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Mechanical and Structural Properties of the Butt Welded Joint in High Strength Structural Steel (ST52-3) using Gas Metal Arc Welding and Oxyfuel Gas Welding

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Abstract:

High strength structural steel plates (ST52-3) can be welded by many types of fusion welding processes. While each type of fusion welding process has its own advantages and disadvantages, direct comparison on the types of fusion welding processes on the mechanical and structural properties are not clearly seen. Therefore, this article focuses on the effects of Gas Metal Arc Welding (GMAW) and Oxyfuel Gas Welding (OFW) on the mechanical and micro structural properties in butt welded high strength structural steel plates (ST52-3). Hardness, tensile, impact and bending strength were investigated while for micro structural properties, Scanning Electron Microscope (SEM) was used. Overall improved mechanical properties were found at the butt welded joint from using GMAW. There is an increase in hardness (3.6%), tensile strength (32%), impact strength (13.7%) and bend strength (300%). SEM images showed that more uniform and smaller sized needle like structures of acicular ferrite were present at the joint surface of the GMAW samples which contributed to the improved mechanical properties. OFW on the other hand, had some porosities and the effect of heat affected zone on the sample lead to lower mechanical properties with the presence of coarser grain structure. GMAW is a better option than OFW in welding ST52-3 steel plates since the former has shown overall improved properties.

***Keywords:** butt welded joint, GMAW, HAZ, mechanical properties, micro structural properties, OFW, ST52-3.*

I. INTRODUCTION

Parts from welded joints in high strength structural steel must be strong enough to possess sufficient mechanical strength to overcome defects and repairing problems. ST52-3 has become popular for its ability to resist a variety of environmental conditions and acts as a suitable material that is used in too many different modern structural applications like buildings, bridges, etc.

There are many types of fusion welding processes that can be used to weld high strength structural steel, such as Gas Metal Arc Welding (GMAW), Oxy-fuel Gas Welding (OFW), Laser Beam Welding (LBW) and Electron Beam Welding (EBW)[1]. The mechanical properties such as hardness strength, tensile strength, impact strength and bending strength and the micro structural characteristic of the joint are distressed either positively or negatively based on the welding process applied. Welding high strength low alloy steels (HSLA) by means of any fusion welding process leads to problems for example cold cracking, distortion and fatigue damage. Therefore, comparative evaluation has been done by Nathan et al. [2] on the mechanical properties and the grain size of HSLA steels joints welded by gas metal arc welding (GMAW), shielded metal arc welding (SMAW) and friction stir welding (FRW). It was observed that the problems associated to fusion welding can be eliminated by using solid state welding processes [2].

Thus, issues like difficulties to penetrate the thick

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plates of hardened steel by arc welding, difficulties to control the welding process particularly for large specimen of high performance steel and outside impurities at the finish surfaces are raised [3],[4]. Various other arc welding techniques including hybrid welding have been successfully applied on nonferrous metals and alloys [5]-[9]. Moreover, solid state welding process may not always be a suitable option for certain engineering structural applications. There are insufficient literatures on the direct comparison of Gas Metal Arc welding (GMAW) and the Oxy-Fuel Gas Welding (OFW) using hardened steel. Therefore, due to constraints in the available welding techniques at the institution, this research intends to investigate the mechanical and micro structural properties of the butt welded joint of hardened steel (ST52-3) using GMAW and OFW.

II. EXPERIMENTAL PROCEDURE

A. Sample Preparation

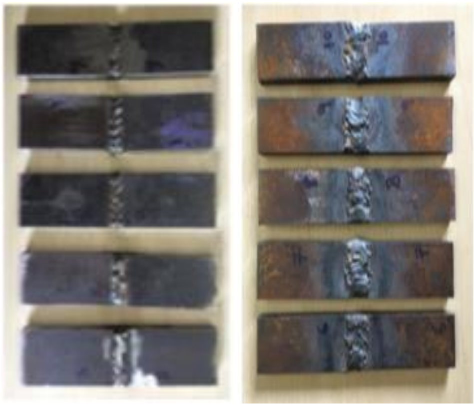
Samples were prepared accordingly for the mechanical testing (hardness, tensile, impact and bending tests) and for the microstructure analysis (SEM). The dimensions and total number of specimens are listed in Table I. Half of the samples were welded using GMAW and the remaining half were welded using OFW.

