Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 75 (2014) 103 – 107

Procedia Engineering

www.elsevier.com/locate/procedia

MRS Singapore - ICMAT Symposia Proceedings

7th International Conference on Materials for Advanced Technologies 2013

Investigation on the Mechanical Properties of SA 210 C Tubular Joints

S. Senthur Prabu[a*], Atin Jain[a], Akhil Gopinath[a], N. Arivazhagan[a], K. Devendranath Ramkumar[a], S.Narayanan[a]

[a]*School of Mechanical and Building Sciences, Vellore Institute of Technology, Vellore – 632014, India*

Abstract

Ferritic steels are widely used for designing water walls and low temperature super heaters of the boilers employed in thermal power plants. The investigations have been made to study about the weldability of SA 210 C tubular steel using Gas Tungsten Arc (GTA) and Shielded Metal Arc (SMA) welding techniques. In this study, an attempt has been made to investigate the metallurgical and mechanical properties of both the GTA and SMA weldments. Formation of Widmanstatten ferrite (white constituent) and pearlite (dark constituent) at the heat affected zone is witnessed in both the weldments. Tensile studies confirmed that the GTA weldments had shown better mechanical properties in terms of strength and ductility compared to the SMA weldments. Weldment has been systematically characterized to understand the structure-property relationships using both optical microscopy and SEM fractography.

Selection and/or peer-review under responsibility of the scientific committee of Symposium [Advanced Structural and Functional Materials for Protection] – ICMAT.

Keywords: SA 210C; SMAW; GTAW

1. Introduction

SA 210 C grade carbon steels are extensively used as water walls and low temperature super heaters in the thermal power plants, waste heat recovery boilers and co-generation power plants because of their excellent strength and good corrosion resistance at high temperature and high pressure in both water and steam sides. Hence it is vital to produce high quality welds on these materials using appropriate welding technique and filler wire is inevitable. Failure of boiler tubes is a very common phenomenon in a power plant. As reported by other researchers, compared to the parent metals, weld strength of the ferritic steels is generally inferior and most of the in-service failures have been reported in the weld regions [1-2]. The investigation into the cause of a boiler tube failure is very important to prevent future tube failure, and it is a must task to select the cost effective, ideal welding technique and appropriate filler wire, forms the basis of this research work.

SA 210 C ferritic steel tubes are fitted in water walls and low temperature super heaters operating at temperatures around 300 - 400 °C in both water side and steam side. When these tubes are exposed at high temperatures in the furnace zone, both corrosion and erosion corrosion attacks from the hot flue gas stream significantly enhance the chances of higher metal wastage rate [3]. For better resistance to hot corrosion in both ambient conditions and high temperature environments, the heat-generating phase needs to be kept to a minimum by selecting proper welding techniques and parameters. The uniformity in the microstructure and quality of the weld is purely based on the performance of the filler metals [4].

As reported by other researchers [5-6], Widmanstatten structure offers superior tensile strength as well as impact strength at room temperature. The formation of Widmanstatten patterns could be due to the rapid growth of the pearlite during the decomposition of austenite. Investigations on the mechanical properties of the medium carbon steel (0.36 % C) were performed by quenching in two different mediums. The steel materials were exposed to a high temperature (850 ˚C), resulting in the carbon present dispersing to form austenite structures and cooling in air precipitates ferrites thereby increasing the tensile strength and hardness. The impact strength considerably decreased with samples that were not heat

***S. Senthur Prabu.** Mobile: +91 9842210982
E Mail: senthurprabu.s@vit.ac.in

1877-7058 © 2013 The Authors. Published by Elsevier Ltd.
Selection and/or peer-review under responsibility of the scientific committee of Symposium [Advanced Structural and Functional Materials for Protection] – ICMAT.
doi:10.1016/j.proeng.2013.11.023

treated [7-8]. Ahmad et al. [9] investigated the failure due to corrosion of boiler tube steel (SA 210 A1) used in water walls. The outer surface of tubes exposed to the gas side failed at the heat affected zone owing to transgranular macro cracks that penetrated deeply onto the internal surface of the welded joints and the tube failed because of thermal fatigue.

This paper describes a comparative study, to assess the metallurgical and mechanical properties of similar welded SA 210 C ferritic steels using the conventional techniques such as GTAW and SMAW.

