International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:10, No:8, 2016

Characterization of Two Hybrid Welding Techniques on SA 516 Grade 70 Weldments

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***Abstract*—**Commercially SA 516 Grade 70 is frequently used for the manufacturing of pressure vessels, boilers and storage tanks etc. in fabrication industry. Heat input is the major parameter during welding that may bring significant changes in the microstructure as well as the mechanical properties. Different welding technique has different heat input rate per unit surface area. Materials with large thickness are dealt with different combination of welding techniques to achieve required mechanical properties. In the present research two schemes: Scheme 1: SMAW (Shielded Metal Arc Welding) & GTAW (Gas Tungsten Arc Welding) and Scheme 2: SMAW & SAW (Submerged Arc Welding) of hybrid welding techniques have been studied. The purpose of these schemes was to study hybrid welding effect on the microstructure and mechanical properties of the weldment, heat affected zone and base metal area. It is significant to note that the thickness of base plate was 12 mm, also welding conditions and parameters were set according to ASME Section IX. It was observed that two different hybrid welding techniques performed on two different plates demonstrated that the mechanical properties of both schemes are more or less similar. It means that the heat input, welding techniques and varying welding operating conditions & temperatures did not make any detrimental effect on the mechanical properties. Hence, the hybrid welding techniques mentioned in the present study are favorable to implicate for the industry using the plate thickness around 12 mm thick.

***Keywords*—**Grade 70, GTAW, hybrid welding, SAW, SMAW.

I. INTRODUCTION

FUSION arc welding processes are mostly used in fabrication industry to increase productivity. A major requirement in the selection of welding technique is to generate minimal welding defects and the affordable range for the industry. Technically, there are diverse welding variables on which the selection of welding process is made. These variables are heat input, travel speed, joint design, type of material, run of length (ROL), welding electrode polarity, depth of penetration, time, current, voltage etc. [1]. In addition to melt the base metal, a filler material is often added to the joint to form a pool of molten material that cools in a short time to form solid joint and mechanical properties of this weldment should be superior or at least compare to that of base metal. Nowadays welding is being employed in every branch of science like computer, electronic, gigantic mechanical and petrochemical industries etc.

A. Hybrid and Fusion Welding

From the last couple of decades, hybrid welding technique is being gained more attention by fabrication industry. In this new developed method, couples of fusion welding processes are used if multiple pass welding is involved [2]. The main objective of using hybrid welding is to take advantage from the benefits of both techniques and finally obtain an optimize mechanical properties and microstructure. Cold Cracking (CC) is a major cause of failure in ASTM 516 Grade 70 steel weldments [3]. To cater this problem PWHT (Post weld heat treatment) is the most affordable recommendations. To avoid PWHT is also a major reason to introduce the hybrid welding process because it also added an extra cost.

B. Welding Heat Input

Heat input of welding technique being used is the main important decisive parameter that influences the cooling rate and ultimately affects the concerned mechanical properties like tensile strength, hardness and impact toughness [4]. Since cooling rate has a significant outcome on the microstructures of weld zone (WZ) and Heat Affected Zone (HAZ). Therefore, desired heat input rate or arc energy is calculated by using:

$$\text{Heat input J/min} = V \times A \times 60/S$$

where V = arc voltage; A = welding current; S = welding speed or arc travel speed (mm/min).

Since the heat transfer efficiency of SMAW is 0.65-0.85, so if heat-input equation is multiplied by this factor then actual heat input during welding will be obtained.

Different heat input in hybrid welding if multiple pass scheme is used then different cooling rate will be obtained which change grain size, microstructures and mechanical properties [5], [6].

II. EXPERIMENTATION

In the present study, two schemes of hybrid welding were used on ASTM 516 Grade 70 having plate thickness of 12 mm. The chemical composition and mechanical properties were mentioned on the Mill Test Certificate (MTC) provided by FABCON Pvt. Ltd, Pakistan has been shown in Tables I & II. Later on, these chemical compositions were also verified from another research Lab in Pakistan.

