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ANALYSIS OF DISSIMILAR WELDING OF AUSTENITIC STAINLESS STEEL TO LOW CARBON STEEL BY TIG WELDING PROCESS

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ABSTRACT

In the current study, the effect of heat treatment on the dissimilar metal welding of austenitic stainless steel (AISI 304L) and low carbon ferritic steel (AISI 1005) using Tungsten Inert Gas (TIG) welding process was investigated with a view to minimize and/ or eliminate the previously reported danger of inhomogeneous hardness distribution experienced across the fusion zone. Heat treatment (Normalizing) of the as welded dissimilar metal was carried out in a muffle furnace at temperatures ranging from 750^0C to 850^0C and held for varied length of time. Micro structural evaluation and mechanical properties of the fusion zone (FZ), heat affected zone (HAZ) and the base metals (BM) were performed using microscopy and micro hardness evaluation. The result shows that for dissimilar metal weldment, the non-uniform hardness distribution in the fusion zone can be essentially eliminated by using appropriate post weld heat treatment.

KEYWORDS: Dissimilar Weld, Micro-Hardness, Microstructure and in Homogeneity

INTRODUCTION

Dissimilar metal welding refers to the joining of two different metals or alloy systems. Generally, the base-material in welded alloys has wrought microstructure, while the weldment consists of cast microstructure [1]. Joining of structural components using dissimilar materials are extensively used in chemical, petrochemical, nuclear, power generation and other industries [2-5] for example in central power station, components operate at different service condition necessitating appropriate material selections, the high temperature section of the boilers are made of stainless steel because it has superior creep and oxidation resistant, while those section operating at lower temperature are made of ferritic steel because of the economical value [5-6]. Dissimilar metal welding encountered in power generation, nuclear, chemical and petrochemical industries are most often, fusion welds made by any of the common welding processes such as tungsten inert gas (TIG) [5] and sound welds have been reportedly obtained between austenitic stainless steels and low carbon steels using ER309L filler metal [2, 5].

During heat treatment processes the phenomena that occur always involve atomic diffusion [7] and normalizing being a type of heat treatment is a micro structural modification process that impact on both the hardness and strength of iron and steel components. In addition normalizing helps reduce internal stresses induced during fabrication and mechanical working of metal [8]. In normalizing, the cooling rate is slower than that of a quench and temper operation but faster than that used in annealing. As a result of this intermediate cooling rate, the parts possess hardness and strength somewhat greater than if annealed but somewhat less than if quenched and tempered. The slower cooling rate means normalized sections will not be as highly stressed as quenched sections

Previous study on dissimilar metal welding have shown that aside a very sharp change in composition along the fusion line, there is also a corresponding mechanical degradation of properties along the fusion line of the weld due to the formation of local high stresses associated with a thermal expansion mismatch between the carbon steel and stainless steel [9,10]. This problem has been reported to be the major cause of failure in joints made of austenitic stainless steel and low carbon ferritic steels [5, 10, and 11]. The mechanical property degradation that occurs in the fusion zone makes this region a stress raiser, easily susceptible to cracks and fatigue failure of components. In addition, austenitic stainless steels have a low coefficient of thermal conductivity, approximately one-third that of ferritic steels at room temperature and a coefficient of thermal expansion some 30% more than that of ferritic steel, which is another major problem encountered in the dissimilar welding of stainless steels to low carbon steel as it results in a non-homogenous microstructure in the weld metal zone [9]. However, there are limited reported investigation and few discussions on possible micro structural modification to ameliorate the as-welded inhomogeneous hardness distribution. The objective of this research is therefore to study and analyze the sharp gradient in the hardness profile across the fusion line with a view to homogenizing the property without consequential damage to the base material property. The results are reported in this communication.

METHODS

The base-materials used in this study was AISI 304L austenitic stainless steel and AISI 1005 low carbon ferritic steel. The base plates were cut to a dimension of 750mm x 30mm x 5mm as shown in figure1. The plates were thereafter welded together by TIG welding process using ER 309L austenitic filler metal of 2.5mm diameter, which has been previously reported to produce sound weld in dissimilar metal of austenitic stainless steel and low carbon steels [2, 5, 11-12]. The chemical compositions of the two base metals and filler metal used are given in Table 1

Table 1: Chemical Compositions (wt. %) of the Base Metals and Filler Metal

Element (wt %) Material	C	Si	Mn	S	Cr	Ni	Mo	P	Fe
Stainless steel	0.05	0.38	2.05	0.02	17.58	8.71	0.94	0.04	69.50
Low-carbon steel	0.04	0.14	0.30	0.03	0.24	0.21	-	0.02	98.90
Filler Metal	0.03	0.60	1.80	-	23.40	13.00	0.15	-	

