Analysis and Investigation into Microstructure and Mechanical Properties of Dissimilar Welded Joints

Siham Al Shukaili
Level 4, BEng Process Operations and Maintenance Student
Department of Mechanical and Industrial Engineering
Caledonian College of Engineering
Muscat, Sultanate of Oman
siham120886@cceoman.net

Murali, R V
Faculty Member
Department of Mechanical and Industrial Engineering
Caledonian College of Engineering
Muscat, Sultanate of Oman
murali@caledonian.edu.om

Mutlag, S Fuhaid
Senior Instructor
Department of Mechanical and Industrial Engineering
Caledonian College of Engineering
Muscat, Sultanate of Oman
mutlag.shafi@caledonian.edu.om

Abstract— **Welding process is the most commonly used joining process in oil and gas industries especially for manufacturing of heat exchangers, pipelines fabrication etc. Investigation on microstructure and mechanical properties of welded joints is a challenging topic and has more useful benefits. The main aim of this work is to do microstructural analysis of welded joints before and after welding process and relate them with variation in mechanical properties of welded joints. The joints are made up of two different metals to analyse before and after welding process. Stainless steel and carbon steel materials are considered for the investigation as they find more industrial applications such as in steam ship manufacture, high temperature bolts, nuclear reactors etc. because of their excellent resistance to corrosion and high temperature etc. Literature studies reveal that the evaluation of the dissimilar metal weld (DMW) of steels, by different welding processes, was carried out in the past. In this project, tungsten inert gas (TIG) welding process is selected for welding the dissimilar metals and further analysis of the microstructures and mechanical properties. All the welding process is done in our workshop and high-resolution microscope and tensile testing machines (UTM) are used in this project to conduct the mechanical testing and microstructure analysis respectively. Results obtained from these tests are in agreement with the published results. Finally, analysis and interpretation of the results leads to correlating microstructures of the base metals with their mechanical properties such as ultimate tensile strength (UTS), ductility and hardness values.**

I. Introduction

Welding is very important because it is used in most of the fabrication industries. Without welding, there would be no vehicles on the road, no buildings, no gates and no fences. Welding is the best-known way to join metals permanently. It is the joining of two pieces of metal together to form one piece. This process is induced by a combination of temperature, pressure, and metallurgical conditions. A very simple process takes two or more pieces of metal and heats the joint areas. Welding can be done anywhere - outdoors or indoors, underwater or in outer space. In addition, it is a very important activity in the industry. Large ships, bridges, huge buildings, railways, roadways, automotive and aircraft construction, pipelines, tanks and vessels essentially depend on welding technology. Mechanical properties that are normally considered significant in any type of welded assemblies are Ultimate Tensile Strength (UTS), % Elongation and Hardness which are determined through Tensile Testing and Hardness Testing methods respectively.

The aim of the project is to investigate the changes in microstructures and mechanical properties (of the base metals) that are influenced by butt welding done by TIG welding processes. This would show us an understanding of how mechanical properties of the weld are related with microstructural changes and welding parameters and variables. This process is sequenced as follows: firstly, to obtain knowledge of welding methods of two different materials, then secondly to select suitable materials for making similar/dissimilar welded joints and welding process, thirdly to understand and analyze how mechanical properties and microstructures are related to each other in welded joints.

II. BACKGROUND STUDIES

In this section, a short summary of literature collected from several journal papers and books and other sources of information that are relevant to the project are presented. These pieces of information are very important for the development of the project to understand more about the ideas and working methods.

Sheikhi (2008) conducted a preliminary study on microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminum alloys (2024-T351) and 6056-T4. In this study, the type of welding used is TRICEPT TR805 robot and the tool rotational speed was varied from 500 to 1200 rpm. The specification of the tool used of FSW with 5 mm diameter threaded cylindrical pin and 15 mm concave shoulder was employed. The mechanical properties for both metals were determined by the testing conventional, flat tensile specimens and micro flat specimens at room temperature. The temperature was obtained at plate surface by used an infrared camera.

