MECHANICAL CHARACTERIZATION OF WELDED AISI 304L STAINLESS STEEL USING TUNGSTEN INERT GAS (TIG) AND MANUAL METAL ARC (MMA) WELDING PROCESSES

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Abstract

AISI 304L austenitic stainless steel is considered weldable at various fusion welding process. Manual metal arc (MMA) welding of austenitic stainless steel is often associated with probems such as residual stresses, cold cracking and inclusion in the weld metal causing premature failure. These identified welding defects can be minimised by the use of tungsten inert gas (TIG) welding process. The effects of tungsten inert gas welding and manual arc welding on the mechanical properties of AISI 304L austenitic stainless steel were investigated. A 300 x 300 x10mm plate of austenitic steel was cut into 8 pieces and each plate faces were chamfered at an angle of 30^0 and 2.5mm root gap. TIG and MMA welding processes were used to join the plates in a single V butt joint. The strength of the weld joint was evaluated for impact, bending, hardness and tensile tests. TIG weld joint was found to exhibit higher yield and ultimate tensile strength of 416MPa and 530MPa respectively while the base metal and MMA showed the least yield and tensile strength of 354MPa and 423MPa. Impact energy of 222J was absorbed by the base metal; while TIG weld joint was 207J and MMA absorbed the least energy of 201J. Microhardness values were higher at the weld metal for both welding processes and TIG joint found to give higher bending strength. Microstructural investigation also indicated that MMA weld metal had more delta ferrite than the TIG weld.

Keywords: AISI 304L stainless steel; Manual metal arc; Tungsten inert gas; Mechanical properties

1.0 INTRODUCTION

Austenitic AISI 304L stainless steels are commonly used in pressure vessels and boilers because of their high heat and corrosion resistance properties [13]. The alloy also exhibit good mechanical properties such as high strength and ductility than mild steel, and as such found useful in other applications under both high and low loading rate conditions [3]. One of the methods of achieving monolithic structure in industries is by welding. Welding produce better joint than soldering and brazing and is the most suitable for joining steels due to flexibility,cost saving and the joint reliability in service [1]. There are basically two types of welding processes and these are fussion welding and pressure welding. Fusion welding is the application of direct heat between the weld surfaces of the workpieces while on the other hand pressure welding is the application of external pressure to produce weld when the work pieces are heated to a plastic state. Gas tungsten arc welding (GTAW),shielded metal arc welding (SMAW),gas metal arc welding(GMAW) and submerged arc welding (SAW) are the common fusion welding techniques for welding stainless steel [2]. However the thermal effect associated with welding process can cause steel structure to fail at the weld joint. Residual stresses and welding defects such as porosity and hot cracking reduce the mechanical strength of the weld joint due to differents in metallurgical phase caused by grain re-arrangement [8]. The use of suitable welding process together with proper filler metals are the most important factors to minimise these problems. Quite a number of work have been carried out to investigate the effect of different grades of stainless steel filler metals (austenitic, duplex and martensitic), heat inputs and welding parameters on the tensile, impact and percentage elongation of TIG welded AISI304L stainless steel. [2,4,9,10]. However, limited attempt has been made available on the effect of welding process on the microhardness variation across the weldment, bending strength and microstructure of TIG and MMA welded AISI 304L stainless steel joint. Hence this work compares the yield strength, tensile strength, impact toughness, bending strength and hardness properties of TIG and MMA of AISI 304L stainless steel.

2.0 Material and experimental procedure

The material used in this work is rolled plate of AISI 304L austenitic stainless steel of 300x 300 x10mm size obtained from Owode Onirin Lagos State. The chemical composition of the steel was investigated at Nigeria Machine Tools Osogbo and the result presented in Table 1. The plate was cut into 8 pieces and each plates was further divided into two and bevelled at an angle of 30^0. Back plate was applied to prevent distortion before tackling.