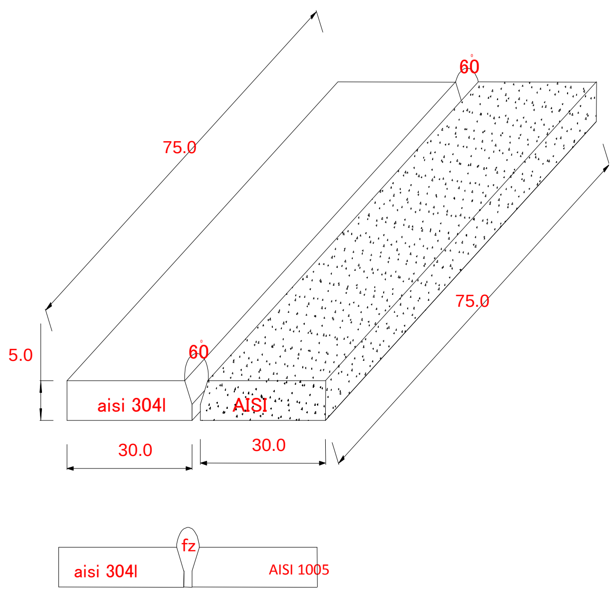

Figure 1: Schematic of the Dissimilar Metal Joint and Location of Metallurgical Observations

The V-shaped welds were produced in 3 passes using the Lincoln TIG welding machine with a current of 110A at Dorman long Engineering Ltd., Lagos State, Nigeria. After welding, heat treatment of the welded samples were carried out at different intercritical temperatures of 750^0C, 800^0C and 850^0C, and holding time of 30 and 60 minutes at each temperature, followed by air cooling. Samples for metallographic observation were wet grounded on progressive finer grit sizes of silicon carbide impregnated emery paper using water as lubricant. Subsequently the grounded samples were mechanically polished using a polishing cloth.

Micro structural features in the as-received, and the as-welded heat treated samples was observed and photographed using optical microscopy on sections of the surface parallel to the weld line. Due to the nature of the dissimilar metal joint, the samples were etched using Nital solution (2% HNO_3 acid and 98% alcohol for the low carbon steel side, and HNO_3 acid (3ml), HCL acid (9ml), acetic acid (2ml) and glycerine (1ml) for the stainless steel side). The specimen were immersed in the solution for 40-45 seconds, washed in running water followed by rinsing with alcohol and finally dried before viewing under the optical microscope.

The hardness profile of the as-received, as-welded and the as-welded heat treated samples was evaluated using Buhler micro hardness tester. Vickers micro hardness profile was determined across the weld line through the heat affected zone and into the base metal with a testing load of 490.3 MN and a dwelling time of 10 seconds.

RESULTS AND DISCUSSIONS

Microstructure and Micro hardness of As-Received Material

The average micro hardness values obtained from the micro hardness testing of the as-received are 189 ± 10HV for the stainless steel and 136 ± 10 HV for the low carbon steel.

Figure 2a shows the microstructure of the as-received stainless steel alloy before welding which is essentially an austenitic matrix with some dark particles that have been reported to be carbides [13]. The microstructure of the low carbon steel alloy (figure 2b) comprises of grains of ferrite and pearlite in form of bands as previously reported in literature [13]. Macro structural examination of the dissimilar welded material shows a perfect weld from the stainless steel side to the low carbon steel side (figure3).

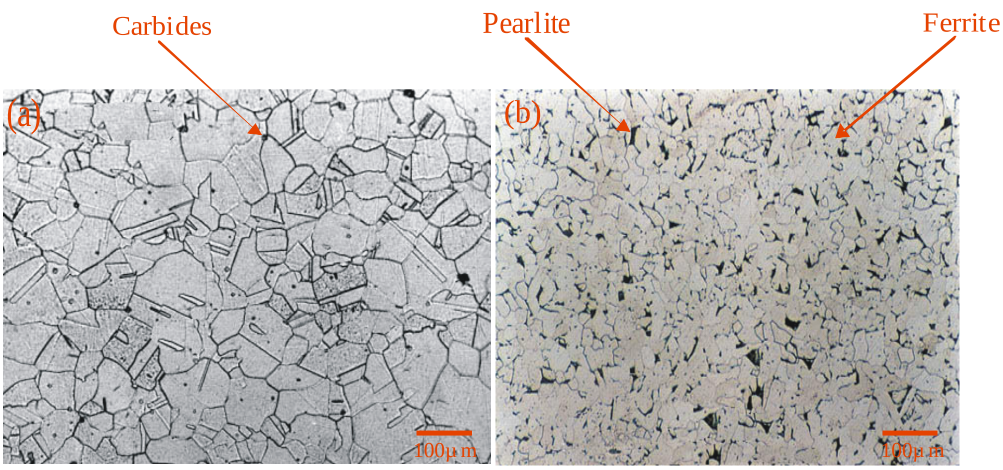

Figure 2: Microstructure of as-Received Materials (a) Stainless Steel (b) Low Carbon Ste

