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The Effect of Pre Weld Heat Treatment on the Mechanical Properties and Corrosion Resistance of Artificially Aged 8011A Aluminum Alloy

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ABSTRACT

In this study, 8011A aluminum alloy was subjected to artificial ageing and joined by tungsten inert gas (TIG) welding process. The effect of welding process on the mechanical (hardness, tensile, impact) properties, corrosion resistance and microstructure of the artificially aged and welded joints were investigated. The sample was divided into pre weld heat treated and as received samples. The pre weld heat treated sample was subjected to solution treatment at 500 °C, soaking for 1 hour, and quench in water before artificial ageing was carried out at 180 °C with holding time of 8 hours. Both the pre heat treated and the as received samples were welded using tungsten inert gas (TIG) welding process. It was observed from the results, that the pre weld heat treatment adopted improved the mechanical properties and corrosion resistance of the weldments in some of the properties examined. In comparison with the welded samples, the hardness, tensile yield strength and corrosion resistance of the pre weld heat treated samples were significantly improved. There was an improvement of 11% in hardness, 9% in yield strength and 92 % in corrosion resistance when immersed in 3.5 wt% NaCl solution.

Key words: *Artificial aging; TIG welding; Pre weld heat treated; Mechanical properties; Microstructure; Corrosion behavior.*

1. INTRODUCTION

The modern world requires the use of light structural and engineering materials in other to improve fuel economy, energy consumption and gas emission in industrial purposes. The properties such as specific strength, specific stiffness, good formability and good corrosion resistance make aluminum alloy an ideal material for the manufacturing of components for automotive and aerospace applications and have increased the use of aluminum and its alloys globally. Components of internal combustion engines such as cylinder head, cylinder block, crankshaft and pistons are the main automotive components where aluminum cast alloys are used. The importance is to achieve the requested properties, which do not depend only on the casting condition and solidification rate, but they are also significantly influenced by their chemical composition [1]. 8011A series is used in many construction industries and automobile applications as a result of their good physical and chemical properties which are it's formability, corrosion resistance, light weight and also because it is possible to control the microstructural composition of the alloy by means of specific thermal and mechanical treatments and the major strengthening agents in 8011A alloy are the Fe-Si constituent particles as these particles are capable of stabilizing a fine grain or subgrain structure which can develop interesting combinations of strength and ductility [2]. The major applications of 8011 aluminum alloy includes: tread plate, boiler making, containers, nameplates, road signs, architectural paneling, welded tubes, chemical industry irrigation, desalination units, pressure vessels, rivets [3]. [4] identified aluminum 8011 alloy as one of the predominant materials in new day industries, which increased knowledge about its distinct properties such as its relatively low cost, light weight, high heat conductivity and proper corrosion resistance and the fact that, they can be heat treated and loaded to relatively high stress levels working conditions makes the alloys a very useful material in engineering fields, all unique properties such as light weight, high mechanical strength, and relatively high resistance to