2. Experimental Procedure

The as-received ferritic SA 210 C steel tube has the typical dimensions of 5.5 mm thickness and OD of 60 mm. Before welding, the tubes were machined to make the conventional V-groove with a bevel angle of 35º, root face of 1mm and root gap of 1.6 mm. Tubes were welded using both GTAW and SMAW techniques. 99 % pure Argon gas was used as shield for tube welding with the filler wire AWS A5.18 ER70S2 for GTAW and AWS A5.1E7018 electrode was used for the SMAW process. The nominal chemical composition of the base metal and the deposited filler wire in % by weight are given in the Table 1 and the welding process employed in this study is 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	0.35	1.06	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	ER70S2	E7018
Root gap (mm)	1.6	1.6
Electrode diameter (mm)	2.4	2.4
Arc current	140 A	100 A
Arc voltage	12.5V	22 V
Number of pass	2	2

X-ray radiograph tests were performed on the weldments at the angles of 0º and 90º to ensure that the weldments were free from any macro/micro scale weld defects. The cross section portions of the weldments were sliced along the transverse direction using the wire-cut EDM process to get coupons of various dimensions of 30 mm x 10 mm x 5.5 mm size. Standard metallographic procedures were adopted on the welded coupons by polishing using various grit size SiC emery papers and followed by disc polishing so as to get mirror-like polished surface of 1μ finish. The polished weldments were then etched in 2% Nital for 20s before they were examined under an optical microscope.

Microstructure studies were performed on the composite region covering all zones of the weldments viz. base metal, weld metal and HAZ. The microstructures of these regions with different magnifications are shown in Fig. 1.

The tensile specimens were cut using wire-cut EDM process as per ASTM E8/8M standards. The weldments were characterized for strength by conducting tensile studies on INSTRON Electronic Tensometer employing a strain rate of 2 mm/min. Three trials were performed on each weldment to ensure the reproducibility of the results. The micro-hardness studies were carried out across the width of the weldments covering all the regions using Vicker's Micro-hardness. A standard load of 500 gf was applied for a dwell period of 10 s and the measurements were made at regular intervals of 0.50 mm. Positive Metal Identification (PMI) studies were carried out on the different zones of the weldments and the elemental composition is tabulated in Table 3.

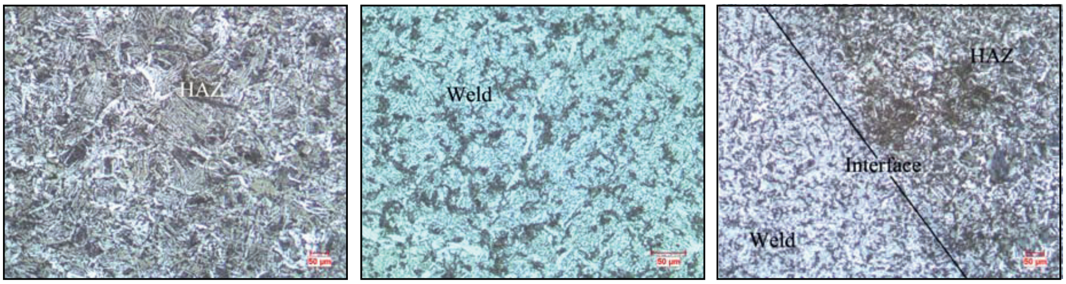
Table 3 Positive Metal Identification results

Weld Technique	Element Composition (HAZ)	Element Composition (Welded Region)
SMAW	Fe – 98.75 Mn – 0.926	Fe – 98.52 Mn – 0.856
GTAW	Fe – 98.69 Mn – 0.875	Cr – 0.472 Fe – 97.16 Mn – 1.29 Ni – 0.534 Ti – 0.097 Zr – 0.086

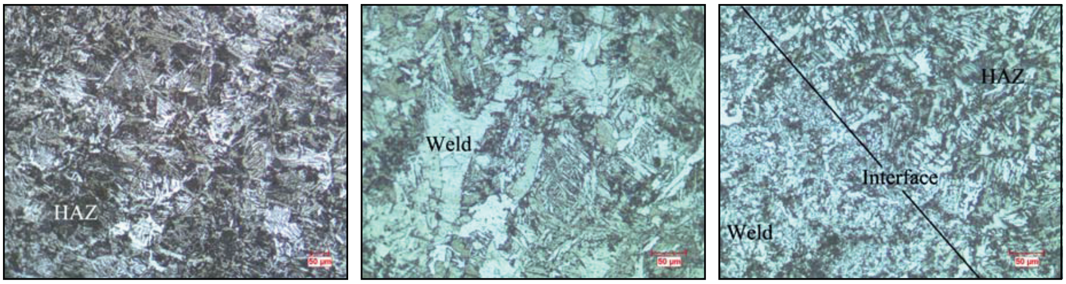
3. Results and Discussions

3.1 Microstructure of the weldments

The microstructures of the base metal, weld metal and HAZ region for both GTAW and SMAW weldments under different magnifications are shown in Fig 1. Microstructure examination revealed a good fusion between the base metals and filler in both the techniques. The micro structure of the base metal has the conventional structure of ferrite (white constituent) and pearlite (dark constituent). A lath like arrangement of acicular ferrite was observed at the SMA weld zone. Whereas the GTA weld metal shows a combination of Widmanstatten type ferrite, pearlite and bainite. The presence of the Cr, Ni in the filler enhances the hardenability and promotes bainite formation on relatively slow cooling (Fig 1 b). Similarly the coarse grains were observed at the HAZ exhibiting the structure of Widmanstatten Ferrite and ferrite-cementite matrix (alternate lamellas) in both techniques. Usually these structures have been found in most of the carbon steels containing less than about 0.6% carbon by weight.