Bharathi (2015) reviewed her study on mechanical properties and micro-macro structural characteristics of Friction Welded Similar Joints of Aluminum Alloys. The following are the main steps followed in this attempt. First, aluminum alloy 6061 materials are used in a cylindrical rod form of 12 mm diameter and 75 mm long. Then, the chemical composition and mechanical properties of the base materials are identified. A hydraulic controlled continuous drive friction welding machine (20 kN capacity) was used to weld the joints. Tensile test was carried out in 100 kN, so that tensile specimen undergoes uniform deformation. The specimen finally fails after the necking and the load vs displacement was recorded.

Chen (2016) analysed the microstructure and mechanical properties of resistance-spot-welded joints for A5052 aluminum alloy and DP 600 steel. The parameters of I1, T1, I2, T2, and F represent preheating current, preheating time, welding current, welding time, and welding force, respectively.

Hajideh (2017) studied of the investigation on the effects of tool geometry on the microstructure and the mechanical properties of dissimilar friction stir welded polyethylene and polypropylene sheets. In this study, the effects of three parameters namely tool shape, rotational speed and traverse speed on the weld quality were studied. In general, two types of material flow were observed in this study: laminar and turbulent. In laminar flows, the weld structure is often regular and uniform and is free of defects such as cavity and porosity. However, on the structure of the welded joint under the turbulent flow condition, defects such as decreased degree of crystallinity and tunnel appear. It was observed that by increasing the tool rotational speed from 1860 rpm to 2920 rpm, the material flow becomes turbulent.

Tan (2017) performed a study on microstructure and mechanical properties of AA 3003 aluminum alloy joints by underwater friction stir welding. The evolution of microscopy and mechanical properties of FSU joints strongly depend on pin / shoulder geometry, rotation and velocity of welding, and the initial microscopic structure.

As a result of the above review of literature, various welding details such as materials, edge types / preparations and joining conditions and testing methods such as tensile and hardness measuring techniques along with microstructural analysis are understood. Therefore, literature studies are an important medium for the present work as reference to an extent possible.

III. MATERIALS & METHODS

In this section, materials selection, welding process, specific parameters used for welding and testing details are presented. Stainless steel and mild steel plates (rectangular plates 150 x 50 x 3 mm) are selected for making the welded joints. Tensile test, hardness test and microstructures of individual base metal are taken before the welding process. Then, TIG welding process is used to unite these two base metals to make a single V-joint as illustrated in figure 1 below. Later, the same parameters and microstructure are measured and analysed for a completed welded assembly.

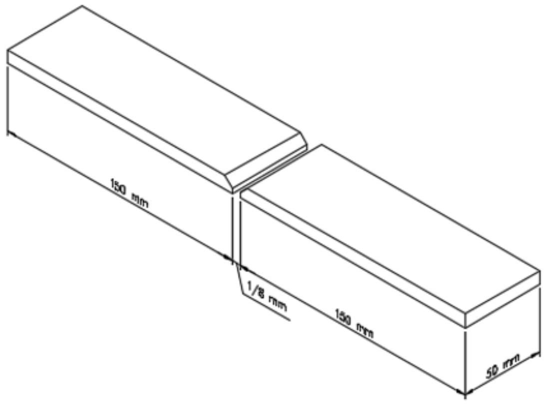


Figure 1 CAD Model of Single V Butt Welding

Figure 2 Tensile Test Specimen for the welded assembly

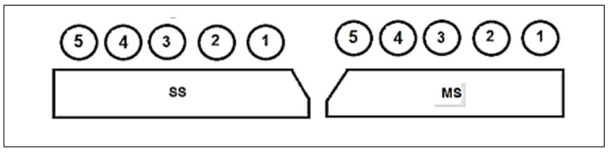
Table 1 Chemical composition of base materials used

Mild Steel					
C	Si	Mn	S	P	Fe
0.16-0.18	0.4	0.7-0.9	0.04	0.04	Balance

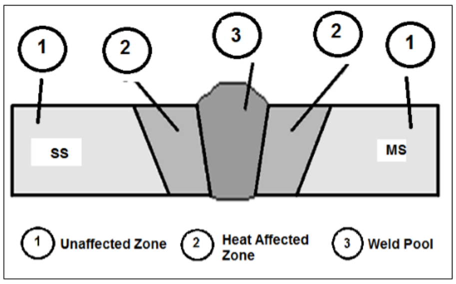
Stainless Steel							
C	Si	Mn	S	P	Cr	Ni	Fe
0.03	1	1.5	0.04	0.04	10.5	1	Balance