2.1 Welding process

Tungsten inert gas welding process which consist of welding machine (TIG 400), non-consumable tungsten electrode and inert gas (argon) contained in a long cylinder attached to the machine to prevent weld area from atmospheric air contamination of Hydrogen, Nitrogen and oxygen. A 1.4mm diameter 347L austenitic stainless steel filler was employed for joint strengthening and welding was achieved in a single V butt joint at 120A welding current and 28V voltage. Similarly, arc welding process consists of arc welding machine and electrode holder. Austenitic E316L stainless steel electrode of 1.4mm diameter was used. Root gap of 2.5mm was maintained and welding was achieved in a single V butt joint at100A welding current and 20V voltage. Both 347L filler and E316L electrode were selected because of their similarities with the base metal. After each laying of weld beads, chipping hammer was used to break the slag while wire brush was applied to clean the weld area. After welding mechanical test specimens were machined and filed to ASTM requirement using grinding machine and mechanical tests were carried out on the joint. Figure 1 shows the tensile test specimen design.

2.2 Mechanical tests

The tensile tests were carried out in the Mechanical Engineering Laboratory of Kaduna Polytechnic using Monsato tensile testing machine (Monsato; Serial no-9875). The specimen was clamped between the movable and the fixed grip of the machine and loaded until fracture occurred. The two fracture specimens were then brought together with final length, width and gauge length measured with Vernier Caliper to determine the elongation. Graph of applied load in kN against the extension in mm were drawn for the specimens and tensile strength was calculated by dividing the maximum load at break by the area of the sheared specimen.

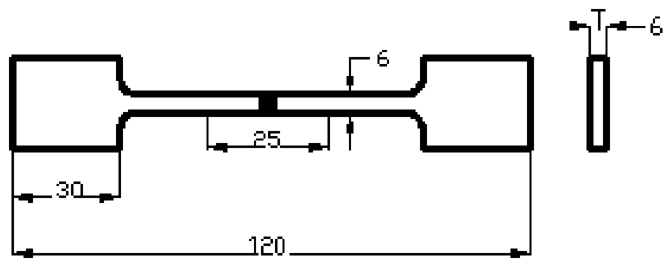

Figure 1: Dimension of tensile test specimen.

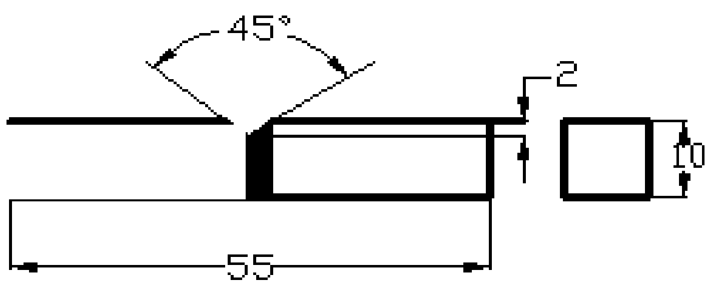

Figure 2: Dimension of impact test specimen

Figure 2 shows the impact test specimen design. Impact test was also carried out in the Mechanical Engineering Laboratory of Kaduna Polytechnic using universal impact testing machine of potential energy of 298.28J at 32.5^{0}C room temperature. A "V" notch depth of 2mm at the weld centre was achieved by machining using shaping machine and notch angle was achieved using a 45^0 tool angle. The impact test specimen was centred at the base of the machine and the pendulum stricker was released to impact the specimen at the opposite end of the notch to produce fractured sample and the energy required was recorded.

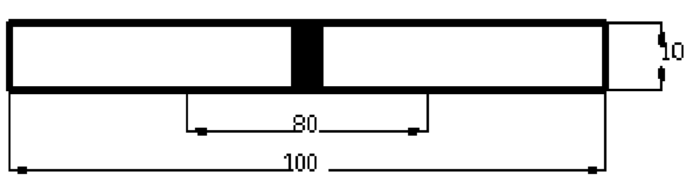

Figure 3: Dimension of bending test specimen

Bending test was carried out in the Mechanical Engineering Laboratory of Ahmadu Bello University, Zaria using Enerpac flexural machine of 100kN. The bending test specimen design is shown in Figure 3. Bending specimens were prepared and placed between the two supports and a point load was applied at the mid point until the material failed. Visual welding inspection was then conducted on the bent sample to expose defects such as cracks. Hardness test was carried out using Brinell hardness tester(Brinell-ISO 6506) of 2mm diameter ball pin indenter under a load of 120kgf. Pressure was exerted on the sample by the indentor for about a minute after which the hardness value displayed on the screen.