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corrosion possessed by these alloys are as a result of suitable alloying and heat treatments and the fact that it is one of the various precipitation hardenable which possess a good combination of strength and good weldability, wall these attributes makes this alloy a good choice in the building of ship decking's [5]. Welding is a process of joining similar or dissimilar metals by application of heat with or without the application of filler materials. TIG is an arc welding process, where arc is produced between non consumable tungsten electrode and base metal [6]. Pulsed TIG welding process is frequently used for welding of aluminum alloys as heat input during welding can be precisely controlled, which in turn leads to grain refinement in fusion zone, width reduction of (Heat Affected Zone) HAZ, segregation of alloying elements, reducing hot cracking sensitivity and residual stresses [7]. [3, 6] identified (TIG) welding process as one of the best processes in welding aluminum and its alloy due to its versatility and flexibility in adaptation. The superior weld quality obtained in TIG elements differentiates the process in comparison with other competing and emerging joining processes. Several works has been done to study mechanical properties of 8011A aluminum alloy and the effect of post weld heat treatment on the properties of welded joints made by different welding processes. [8] studied the influence of iron content and plastic deformation on the mechanical properties of 8011-type Al-Fe-Si alloy and identified that equilibrium solid solubility of Fe in the Al solid solution (α-Al) is low; that, Fe exists in aluminum alloys in the form of Fe-bearing intermetallic compounds as these compounds are often of the morphologies, either as long needles or large plates, which drastically reduce the ductility of the alloys. And he concluded that wherever possible, iron level in Al-Si alloys should be kept at the bearable minimum level in order to avoid the detrimental effect on mechanical properties, particularly ductility and fracture toughness, [9] evaluates the influence of ageing temperature on the mechanical properties of Al-Mg-Si Alloy, The material was machined into different shapes of the tests carried out, tensile, impact and hardness. The results show that at low ageing temperature of 160°C, the ductility and impact were high, while at 180°C, the ultimate tensile strength and hardness are higher compared to the value obtained at 160°C [5] studied the effect of post weld heat treatment (PWHT) on the mechanical and corrosion behavior of welded Al-Fe-Si alloy joint, the welded samples were divided into as-weld (AW), PWHT, base metal (BM) and heat treated base metal (HT BM) samples. Artificial aging was carried out on part of the welded sample at 177 °C with holding time of 8 hours to obtain the PWHT samples. They concluded that, although Al-Fe-Si alloy has good strength and corrosion resistance properties but after welding it suffers a substantial decline. The loss of strength is on account of rapid melting and solidification process which causes all the strengthening precipitates to dissolve into the aluminum matrix and the complete dissolution of the precipitates does not take place in weld metal only but also at the over aged heat affected zone (HAZ) and concluded that the strength and other mechanical properties of this alloy can be enhanced by ageing. [10] also investigated mechanical and corrosion properties of AA8011 sheets and foils and identified 8011 aluminum alloy is one of the most popular commercial alloys in the Al-Fe-Si ternary system, and concluded that Si present in this alloy in quantities which is nearly as large as Fe limits the super saturation of the matrix phase with Fe by causing a substantial level of Fe precipitation.

Several attempts has been made by different researchers to study the mechanical properties and corrosion resistance of different aluminum alloys and their weldments as well as the effect of post weld heat treatment on these properties, however, much has been done on the effect of pre weld heat treatment on most of these alloys. This research was specifically carried out to investigate the effect pre weld heat treatment operation on the mechanical properties and corrosion resistance of artificially aged aluminum 8011 alloys. This was done to investigate the influence of pre conditioning/treatment on weld metals. This become necessary since structural integrity is crucial in many industrial sectors where welding is the main technique for joining [11].

2. Materials and Methods

2.1 Sample preparation

Commercial 8011A aluminum alloy plate of thickness of 6mm was used for this research. The chemical composition was given in Table 1.

Table 1- Chemical composition of base metal (%)

CE*	Al	Mg	Si	Na	Fe	Mn	Cr	Ca
Comp.	97.99	0.012	0.053	0.004	1.07	0.112	0.017	0.10

*Chemical elements

The 8011 aluminium alloy samples were divided into two groups viz; Pre weld heat treated and as received samples. For the as received sample, the 8011 aluminum alloy was welded directly using Tunsgten Inert gas (TIG) welding process, and mechanical tests (hardness, tensile, impact), microstructure and corrosion test were performed directly after the welding process, while for the Pre weld heat treated sample, heat treatment was conducted before the welding process and the latter tests.

2.2 Experimental procedures

The heat treatments conducted were; solution treatment performed at 500 °C for a soaking time of 1 hour, and quenched in a water bath. Artificial aging was carried out at 180 °C for a soaking time of 8 hours. The Pre weld heat treated and the welded samples of the 8011A aluminium alloy were prepared and cut into dimensions of 150 mm by 75 mm, afterwards butt-end joints were prepared such that the connection between the ends or edges of two parts making an angle of about 180° to one another i.e. the inclusive region of the joint. The surfaces were prepared before carrying out the welding with TIG welding specification, the polarity used is (AC), alternating current, the welding parameters are; current amperage of 160 A, with the shielding gas (argon) flow rate of 10.6 L/min, nozzle diameter of 9.5 mm, flat position was used with two weld pass. Metal are being deposited as an arc was struck between the electrode and the plate. Test specimens were marked and sectioned from the welded plates as shown in Figure 1. Test samples were cut transversely across the welded joint to obtain tensile, impact, hardness, corrosion and microstructure samples. Also sections were taken from the based metal to obtain the base metal tensile, impact, hardness, corrosion and microstructure samples.