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TABLE I
CHEMICAL COMPOSITION OF BASE METAL (BM)

Elements	C	Mn	Si	Cr	Al	P	Ni	Ti	V	Mo	Nb
Wt%	0.18	1.46	0.36	0.34	0.031	0.017	0.007	0.005	0.004	0.001	0.004

TABLE II
MECHANICAL PROPERTIES OF BM

Yield Strength	Tensile Strength	Elongation
385 N/mm^2	570 N/mm^2	21%

A. Scheme 1: Hybrid Welding (SMAW & GTAW)

In Scheme 1, hybrid weldment joint was completed in four (04) passes by using two welding technique SMAW & GTAW. Root pass and Hot pass was performed by GTAW, while Filling and Capping was done by SMAW. The voltage, current, bevel angle and other welding parameters of hybrid weld has been shown in Table III.

Heat Input Calculations for Scheme 1:

By using the formula of heat input and welding parameters mention in Table III, heat input for GTAW & SMAW has been calculated.

$$H = \frac{60\ EI}{1000\ S}$$

Heat Input for GTAW = H = 0.6364 KJ/mm
Heat Input for SMAW = H = 2.52 KJ/mm

B. Scheme 2: Hybrid Welding (SMAW & SAW)

In Scheme 2, hybrid weldment joint was completed in 05 passes by using two welding technique SMAW & SAW. Root pass, Hot pass and Back pass was performed by SMAW, while Filling and Capping pass was done by SAW. The voltage, current, bevel angle and other welding parameters of hybrid weld has been shown in Table IV.

Heat Input Calculations for Scheme 2:

By using the formula of heat input and welding parameters mention in Table III, heat input for GTAW & SMAW has been calculated.
Heat Input for SMAW = H = 2.52 KJ/mm
Heat Input for SAW = H = 4.9 KJ/mm

TABLE III
WELDING PARAMETERS FOR SCHEME 1: HYBRID WELDING

Welding Parameters	Electrode	Electrode Dia. (mm)	Thickness Covered (mm)	Polarity	Current (Amp)	Voltage (V)	Bevel Type	Bevel Angle	Travel Speed mm/s
GTAW	ER70S3	2.4	RP= 3 HP= 2.5	DCEN	80-100	9-13	Single-V	30°	0.94
SMAW	E7018	3.2	FP= 3(3) CP= 3(3)	DCEP	80-120	20-30	Single-V	30°	0.84

TABLE IV
WELDING PARAMETERS OF SCHEME 2: HYBRID WELDING

Welding Parameters	Electrode	Electrode Dia. (mm)	Thickness Covered (mm)	Polarity	Current (Amp)	Voltage (V)	Bevel Type	Bevel Angle	Travel Speed mm/s
SMAW	E7018	3.2	RP= 2.5 HP= 3 BP= 3	DCEP	80-120	20-30	Single-V	30°	0.84
SAW	57A2/EM12K	3.2	FP= 2(3) CP= 3(2)	DCEN	400-500	30-40	Single-V	30°	3.2

III. MECHANICAL TESTING AND METALLOGRAPHY

Samples for the evaluation of mechanical testing like tensile test, hardness, impact toughness and bend test were acquired by using wire cut machine from both Schemes 1 & 2 weldments. Further, four samples were also taken from each scheme for heat treatment at 610 °C for 1 hour in carbolite furnace and allow it to furnace cool. The main purpose was stress relief annealing of the material. It is important to note here that all the fracture type in Schemes 1 & 2 were ductile in nature except that in Scheme 1, samples were fractured in BM zone, while in Scheme 2, samples were fractured in weld metal (WM) zone. UTS values are mentioned in Fig 1.

When the four point bend test was performed using samples from Schemes 1 & 2 weldments and also from the heat treated, it was found that no crack was observed in any bended sample. Bended samples are shown in Fig. 2.

