International Journal of Research in Advanced Engineering and Technology
ISSN: 2455-0876; Impact Factor: RJIF 5.44
Received: 07-08-2019; Accepted: 09-09-2019
www.newengineeringjournal.in
Volume 5; Issue 4; October 2019; Page No. 30-33

Effect of welding parameters on the mechanical properties of arc–welded C1035 medium carbon steel

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Abstract
This study explored the influence of process parameters on the microstructure and mechanical properties of C1035 medium carbon steel weldments prepared using shielded metal arc-welding process. Electrode type (E6013) with gauges 10, 12, and 14 were utilized and the welding current varied in the range 77-211 A at constant welding voltage of 230V. Properties examined were ductility, ultimate tensile strength (UTS), and yield strength. The chemical constituents of the parent metal were analyzed using x-ray fluorescence and the microstructural evolution in the parent metal and weldment analyzed using optical microscope (OM). Results showed that at different electrode gauges, the ultimate tensile strength, yield strength, and percentage elongation of the weldment decreased with increasing welding current. Maximum ultimate tensile and yield strength of 497.801 MPa and 496.04 MPa respectively were obtained using electrode of gauge 14 E6013 (2.0 mm) at welding current of 77 A. This range of properties was guaranteed by the precipitation of widmanstatten ferrite at the transition area. Weldments produced using electrode of gauge 10 E6013 (3.25 mm) at welding current of 173 Amps showed better percentage elongation (7.33%) compared with other weldments, but lower than the parent metal. The results suggest that electrode diameter can influence the properties of steel weldment at different current supply.

Keywords: welding current, electrode diameter, tensile strength, yield strength, ductility

1. Introduction

The unique properties of steel such as excellent ductility, malleability, strength, high yield strength and hardness have made it a very important engineering material mostly used for the fabrication of components such as doors, truck bed, nails, and vehicle bodies, etc. Most engineering components are mostly prepared via casting, fabrication, forging, and welding. Among these engineering production techniques, the welding process is mostly used as it enables joining different materials of different sizes and shapes including guided missiles, jet aircraft, pressure vessels, and nuclear power plants [1]. Apart from the reduction of materials' production cost and time, the welding process is quite flexible, easy to set up and operate. It also enables the production of engineering components with enhanced mechanical properties [2].

In the welding process, the following parameters are paramount: welding current, voltage, and speed; time, temperature, and pulse frequency. These parameters and the electrode composition enhance the properties of the weldment [3, 4]. So, to obtain weldment with enhanced properties and excellent bead geometry, a good combination of welding parameters is very essential. Hence, the recent use of arc welding controls system, for enhancing the proper selection of welding process parameters [5]. In the welding process, initial consideration of joint design and configurations, and the welding process parameters are very essential to obtain appropriate joint of unique properties [6]. Numerous researchers have carried out studies on the effect of welding parameters on the properties of welded joint. Agarwal and Manghnami [7] in their study revealed that the arc column measures about 6000^{o}C across its length and diameter. It is a particularly suitable source of heat energy for welding since its heat is effectively concentrated. This effective concentration of heat energy is due to current density factor. Kim *et al.* [8] revealed in their study the need to properly select optimal welding parameters to provide good weld quality which is identified by its microstructure and mechanical properties. Medium carbon steel has found wide applications in the building industry. One of the applications of medium carbon steel is the construction of bridge beams. The safety factor is a major factor to be considered in the construction of bridges because it involves the lives of the bridge users. The factor of safety depends on the type and quality of medium carbon steel used in building a strong bridge frame. Therefore, there is need for high-quality materials that have good mechanical properties and can withstand high loading forces in building of bridge frame to sure it does not collapse easily during and after fabrication. Study by Adzor *et al.* [9] established that with increasing welding current, the hardness, yield strength, and tensile strength of micro-alloyed steel joints decreased, while both impact strength and percent elongation showed increasing trends. The study also revealed E7016 electrode as the best for excellent hardness, yield and tensile strength, whereas E7024 electrode produced joints of better impact strength and percent elongation. Study by Adedayo *et al.* [10] revealed that with excellent power supply, the toughness of steel joints can improved significantly with corresponding decrease in hardness. Boumerzoug *et al.* [11] revealed that grain characteristics of weld regions significantly improve the hardness of a weld joint.

This study is focused on exploring the influence of welding process parameters on the microstructure and mechanical properties of medium carbon steel weldment prepared via the arc-welding process.

