[1.]I.O. OLADELE, [2.]O.T. BETIKU, [3.]A.M. OKORO, [4.]O. EGHONGHON

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 304L AND MILD STEEL PLATES DISSIMILAR METAL WELD JOINT

[1-4.]Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, NIGERIA

Abstract: Weldment of dissimilar metals has been of increasing demand and importance in many structural and industrial applications to optimize properties combination, reduce weight of component and cost. In this research, the microstructural and mechanical properties of dissimilar metal welded joint (DMWJ) of austenitic stainless steel (304L; 18/8) and mild steel plates of 5 mm thickness were experimentally investigated. A single V butt joint was prepared and the plates were welded using Gas Tungsten Arc Welding (GTAW) process with ER308L as filler metal. The mechanical properties were examined by tensile, hardness and bending tests while the microstructural characteristics were studied using the Scanning Electron Microscope (SEM). From the results, it was observed that tensile and hardness properties of the dissimilar weld fall between that of the austenitic stainless steel and the mild steel base metals while the bending strength emerges as the best. Austenitic stainless steel possesses bending strength property that was next to the welded sample as well as the best tensile and hardness properties.
Keywords: dissimilar metal weld, austenitic stainless steel, mild steel, mechanical properties, microstructure

INTRODUCTION

Welded dissimilar metals have emerged as structural materials for various industrial applications which provide good combination of mechanical properties like strength, corrosion resistance with lower cost. They have found widespread application in power generation, electronic, nuclear reactors, petrochemical and chemical industries mainly to get tailor-made properties in a component and reduction in weight [1-3].

Austenitic stainless steels posses' good mechanical properties and corrosion resistance which account for its application in many equipment and environments like low and high pressure boilers and vessels, fossil-fired power plants, flue gas desulphurization equipment, food processing plants and surgical implants [4].

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used.

GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger and higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques [5].

Conversely, due to difference in thermo-mechanical and chemical properties of the materials to be joined under a common welding condition, it causes a steep gradient of the thermo-mechanical properties along the weld. Also when joining dissimilar metal welds, diffusion in the weld pool often results in the formation of inter-metallic compound in the welded region. These inter-metallic compounds can be deleterious to the mechanical properties, especially particles of primary crystals, which represent strong stress concentrators and promote the initiation of sharp microcracks [6]. The growth of microcracks may cause brittle fracture thereby reducing the ductility of the joint [3].

Tanaka et al., [7] showed that the mechanical properties of the joints are greatly influenced by the formation of inter-metallic compounds. Therefore, inter-metallic compounds should be checked in order to find problems related to crack sensitivity, ductility, corrosion, and many more which makes the study of microstructure significant [8].

Radha et al., [1] studied the tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel. Stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes.

The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG welded dissimilar metal joints have better properties than MIG welded joints. Jamaludin et al., [9] studied the mechanical properties of welded joint by tension test. It was observed that, the yield strength and tensile strength of welded samples using mild steel welding electrode were slightly lower than welded samples using stainless steel welding electrode.

Giridharan et al., [5] carried out an experimental work to study the mechanical properties of a dissimilar welding joint between IS 2062GrC mild steel and AISI 316L stainless steel, using AISI 309L filler rod. Tensile test, bend test and the microstructural characteristics were studied. The result showed good bending behavior, and improved tensile strength in the weld area. Electron microscopy showed the dilution of base metals in the weld zone.

In this work, dissimilar welding of austenitic stainless steel (304L; 18/8) and mild steel plates of 5 mm thickness was carried out using GTAW process. Assessment of the microstructural characteristics and mechanical properties of the dissimilar joints were investigated and the formation of dissimilar joints produced by GTAW based on the experimental results was discussed.

EXPERIMENTAL PROCEDURE

— Chemical Analysis

The major materials used for this experiment were austenitic stainless steel (ASS) (304L/18:8; that is 18% Cr and 8% Ni) and mild steel in the form of a rectangular plate both with thickness of 5 mm. The chemical compositions of the base metals under study were obtained by spectrometry and were as shown in Table 1.

