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# Assessment on the Metallurgical and Mechanical Properties of SA 210 A1 Rifle Tubular Joints

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## Abstract

Heat exchangers tubes in critical thermal power plants and waste heat recovery boilers are typically made of SA 210 A1 ferritic steels operated in the temperature range of 300-400 °C. In this study, an attempt has been made to investigate the weldability of SA 210 A1 rifle tubular steel using Gas Tungsten Arc (GTA) welding technique employing ER70S2 filler wire and Shielded Metal Arc (SMA) welding technique using E7018 electrode. Comparative studies were performed to investigate the effect of welding process on the metallurgical and mechanical properties of these weldments. Microstructure studies inferred the formation of Widmanstatten ferrite and ferrite-cementite matrix (alternate lamellas) at the heat affected zone in both the weldments. Tensile studies confirmed that the GTA weldments have better mechanical properties compared to the SMA weldments. A detailed structure - property relationship has been made using the combined techniques of optical and SEM microscopy.

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## 1. Introduction

Ferritic steels are extensively used as heat exchangers (water walls, economisers, low temperature super heaters) in the thermal power plants and waste heat recovery boilers because of its structural integrity, good strength and excellent resistance to high temperature and high pressure water or steam. SA 210 A1 ferritic steel tubes are fitted in water walls operating at temperatures around 300-400°C and moreover these steels tubes are exposed in the furnace with high temperature. Both corrosion and erosion attack from the hot flue gas stream significantly enhances the higher metal wastage rate [1]. Also the authors investigated the oxidation behaviour of base metal, weld metal, and HAZ regions in ASTM SA 210 Grade A1 steel weldments prepared by SMAW process at 900 °C in air. However, the strength of the weldments of the ferritic steels is generally inferior in weld regions compared to the parent metals and most of the in-service failures are reported to take place in the weld region. Several researchers reported that the occurrence of failures in these steel pipes is more frequent at the weld region. [2-3]. Devendranath et al. [4] investigated the performance of filler wires on the dissimilar weldments of Monel 400 and AISI 304 exposed in high temperature environments. The authors suggested that for better hot corrosion resistance, the heat-generating phase needs to be kept to minimum by selecting proper welding techniques and parameters for ensuring uniformity of microstructure of the weld.

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Widmanstatten pattern of low-carbon Ferrite (dark patches) (an interstitial solid solution of carbon in b.c.c. iron) and ferrite-cementite matrix (white) offer better mechanical properties in terms of tensile strength as well as impact strength at room temperature. Also the steels containing Widmanstatten structure showed better strength even at elevated temperature of 300-500°C [5-6]. As evident from the open literatures, the carbon steel SA 210 A1 is widely being operated in the boiler tubes. Hence it is vital to produce high quality welds on these materials using appropriate welding technique and filler wire so that the weldments will offer better service life. This forms the significance of the project work. In this study, the SA 210 A1 rifle carbon tube steel has been welded using the well known conventional techniques such as GTAW and SMAW and comparative studies were carried out to assess the metallurgical and mechanical properties of these weldments.

## 2. Experimental Procedure

The as-received SA 210 A1 rifle carbon tube steel has the typical dimensions of 6.5 mm thickness and OD of 51mm. Before welding, these tubes were machined by making the conventional V-groove with bevel angle 35°, root face 1mm and root gap 1mm. Joining of these tubes were carried out using GTAW and SMAW techniques employing AWS A5.18 ER70S2 and AWS A5.1E7018 electrode respectively. 99 % pure Argon gas was used as shield for welding the tubes. The electrode and the base metals were preheated before welding. The nominal chemical composition of the base metal and the filler wires in % by weight are given in the Table 1 and the weld process parameters employed in this study are represented in Table 2.

Table 1 Chemical Composition of base metal and filler material in % by weight

Material	C	Mn	Si	S	P	Cr	Ni	Ti	Zr	Fe
Base Metal	0.26	0.93	0.1	0.058	0.048	--	--	--	--	Bal.
Electrode (E7018)	0.07	1.08	0.54	0.012	0.020	--	--	--	--	Bal.
Filler Wire (ER70S2)	0.07	1.40	0.70	0.035	0.025	0.15	0.15	0.15	0.12	Bal.

Table 2 Welding Parameters used for GTA and SMA welding processes

Parameter	GTAW	SMAW
Filler/Electrode	E70S2	E7018
Root gap (mm)	1.00	1.00
Electrode diameter (mm)	-----	2.40
Arc current	140A	105A
Arc voltage	13.5V	23.5V
Number of pass	2	2

Followed by welding, X-Ray radiography testing was employed to investigate the weldments for macro and micro level defects. Ensuing to the NDT results, the weldments were sliced using the wire-cut EDM process to get coupons of various dimensions to perform metallurgical and mechanical studies. The composite region of the coupons having the dimensions of 30 mm x10 mm x 6.5 mm was used to study the microstructure at the various zones of the weldments. Standard metallographic procedures were employed for metallurgical examination and Nital was the etchant used to reveal the microstructure at the various zones of the weldments.