2. Experimental

2.1 Materials

For this experimental study, medium carbon steel (C1035) was used as the base material. Electrodes used were gauge 10 (E6013 (3.25 mm)), gauge 12 (E6013 (2.5 mm)), and gauge 14 (E6013 (2.0 mm)). The equipment used were universal tensile testing machine (model: M500 – 25CT), Leitz Aristomet light optical microscope (Model: 100229), SMAW welding machine (Lorch LS 230), X-ray fluorescent (XRF) analyzer, hacksaw, chipping hammer, wire brush, and pedestal grinder.

2.2 Method

A cylindrical shape medium carbon steel of dimension 4500 mm x 12mm was obtained from Ajaokuta Steel Company Limited and machined into the required dimension 8mm x 150mm. To ensure adequate removal of inclusions, the mild steel samples were properly cleaned and degreased. Double V-groove of 3.2 mm with depth of 4mm was made on each sample to be welded. The welding process was carried out using SMAW machine. One run in a rotary flat welding position was utilized in producing the butt joint. The welding currents, electrode sizes, heat input were varied while the welding speed (2mm/s) was kept constant throughout the entire processes. An arc voltage of 230 volts and open circuit voltage (65V) were maintained throughout the welding process. The heat input was calculated using equation 1.

$$H = \frac{60EI}{1000S} \quad (1)$$

where, H represents the heat input (in kJ mm^{-1}), E equals the applied voltage (in Volts), I represent the current (in Ampere), S equals the speed (in mm min^{-1}).

The weldments were prepared for tensile and microstructural investigation. For each test, three samples were measured and the average results taken. The tensile properties of the weldments were measured using universal tensile testing machine (Model: S/N M500 – 25CT) with the UTS and percentage elongation calculated using equations 2 and 3 respectively.

$$UTS = \frac{\text{maximum load applied}}{\text{Original cross sectional area}} \quad (2)$$

$$\%E = \frac{\text{final gauge length} - \text{the original gauge length}}{\text{original gauge length}} \times 100 \quad (3)$$

The microstructural analysis of the weldment was done using Leitz Aristomet light optical microscope (Model 100229). The specimens underwent the following preparation prior to the microstructural analysis: grinding using 220, 320, 400, 600, and 900 grit sizes of emery paper, polishing using an alumina powder, and etching. After the grinding operation, the specimens were subjected to thorough polishing to ensure even and smooth surfaces. The polished specimens were etched in a solution of 100 ml ethanol and 5 ml nitric acid for 30 seconds, washed with distil water, dried, and viewed using an optical microscope of x400 magnification.

3. Results and discussion

3.1. Mechanical properties of the base metal and mild steel weldments

Tables 1 and 2 depict the chemical constituents of the base metal and welding electrodes respectively. Figure 1 demonstrates the effect of welding currents (77, 96, 115,134, 153, 173, 192 and 211 A) on the UTS of the welded joints using welding electrodes of gauges 10, 12 and 14. Figure 1 showed that at welding currents of 77, 96 and 115 A, only gauge 14 electrode produced weldments. Figure 1 showed that at different electrode gauges, the ultimate tensile strength of the weldment decreased with increasing welding current. Electrode of gauge 14 produced weldment of higher ultimate tensile strength (497.801 MPa) at welding current of 77 A, compared with the parent metal and weldments produced with gauge 10 and 12. Applying welding current of 173 A, electrode of gauge 10 produced no weldment unlike gauge 14 electrodes. With gauge 12 electrodes, weldments showed lower UTS compared with the base metal. Figure 1 showed that gauge 10 and 12 electrodes produced weldment of maximum ultimate tensile strength using welding current of 173 and 134 A respectively. It was observed that the gauge 10 (3.25mm) electrode produced weldment of better UTS compared with the weldments produced using gauge 12 (2.5mm) electrode.

Figure 2 shows the effect of welding currents (77, 96, 115, 134, 153, 173, 192 and 211 A) on the yield strength of the weldments using welding electrodes of gauges 10, 12 and 14. Figure 2 showed that with the welding currents of 77, 96 and 115 A, no weldment was produced using electrodes of gauge12 (2.5mm) and gauge10 (3.25mm). The yield strength values for the three weldments produced were lower compared with the parent C1035 metal. Figure 2 showed the yield strength of the weld joints produced with different electrode gauges decreased with increasing welding current. Gauge 12 electrode produced weldment of maximum yield strength at a welding current of 134 A while gauge 10 and gauge 14 electrodes produced weldments of maximum yield strength at welding current of 173 and 77 A respectively. The weldment show better yield strength at different welding current using gauge 14 electrode.