Table 1: Chemical composition of austenitic stainless steel (ASS) and mild steel (wt.%)

Elements	C	Si	Mn	P	S
ASS	0.091	0.430	1.310	0.039	0.011
Mild Steel	0.071	0.327	1.155	<0.001	<0.001
Elements	Ni	Cr	Mo	N	Cu
ASS	8.050	18.09	0.220	0.038	0.350
Mild Steel	0.169	0.062	0.013	0.008	0.022

— Welding and Sample Preparation

The base metals were cut into the desired length of 150 x 60 mm and a single-V butt joint was prepared for better root penetration. The welding operation was carried out afterwards using the Gas Tungsten Arc Welding (GTAW) and a stainless steel filler metal (ER308L) was used. Direct Current Electrode Negative (DCEN) was employed with welding speed of 150 mm/min and welding current of 110 A.

The arc length, filler tip angle, filler type and size are; 2.0 mm, 60°, ER308L and 3.2 mm, respectively. Pure argon gas was used as the shielding gas to prevent oxidation of molten steel. After completion of the welding process, tensile test samples with dumbbell shapes were cut transversely from the welded joint and the base metal. Machining was also done for the hardness test and microstructural samples which were sectioned from the Weld metal (WM), Heat affected zone (HAZ) and the Base metal (BM).

PROPERTY TESTS

— Determination of Tensile Properties of the Samples

Tensile test samples were prepared in accordance with ASTM A370-08A [10] and the test was carried out using Su Zhou Long Sheng universal testing machine. Three samples were tested with a load of 300 KN and crosshead speed of 5 mm/min correlating with an initial strain rate of 0.98 s^{-1} respectively. The specimen was mounted by its ends into the holding grips of the test apparatus. The tensile testing machine was designed to elongate the specimen at a constant rate, and to continuously and simultaneously measure the instantaneous applied load and the resulting elongations. The applied load permanently deformed and fractured each sample into two parts.

— Determination of Bending Properties of the Samples

The bending test was carried out by using Testometric universal testing machine in accordance with ASTM E190-92 [11] standard test method for bending properties of welded samples. The bending test was performed at the speed of 100 mm/min. Three samples were tested for each representative samples from where the average values for the test samples were used as the illustrative values.

— Determination of the Hardness of Samples

This method consists of indenting the test material with a hardened steel ball indenter using Indentec hardness testing machine. Rockwell hardness test produces a much smaller indentation more suited for hardness traverses. The hardness samples were separated into three parts- Base metals (BM) for mild steel and stainless steel, HAZ for mild steel and stainless steel and the weld metal (WM).

The test samples were cut into 9 x 9 mm for the different zones and were used for the hardness as well as the microstructural characterization using the Scanning Electron Microscope (SEM). The indenter was forced into the test material under a preliminary minor load of 60 kgf which gradually increased to 100 kgf and 150 kgf. The test was carried out 3 times at different locations on BM, HAZ and WM and, the readings were recorded as displayed by the hardness testing machine.

RESULT AND DISCUSSION

— Mechanical Properties

The tensile properties such as yield strength, ultimate tensile strength and the tensile modulus were evaluated. All the data were the average of the measured values obtained as shown in Figure 1.

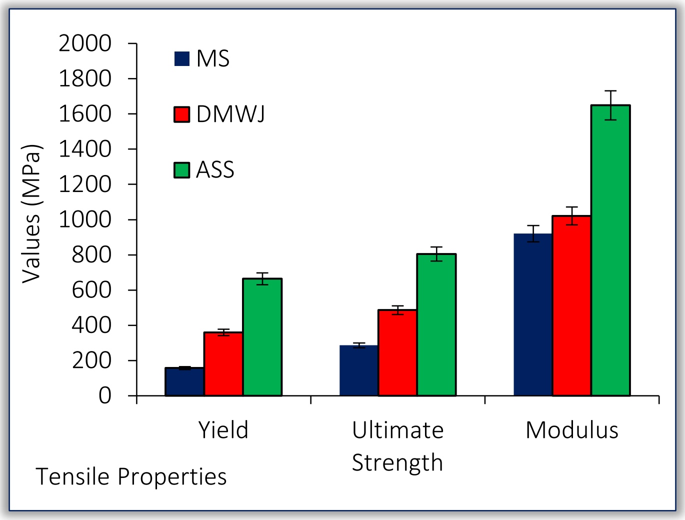


Figure 1: Charts of the tensile properties for the various zones

The charts for the various tensile properties of the welded dissimilar metals were as shown in Figure 1. The plot shows the yield, ultimate tensile strength and tensile modulus of the weld and base metal samples. It was revealed from the results that similar trends emerged in the response of the materials to these properties. In all the properties examined, austenitic stainless steel gave the optimum performance followed by the weld and mild steel samples, respectively. This trend in terms of materials and values for the properties were ideal for structural integrity where gradual decrease in property from one end to another is essential for effective service performance. The values at the weld joints form the transitional values between that of austenitic stainless steel and the mild steel.