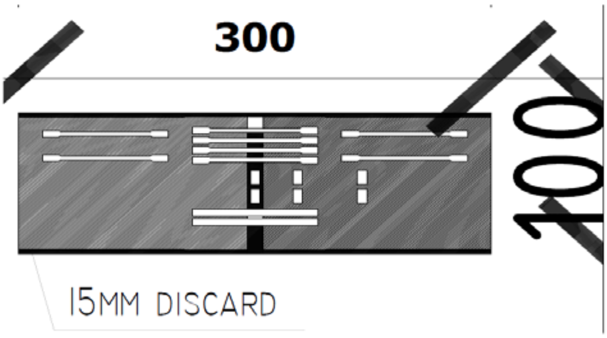

Fig.1. *Welded plate showing sectioned samples*

A digital Vickers hardness tester machine shown in Fig. 2, was used to measure the hardness across the joints at different regions of the weld; Base metal (BM), Heat affected zone (HAZ) and weld metal (WM), the hardness values across all the weld regions for both pre heat treated and welded samples were measured.
Tensile specimens were prepared fitted onto an electro-mechanically controlled Instron universal testing machine (UTM) shown in Fig. 3, and testing was conducted. The samples deformed and fracture into two parts on accounts of the applied load. The tensile test result was plotted using computer software.

Fig.2. *Vickers hardness testing machine*

The specimens for impact test were prepared to specification for impact test as the test was conducted at room temperature of 24 $\pm$ 2 ℃ using the Izod impact testing machine. The specimen was then clamped to the vice on the machine with the notch facing the pendulum. The pendulum was raised to a certain height and the gauge was set at zero before it was released and the energy absorbed in breaking the specimen was then taken and recorded.
The corrosion samples were divided into two sets; pre weld heat treated samples which comprise of the Base metal (BM), Heat Affected Zone (HZ) and weld Metal (WM), also the welded samples which comprise of the Base metal (BM), Heat Affected Zone (HZ) and weld Metal (WM). The samples were subjected to Tafel corrosion test using AUTOLAB potentiodynamic, with 3.5wt% NaCl solution as the corrosive medium.

Fig.3. *Instron universal testing machine*

Samples from different zones, comprising of weld metal (WM), Heat Affected Zone (HAZ) and base metal (BM) regions, of the pre weld heat treated and the welded samples were examined (Fig. 4). These samples were ground with different grades of emery papers and polished with diamond paste. After polishing, specimens were etched with Keller's reagent to reveal the microstructure. The microstructural examination was carried out using Optical Microscope, (Leica Galen III, S/No- 1147XP) shown in Fig. 6.

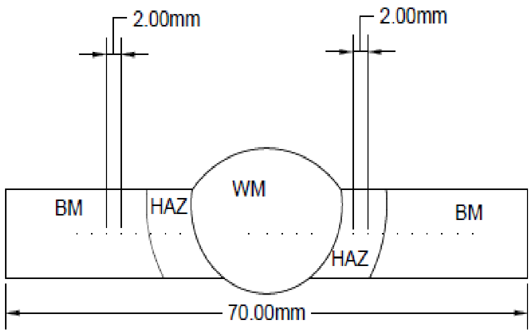

Fig.4. *Schematic showing points of indentation across the weld at a successive distance of 2mm from the weld centre*

3. RESULTS AND DISCUSSION

3.1. *Hardness properties analysis*

It can be deduce from the result shown in Fig. 6, that there is variation in the hardness value obtained as a result of the heat treatment process and the welding process. The average hardness value of the Weld Metal (WM) of the welded joint is 31.4 HV and that of the pre weld heat treated joint weld metal (WM) is 35.3 HV. This implies 11% increase in the hardness of the pre weld heat treated joint compared to the welded samples. The average hardness value of the HAZ and BM of the welded joint were 29.4 HV and 31 HV, The average hardness values in HAZ and BM of the pre weld heat treated sample were 34.1 HV and 32.8 HV which culminated to about 13.7% and 5.5% increments, respectively. The increment in hardness of the WM, HAZ, BM of the pre weld heat treated samples can be attributed to the effect of the precipitation due to ageing treatment which offer more barriers to the movement of dislocation, and the thermal stresses induced by the welding process, similar result were reported by [8,12, 13].

