International Journal of Research in Advanced Engineering and Technology
ISSN: 2455-0876; Impact Factor: RJIF 5.44
Received: 06-08-2019; Accepted: 08-09-2019
www.newengineeringjournal.in
Volume 5; Issue 4; October 2019; Page No. 27-29

The hardness and impact strength of arc: Welded C1035 medium carbon steel

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Abstract

This study examined the hardness and impact strength of arc-welded C1035 medium carbon steel at varying welding current, electrode size, and constant welding voltage (230V). The chemical constituents and the microstructure of the parent metal and welded joints were analyzed using x-ray fluorescence and optical microscope (OM) respectively. The results of the analysis indicate that the parent metal has better hardness and impact strength compared to the welded joints. Among the welded joints prepared, joint prepared using gauge 12 E6013 (2.5 mm) electrode at welding current of 173 A showed better hardness (77.3 RHN) while the joint prepared using gauge 10 E6013 (3.25 mm) at welding current of 173 A showed better impact strength (42.5 J). The change in hardness and impact strength of the parent metal was guaranteed by the microstructural evolution that accompanied the welding process.

Keywords: welding current, voltage, electrode diameter, hardness, impact strength, medium carbon steel

1. Introduction

Medium carbon steel remains an important alloy for fabrication of different engineering components owing to their excellent mechanical properties including excellent strength, malleability, ductility, and hardness etc. Various engineering processes such as casting, forging, welding, extrusion, and rolling are mostly employed for fabrication of engineering components, among which welding process is mostly utilized for joining engineering components of different materials and sizes. Engineering components such as pressure vessels, nuclear power plants, guided missiles, and jet aircraft are mostly fabricated using welding process (Howard and Scott, 2005) [7]. The application of welding process enables minimization of materials waste and production cost of engineering components. Welding process is also very flexible and easy to carry out unlike other fabrication techniques without hampering the excellent mechanical properties of the welded materials (Armentani *et al*, 2007) [5].

Studies by Jariyaboon *et al*. (2007) [8] and Afolabi (2008) [3] have shown that the mechanical behavior of steel weldment is mostly influenced by the voltage supply, welding current, pulse frequency, temperature, speed and time of arching. Other parameters that also determine the strength, hardness, and impact strength of steel weldments are electrode composition, type, and gauge. To ensure excellent mechanical properties of steel weldments, appropriate combination of welding parameters through the use of arc welding controls system are paramount (Lee and Um, 2000) [11]. Also initial consideration of joint design and configurations is very essential to obtain appropriate joint of unique properties (Kalpakjian *et al*, 2001) [9]. Study by Agarwal and Manghnami (1991) [4] revealed that the arc column can measure up to 6000°C across its length and diameter, so acts as a source of heat energy for a welding process. Kim *et al*. (2003) [10] established that optimal welding parameters induced formation of appropriate grain characteristics which enhanced the mechanical properties of steel joints. Study has shown that micro-alloyed steel joints prepared via the use of arc welding process showed a decreasing hardness, yield strength, and tensile strength with increasing welding current (Adzor *et al*., 2019) [2]. In the study, E7016 electrode type produced steel joint with better hardness, yield and tensile strength, while E7024 electrode produced joints of greater impact strength and percent elongation. Study by Adedayo *et al*. (2011) [1] established that to ensure improved toughness of steel joint, an appropriate power supply is paramount. Boumerzoug *et al*. (2010) [6] revealed that with excellent grain characteristics, weldment with improved hardness can be obtained.

The quest for the development of weldments of improved essential mechanical properties that could minimize the trending sudden failures of engineering components in industries has necessitated this present research work. This study will help to establish the appropriate combination of welding process parameters and electrode gauge that could produce medium carbon steel weldment of excellent mechanical properties.