Figure 3 shows the effect of welding currents (77, 96, 115, 134, 153, 173, 192 and 211 A) on the percentage elongation of the welded joints using welding electrode of gauges 10, 12 and 14. At welding currents of 77, 96 and 115 A, weldments were only obtained using gauge 14 (2.0mm) electrode. Also, the percentage elongation decreased with increasing welding current using different electrode gauges. Figure 3 showed that gauge 14 electrodes produced weldment of higher percentage elongation at a welding current of 77 A.

Table 1: Chemical compositions of the base metal

Element	Composition (wt %)	Element	Composition (wt %)
C	0.348	Nb	<0.005
Fe	98.52	Ti	<0.0010
Si	0.122	V	0.0085
Mn	0.692	W	0.016
P	0.033	Pb	<0.0050
S	0.043	Sn	0.0050
Cr	0.054	Zn	0.011
Mo	<0.0050	Co	0.044
Ni	0.064	Cu	0.33
Al	0.0026		

Table 2: Chemical composition of the welding electrodes

Element		Composition (wt %)	
	G1 0(E6013) (3.25mm)	G12 (E6013) (2.5mm)	G14 (E6013) (2.0mm)
C	0.08	0.08	≤0.10%
Mn	0.45	0.45	0.4
Si	0.18	0.18	0.25
P	0.014	0.014	-
S	0.012	0.012	-
Fe	Bal	Bal	Bal

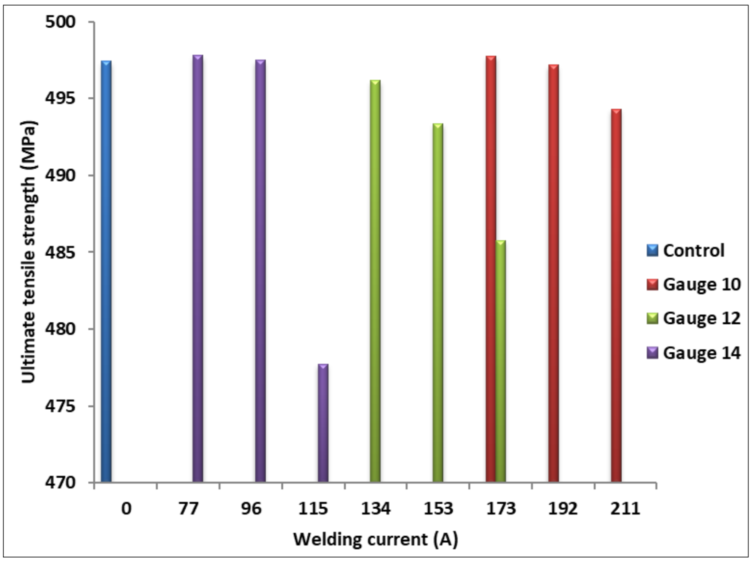

Fig 1: Effect of welding current and electrode size on the ultimate tensile strength of arc-welded medium carbon steel (C1035).

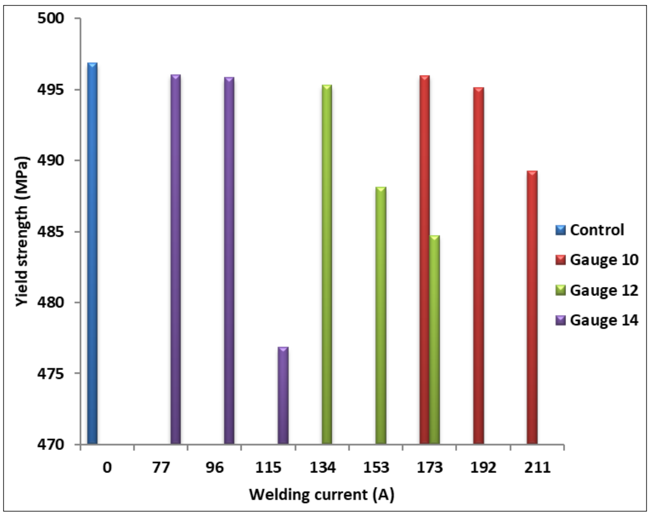

Fig 2: Effect of welding current and electrode size on the yield strength of arc-welded medium carbon steel (C1035).