Fig.5. *Optical Microscope (Leica Galen III)*

3.2. *Tensile Properties Result Analysis*

The results of tensile properties of the joints in the pre weld heat treated and welded conditions were evaluated as shown in Fig. 7-8. It was observed from Fig. 3 that, the welded BM has the highest ultimate tensile strength of 131.6 MPa, the ultimate tensile strength of the pre weld heat treated WM and welded WM joints are 72.60Mpa and 85.50 MPa, respectively, which invariably means, the welded joint causes a decrease in the tensile strength of the 8011A alloy. The joint efficiency is the ratio of ultimate tensile strength of welded joint to that of the base metal, the pre weld heat treated WM has the lease ultimate strength and a joint efficiency of 57.4% while the welded WM has a joint efficiency of 64.97%. It was observed that the welded WM has the best joint efficiency with increase of 7.57% when compared with the pre weld heat treated WM. From the test, it was very clear that the tensile strength of the 8011A aluminium alloy joint is reduced by the welding processes they undergo after the heat treatment. Figure 4 revealed that the welding cause reduction of 46% in the yield strength of the welded WM and 15.4% in pre weld heat treated WM of the 8011A aluminium alloy. This showed that pre weld heat treated joint had higher yield strength after welding compared to the weld sample. This may likely due to the reason discussed in Fig. 6.

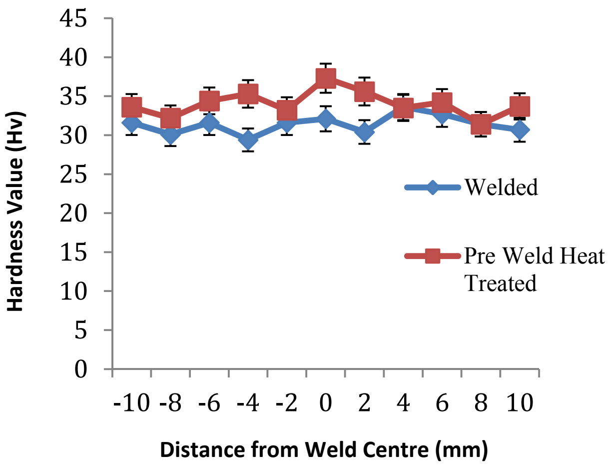

Fig. 6. *Hardness values for pre weld heat treated and welded samples at different points from the center*

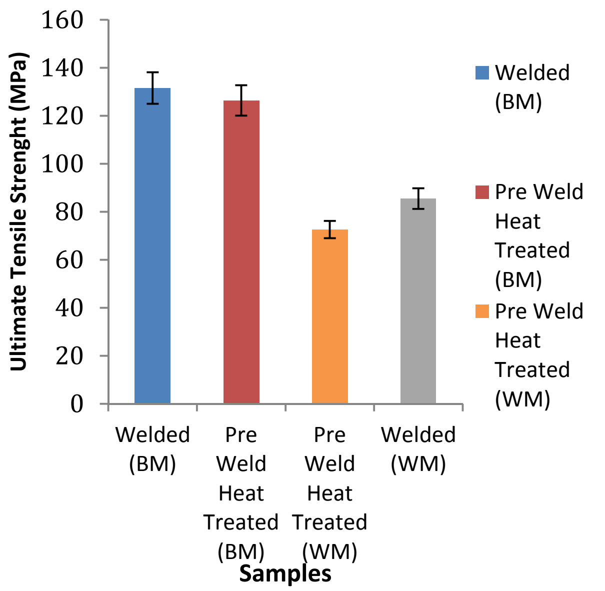

Fig. 7. *Ultimate tensile strength of pre weld heat treated and welded samples*

3.3. *Impact Properties Result Analysis*

The impact properties of the joints in the pre weld heat treated and welded conditions were evaluated and presented in Fig. 9. The average impact energy of the welded joint was obtained to be 19.67 J while that of the pre weld heat treated joint was obtained to be 15.3J. The welded joint has the highest impact energy, which reduces by 22.21 % when compared with pre weld heat treated joint.