(a)Widmanstatten Ferrite in GATW HAZ, 100x (b) GTA weldments, 200x (c) GTA Weld- HAZ interface, 100x



(d) Widmanstatten Ferrite in SMAW HAZ, 100x (e) SMA weldments, 200x (f) SMA Weld- HAZ interface, 200x

Fig.1 Optical micrographs of the etched microstructures in the different regions of the weldments of SA 210 C carbon steel

3.2 Mechanical Characterization of the Weldments

It can be observed from the micro hardness curve that the weld zone has a lower strength when compared to HAZ in both GTA and SMA specimens. As reported by other researchers [5&10], Widmanstatten Ferrite in the heat affected zone contributed for better mechanical properties. The incidence of a mixed microstructure of ferrite and upper transformation products like Widmanstatten ferrite in the HAZ indicated that it has possibly occurred at a high temperature between AC1 and AC3 (723–900°C) [10]. This is well matching with the hardness results obtained from the studies that the maximum hardness is observed at the HAZ for both GTA and SMA weldments compared to the parent and weld metal because of the formation of Widmanstatten ferrite. From the hardness test results, it is clear that the average hardness of GTA weldments (171.3 HV) is higher than that of the SMA weldments (167.3 HV).

Table 4 represents the comparison of tensile properties for both the GTA and SMA weldments. It was observed that both the weldments had undergone considerable amounts of plastic deformation prior to fracture. In all the trials, the fracture occurred at the parent metal of SA 210 C for GTA weldments whereas the weld zone had undergone failure for SMA weldments. It is also evident from the PMI studies that the weld zone of GTA weldments are enriched with the elements of Fe, Mn, Ni and Cr. These elements could have positively stabilized the weld matrix and contributed for additional strength.

SEM fractography studies confirmed the mode of failure to be ductile as the fractured morphology depicts the presence of micro-voids and dimples which coalesce in the fibrous network.

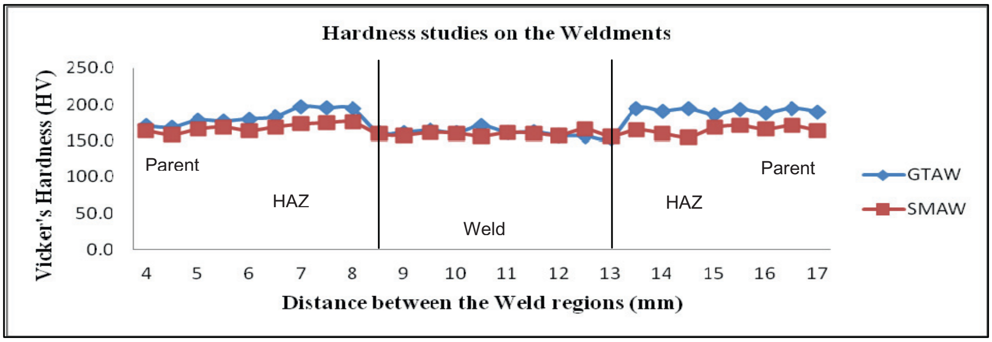


Fig.2 Variation of Micro-hardness along the parent-HAZ-weld interface

Table 4 Tensile Properties of the Weldments

Characteristic Property	GTAW Weldment	SMAW Weldment
Maximum UTS (MPa)	557	497
Young's Modulus (GPa)	67.45	64.69
Elongation at break load (%)	24.89	22.55
Fracture Zone	Parent Metal zone	Weld Zone

3(a)

3(b)

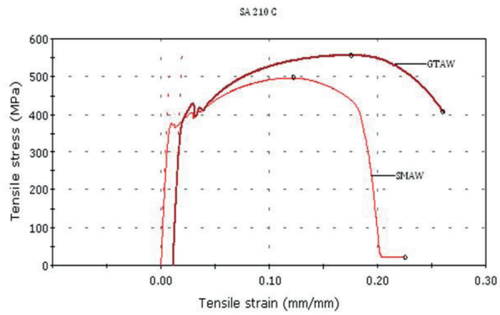


Fig.3 (a) Weldments of SA 210 C ferritic tubular steel using GTAW (top) and SMAW (b) Comparison of GTAW and SMAW tensile strengths

