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Effects of Welding Power Input on the Microstructure and Impact Toughness of the Heat Affected Zone of 304L Austenitic Stainless Steel

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Abstract -The effects of welding power input on the microstructural characteristics and impact behaviour of the Heat Affected Zone (HAZ) of type 304L austenitic stainless steel were investigated. This is with a view to optimize the welding process and ensure high weldment integrity of the heat affected zone. Chemical analysis of the as-received 304L austenitic stainless steel was determined using **an** Optical Emission Spectrometry AR 4 30 metal analyzer. Thereafter, 30 samples of the as-received 304L austenitic stainless steel plate with dimensions of 70 mm length, 45 mm breadth and 8 mm thickness were cut and labelled into A, B and C each of 10 numbers. The grouped samples were further cut into two equal halves with hacksaw and welded using Gas Metal Arc Welding (GTAW) process and 304L electrode to produce butt joint HAZ square geometry samples. The obtained HAZ and as-received samples were machined to standard charpy impact test specimens. Also, the HAZ and as-received specimens were prepared for microscopy studies using optical microscopy. Results obtained showed that the microstructures are composed majorly of mixture of austenite and ferrite phases, also variations in volume fraction and grain size of the phases were observed under varied range of power input. In addition, chromium carbide formation and precipitation due to sensitization was seen at the grain boundaries. Optimum impact toughness (IT) of 42 J was obtained for HAZ sample at power input of 12.0 KW while the least IT of 39 J was obtained from sample welded using power input of 4.6 KW as compared with the as-received with IT of 58 J.

Keywords - 304L austenitic stainless steel, gas metal arc welding, impact toughness, microstructures

1 INTRODUCTION

The type 304L Austenitic Stainless Steel (ASS) is a versatile material whose engineering property has been well acknowledged in various applications requiring welding (Korinko, and Malene, 2001). It is the most weldable of all the 304 series and this has underscored its successful use as structural steel parts in chemical, mechanical, automobile, metallurgical, nuclear, and cryogenic applications such as the handling of Liquefied Natural Gases (LNG) (Korinko and Malene, 2001; Cunat, 2007). However, failures of this material at the welded parts have been recorded in service under static and dynamic loading conditions (Cunat, 2007 and Korinko and Malene, 2001). Generally, metallurgical processes that include alloying and heat treatments have been used to enhance the service integrity of steel materials (Gunaras and Murugan, 2002). However, during welding the microstructure of the welded area are altered in the regions of the Heat Affected Zone (HAZ), which attain temperatures of over 1000° C (Bipin and Tewan, 2010). Hence, neither alloying nor heat treatment prior to the welding process has provided the needed recipe to welded joints failures.

Welding as a local melting-freezing process is known to create high temperature gradients in the metal around the weld (Cunat, 2007; Bipin and Tewan, 2011). Research findings have revealed that the performance of the welded structure is usually limited by cracks initiation within the HAZ of the base material, particularly within the coarse-grain region of the HAZ adjacent to the weldment (Woel-Shyan, Fan-Tzeng, & Chi-Feng, 2005). Hence, the role of HAZs at enhancing weld joint integrity cannot be overemphasized. During welding, weld thermal cycle produces differently featured heat-affected zone (HAZ) microstructures which correspond to different mechanical properties (Gunaras and Murugan, 2002; Akor and Tuleun, 2014; Bodude and Momohjimoh, 2015). Hence if the microstructural changes in the HAZ are not controlled as a result of improper selection of welding variables, the resulting metallurgical structures may be undesirable, and as a consequence, poor weld joint quality may be produced (Bipin and Tewan, 2010; Bodude and Momohjimoh, 2015). Choosing suitable welding variables that will produce balanced (optimum or acceptable) HAZ microstructure is one profound means by which weld joint integrity can be ensured and improved (Eldridge and Morrison, 1994; Akor and Tuleun, 2014). Therefore, adequate and fundamental understanding of the behaviour of 304L austenitic stainless steel under varied welding variables is necessary, if incidences of weld joints failures are to be mitigated. Consequently, this work made effort to investigate the HAZ microstructure and impact toughness characteristics of this material at different ranges of welding power inputs.