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 digital display hardness tester of model: HRS-150 (Rockwell Diamond Indenter Hardness Testing Machine), impact tester (Model: JB-300B), Leitz Aristomet light optical microscope (Model: 100229), SMAW welding machine (Lorch LS 230), hacksaw, chipping hammer, wire brush and pedestal grinder.

2.2 Method

A cylindrical shape medium carbon steel rod of length 4500 mm and diameter 12 mm was cut into specimens of required lengths with a power saw. These rods were cleaned and greased to remove foreign inclusions. The sourced steel rods were reduced to dimensions 30mm x 8mm and 100mm x 8mm for hardness and impact test respectively. 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 process. 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.

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

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 hardness, impact and microstructural investigation. For each test, three samples were measured and the average results taken. The hardness of the welded joints was measured using digital display hardness tester (Model: HRS-150). The impact strength was measured using impact tester (Model: JB-300B).

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 medium carbon steel weldments

Tables 1 and 2 depict the chemical constituents of the base metal and welding electrodes respectively.

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 %)	
	G10(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 shows the effect of welding currents (77, 96, 115, 134, 153, 173, 192 and 211 A) and electrode sizes (gauge 10, 12 and 14) on the hardness of arc-welded C1035 carbon steel. Fig. 1 showed that at increasing welding current, the hardness of the welded joints prepared using different electrode sizes increased correspondingly. The gauge 14 (2.0mm) electrode produced joint with better hardness at welding current of 115 A, while gauge 12 (2.5mm) and gauge 10 (3.25mm) electrodes produced joints of better hardness at welding current of 173 A and 211 A respectively. Among the weldments produced using different electrode sizes at varying welding current, joint prepared using electrode of gauge 12 showed better hardness at welding current of 173 A. The hardness of the welded joints was generally lower compared with the parent metal.

Fig. 2 shows the effect of welding currents (77, 96, 115,134, 153, 173, 192 and 211 A) and electrode sizes (gauge 10, 12 and 14) on the impact strength of arc-welded C1035 carbon steel. Fig. 2 showed a decreasing trend in impact strength of the welded joints prepared using gauge 14 (2.0 mm) electrode, when welding current increased from 77 to 115 A. The impact strength of wel d joints prepared using gauge 12 (2.5mm) electrode showed decreasing trend at increasing welding currents (from 134 to 173 A). At welding current of 173 A, the impact strength of the welded joint prepared using electrode of gauge 10 (3.25mm) was higher compared to the joint prepared using gauge 12 (2.5mm) electrodes. Welded joint prepared using gauge 10 (3.25mm) electrode showed better impact strength compared to other joints at welding current of 173 A. At increasing welding currents (from 173 to 211 A), joints prepared using gauge 10 (3.25mm) electrode showed decreasing impact strength.

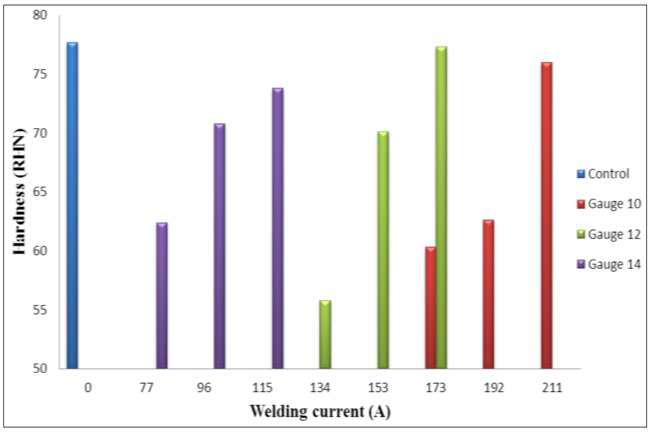

Fig 1: Effect of welding current and electrode size on the hardness of arc-welded medium carbon steel (C1035)