Figure 3: Macrograph of the as-Welded Samples

Effect of TIG welding on the Microstructure and Micro hardness of the Welded Specimens

Figure 4 shows the micro hardness profile of the as-welded sample with a variation in hardness from the stainless steel base-alloy to the low carbon steel base alloy. The measurements were taken along a line from the base-alloy of the austenitic stainless steel to the heat affected zone of the austenitic stainless steel side through the weld area to the heat affected zone of the low carbon steel side to the base-alloy of the low carbon steel.

Evidently from figure 4, it can be seen that the distribution of the hardness across the weld profile is inhomogeneous and varies depending on the material side been tested. The hardness value of the heat affected zone on the austenitic stainless steel side gives an average of 222 ±10 HV while that in the low carbon side gives an average of 153 ±10 HV. Most importantly, the hardness value of the fusion zone varies from 247 ±10 HV close to the austenitic stainless steel side to 177 ±10 HV at the region close to the low carbon steel side. There is a gradual increase in hardness in the fusion zone from the low carbon steel side to the stainless steel side, suggesting an inhomogeneous mixing in the weld pool during the welding process of the two dissimilar materials.

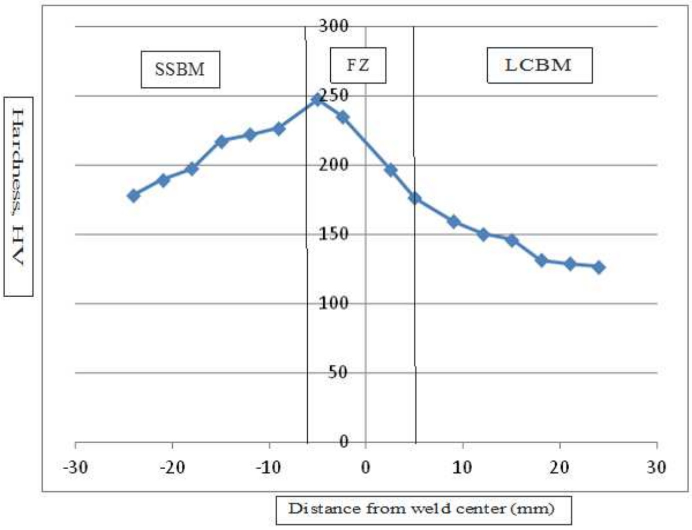

Figure 4: Hardness Profile across the Weld of the as-Welded Sample

The microstructure across the as-welded samples (figure 5a-e) shows micro structural variations from the base-alloy of the stainless steel to the HAZ of the stainless steel to the fusion zone and the HAZ of the low carbon steel to the base metal of the low carbon steel similar to previously reported investigation [5]. These variations may be attributed to the difference in the materials solvus temperature and the peak temperature experienced by the two base-alloys at the joint during the welding process. Generally during fusion welding processes the fusion zone experiences peak temperature that is well above the liquidus temperature of the materials been joined, hence complete melting and solidification is expected to takes place in the fusion zone, however, complete mixing to produce a homogeneous liquid within the fusion zone may be limited. The microstructure observed in the fusion zone (figure 5a) of the dissimilar welded sample is completely different from that in the base-alloys. The fusion zone consists of both alloys that had melted and subsequently solidified with features of ferritic-austenitic solidification mode which has also been reported in previous work [5]. In addition, micro segregation across the dendritic structure as a result of solute redistribution during solidification is possible as a result of grain growth rate fluctuations [5]. The microstructure of the base-alloys in the stainless steel side (figure 5b) is expectedly unaffected by the welding process, while in the heat affected zone significant increase in grains size (figure 5c) was observed. Similarly the base-alloy of the low carbon steel was also not affected by the welding process (figure 5e), however the microstructure of the heat affected zone of the low carbon steel (figure 5d) appears to indicate solid state transformation without significant difference in the ferritic and pearlitic structure distribution and morphology previously described.