The austenitic stainless steel (ASS) base metal possesses the highest ultimate tensile strength with a value of 805.3 MPa followed by weld sample with a value of about 486.2 MPa while the lowest was the mild steel (MS) base metal with a value of about 286.3 MPa. The results showed that ultimate tensile strength of the weld joint shows an increase of about 38.9 % compared to the mild steel base metal. This shows that the weld joint aids balance in transition from low strength mild steel to high strength austenitic stainless steel. The yield strength and tensile modulus also followed the same trend, the highest been 664.31 and 1649.33 MPa, respectively exhibited by the austenitic stainless steel while the lowest was 157.77 and 920.77 MPa, respectively exhibited by the mild steel.

The weld joint shows an increase of about 56.1 % in yield strength and 9.8 % in tensile modulus compared to the mild steel base metal. Part of the reason for this may be the presence of high amount of Chromium and Nickel in the austenitic stainless steel than the mild steel as shown in Table 1. The welded dissimilar metal samples fractured closed to the mild steel due to the low strength possess by the steel compared to the austenitic stainless steel as shown in Figure 2.

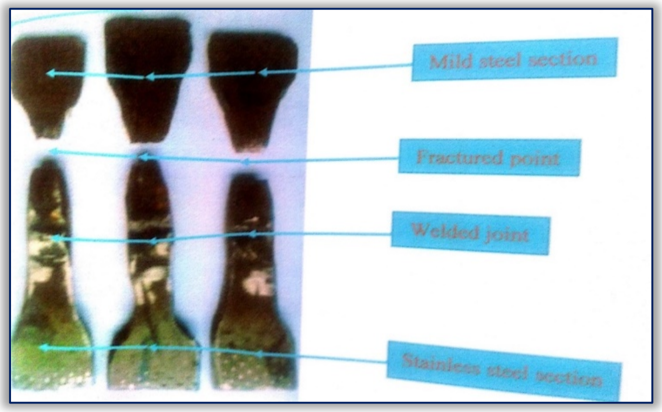


Figure 2: Fractured sample after tensile test showing fracture of sample at mild steel side

Rockwell hardness test was carried out on the samples to measure the variation in hardness across the weld zones of austenitic stainless steel 304L and mild steel. The hardness assessment in Figure 3 shows the average hardness values across the weld interface covering the base metals.

The hardness value obtained is higher for ASS 304L when compared to the mild steel. The highest average hardness value is 37.38 HRC for the austenitic stainless steel base metal while the lowest hardness value is 27.1 HRC for mild steel heat affected zone. The hardness value obtained at the DMWJ which is lower than that of the stainless steel but higher than that of the mild steel. This implies that, there is diffusion of alloying elements in the weld pool which affects the mechanical properties, hence, an intermediary hardness in the joint.

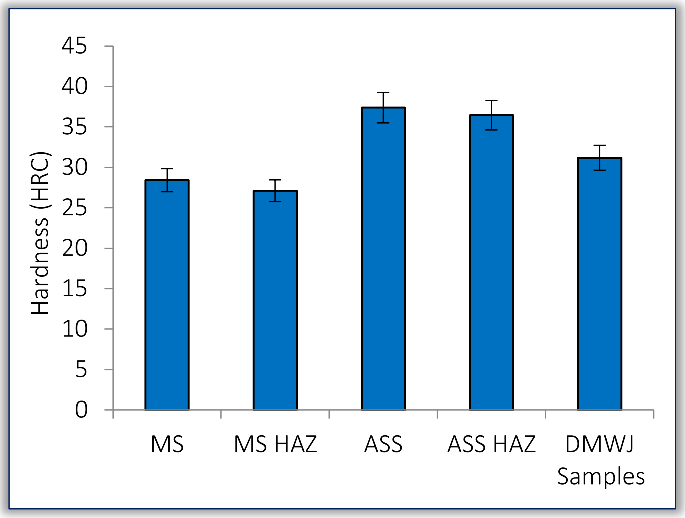


Figure 3: Rockwell hardness values of samples at different regions

In agreement with the findings of Muralimohan et al., [12], it was revealed from the results in Figures 1 and 2 that, there is an analogous tendency in hardness distribution in the various zones like that of the tensile properties. The reason for the variation in hardness can be due to the varying carbon content in the base metals.