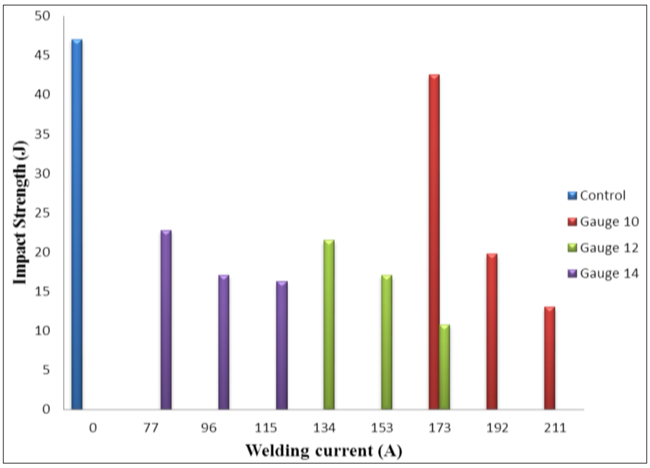

Fig 2: Effect of welding current and electrode diameter on the impact strength of arc-welded medium carbon steel (C1035)

3.2 Microstructural examination

The optical microstructure of the C10348 carbon steel, both in welded and unwelded conditions is presented in Fig. 3. Fig.3a shows the microstructure of the parent (unwelded) C10348 carbon steel. The micrograph revealed even distribution of pearlite, which appeared in the form of white patches in the alloy structure. Figs. 3b-d show the optical microstructure of the C10348 carbon steel welded joints prepared using different electrode sizes at different welding current. The micrographs showed decreasing amount of pearlite which is scarcely distributed in the alloy structure. This probably caused the decrease in hardness and impact strength of the welded joints compared to the parent metal.

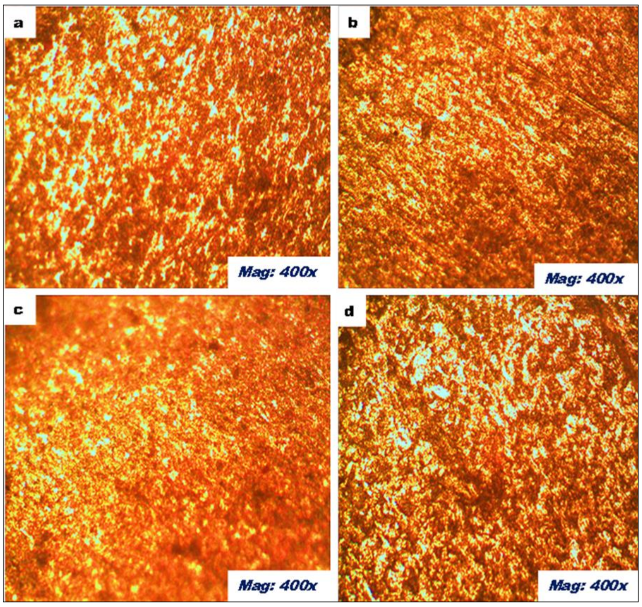

Fig 3: Optical microstructure of C10348 carbon steel (a) parent metal (b) welded using gauge 14 electrode at welding current of 115 A, (c) welded using gauge 12 at welding current of 173 A, and (d) welded using gauge 10 at welding current of 211 A.

4. Conclusion

This study explored the effect of electrode size and welding current on the hardness and impact strength of C1035 medium carbon steel joints prepared at constant voltage of 230 V. The analysis of the study showed that the parent metal (unwelded) has better hardness and impact strength compared to the welded joints. This was guaranteed by greater amount and even distribution of pearlite revealed in the alloy structure compared to the structure of the welded joints prepared using different electrode sizes at different welding current. The study established that at increasing welding current, the hardness of the welded joints increased correspondingly, with the joint prepared using gauge 12 electrode showing better hardness at welding current of 173 A. But at increasing welding current, a decreasing trend in impact strength of the welded joints was noted at which joint prepared using gauge 10 (3.25mm) electrode showed better impact strength compared to other joints at welding current of 173 A.

5. 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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