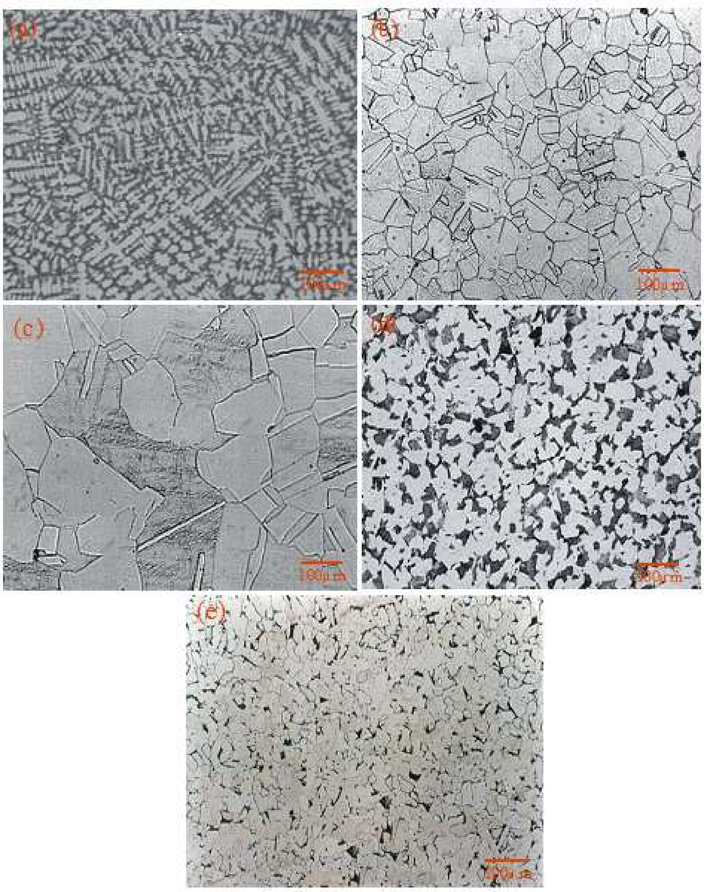

Figure 5: Microstructure of the AS-Welded Samples: (a) Fusion Zone, (b) Base Metal Stainless Steel, (c) HAZ of Stainless Steel, (d) HAZ Low Carbon Steel, (e) Base Metal low Carbon Steel

Effect of Post-Weld Normalizing Heat Treatment on the Microstructure and Micro hardness of the welded samples

A major means of reducing micro structural in homogeneity and minimizing induced residual stresses from welding fabrication is by post-weld heat treatment. In this study a series of post weld heat treatment was carried out on the as-welded material with a view to homogenize the weld zone without damaging the inherent properties of the base-alloy.

Figures 6 to 11, shows the micro hardness profile of the post welded heat treated samples, it can be seen that the best post weld heat treatment for the homogenization of dissimilar metal weld of austenitic stainless steel to low carbon steel in this study is by heat treating the welded sample at a temperature of 750^{0}C and holding for 30 minutes (figure 6). In other post-weld heat treated samples the problem of inhomogeneous hardness distribution persist to varying degree of severity depending on the heat treatment temperature and holding time.

Welding is a non-equilibrium process that produces formation of non-equilibrium microstructures in the fusion zone, and the tendency for these non-equilibrium microstructures to move towards equilibrium can aid the driving force for homogenization during the post-weld heat treatment.