The bending test was used to determine the maximum breaking load the materials can withstand before failure as shown in Figure 4.

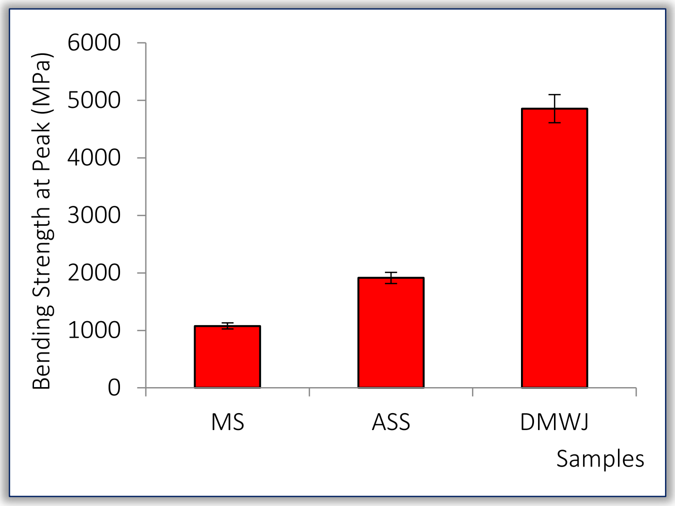


Figure 4: Bending Strengths of base metals and the dissimilar metal welded joint

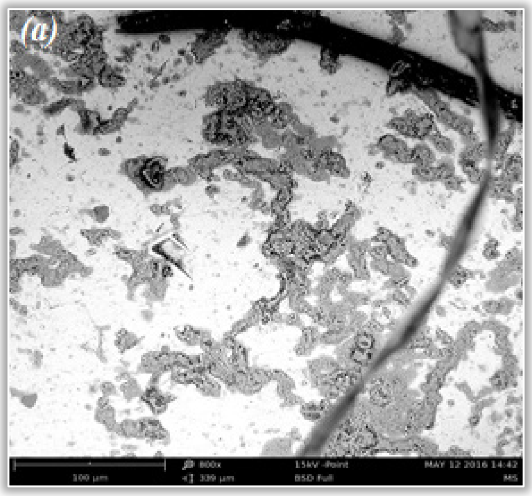
The bending test result shows that the dissimilar metal weld sample possess the best bending strength due to the highest bending resistance capability. The sample was with a value of about 4857 MPa followed by the austenitic stainless steel base metal with a value of 1913 MPa while the mild steel possess the lowest bending strength with a value of 1436 MPa. Considering other mechanical properties, the response of the dissimilar metal weld shows that, it possesses good combination of mechanical properties. The fractured points from the tensile test results as shown in Figure 2 further confirmed this since it occurred at the end close to mild steel and not at the weld joint.

The dissimilar metal welded samples possess intermediate strength and hardness between austenitic stainless steel and mild steel but it possesses the best bending strength. This therefore, implies that by joining these two different metals for applications in areas where changes in structural properties are essential based on environmental effects and cost, this product may be considered for such.

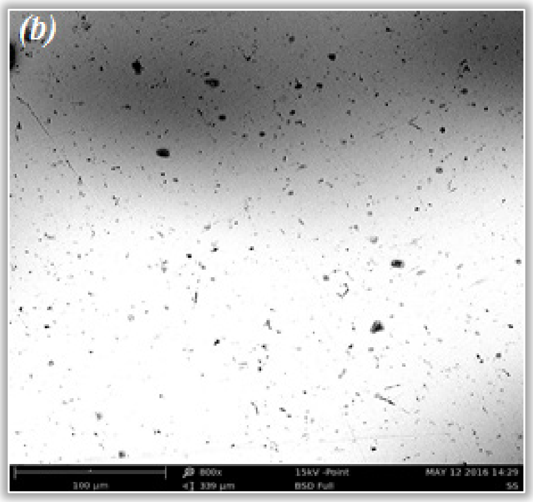
— Microstructural Examination

The welded sample, base metal and HAZ of the two dissimilar materials were examined with the Scanning Electron Microscope and the microstructures were analyzed as shown in Figure 5.