2 MATERIALS AND METHODS

2.1 MATERIALS

Type 304L austenitic stainless steel plate sheet of thickness 8 mm was used in this study. The sample was obtained from Universal Steel at Ilupeju, Lagos Nigeria. The chemical composition of the as-received 304L austenitic stainless steel plate was performed using Optical Emission Spectrometry AR 4 30 metal analyzer and the result is shown in Table 1.

2.2 METHODS

2.2.1 Sample Preparation

The as-received 304L austenitic stainless steel (SS) plate was cut with hacksaw into samples of dimensions 70 mm length, 45 mm breadth and 8 mm thickness. Thirty

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samples were produced and grouped into A, B and C, each group containing ten samples.

2.2.2 Welding

Samples with of 50 mm x 45 mm x 8 mm were marked out and cut with hacksaw. Thereafter, one half of the samples were joined to the corresponding ones by Gas Metal Arc Welding (GMAW) process using 304L electrode to produce the square geometry butt joint HAZ samples at a range of welding power inputs range from 4.60, 9.20, and 12.00 KW. Constant parameters used are Square geometry, 304L electrode, 9.20 KW power input, and moderate speed (4.5 mm/s). Welding machine with specifications: GMAW 500; duty 60 % and 24.7 KVA input capacity was used.

2.2.3 Machining

The obtained butt joint samples as well as the as-received sample were machined to shapes with lathe machine to produce standard impact toughness and microstructural test specimens.

2.2.4 Charpy-V Impact Toughness

Specimens for Charpy-V impact test with dimensions 40 mm length, 20 mm breadth and 8 mm thickness (Fig. 1) were made from the HAZ and as-received samples according to ASTM 6100-18 (Oyetunji, 2015). Notches were made on the centerlines to a depth of 2 mm at angle of 45°. The specimens were tested for impact energy at ambient temperature (25° C) while maintaining a uniform striking velocity. The absorbed energy to fracture by the samples was measured.

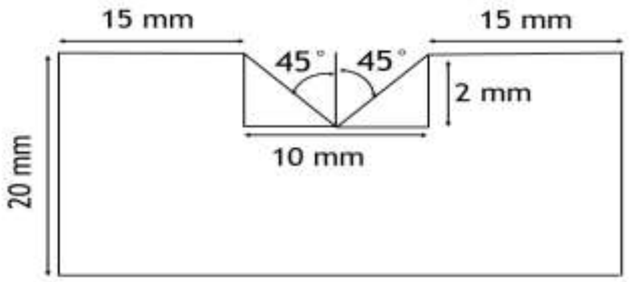

Fig. 1: Impact toughness samples

2.2.5 Microstructural Examination

Specimens for microscopy studies were prepared from the as-received and HAZ samples by machining to dimensions of 10 mm length, 10 mm breadth and 8 mm thickness, they were mounted on thermosetting material known as Bakelite in order to make them convenient for handling. Thereafter, the surfaces of the specimens were flattened by filing and grinding using laboratory grinding and polishing machines with a set of emery papers of 240, 320, 400, 600, 1000 and 1200 microns. The grinding was done in order of coarseness of the papers. As each specimen was change from one emery papers to the other, it was turned through an angle of 90° to remove the scratches sustained from the previous grinding. After grinding, the specimens were polished using rotary polishing machine, to give it mirror-like surface, a polishing cloth was used to polish the surface of the specimens with technic described. The microstructures of the as-received sample and HAZ samples at different power input were examined after etching in a solution of 1ml HCl + 3ml HNO_3 + 1ml glycerol using metallurgical microscope Model- Axio with camera attached at magnification of 400xx.

3 Results and Discussion

3.1 Spectrometry Analysis of the 304L Stainless Steel

The result of the chemical analysis of the 304L stainless steel sample used for this study, is shown in Table 1. From this table, the stainless steel contains about 18 % Cr and 8 % Nickel.

3.2 Effects of Power Inputs on Impacts Toughness of HAZ

Fig. 2 shows the impact toughness characteristics of HAZ samples. The trend observed may be due to difference in volume fraction of austenite phase. This results is in agreement with the statement of Ramazan and Huseyin, (2002) that impact toughness is critically dependent on achieving sufficiently high austenite content. Also Fowless and Blake, (2008) revealed that transition in solidification from austenite to ferrite is related with cooling rather than composition of the austenitic stainless steels, and microstructures with austenite and ferrite phases are produced.

