	0.50	0.37
Tensile Stress at Yield (MPa)	391.26	410.92	318.34	395.86	253.58
Load at Break (N)	18187.36	18917.48	11488.97	20902.98	11830.42
Tensile Strain at Break (mm/mm)	0.68	0.68	0.63	0.60	0.47
Tensile Stress at Break (MPa)	303.12	315.29	191.48	348.38	197.17
Tensile Extension at Break (mm)	34.00	34.00	31.25	29.85	23.65
Tensile Extension at Yield (mm)	24.50	25.35	23.10	25.15	18.55
Tensile Strain at Max. Tensile extension (mm/mm)	0.68	0.68	0.63	0.60	0.47
Tensile Stress at Max. Tensile Extension (MPa)	177.40	177.43	149.48	204.84	118.55
Load at Maximum Tensile Extension. (N)	10643.78	10645.91	8968.90	12290.16	7112.74

where: BV is Bevel Angle, BM is Base Metal As–Received

The 60° bevel angle has the highest percentage heat input of 27% (13.61 kJ/mm); this gave a better grain structure due to slower cooling rate while 90° bevel angles has the lowest percentage heat input of 22% (11.38 kJ/mm) as shown in Table 1; which implied rapid cooling. The heat input influenced the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ. Higher heat input caused slower cooling rate and lower heat input led to faster cooling rate. The heat input increases from 30° to 45° to 60° as shown in Table 1. Metallurgical changes occurred during the cooling from one phase to another which altered the mechanical and microstructural properties of the weldment and the Heat Affected Zone (HAZ) as the rate of cooling will affect the length of HAZ.

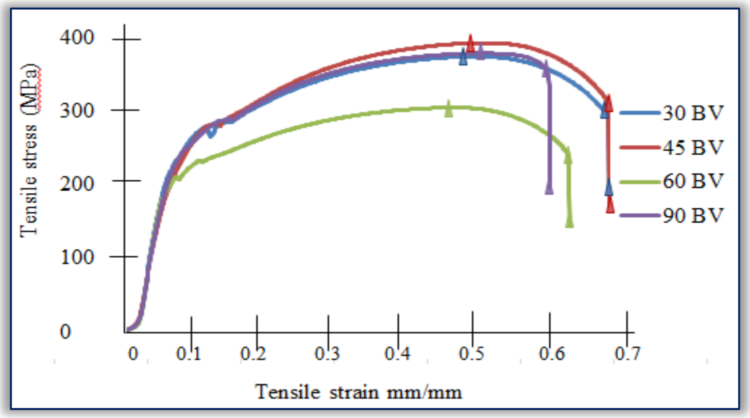

Figure 3: Variation of Tensile Stress for Welded Samples at Different Bevel Angles

— Effect of Bevel Angle on the Tensile Property

From Fig. 3 it can be seen that 45° bevel angle has the maximum tensile strength (410.92 MPa) at yield while 60° bevel angle has the minimum tensile strength (318.34 MPa) at yield for the as – welded sample. Also, 90° bevel angle has the maximum tensile strength (348.38 MPa) at break while 60° bevel angle has the minimum tensile strength (191.48 MPa) at break for the as– welded sample.

The maximum ductility was found to be at 45° bevel angle as–welded sample. The maximum ultimate tensile strength was attained at 45° bevel angle samples.

— Effect of Heat Input Rate on the Tensile of Weld Zone and Heat Affected Zone (HAZ)

It can be deduced in accordance to the mechanical properties that pearlite has properties intermediate to soft, ductile ferrite and hard, brittle cementite (in the micrograph, the dark areas were the FeC_3 layers and light phases were α–ferrite). Variation in volume fraction and the grain size of ferrite was observed in all the Heat Affected Zone (HAZ) microstructures examined. Pearlite phase was equally seen to be present in all the microstructures examined, also observed in the microstructures of HAZ samples were inclusions in form of dark spots which may have resulted from impurities such as moisture and dirt, porosities in form of pin holes which may be due to relative effectiveness of the arc welding process.

Microstructures with different weld profiles due to vary bevel angle during edge preparations were obtained for 30°, 45°, 60° and 90° bevel angles geometries and as–received base metal both for treated. One of the major factors that affect the hardness of the Heat Affected Zone (HAZ) is cooling rate. From the previous literature review, it has been seen that the heat input is inversely proportional to cooling rate [16]. That means as the heat input increases the cooling rate decreases and due to which the concentration of the pearlite increases as shown in Plates 1(a-c);2 (a-c), 3 (a-c), 4 (a-c).

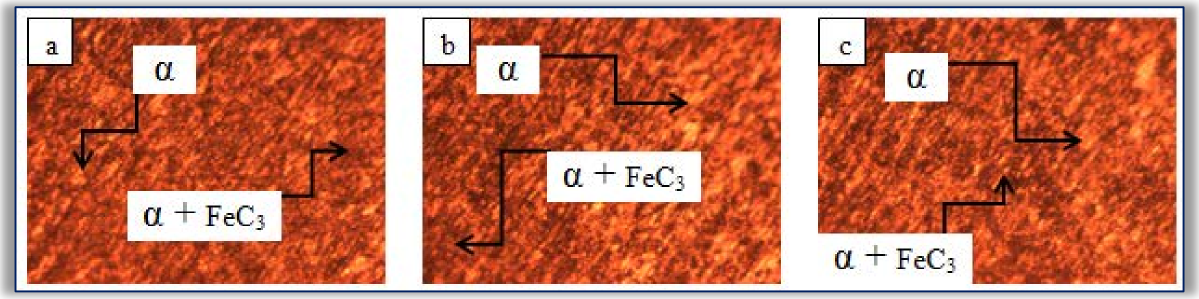

Plate 1. Micrograph of the (a) weldment; (b) HAZ; (c) base metal of 30° bevel angle after etched in 2% Nital solution at magnification 100x