3.4. *Corrosion Properties Result Analysis*

From the potentiodynamic polarization curves of the pre weld heat treated and welded samples immersed in 3.5wt. % NaCl solution as presented in Fig. 10, the samples shows similar passivity and polarization behaviors.

However, corrosion current densities and the corrosion potentials differentiate their corrosion resistances. It was observed that, the corrosion current density was more in the welded WM than it was in the pre weld heat treated WM. This shows that the pre weld heat treated weldment has more resistance to corrosion than welded weldment. In comparison, the pre weld heat treated samples shows 92% reduction in corrosion rate when compared with the welded samples. The Icorr and the Ecorr values also support the claim and shows that the pre weld heat treated WM has more resistance to corrosion than the welded WM which may be attributed to the ageing treatment they are subjected to before welding. When these samples are subjected to ageing, the precipitate form is coherent with the matrix. Also, due to the fact that, there is little or no differences in the electro potentials of the precipitates and the matrix of pre weld heat treated samples, corrosion rate is reduced,. This shows that the pre weld heat treated samples are more thermodynamically stable and less susceptible to corrosion in a solution of 3.5 wt. % NaCl.

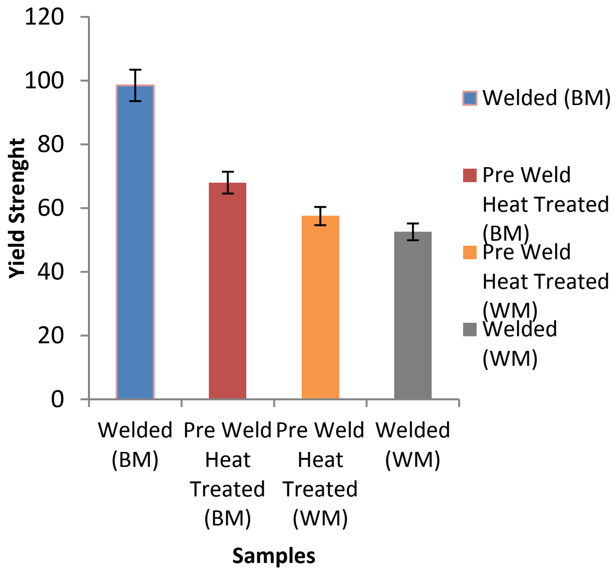

Fig. 8. *Yield strength of pre weld heat treated and welded samples*

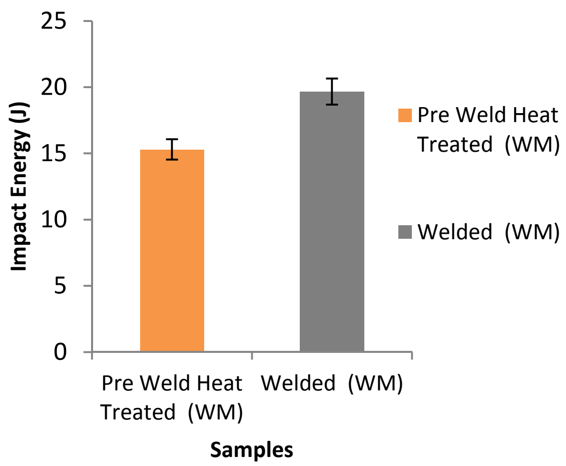

Fig. 9. *Impact Energy of pre weld heat treated and welded joint*

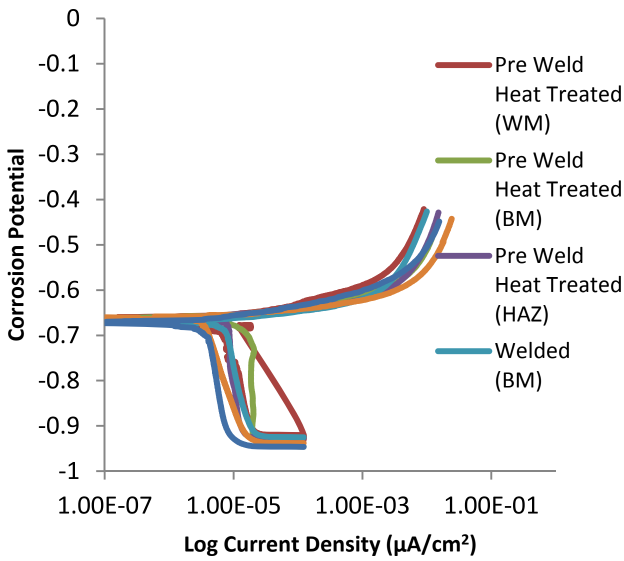

Fig. 10. *Potentiodynamic polarization curves of the aged and un-aged samples in 3.5 wt. % NaCl solution*

3.5. Microstructural Analysis