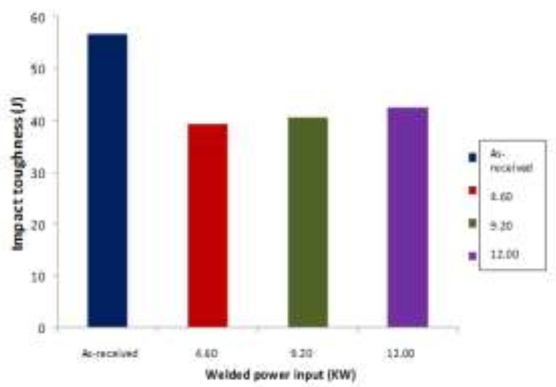

Fig. 2: Variation of impact toughness with Power Input for the HAZ and as-received samples.

The increased in impact toughness observed in the HAZ samples with increasing power inputs could be corroborated by the findings of Ramazan and Huseyin, 2002; Akor and Tuleun, (2014). The authors noted that a greater number of passes with less heat input produces lower toughness. Other factors contributed to the observed impact behavior of the HAZ samples includes greater reformation of austenite, difference in grain size of the phases, and plastic deformation caused by multi-pass welding (Fowless and Blake (2008). The low impact toughness of the HAZ samples at the range of power inputs relative to the as- received sample is attributable to change in ferrite number (FN) at the root during thermal cycling.

Table 1. Chemical Composition of the As-received 304L Austenitic Stainless Steel Plate Sheet

Elements	C	Si	S	P	Mn	Ni	Cr	Mo	V
% wt	0.038	0.649	0.05	0.051	1.859	8.079	18.403	0.319	0.075
Elements	Cu	Nb	Co	Al	Pb	Ca	Zn	Fe	
% wt	0.871	0.104	0.172	0.027	0.013	0.005	0.031	69.656	

3.3 MICROSTRUCTURE

Results for the as-received and HAZ samples at heat different inputs are depicted in Figs. 3, 4 and 5(a-c) respectively. Generally, the phases are composed majorly of austenite and ferrite. Also, chromium carbide formation and precipitation due to sensitization was observed at the grain boundaries. After etching, the ferrite phase was obtained as a lighter phase in between the darker austenite phase. Little difference was observed to exist between the microstructure of the as-received sample and that of the HAZ samples at varied range of power input. The ferrite phase was seen to be uniformly dispersed in the austenite matrix of the as-received sample (Fig.3) as compared to austenite matrix of the HAZ samples in Fig. 4 and Fig. 5(a-c). Austenite grain boundaries are readily observable in the microstructures of the as-received sample as well as the HAZ samples. At the varied power input, no noticeable modification of δ-phase throughout the microstructure was observed, only variations in grain size of austenite could be noticed. Also, inclusions and porosities in form of dark dots were noticed in some of the microstructures, none of micro-cracking was encountered during the investigation. Weld solidification cracking were present as white stretches in the microstructures of the HAZ samples evaluated. In addition, it could be observed that the grains appeared to be coarser with increasing power input. However, effect of power input on grain size appears to be relatively less when comparing (Figs 4 and 5(a-c)).

The obtained microstructural features of the as-received sample (Fig. 4) may have resulted from the initial treatments (pre-history) given to the sample prior to welding and the microstructural features of the HAZ samples at the varied power inputs Fig. 5(a-c) may have been influenced by the chemical composition of the sample (Akselen *et al.* 2004) and (El-Batany, 1997).

Fig. 3: Micrographs of as-received sample

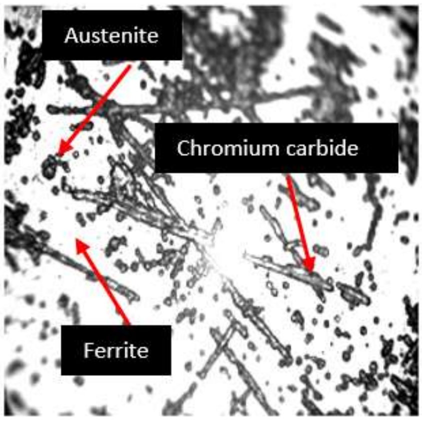

Fig. 4: Micrographs of HAZ samples welded by GMAW process

When Cr_{eq}/Ni_{eq} ratio is lower than 1.5, phase transition is trended to austenite, the existence of about 2 or 3 volume % ferrite in the weld metal reduces trend of crack susceptibility because more residual elements that spoil pureness can be easily solute in the ferrite (Akor and Tuleun, 2014). The existence of a few percent of ferrite is useful to remove the tensile stress thereby preventing risk of micro cracking during solidification (Akor and Tuleun, 2014).