Table I. Dimensions of the samples

Test	Specimen size (*w* x *l* x *t*) in mm	No. of specimens
Tensile and hardness	25 × 60 × 8	16
Impact and SEM	10 × 30 × 10	16
Bending	10 × 75 × 10	20

B. Welding

Gas Metal Arc Welding machine (YC-200TWSP) was used to weld 26 pieces in order to produce 13 samples. The wire electrode (ER70S-6) with a diameter of 0.8 mm was used with a welding current around 120 A, welding voltage 450 V, and a travel speed of about 6.7 mm/min. OFW was carried out with oxygen and acetylene gas using a filler metal (A5.2). Fig. 1 shows the welded samples by GMAW and OFW.



(a) (b)

Fig. 1: Welded samples (a) GMAW (b) OFW

C. Mechanical Testing

Four different tests were conducted; hardness, tensile, impact and bending tests. Rockwell hardness testing machine (660RLD/T) was used to determine the hardness values along the butt welded joint of the specimen. An average of five readings was taken for GMAW and OFW each.

The Universal Testing Machine (INSTRON 5582) was used to measure the tensile strengths of the butt welded samples from GMAW (4 samples) and OFW (4 samples). The speed and force were set to be 2.0 mm/min and 100 kN respectively.

Pendulum type impact testing machine (INSTRON SI-1C3) was used to determine the impact strengths of the butt welded samples from GMAW (3 samples) and OFW (3 samples). The impact tests were conducted at room temperature. The amount of energy absorbed in fracture was recorded in order to determine the impact strength.

Three point bending tests were performed using the Universal Testing Machine (INSTRON 5582) with a load of 100kN on the butt welded samples; GMAW (5 samples) and OFW (5 sample). The bend strengths were measured and compared with both welding methods.

D. Micro structural Investigation

Micro structural investigation was performed using a Scanning Electron Microscope (SEM) (JSM – IT100). Samples were sectioned and cut along the butt welded joint and prepared for SEM accordingly. The samples were ground using a rotary grinding machine (MECAPOL P260) with grades of adhesive cloth ranging from 80, 240, and 1200. The samples were then polished using alumina solution (particle size of 1.0 μm) on the disk polishing machine (BUEHLER PHOENIX BETA). Lastly, the samples

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were etched with 2% of Nital solution for 3 seconds to reveal the microstructure features of the joints.

RESULTS AND DISCUSSION

A. Mechanical Properties

The mechanical properties of the welded joints in ST52-3 are presented in Table II. The butt welded joint by GMAW exhibited higher hardness value of 116 HRB compared to OFW which exhibited 112 HRB. There is around 3.6% increase in the hardness using GMAW. Meanwhile, the tensile strengths of GMAW and OFW butt welded joints are 198 MPa and 150 MPa respectively. The joint fabricated by GMAW has exhibited 32% increase in tensile strength compared to OFW [2].

The impact strength of the butt welded joint by GMAW is 108 kJ/m^2. This is 13.7% higher than the joint produced by OFW (95 kJ/m^2). Thus, GMAW produces butt joints with higher toughness compared with OFW for ST52-3. The bend strength of the butt welded joint using GMAW is 300 MPa which is four times the bend strength of the butt welded joint using OFW (75 MPa). This shows that the butt joint using GMAW functions best under compressive loading.