The micrograph of the HAZ, BM of both the pre weld heat treated and welded samples were displayed in Fig. 6. The welded BM, HAZ shows a distribution of fine grains compared to the equiaxed fine grains observed in the pre weld heat treated samples of BM and HAZ as shown in Fig. 11(a), (b), (c), and (d), respectively. The changes in the microstructure of the BM and HAZ can be attributed to the effect of the heat treatment and the subsequent welding process the samples were subjected to, which results in the changes that was observed in the mechanical and corrosion properties of the 8011A alloy. In comparison, the grains size in the HAZ of both the pre weld heat treated and welded samples are larger than that of the BM as observed in Fig. 11(c) and (d), perhaps as this grains coalesce and grow in to larger scale, it has detrimental effect on the mechanical properties [8,14].

The pre weld heat treated WM zone has an equiaxed uniformly distributed fine grains as shown in Fig. 12(a) compared to the WM of the welded sample in Fig. 12(b). It was seen that the grains of the WM of the welded samples appears to be slightly bigger than that of the pre weld heat treated WM, even though, changes in the grains is not really obvious.

From the micrographs, there are slight changes in the size, distribution and arrangement of grains when the micrographs of the WM are compared to their respective HAZ and BM, which indicates the welding parameters are well controlled. Moreover, the pre weld heat treated samples has more fine, equiaxed, uniformly distributed grains which resulted into improvement in the corrosion resistance and some of the mechanical properties. Studies have shown that the iron in aluminium alloys tends to form intermetallic secondary phases as some of these can be identified in the micrograph of the un-aged samples.