Tensile studies were performed on the ASTM E8/8M standard samples. Three trials on each weldment were performed to ensure the reproducibility of the results. Tensile properties were analyzed using the Instron Universal Testing Machine employing a strain rate of 2 mm/min. Further micro-hardness studies were performed on the weldments using Vicker's Micro-hardness tester across the width of the weldments. A standard load of 500 gf was applied for a dwell time of 10 s and the measurements were made at regular intervals of 0.50 mm.

## 3. Results and Discussions

### 3.1 Microstructure of the weldments

The macro-photographs and microstructure of the weldments are shown in Fig. 1 and Fig. 2. Macrostructure studies revealed that proper fusion has occurred on the base metals while employing GTA and SMA welding process. The microstructure of the base metal shows ferrite (white constituent) and pearlite (dark constituent). Coarse grains were

observed in HAZ region in both techniques exhibits Widmanstatten ferrite and ferrite-cementite matrix (alternate lamellas). These structures usually have been found in most of the carbon steels containing less than about 0.6% carbon by weight.

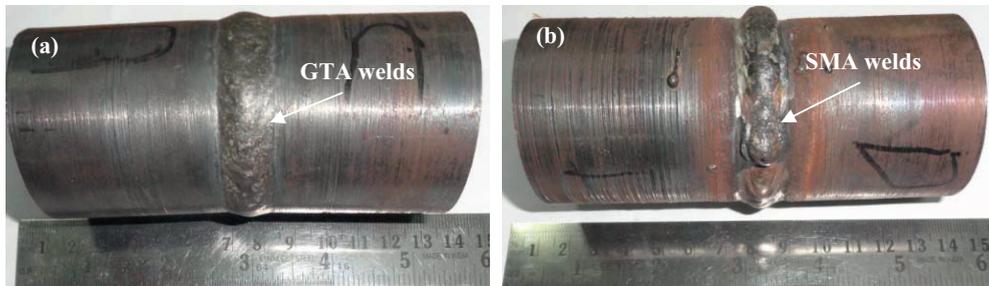


Fig.1 Weldments of SA 210 A1 ferritic rifle tubular steel using (a) GTAW and (b) SMAW process

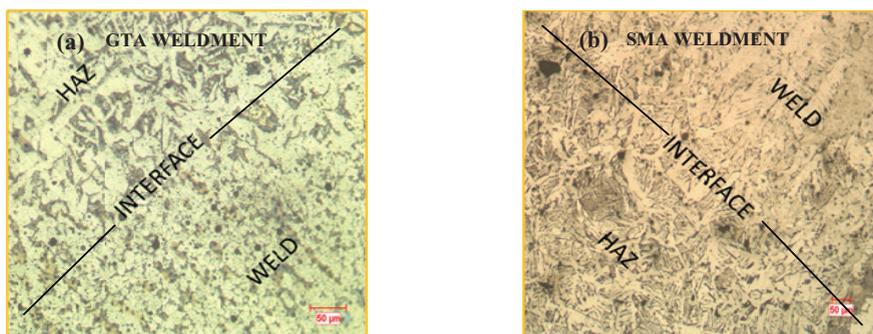


Fig. 2 Microstructures showing the various zones of welded SA 210 A1 boiler tube steels  
 (a) GTA Weld- HAZ interface  
 (b) SMA Weld- HAZ interface

### 3.2 Mechanical Characterization of the Weldments

Tensile results envisaged that both the weldments had undergone significant amounts of plastic deformation before fracture. The fracture occurred at the parent metal zone in GTA weldments whereas the failure took place at the weld zone in case of SMA weldments in all the trials. This could clearly infer that the GTA weldments were found to offer better mechanical properties in terms of strength and ductility as compared to SMA weldments. Further the SEM fractographs also confirmed the mode of fracture in both the cases as ductile ones due to the formation of dimples and micro-voids which coalesce to undergo the fracture. Table 3 represents the comparison of tensile properties for both the GTA and SMA weldments.

Hardness measurements were performed on the composite zones covering all the regions of the weldments. The measurements were taken at regular intervals and across the entire width of the weldment. The hardness profile indicates clearly that the HAZ of the GTA weldments (178.1 HV) has maximum hardness as compared to SMA weldments (169.5 HV). However the maximum hardness is observed at the HAZ in both the weldments. This could be owing to the formation of Widmanstatten ferrite which enhances the mechanical properties as reported by other researchers [5-6].