Another important test for the evaluation of this hybrid technique is the impact toughness test. Impact toughness value has been represented in Fig. 3, while the hardness testing results of Schemes 1 & 2 hybrid welding and also heat treated samples have been shown in Fig 4.

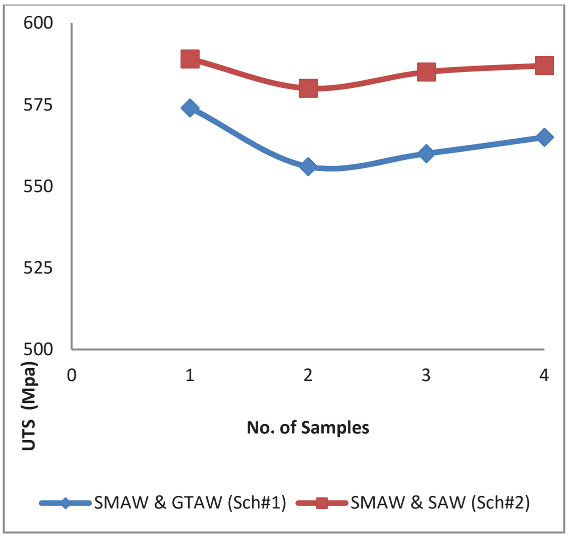

Fig. 1 UTS Comparison of Schemes 1 & 2

Fig. 2 (a) Fractured tensile test samples of Schemes 1 & 2

Fig. 2 (b) Bended samples after 4-point bend test (Both Schemes 1 & 2)

Fig. 2 (c) Hardness Test samples (Both Schemes 1 & 2)