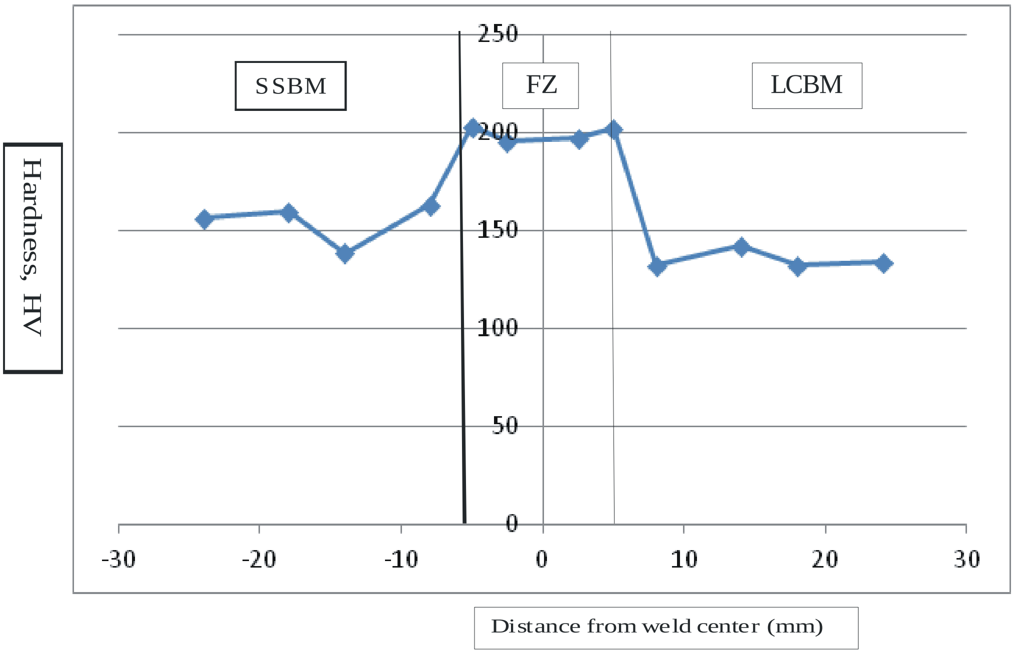

Figure 6: Hardness Profile across the Weld of the Post Weld Heat Treated Sample (750/30mins)

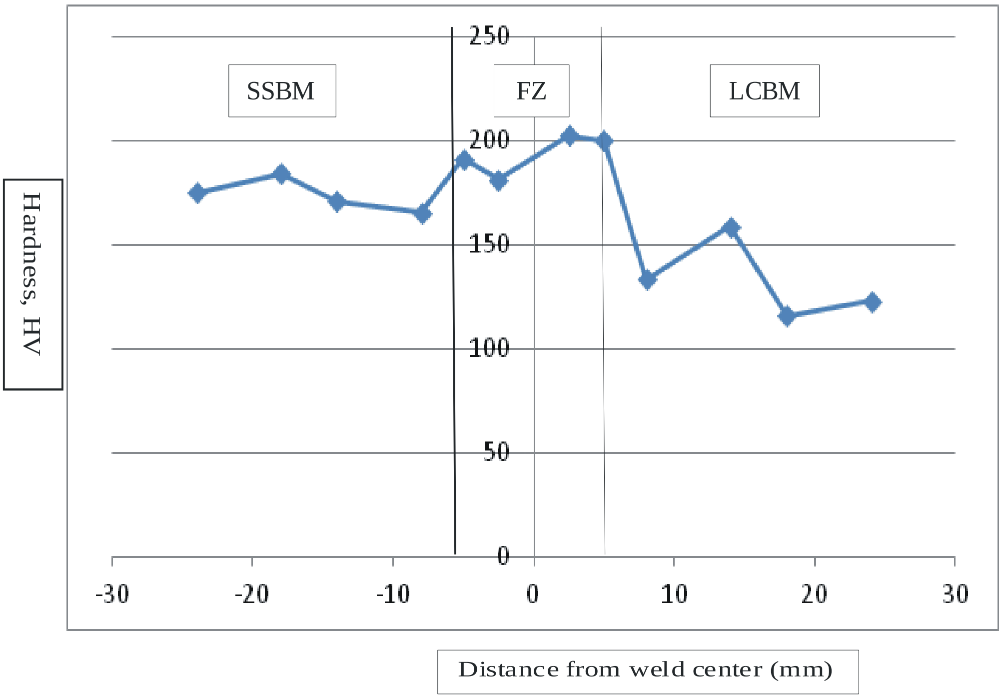

Figure 7: Hardness Profile across the Weld of the Post Weld Heat Treated Sample (750/60mins)