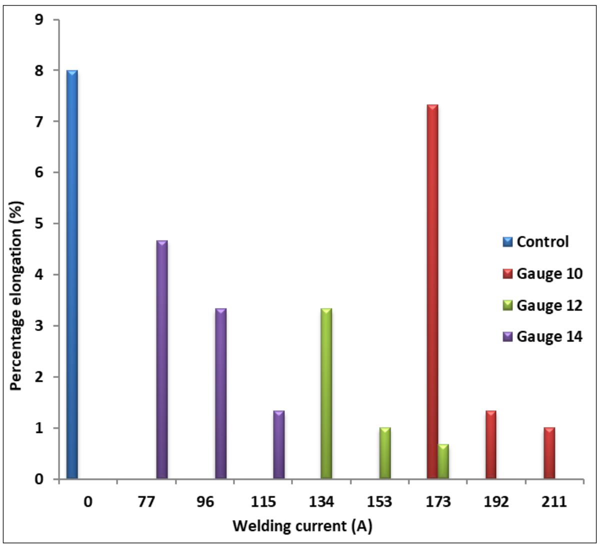

Fig 3: Effect of welding current and electrode size on the percentage elongation of arc-welded medium carbon steel (C1035).

3.2. Microstructural analysis of the base metal and mild steel weldments

Figure 4a shows the microstructure of the unwelded medium carbon steel (control sample). The micrograph revealed dark and bright regions which probably indicate the presence of bands of pearlite and ferrite respectively. Figure 4b-d shows the microstructure of the medium carbon steel welded with electrode of gauges 14, 12, and 10 at welding current of 77, 134, and 173 respectively. The micrograph of the weldment produced using gauge 10 at welding current of 173 A contains more pearlitic structure unlike in Figure 4c and d where ferrite phase dominated.

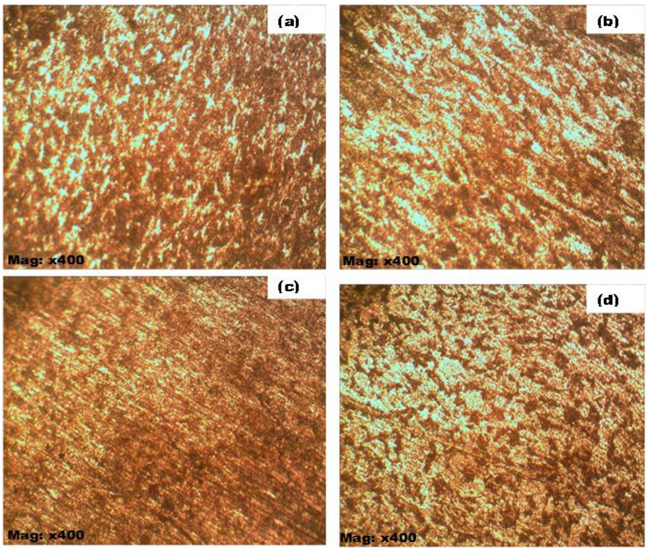

Fig 4: Microstructure of medium carbon steel (C10348) (a) unwelded (b) welded using gauge 14 electrode at welding current of 77 A, (c) welded using gauge 12 at welding current of 134 A, and (d) welded using gauge 10 at welding current of 173 A.

4. Conclusion

This study explored the influence of process parameters on the microstructure and mechanical properties of C1035 medium carbon steel weldments prepared using shielded metal arc-welding process. The UTS, yield strength, and ductility of the welded joints decreased with increasing welding currents using electrodes of different gauges. This was probably induced by the martensitic phase. At higher welding current, the heat input and cooling rate increased correspondingly which induced the formation of martensitic structure. The electrode of gauge 14 produced weldments of higher ultimate tensile strength of 497.801 MPa and yield strength of 496.04 MPa at welding current of 77 A respectively, compared to other electrodes gauges. This was guaranteed by the absence of phosphorus and sulfur in the electrode composition. The weldments produced using different electrodes gauges showed lower percentage elongation compared with the base metal. Among the weldments produced usinf different electrode gauges, weldment produced with electrode gauge 10 gave higher percentage elongation (7.33%), indicating presence of more pearlite zones in the weldment structure.

Acknowledgement

The authors wish to express their sincere gratitude to Engr. Dr. C. N. Mbah for his technical support towards successful completion of this research work.

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