Table II. Mechanical properties of the butt welded joints in ST52-3

Sample	Hardness (HRB)	Tensile Strength (MPa)	Impact Strength (kJ/m^2)	Bend Strength (MPa)
GMAW	116	198	108	300
OFW	112	150	95	75

B. Micro structural Properties

Fig. 2 shows the SEM images of specimen welded by OFW taken from three distinctive regions of the ST52-3 samples; base metal, heat affected zone (HAZ), and weld zone. Base metal consists of white ferrite grains and relatively dark grey pearlite phases, which are located on the grain boundaries or adjacent to the grains. Most of grains are uniformly distributed. When moving to the HAZ, specimen undergoes extremely high temperature, and the surface property changes compared to that of the base metal. Since the area is subjected to high temperature, excessive grain growth and formation of cementite, martensite, and pearlite is visible in this region. The presence of these matrices improves the hardness in HAZ area. In the fusion zone due to stress build-ups, surface cracks are visible near the grain boundaries. Fine oxide particles from the filler metal that permit the nucleation of fine grains. When the weld solidifies, the grains grow from the course grain structure in the HAZ region; further refinement takes place within the grains creating the typical acicular ferrite formation.

In the case of GMAW, grain growth as shown in Fig. 3 is comparatively less but uniformly distributed needle like structures of acicular ferrite are visible. In the weld zone, material is melted and rapidly cooled where Widmanstätten and acicular ferrite are formed. Widmanstätten plates are originated from the grain boundaries through the centre of the grains, but acicular ferrite is squeezed in the middle of the grains. The microstructure of the butt welded region of OFW shows that it has some large sized pores most likely due to air trapped inside during welding.

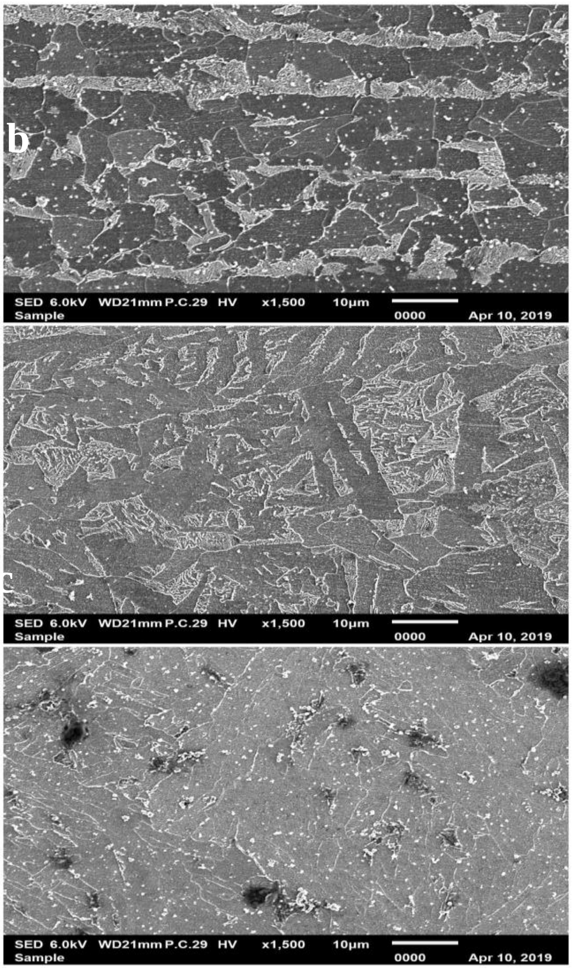

Fig. 2: SEM images of OFW sample (a) base metal (b) heat affected zone (c) weld zone

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The weld metal microstructure and mechanical properties of fusion welded joints is greatly influenced by the chemical composition of the filler metal and the heat input of the process. Generally, higher heat input prompts to slower cooling rate which results in the coarse grains in weld metal. Although, lower heat input prompts to fast cooling rate which results in fine grains. The basic nature of the process also plays important role in refining the weldment's microstructure. Owing to higher heat input, phase transformation occurred in the OFW and GMAW joints.