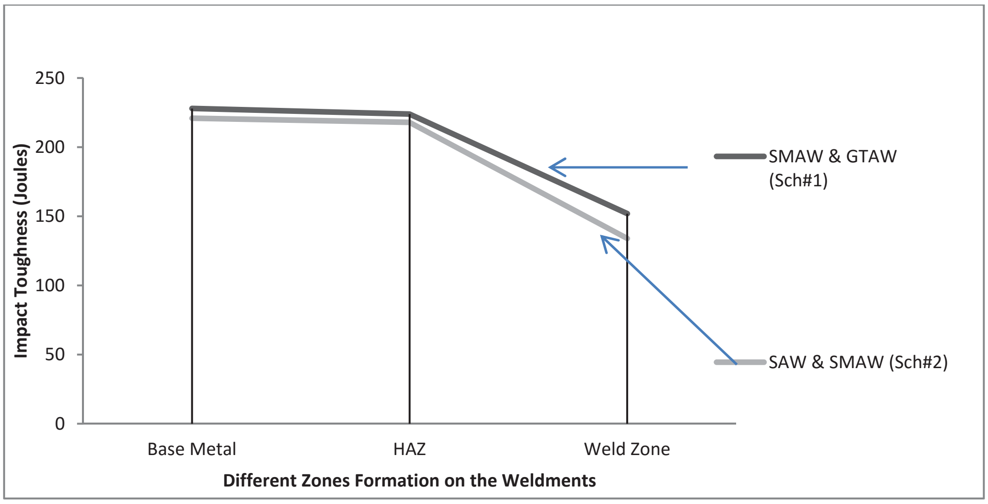

Fig. 3 Impact Toughness of Hybrid welding Schemes 1 & 2

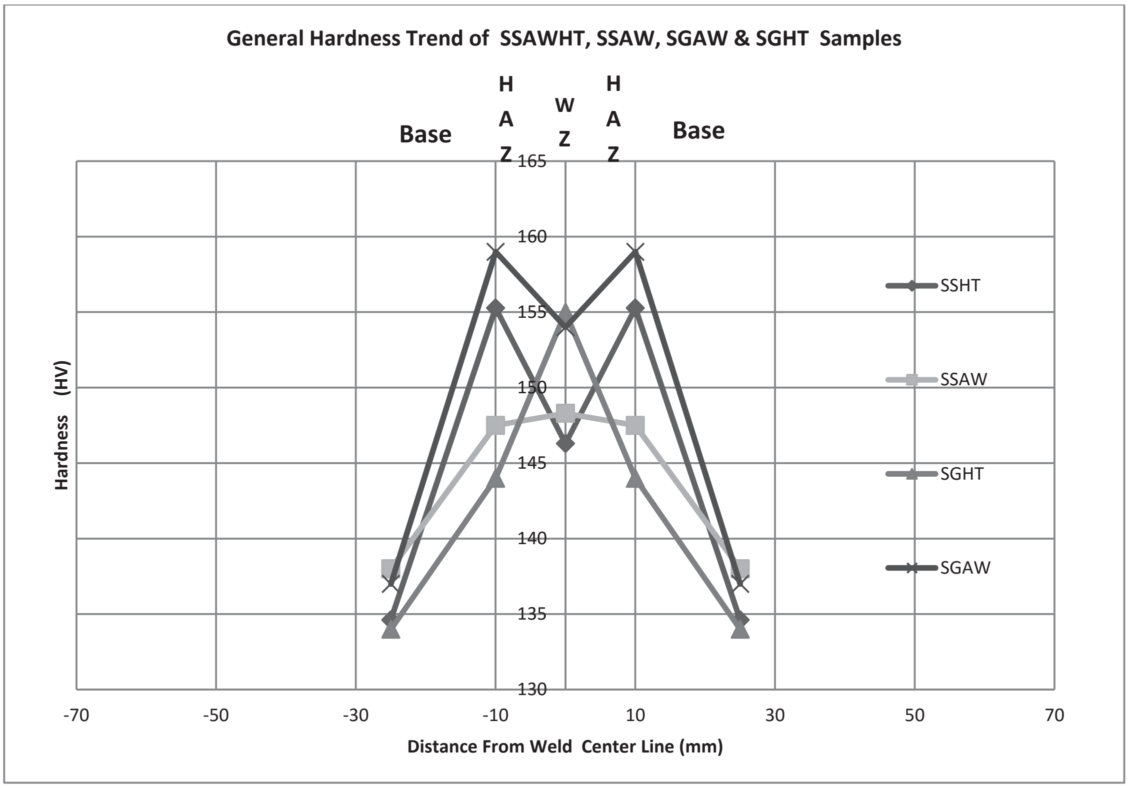

Fig. 4 Graphical representation of hardness Testing Schemes 1 & 2

IV. METALLOGRAPHY

A. Microstructure of Base Metal

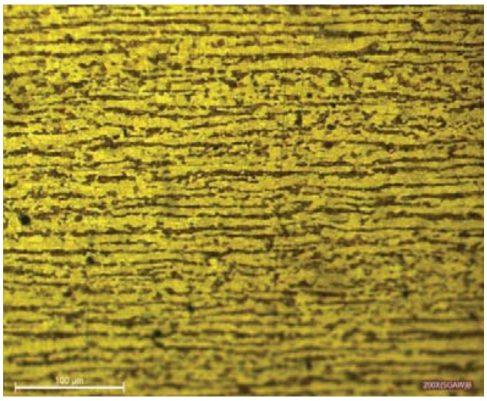

Fig. 5 (a) Microstructure of Base Metal 516 Grade 70 at Magnification 200X

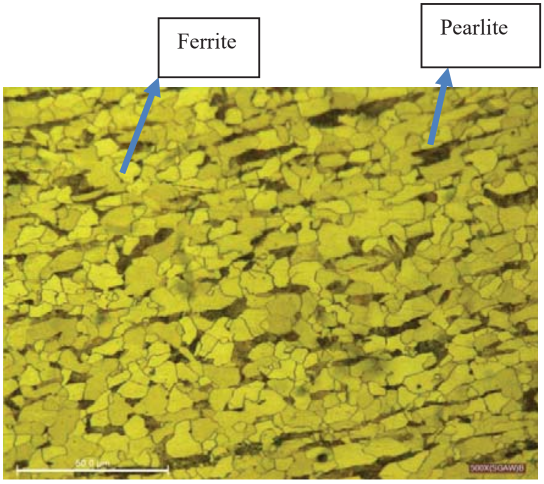

Fig. 5 (b) Microstructure at of Base metal 500 X

B. Microstructure of Hybrid Weld Scheme # 1 (SMAW & GTAW)

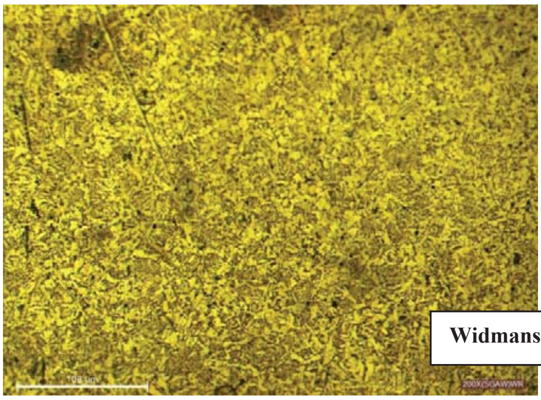

Fig. 6 (a) Microstructure of WZ (Middle portion) at 200X

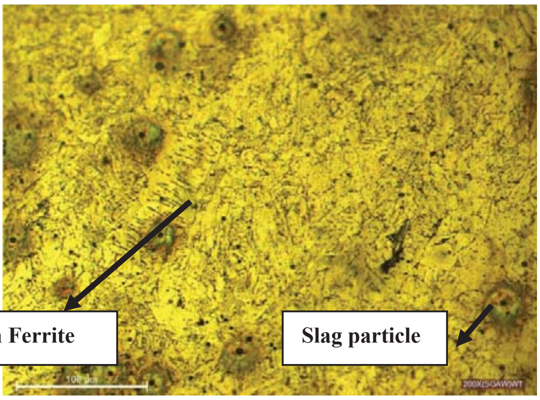

Fig. 6 (b) Microstructure of WZ (Top portion) at 200X

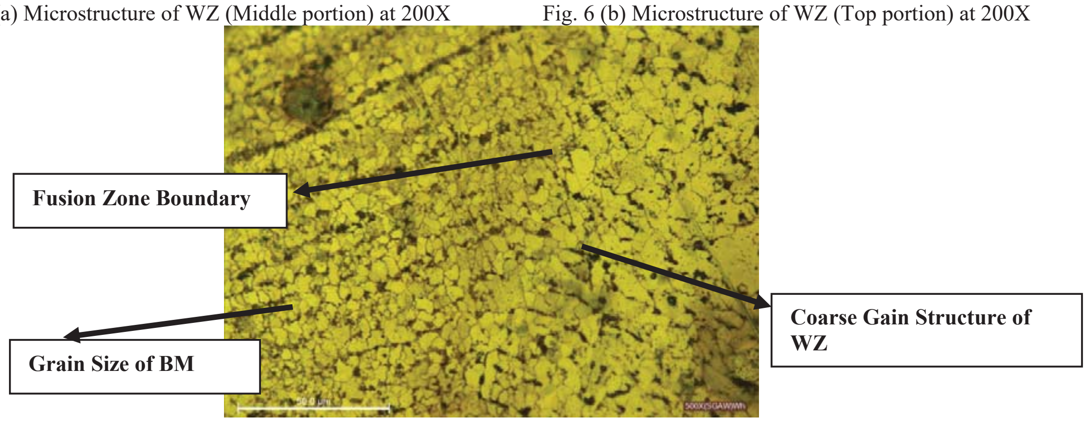

Fig. 6 (c) Microstructure of HAZ at 500X

C. Microstructure of Hybrid Weld Scheme # 2 (SMAW & SAW)

