HOT TENSILE PROPERTIES OF AUTOGENOUS PULSED CURRENT GAS TUNGSTEN ARC WELDED SUPER 304HCu AUSTENITIC STAINLESS STEEL JOINTS

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Abstract: *The super 304HCu austenitic stainless steel tubes containing 2.3 to 3 (% wt) of Cu is mainly used in superheaters and reheater of ultra super critical boilers. The addition of Cu to super 304HCu has caused improvement in its corrosion and creep resistance. Austenitic stainless steels welded by constant current gas tungsten arc welding (GTAW) produce coarse columnar grains, increase alloy segregation and may result in low mechanical properties of the weld joint. Hence, autogenous pulsed current GTAW (PC-GTAW) was used to weld super 304HCu tubes of 57.1 mm outer diameter and 3.5 mm thick to control the solidification structure by altering the prevailing thermal gradients in the weld pool. The microstructure, hot tensile properties (550 ºC, 600 ºC and 650 ºC), and fracture surface of the autogenous PC-GTAW welded joint was evaluated. Current pulsing in PC-GTAW joint cannot eliminate segregation in weld metal and exhibited lower tensile strength than the parent metal at all test temperature.*

Keywords: *Super 304HCu Stainless Steel, Autogenous Pulsed Current Gas Tungsten Arc Welding, Hot Tensile Properties, Microstructure.*

1. INTRODUCTION

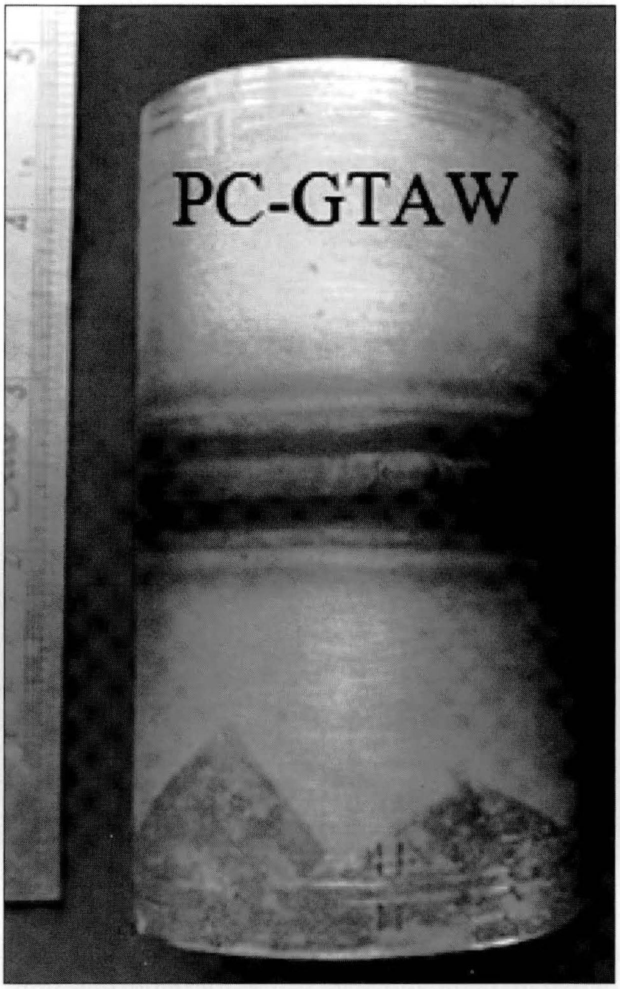
The super 304HCu austenitic stainless steel tubes containing 2.3 to 3 (%wt) of Cu is used in super heaters and reheaters of ultra super critical (USC) boilers due to its corrosion resistance and oxidation resistance. In addition to that, it posses excellent creep strength derived from the fine Cu rich precipitates which evolves during exposure to creep conditions [1]. Cu slightly increases the hot cracking sensitivity and with regard to weld metal the effect of Cu is to be investigated [2]. Austenitic stainless steels welded by conventional constant current gas tungsten arc welding (CC-GTAW) produce coarse columnar grains in the fusion zone of welds and such microstructure can result in low mechanical properties of the weld joint[3]. It is preferable to control the solidification structure of the fusion zone in weld by altering the prevailing thermal gradients in the weld pool during welding [4].