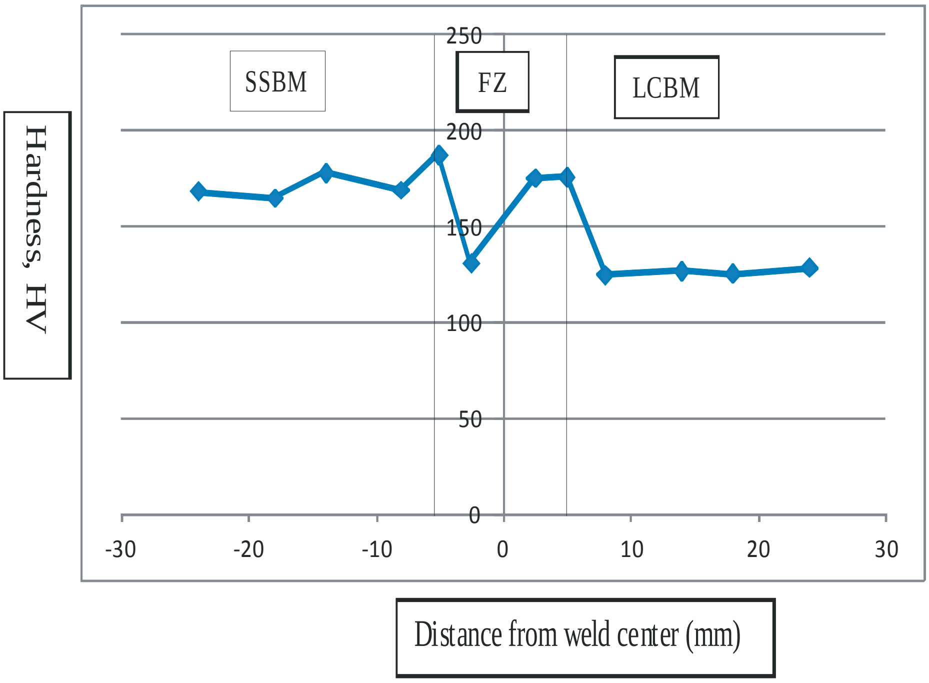

Figure 8: Hardness Profile across the Weld of the Post Weld Heat Treated Sample (800/30mins)

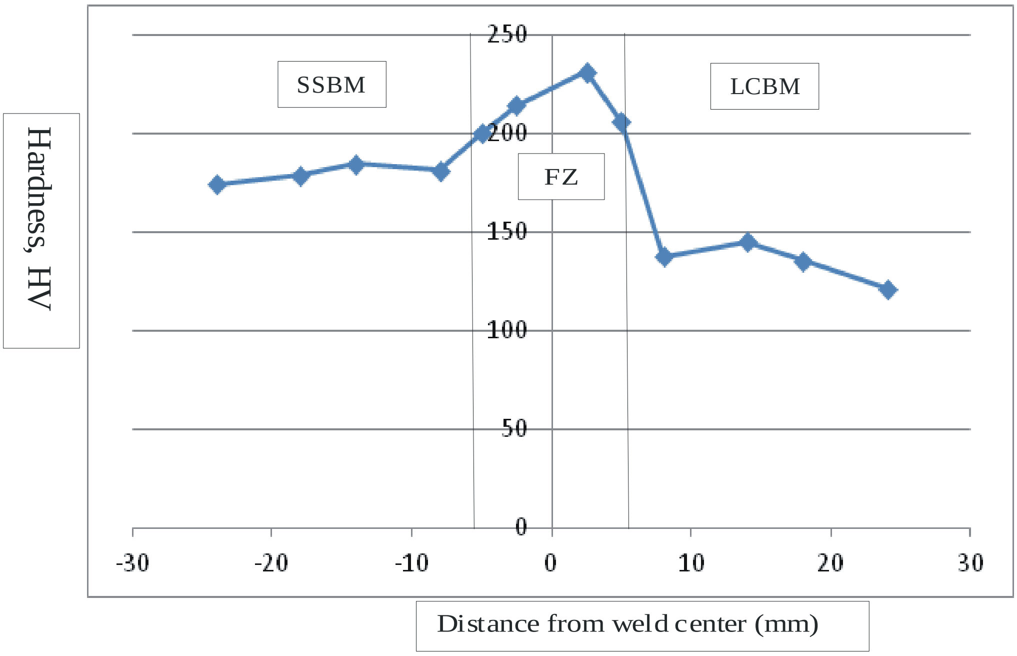

Figure 9: Hardness Profile across the weld of the Post weld Heat Treated Sample (800/60mins)