Before welding of these two base metals, uniaxial tensile test was carried out on individual plates and microstructural images were taken for analysis. Then, welding process was carried out using a TIG welding machine in our workshop. As many as 6 samples are made using this TIG welding machine and subjected to mechanical testing and microstructural analysis. The results were recorded and then compared for deriving the correlation between the mechanical properties and microstructures. Vickers hardness machine was used to measure the hardness values of the specimen at different locations. Mechanical load applied in the hardness testing machine as 10 kg and the materials of the indenter was Diamond. A 600 kN tensile tester machine was used to conduct the tensile testing operation. Scanning Electron Microscope (SEM) was used to capture the microstructural images of the specimen. Figure 3 shows the testing points on the individual base metals as well as welded assembly for hardness and microstructural analysis.

LOCATION OF TESTING POINTS



(i) BEFORE WELDING



(ii) AFTER WELDING

Figure 3 Location of the Test Points

Table 1 presents the chemical composition of base materials used in this work and Table 2 below shows the welding parameters used for making the single V joint butt joint out of the base metals.

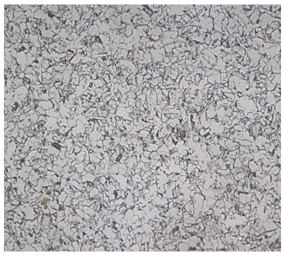
Table 2 Welding Parameters Used for TIG

Parameters	Values Set
Voltage (V)	50 V
Speed (mm/s)	3.5 - 4
Current (A)	20 - 200 (AC)
Filler Rod	E 316 L
Electrode	Single, ø1.6 mm

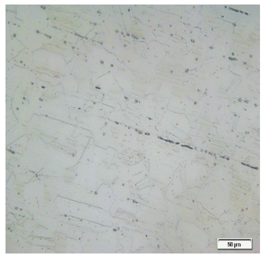
IV. RESULTS AND DISCUSSION

The core aim of this experimental based work is to measure the mechanical properties and microstructural analysis of the base metals before and after the welding process. This will provide an insight on how the mechanical properties are varied in relation to the changes in the microstructures.

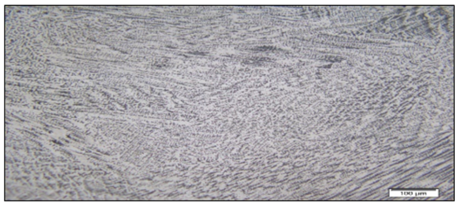
Figure 4 shows the microstructural images of base metals before welding process took place. In the case of Mild Steel plate, the microphotographs at the parent metal area (after etching, 2% Nital being the etchant) shows a typical parent metal structure with ferrite and pearlite in the examined location at 500X magnification. The grain size, when assessed in accordance with ASTM E112, was estimated to be 6. In the case of Stainless Steel plate, when examined with a magnification of x100, the microstructure showed equiaxed grains of austenite. No evidence of deleterious phase or continuous network of ferrite observed. The grain size was estimated to be ASTM No. 4. Etchant used was 10% oxalic acid (electrolytic).



(a)



(b)



MS & SS Weldment

(c)

Figure 4 Microstructures before welding (a) MS (b) SS (c) after welding

Hardness test was carried out on each sample before welding and after welding. It was observed that the average for Stainless Steel was 173 and for Mild Steel was 181 in Vickers hardness scale. Load applied was 10 kg and the materials of the indenter was diamond. Tensile Test for the both sample Stainless Steel and Mild Steel was carried out before welding and the figure 4 presents the results of the microstructures before welding base metals. Figure 5 presents that tensile test values of the base metals before welding and Table 3 presents the results of tensile test along with % elongation and fracture location.