2.3 Microstructural investigation

The specimen size 100 x 10 x 10 mm used for microstructural investigation and microhardness(using brinell hardness tester machine) were cut from each of the welded joint. These were cleaned, ground with different grits of emery paper of 180,240,320,400,600 and 1200 untill the scratches have been reduced to fine sizes. Polishing operation was done before etching with a mixture of 34% water,33% nitric acid and 33% hydrochloric acid.

3.0 Results And Discussions

Table 1: Chemical composition of parent metal and the electrodes

Element	C	Si	S	P	Mn	Cr	Mo	Ni	V	Cu	Nb
Base metal AISI 304L	0.03	0.877	0.002	0.005	1.13	18.4	0.503	8.6	0.106	-	-
AISI 347L Filler metal	0.05	0.62	0.01	0.003	1.22	19.0	0.53	9.0	-	0.12	0.4
Electrode E316L	0.012	0.02	0.14	0.025	1.62	16	-	10	-	0.12	-

3.1 Tensile and Impact Test Results

Three specimens were tested for each welding process and the average results are presented in Table 2.

Table 2: Impact and tensile result for the base metal and welded joints

Process	**YS(MPa)**	**UTS(MPa)**	**Impact Energy(J)**	**% Elongation(mm)**
TIG	416	530	207	20.00
MMA	354	423	201	14.17
BM	383	522	222	29.95

TIG: Tungsten inert gas, MMA: manual metal arc, BM: base material, YS: yield strength, UTS: ultimate tensile strength

From Table 2, it is observed that the base metal average yield and ultimate tensile results were 383MPa and 522MPa respectively which is in conformity with ASTM standard of AISI 304L stainless steel. TIG welded joint exhibited the highest yield and tensile strength of 416MPa and 530MPa which are higher than the strength reported by [12]. This could be as a result of presence of Niobium in 347L stainless steel filler metal which might have impacted strength into the weld. Scanning electron microscope SEM micrograph revealed that the width of the TIG heat affected zone was 140µm while the average of MMA heat affected zone was 346µm under the same magnification. This implies that the influence of residual stresses may be more in MMA weld joint. Increase in width of heat affected zone as a result of heat input was also reported in the work of [10]. MMA joint exhibited the least yield stress and ultimate tensile strength of 354MPa and 423.3MPa which is also in agreement with the results that are reported in [12] and [7] for similar materials. However, the strength and impact energy of the stainless steel reduced compared with TIG joint. In the base metal, more energy (222J) was absorbed compared with the welded specimens. This result is close with the one specified in AISI 304L ASTM standard, which was reported to be 216J. TIG joint absorbed an energy of 207J, which is 7.2% lower than that of the parent metal while MMA joint exhibited the least energy of 201J which is also 9.5% lower than that of the parent metal. This could be explained by the presence of more delta ferrite which reduces ductility [14]. Grain structures in both weld metal and the heat affected zone of TIG weldment were also found to be finer than in MMA which might also account for higher energy displayed by TIG. Similar observation was also reported by [11].

3.2 Hardness test result and discussion

Table 3 shows the brinell hardness experimental results for both TIG and MMA weldments, while the hardness profiles are plotted in Figures 4 and 5.

Table 3: Microhardness values across TIG and MMA weldment

Distance from weld center	TIG weld	MMA weld
-2.5	175	197
-2	197	197
-1.5	149	175
-1	130	175
-0.5	217	217
0	261	285
0.5	197	259