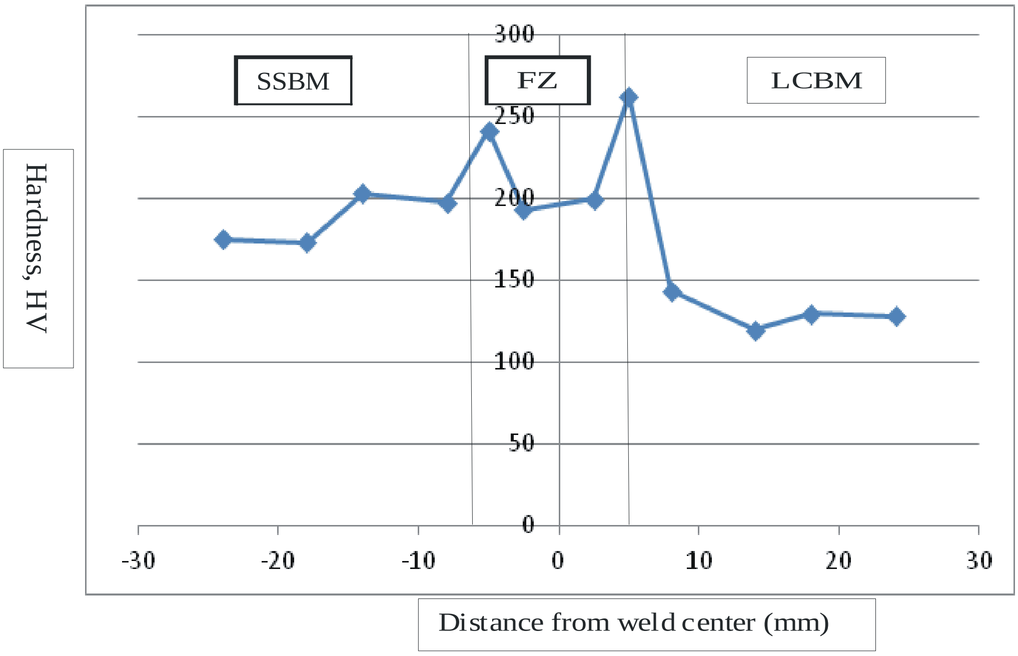

Figure 10: Hardness Profile across the weld of the Post weld Heat Treated Sample (850/30mins)

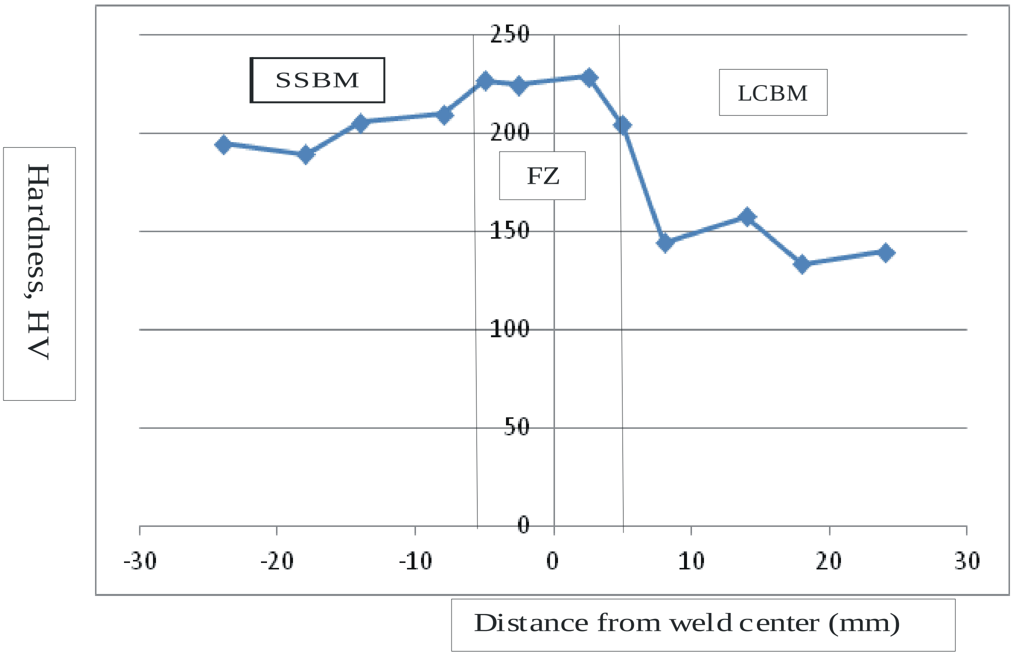

Figure 11: Hardness Profile across the Weld of the Post Weld Heat Treated Sample (850/60Mins)

Micro segregation in the fusion zone can be reduced significantly by solid-state diffusion during and after solidification in the fusion zone [14] and this is evident in the post-weld heat treated materials. Figures 12 a-e shows the microstructure of the post weld normalized heat treated sample at 750^{0}C, and a holding time of 30 minutes.

Figure 12a shows the microstructure of the normalised 750^{o}C for 30 minutes post-weld fusion zone indicating dendritic solidification with apparent shorter dendritic arm compared to the as-welded fusion zone microstructure which could have contributed to the improved homogeneity of the previously inhomoginized fusion zone microstructure. The microstructure of the heat affected zone close to the austenitic stainless steel (figure 12c) and the low carbon steel side (figure 12d) after post-weld normalising heat treatment both indicate a coarse microstructure relative to the as received microstructure. The base alloy microstructure after welding and post-weld normalising treatment (figure 12b and 12e) however remain essentially comparable to the as-received microstructure.

Therefore during dissimilar metal welding, the danger associated with the non-equilibrium process as shown by the inhomogeneous hardness profile of the fusion zone can be attributed to the non-equilibrium mixing of the two materials being joined together owing to the short time available for complete mixing and homogenization during solidification of the materials been joined. The results from the analysis of the post-weld normalizing heat treatments have however revealed the possibility of eliminating and/ or reducing the dangers of non-homogenous hardness.