Table 3 Tensile Properties of the Weldments

Characteristic Property	GTAW Weldment	SMAW Weldment
Maximum UTS (MPa)	556	526
Young's Modulus (GPa)	71.2	66.3
Elongation at break load (%)	31.07	26.48
Fracture Zone	Parent Metal zone	Weld Zone

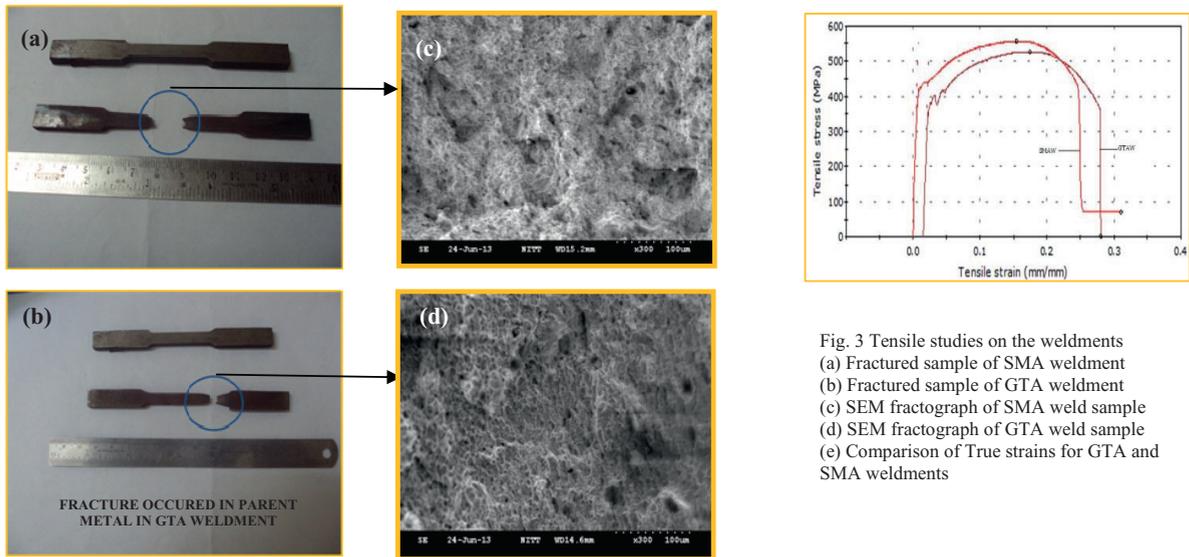


Fig. 3 Tensile studies on the weldments  
 (a) Fractured sample of SMA weldment  
 (b) Fractured sample of GTA weldment  
 (c) SEM fractograph of SMA weld sample  
 (d) SEM fractograph of GTA weld sample  
 (e) Comparison of True strains for GTA and SMA weldments

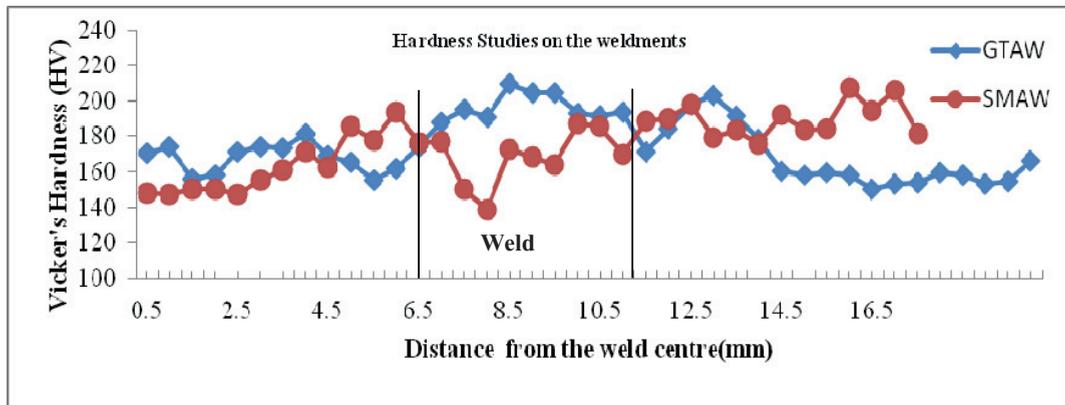


Fig. 4 Hardness trend of the GTA and SMA welded SA 210 A1 tubular steel joints

#### 4. Conclusions

From the present study, the following points are concluded.

- Sound and successful welds of the SA 210 A1 boiler tubular steel could be obtained from both the GTA and SMA welding techniques.
- Widmanstatten ferrite structure was observed at the HAZ of the SA 210 A1 steel in both the cases of welding techniques.
- The higher mechanical properties of the carbon steel with a Widmanstatten structure is due to the higher percentage of quasi-eutectoid.
- In general, GTA weldments offer better mechanical properties as compared to SMA weldments since the fracture had occurred at the parent metal.

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