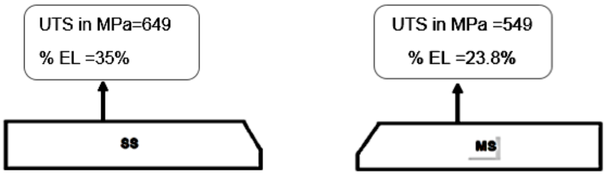


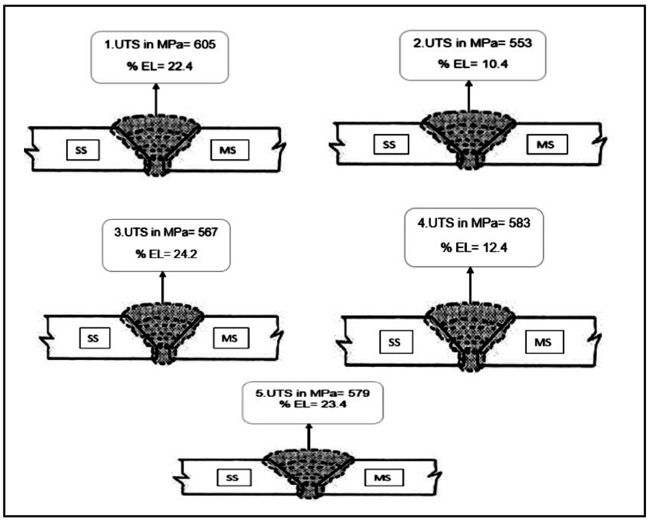
Figure 5 Tensile Test Results before welding

Table 3 Tensile Test Results after welding

AFTER WELDING (Mild Steel & Stainless Steel weldments)						Ave Value
Parameters	Test Trial No					
	1	2	3	4	5	
UTS in MPa	605	553	567	583	579	577.4
% EL	22.4	10.4	24.2	12.4	23.4	18.56
Fracture Location	Mild Steel	Weld Interface	Unaffected Zone	Weld Interface		

Figure 6 Fractured Weldments of MS-SS plates

Table 4 Results of the UTM



V. CONCLUSION

The main objective of this research was achieved by welding two dissimilar metals namely Stainless Steel and Mild Steel plates by using TIG welding and investigated through correlation between mechanical properties and microstructural analysis. This project concludes that the strength at weld interface changes considerably in relation to the grain size. However, there are changes in the hardness values along the length of the welded assemblies. Future works. Currently, this project deals with investigation and microstructure analysis of dissimilar welded joints made up of mild steel and stainless steel plates. In our recommendations, the same work can be further extended to cover a range of dissimilar ferrous and non-ferrous metals such as copper and copper alloys, aluminum and aluminum alloys etc. also, the geometry of the welded base metals can be changed to circular from rectangular shapes in order to have a wider understanding of the relationship between the microstructure and the mechanical properties. Finally, mechanical testing methods such as torsion, fatigue and impact also can be done in addition to hardness, tensile and microstructure analysis.

REFERENCES

[1] Hajideh, M., 2017. Journal of Manufacturing Processes. Investigation on the effects of tool geometry on the microstructure and the mechanical properties of dissimilar friction stir welded polyethylene and polypropylene sheets [e-journal]. 26 (10). p. 269–279. Available from: https://www.researchgate.net/publication/314439071. [Accessed 22nd May 2017].

[2] Bharathi, S., 2015. Mechanical Properties and Micro-Macro Structural Characteristics of Friction Welded Similar Joints of Aluminum Alloys. International Journal of Applied Engineering Research [e-journal]. 10 (19).p. 14485-14489.Available from: https://www.researchgate.net/publication/294065694. [Accessed 22nd May 2017].

[3] Tan, Y., 2017. Materials Characterization. A study on microstructure and mechanical properties of AA 3003 aluminum alloy joints by underwater friction stir welding [e-journal]. 127 (10).p. 41–52.Available from: http://dx.doi.org/10.1016/j.matchar.2017.01.039. [Accessed 22nd May 2017].

[4] Chen, J., 2016. Materials Characterization. Microstructure and mechanical properties of resistance-spot-welded joints for A5052 aluminum alloy and DP 600 steel [e-journal]. 120 (12).p. 45–52.Available from: http://dx.doi.org/10.1016/j.matchar.2016.08.015. [Accessed 22nd May 2017].

[5] Sheikhi, S., 2008. Journal of Materials Processing Technology. Preliminary Study on the Microstructure and Mechanical Properties of Dissimilar Friction Stir Welds in Aircraft Aluminium Alloys 2024-T351 and 6056-T4.[e-journal]. 235 (12).p. 13565-905.Available from: https://www.researchgate.net/publication/222696785. [Accessed 22nd May 2017].