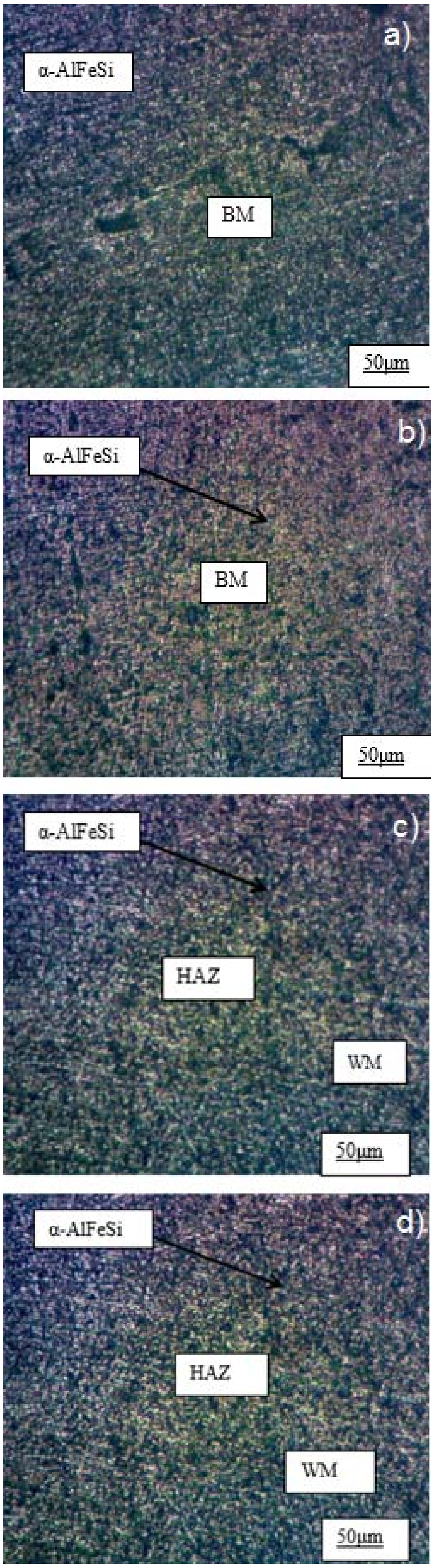

Fig. 11. *Optical micrographs in different zones of the pre weld heat treated and welded samples; (a) BM of pre weld heat treated (b) BM welded (c) HAZ of pre weld heat treated (d) HAZ welded*

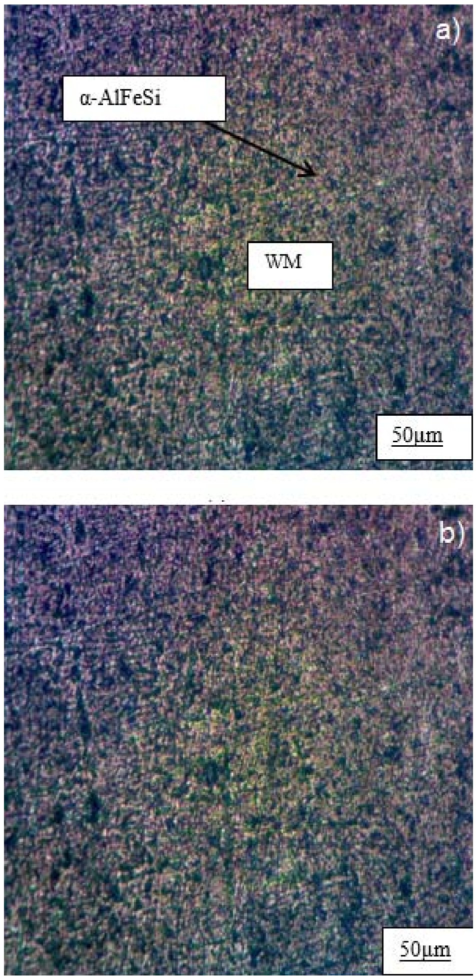

Fig.12. *Optical Micrograph of the Weld Metal of pre weld heat treated and welded samples; (a) WM of pre weld heat treated; (b) WM of welded*

Nevertheless, after the ageing heat treatment, a uniform grain distribution was observed and reduction of the intermetallic phases occur [5] [15] confirming that the binary Al-Fe phases that can be formed in 8011A aluminium alloy at equilibrium are Al_3Fe or metastable Al_6Fe and Al_9Fe_2 and these have influence on the mechanical properties [16] identified the α-Al_3Fe and ß phases to be detrimental to the mechanical properties, as they represent stress concentrators and promote micro crack initiation and the coalescence of these micro cracks leads to fracture. Heat treatment has been employed as a means of improving mechanical properties of materials by controlling the distribution and morphology of these phases and reduces the delirious effect of these phases to the barest minimum. In this research, the pre weld heat treatment has aided the reduction of the tendency to form these deleterious compounds.

4. CONCLUSIONS

The following conclusions were drawn out from the research;

The pre weld heat treated WM has the better yield strength with an improvement of 8.63% when compared to the welded WM. This indicates that the pre weld heat treatment was able to improve the yield strength of 801lA alloy weldments.

The pre weld heat treated sample has the best hardness property across all the zones as this shows that pre weld heat treatment has brought about increase in hardness as a result of the precipitation during ageing treatment and stresses induced during welding.

The corrosion susceptibility of the alloy in 3.5 wt% NaCl shows that the pre heat treated WM has the best corrosion resistance. This was made possible because the pre weld heat treatment of the 8011A alloy helped in the reduction of the Al_3Fe and ß phases which has detrimental effects on both mechanical properties and corrosion resistance of aluminum the alloy.

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