1	216	236
1.5	173	175
2	175	197
2.5	173	197
Average	188	210

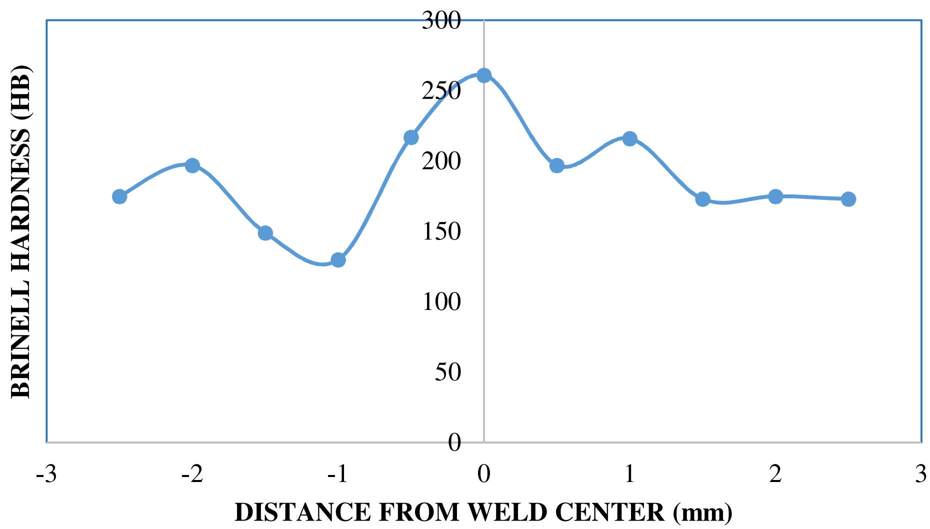

Figure 4: Micro-hardness from the weld center for TIG weld.

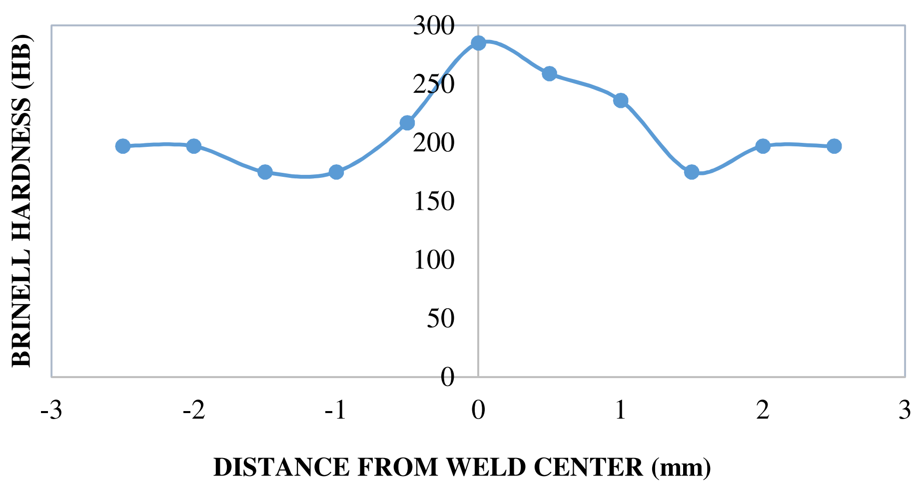

Figure 5: Micro-hardness from the weld center for MMA weld

Hardness profile in Figure 5 shows that MMA joint exhibited higher hardness of 285HB at the weld metal than TIG hardness value of 261HB (figure 4), which is an indication of brittleness in MMA weld metal. The average microhardness value of 188HB was obtained across the weldment for TIG joint and 210HB for MMA weldment. This implies that TIG weldment has better ductility. The higher hardness value in the MMA weld metal could be due to the delta ferrites which are more in the weld metal and their ability to increase hardness and reduce ductility [14]. Other variation in hardness may also be attributed to heat retention and residual stresses caused by the heat input. The hardness test result is in agreement with the work of [5] and [6].

3.3 Bending strength result and discussion

Bending test carried out on both the weld face and the root face is presented in the Table 4(a and b).

Table 4 (a): Bending test result for MMA welding

Specimen	Bending load kN		Bending strength (MPa)		Average bending strength(MPa)
	Weld face	Root face	Weld face	Root face	
1	18.59	15.12	84.50	68.73	76.62
2	18.45	16.75	83.86	76.14	80.00
Average					78.31

Table 4(b): Bending test result for TIG welding

Specimen	Bending load (kN)		Bending strength (MPa)		Average bending strength(MPa)
	Weld face	Root face	Weld face	Root face	
1	22.10	20.20	100	91.82	95.91
2	23.42	19.90	106	90.45	98.23
Average					97.07

From the Tables, it is observed that ductility of TIG weld was found higher with average bending strength of 97.07kN/mm^2 while MMA joint exhibited lower ductility with bending strength of 78.31kN/mm2. TIG process gives better ductility because of the quality of the weld with minimum welding defects. Visual inspection also shows that there is better fusion and good weld penetration between the weld metal and the parent metal in TIG than MMA; this might have contributed to its ductility.