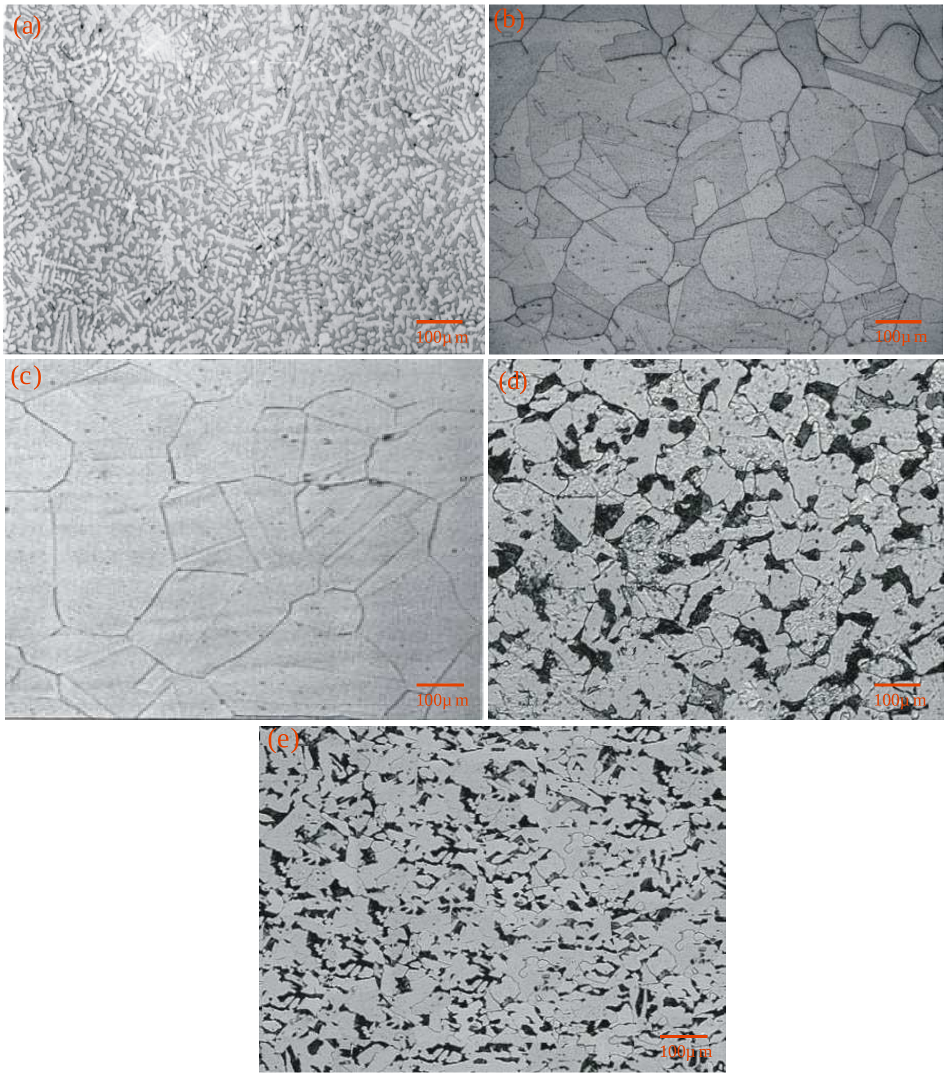

Figure 12: Micro Structure of the Post Weld Heat Treated (750^{0}C for 30 Minutes): (a) Fusion Zone (b) HAZ of the Stainless Steel Side (d) HAZ of the low Carbon Steel Side

CONCLUSIONS

The dissimilar welded joint of stainless steel to low carbon steel was investigated with a view to homogenise the as-welded fusion zone hardness, which could eliminate or minimize the potential detrimental effects of inhomogeneous fusion zone on other salient mechanical properties. The conclusions derived are as follows:

- Sound welds were obtained between AISI 304L austenitic stainless steel and AISI 1005 low carbon ferritic steel using ER 309L electrodes.
- The micro hardness profile in the fusion zone of the as-welded material shows a steep variation from the austenitic stainless steel region to the low carbon ferritic steel region.
- Post weld normalising heat treatment of dissimilar metal weld of austenitic stainless steel and low carbon steel were carried out at temperatures of 750^{0}C, 800^{0}C and 850^{0}C and held for 30 and 60 minutes each. The best homogenization of the fusion zone was found to occur at normalizing temperature of 750^{0}C and holding time of 30 minutes, where the deviation of micro hardness values were found to be minimum without damage to the base-

alloy hardness.

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