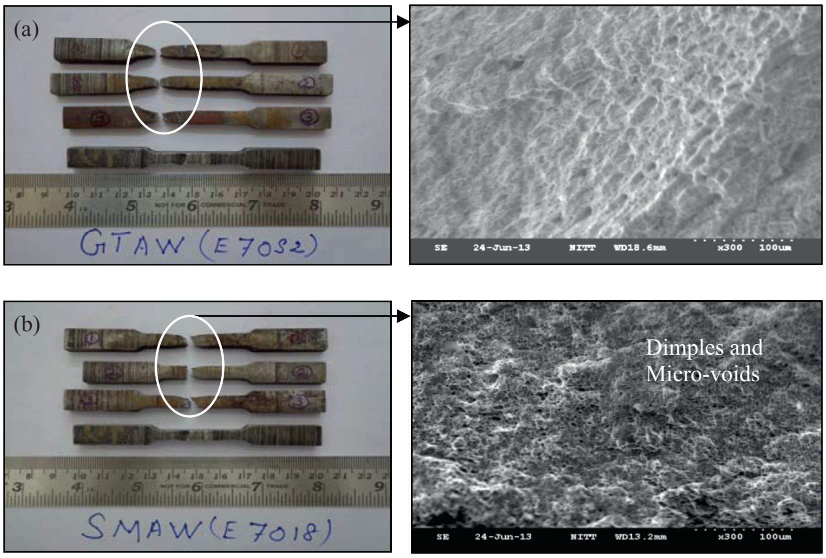


Fig.4 SEM Fractography image analysis of the fractures (a) GTAW (b) SMAW

4. Conclusions

From the present study the following points were concluded:

a) SA 210 C ferritic boiler tubular steels could be welded successfully using GTA welding techniques.
b) GTA weldments offer better mechanical properties as compared to SMA weldments since the fracture had occurred at the parent metal in GTAW, whereas fracture occurred at the weld region for SMAW.
c) Widmanstatten ferrite was observed in both techniques at the HAZ of the SA 210 C steel. This structure resulted in higher strength.

Acknowledgements

The authors would like to thank Mr. Natarajan, Delta Ware tech Engineer's, Pvt. Ltd. Chennai for providing the facility to carry out welding and for the technical support. Also we thank to Department of Science and Technology for the funding received from them under the FIST programme; Instron make universal testing machine used in the present study was procured under this programme.

References

[1] A.Wahid, D.L. Olson, D.K. Matlock, Corrosion of weldments, in: ASM Handbook, Welding, Brazing, and Soldering, vol. 6, 10th ed., ASM International, Materials Park, OH, USA, 1990, pp. 1065–1069.
[2] A.K. Khare, ed, Warren, PA, "Ferritic Steels for High Temperature Applications" ASM Int. Conference, (1981) Metals Park, OH.
[3] Ravindra Kumar, V.K. Tewari, Satya Prakash, "Oxidation behavior of base metal, weld metal and HAZ regions of SMAW weldment in ASTM SA210 GrA1 steel", Journal of Alloys and Compounds, 479 (2009) 432–435.
[4] Devendranath Ramkumar K, Arivazhagan N, Narayanan S, "Effect of filler materials on the performance of gas tungsten arc welded AISI 304 and Monel 400", Journal of Materials and Design 40 (2012) 70–79.
[5] B. A. Leont'ev, Yu. N. Buzovskii, "Mechanical properties of steel with a Widmanstatten structure", Metal Science and Heat Treatment 10 (1968) 930-932.
[6] G.R. Purdy, "Widmanstätten Structures", Encyclopedia of Materials: Science and Technology (2001) 9575–9578.
[7] M. B. Ndaliman, "An Assessment of Mechanical Properties of Medium Carbon Steel under Different Quenching Media", AU J.T. 10(2) (2006)100-104.
[8] T. Senthilkumar, and T. K. Ajiboye, "Effect of Heat Treatment Processes on the Mechanical Properties of Medium Carbon Steel", Journal of Minerals & Materials Characterization & Engineering, 11, No.2 (2012) 143-152.
[9] J. Ahmad, J. Purbolaksono, L.C. Beng, "Thermal fatigue and corrosion fatigue in heat recovery area wall side tubes", Engineering Failure Analysis 17 (2010) 334–343.
[10] R. P. Todorov, Kh. G. Khristov "Widmanstatten structure of carbon steels", Metal Science and Heat Treatment 46 (2004) 3 – 7.