3.4 Microstructural Examination Results

The micrographs from the microstructural examination are shown in Figure 6 (a-g)

Figure 6(a): Microstructure of parent AISI304L stainless steel (200X)

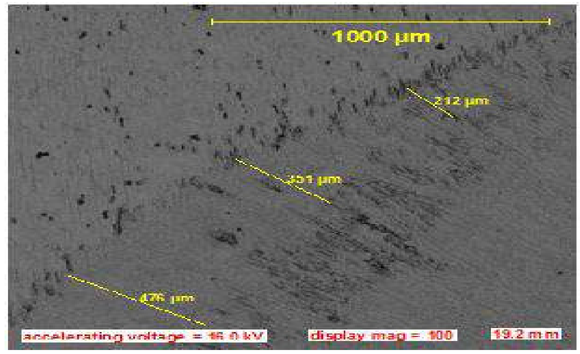

Figure 6(b): Microstructure of HAZ,Fusion boundary and MMA weld metal

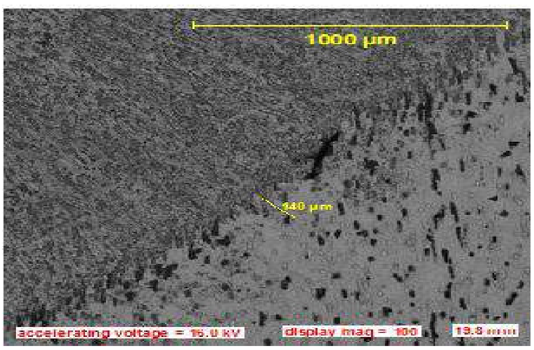

Figure 6(c): Microstructure of HAZ ,fusion boundary and TIG weld metal.

Figure 6(d): Microstructure of heat affected Zone of MMA joint (200X)

Figure 6(e): Microstructure of heat (200X) affected zone of TIG joint (200X)

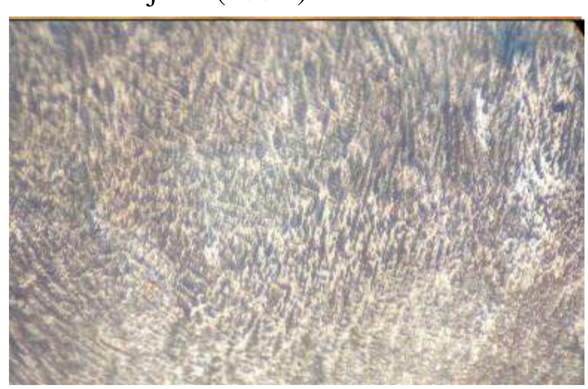

Figure 6(f): Microstructure MMA weld metal

Figure 6(g): Microstructure of weld metal of TIG joint (200X)

The microstructure of the parent metal 304L stainless steel is shown in figure 6(a). The alloy possesses a uniform grain distribution consisting of two micro-consistuent namely ferrite (dark) and austenite (light) at 200X magnification. The microstructure of heat affected zone of both welding process figure 6(d & e) show no Cr depletion but grain refinement taken place. Figure 6(f) shows the microstructure of MMA weld metal in which the dark phases are not pearlite but acicular dendrite structures called delta ferrite in which the delta ferrite may be acicular, vermiculite, lacy or lathy in morphology. Figure 6(g) shows the microstructure of TIG weld metal consisting of less delta ferrite than MMA and with finer grains.

4.0 **Cconclusions**

AISI304L stainless was welded using tungsten inert gas and manual metal arc welding processes and the joint mechanical strengths were investigated. The following conclusions were drawn:

1. The microstructural result shows that AISI 304L base metal consists of uniform grain distribution of two micro consistuents of ferrite and austenite, MMA weld metal consist of delta ferrite while TIG weld metal maintained higher austenite structure.
2. The TIG welded joint displayed better mechanical properties compared with MMA welded joint because it yields better ultimate tensile strength, toughness and ductility.
3. Microhardness values were higher at the weld metal for both welding processes with maximum hardness of 285HB for MMA joint and 261HB for TIG due to more delta ferrite in MMA weld metal.

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