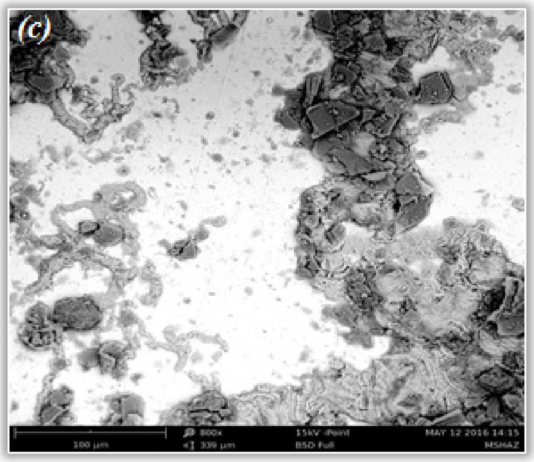
In stainless steel welds, the microstructures were usually related to types of solidification and subsequent transformation behavior. The heat input is handled differently for each welding process and can result in different effects on the dissimilar stainless steel welded joints.



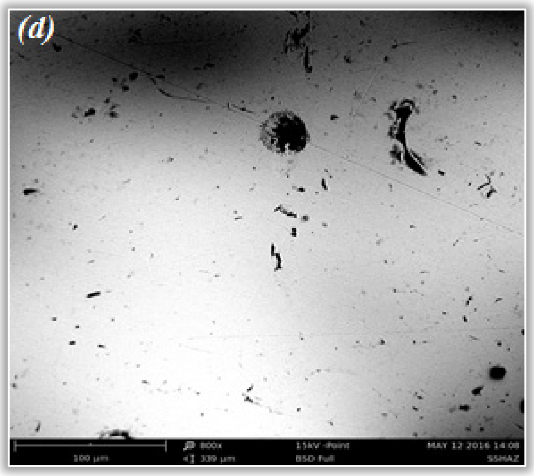
a)



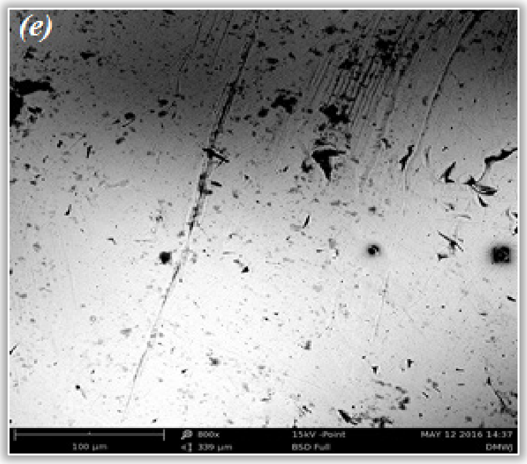
b)



c)



d)



e)

Figure 5: SEM images of a. BM of mild steel b. BM of ASS
c. HAZ of mild steel d. HAZ of ASS
e. fusion zone of the dissimilar weld metal

Figures 5 (a-e) showed the various sections of the metals where it became obvious the influence of heat input and solidification on the transformation behavior.

Figures 5 (a) and (c) shows the micrograph of the mild steel BM and HAZ. The mild steel BM reveals a heterogeneous microstructure, consisting of ferrite, and pearlite.

The globular and laminar pearlite phases are dispersed across the ferrite phase. This corresponds to mild steel HAZ showing fragmentation of pearlite, noticing clearly iron carbide (cementite) globular dispersed in the ferrite phase as a result of recrystallization occurred by the heat generated during welding.

Figures 5 (b) and (d) shows the micrograph of the ASS BM and HAZ, the HAZ exhibits low level of isolated inclusions similar to Andrés et al., [13] but this increases in the WM. Hsieh et al., [14] studied the microstructure, recrystallization, and mechanical properties in the heat affected and fusion zones of dissimilar stainless steels. Two types of stainless steels, namely 304 (X5CrNi18-10 according to EN 1.4301) (fully austenite containing a few ferrite phases) and 430 (X6Cr17 according to EN1.4016) (fully ferritic microstructure) were welded using GTAW without a filler material.

The recrystallization phenomenon was evident with the second pass heat-affected zone (HAZ-2) and indicated equi-axed grains after second pass welding. The contents of δ-ferrite exhibited the highest value of all situations in the first pass fusion zone (FZ-1) during first pass welding. These findings confirm the effect of heat input even when filler is not used. However, it should be pointed out that the filler metal and buttering are unavoidable when the dissimilarity between the base metals cannot result in joints that are free of flaws [15].