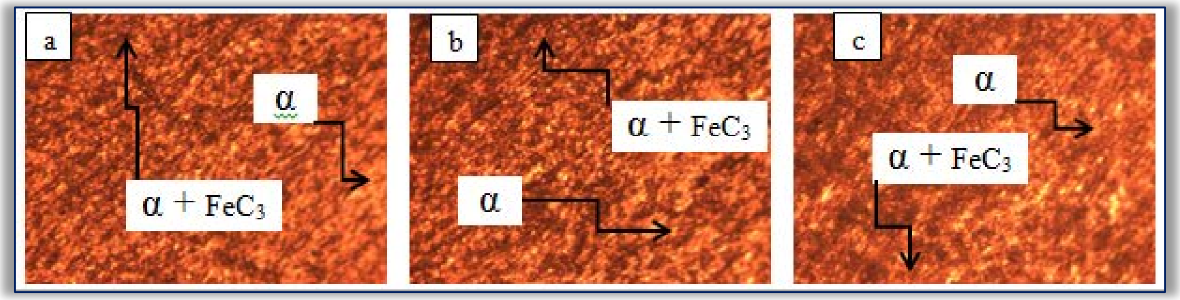

Plate 2. Micrograph of the (a) weldment; (b) HAZ; (c) base metal of 45° bevel angle after etched in 2% Nital solution at magnification 100x

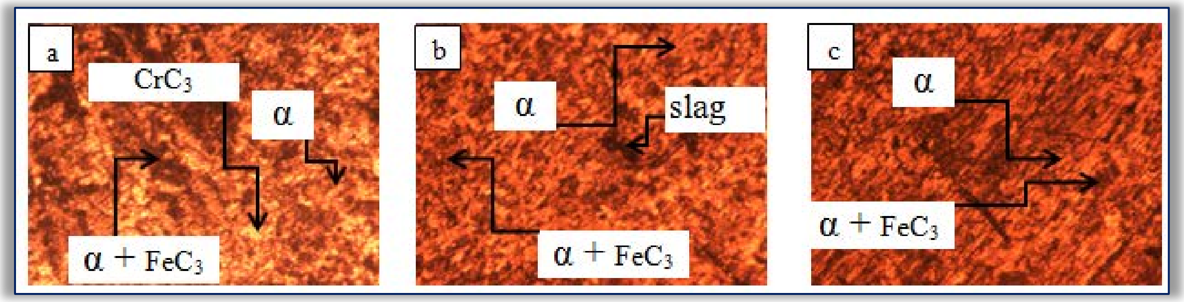

Plate 3. Micrograph of the (a) weldment; (b) HAZ; (c) base metal of 60° bevel angle after etched in 2% Nital solution at magnification 100x

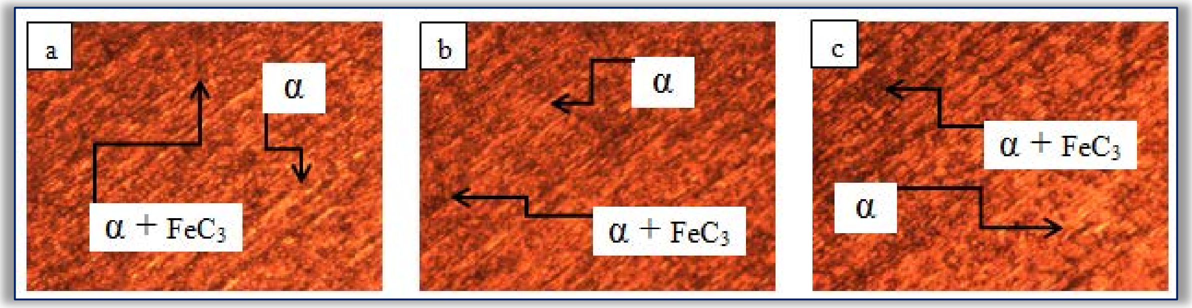

Plate 4. Micrograph of the (a) weldment; (b) HAZ; (c) base metal of 90° bevel angle after etched in 2% Nital solution at magnification 100x

5. CONCLUSIONS

The effect of bevel angles and heat input on tensile property and microstructures of mild steel weldments were investigated; the tensile property and microstructures of welded samples were determined; and these properties were evaluated. The following conclusions were drawn:

(i) At constant voltage, 60° bevel angle has the highest percentage heat input of 27% (13.61 kJ/mm); this gave a better grain structure due to slower cooling rate while 90° bevel angles has the lowest percentage heat input of 22% (11.38 kJ/mm) The finding established that heat input for optimum tensile property of the weldments was 60° bevel angle.

(ii) From the tensile results, 45° bevel angle has the maximum tensile strength (410.92 MPa) at yield while 60° bevel angle has the minimum tensile strength (318.34 MPa) at yield for the as – welded sample. The maximum ductility was found to be at 45° bevel angle as – welded sample. The maximum ultimate tensile strength was attained at 45° bevel angle samples.

(iii) The microstructural analyses showed that the microstructure has finest grain at 45° bevel angle sample as compared with the base metal as – received sample.

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