Fig. 7 (a) Microstructure of WZ (Root portion) at 200X

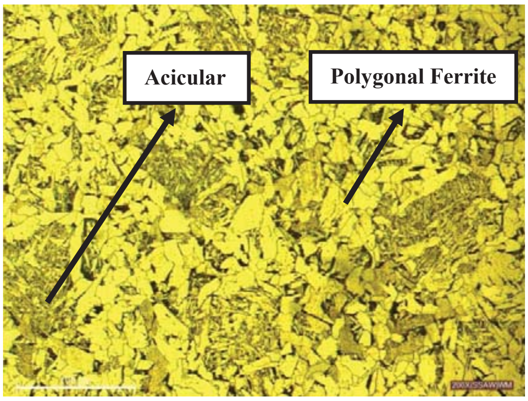

Fig. 7 (b) Microstructure of WZ (Middle portion) at 200X

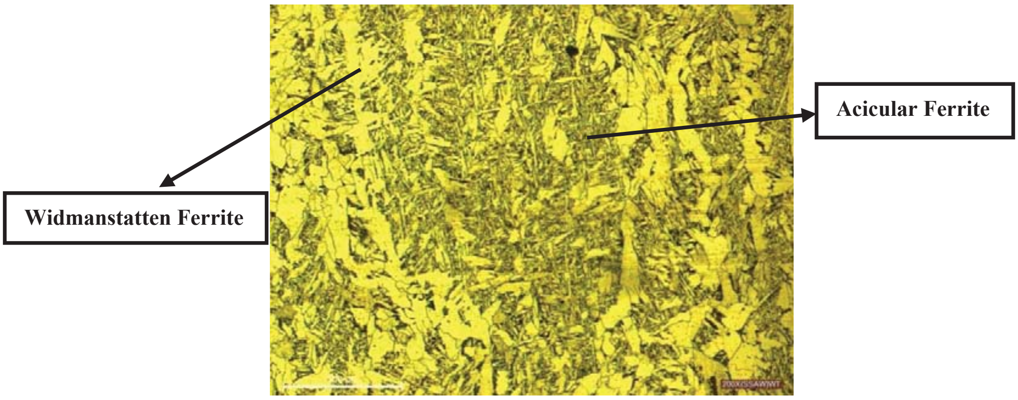

Fig. 7 (c) Microstructure of WZ (Top portion) at 200X

V. DISCUSSION

Tensile strength of hybrid welded samples (Scheme 1) was 565 MPa and that of welded samples (Scheme 2) was 584 MPa. Also, it is pertinent to note here that tensile fracture (Scheme 1) took place at BM while tensile fracture (Scheme 2) took place at WZ. The hardness profile of hybrid welding Scheme 1 is 139, 160, 154 (VPN) Vickers Pyramid Number, for BM, HAZ and WZ respectively while that of Scheme 2 hardness values are 138, 147, 148 VPN for BM, HAZ and WZ respectively. No crack was observed in all the samples from Schemes 1 & 2 during bending test. However, if we observe the impact toughness results of both the hybrid welding schemes, it was found that the fracture toughness of WZ of hybrid welding Scheme 1 is slightly higher than the Scheme 2.

VI. CONCLUSION

In this research work, comparative study was performed between two hybrid welding techniques Scheme 1 (SMAW & GTAW) and Scheme 2 (SMAW & SAW). Therefore, from the above results of mechanical testing and microstructure obtained, it may be concluded that the mechanical properties of both schemes are more or less similar. However, the impact toughness of Scheme 1 (SMAW & GTAW) are more or less same. This implies that at the suggested heat input conditions and parameters used in the hybrid welding did not make any detrimental effects on the mechanical properties. Therefore, both schemes are favorable to implicate in the industry.

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