CONCLUSIONS

This experimental work presents the study on the microstructural and mechanical properties in a dissimilar welding joint between 304L austenitic stainless steel and mild steel using ER308L filler rod. From the study, the following conclusions were made:

- Gas Tungsten Arc Welding process was successfully used to produce the ASS and mild steel dissimilar metal joint
- The tensile strength obtained in dissimilar welded joint was 38.9% higher than parent material of mild steel whose tensile strength was 286.3 MPa. Fracture of the tensile test sample occurred at the mild steel base metal side.
- The hardness value in the ASS side was higher than the mild steel side, this can be attributed to the varying carbon content
- The welded joint possesses the highest bending strength with a value of 4857 MPa. This was followed by the ASS base metal and then the mild steel base metal.

References

[1] Radha, R.M.; Visnu, K.T.; and Rajesha, S: A Study of Tensile Strength of Mig and Tig Welded Dissimilar Joints Of Mild Steel And Stainless Steel, International Journal of Advances in Materials Science and Engineering, 3(2), 23-32, 2014.
[2] Pouraliakbara, B.H.; Hamedia, M.; Kokabia, A.H.; and Nazarib, A: Designing of CK45 Carbon Steel and AISI 304 Stainless Steel Dissimilar Welds, Materials Research, 17(1), 106-114, 2014.
[3] Tayyab, I: Analysis of Dissimilar Metal Welding of 1020 Mild Steel and 304 Stainless Steel, Master Thesis, Department of Mechanical Engineering, National Institute of Technology, Rourkela, 2014.
[4] Oladele, I.O.; Omotoyinbo, J.A.; and Akinwekomi, A.D: The Effect of Weld Goemetry and Post Weld Heat Treatment on the Corrosion Behaviour of Austenitic Stainless Steel Immersed in 1.0 M NaCl Solution, Material Research, 13(1), 405- 418, 2010.
[5] Giridharan, S.; Kannan, T.M.; Balamurugan, K.; Kumar, A.; and Vignesh: Experimental Investigation and Analysis of Dissimilar welding of AISI 316L and IS 2062 using GTAW, International Journal of Innovative Research in Science, Engineering and Technology, 5(6), 11052-11058, 2016.
[6] Oladele, I.O.; Betiku, O.T.; and Fakoya, M.B: Effect of Post Weld Heat Treatment on the Mechanical and Corrosion Behaviour of Welded Al-Fe-Si Alloy Joints, Leonardo Electronic Journal of Practice and Technologies, (30), 75-86, 2017.
[7] Tanaka, T.; Morishige, T.; and Hirata, T: Comprehensive Analysis of Joint Strength for Dissimilar Friction Stir Welds of Mild Steel to Aluminum Alloys, Scripta Materialia, 61, 756–759, 2009.
[8] Shahid, F.; Khan, A.A.; and Hameed, M.S: Mechanical and Microstuctural Analysis Of Dissimilar Metal Welds, International Journal of Research and Reviews in Applied Sciences, 25(1), 6-14, 2015.
[9] Jamaludin, S.B.; Noor, M.M.; Kadir, S.K.; and Ahmad, K.R: Mechanical Properties of Dissimilar Welds between Stainless Steel and Mild Steel, Advanced Materials Research, 795, 74-77, 2013.
[10] ASTM A370-08A: Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM international, 2008.
[11] ASTM E190-92: Standard Test Method for Guided Bend Test for Ductility of Welds, ASTM International, Re-approved 2008.
[12] Muralimohan, C.H.; Haribabu, S.; Hariprasada, R.; Muthupandi, V.; and Sivaprasad, K: Evaluation of Microstructures and Mechanical properties of Dissimilar Materials by Friction Welding, Procedia Materials Science, 5, 1107-1113, 2014.
[13] Andrés, G.F.; Rafael, S.A.; Leiry, C.B.; and Alberto, V.R: Crack growth study of dissimilar steels (Stainless-Structural) butt-welded unions under cyclic loads, Procedia Engineering, 10, 1917–1923, 2011.
[14] Hsieh C.C.; Lin D.Y.; Chen M.C.; and Wu W: Microstructure, Recrystallization, and Mechanical Property Evolutions in the Heat-Affected and Fusion Zones of the Dissimilar Stainless Steels, Materials Transactions, 48(11), 2898-2902, 2007.
[15] Mvola, B.; Kah P.; and Martikainen J: Dissimilar Ferrous Metal Welding Using Advanced Gas Metal Arc Welding Processes, Rev. Adv. Mat. Science, 38, 125-137, 2014

ISSN: 2067-3809