"Parent metal microstructure (ferrite and small amount of pearlite) was transformed into acicular ferrite, small amount of retained austenite and martensite by heat input and chemical composition. Variations in filler metal and parent metal chemical composition lead to the thermal variations in weld metal and parent metal as well as the solidification of weld metal. Slow cooling rate may reduce the interfacial energy between the austenite and ferrite, which results in the formation of acicular ferrite. An acicular ferrite microstructure has the potential of combining high strength and toughness" [2]. High heat intensity of OFW process resulted in the formation of coarse grains in the weld region. The effect of HAZ was more prominent. The relatively slow cooling rate of OFW process led to the formation of martensite and acicular ferrite with some retained austenite in the weld region. Thus, it explains the decrease in the overall mechanical properties from OFW. Hardness, tensile, impact and bend strengths in the butt welded joint from GMAW are enhanced. Moreover, the addition of the filler metal plays a vital role in weld metal microstructure. It is indeed very challenging to produce a homogeneous weld joint by fusion welding processes.

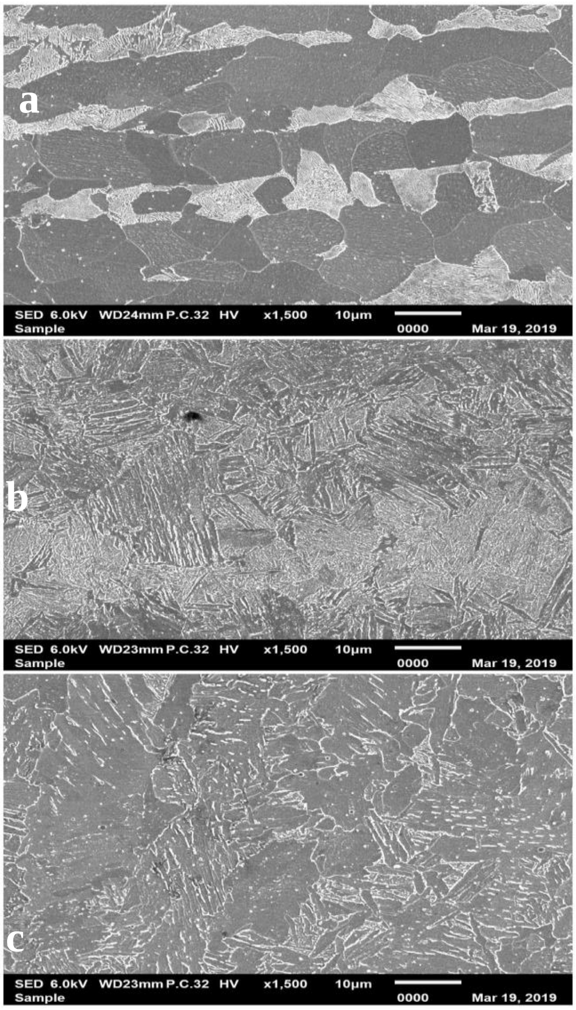

Fig. 3: SEM images of GMAW sample (a) base metal (b) heat affected zone (c) weld zone

III. CONCLUSION

GMAW has shown to produce joint parts with improved mechanical and micro structural properties when compared with OFW. More uniform and smaller sized needle like structures of acicular ferrite at the joint surface of the GMAW samples justifies the enhancement of mechanical properties. Hardness, tensile, impact and bend strengths have increased by 3.6%, 32%, 13.7% and 300% respectively. The findings from this study can be used to benefit further studies related to engineering applications in the field of construction, buildings, automotive and machinery parts.

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Tasnim Firdaus Ariff is an Associate Professor at the Department of Manufacturing and Materials Engineering, International Islamic University Malaysia. She did her PhD at the University of Waikato, New Zealand in hybrid microwave sintering. However, she has indulged in many other research fields such as eco-friendly machining, ductile machining, biocomposites and welding. She has published various papers and is a member of the Board of Engineers Malaysia and the Institute of Engineers Malaysia.

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