Based on schaeffer diagram, Cr_{eq}/Ni_{eq} ratio in this work was obtained as 1.9 as compared to the 1.5 proposed. Therefore, more than 2 or 3 volume % ferrite is expected to be present in the HAZ microstructures with attendant improved impact properties resulting from none micro-cracking during solidification (Fowless and Blake, 2008).

The presence of ferrite phase in the microstructure of HAZ sample may have resulted from high temperatures of over 1000° C attained in the regions of the HAZ during welding, the austenite fraction being transformed to a high temperature ferrite (Bipin and Tewan, 2010). Welding power in-put may also have influenced the microstructural features of the HAZ samples. Welding conditions which result in higher heat input and/ or slow cooling tend to promote a greater reformation of austenite and an increase in the ferrite grain size, (Akor and Tuleun, 2014), fast cooling rates depress the reformation of austenite, resulting in higher level of retained ferrite which adversely affects ductility, toughness and corrosion resistance (Fowless and Blake, 2008). Transition in solidification from austenite to ferrite is related with rate of cooling rather than composition of the austenitic stainless steel and austenite and ferrite microstructure occurrence.

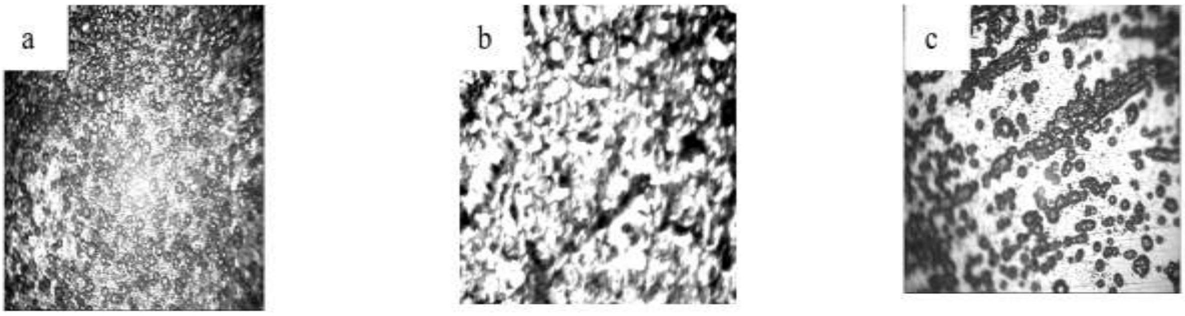

Fig. 5 (a-c): Micrographs of HAZ samples at 4.60 kW, 9.20 kW and 12.00 kW power inputs respectively

The noticed variations in austenite and ferrite grains throughout the microstructures of the HAZ samples may have resulted from thermal cycling which produces differently featured heat- affected zone accompanied by microstructural changes in the engineered microstructure (Oyetunji, 2015). It may also have resulted from a different cooling rates, heat input is low due to fast cooling rate, the weld freezes quickly with resulting small grains. While, the relative coarse grains of the HAZ samples with increasing power input is attributable to slow cooling rate resulting from high heat input.

4 Conclusions

Based on the results of this study, the following conclusions were drawn:

i. Variations in volume fraction and grain size of austenite were observed in all the HAZ microstructures examined. In addition, chromium carbide formation and precipitation due to sensitization was observed at the grain boundaries.

ii. Ferrite phase was equally seen to be present in all the microstructures examined. Also observed in the microstructures of HAZ sample were inclusions in form of dark spots which may have resulted from impurities such as moisture and dirt, and porosities in form of pin holes which may be due to effectiveness of shielding gases of GMA welding process in protecting the work piece from atmospheric contaminates (nitrogen and oxygen).

iii. Optimum impact toughness of the HAZ sample was obtained with double V geometry sample welded by GTA process and 316L electrodes at slow power input of 12.00 kW. At this optimum range, impact toughness of the as-received sample was found to be superior.

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