In Pulsed current gas tungsten arc welding (PC-GTAW) process the welding current is pulsed between high and low value for different time intervals at a pulsing frequency. The high current pulse will bring the weld zone above the melting point while the low current period in the pulse allows the weld pool to partially solidify and maintains a consistent arc. The weld bead is observed as a series of over lapped spot weld in which the overlap depends on the pulsing frequency [2,3,5]. In PC-GTAW the controlled heat input in form of pulses may result in reduced alloy segregation in the weld metal.

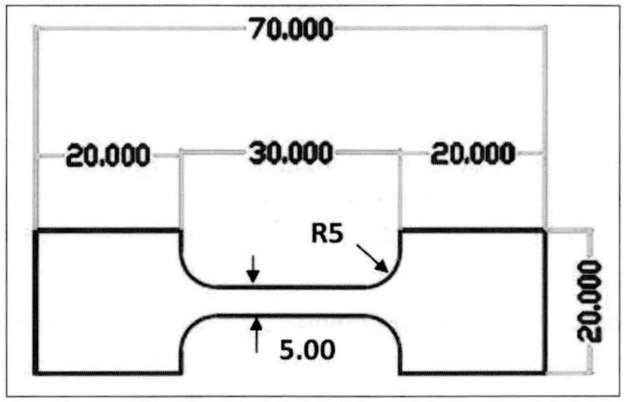
From the literature review [6-10], the works on high temperature ageing behaviour, microstructure evolution and precipitation behavior for unwelded super 304HCu were carried out. However, the work on properties of pulsed current GTA weld joints of super 304HCu in open literature is very scant. Hence in this investigation, it is planned to study the hot tensile properties

Table 1: Chemical Composition (wt %) of Super 304HCu Tube

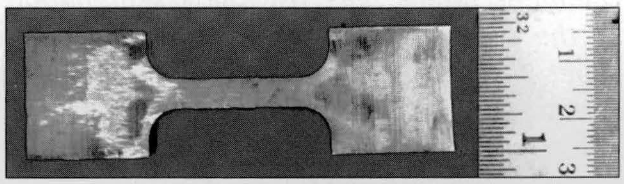
C	Si	Mn	P	S	Cr	Ni	N	Cu	Nb	B	Al
0.086	0.23	0.81	0.021	0.0003	18.18	9.06	0.095	3.080	0.045	0.0039	0.01



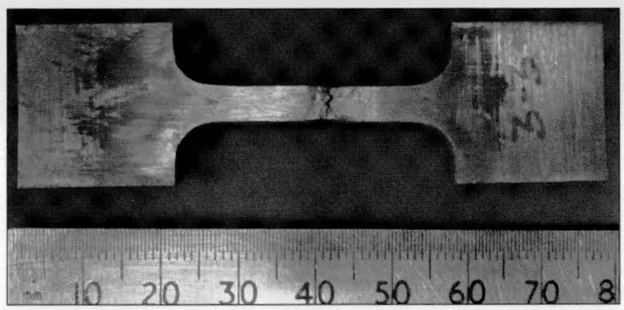
a. Photograph of CC-GTAW and PC-GTAW Welded Specimens



b. Schematic Representation of Tensile Specimen Dimensions (mm)



c. Photograph of PC-GTAW tensile specimen before test



d. Photograph of PC-GTAW Tensile Specimen After Test

Fig 1. Photograph of Weld Sample and Details of the Tensile Specimen

Table 2: Welding Parameters for Autogenous PC-GTAW Welding of Super 304HCu

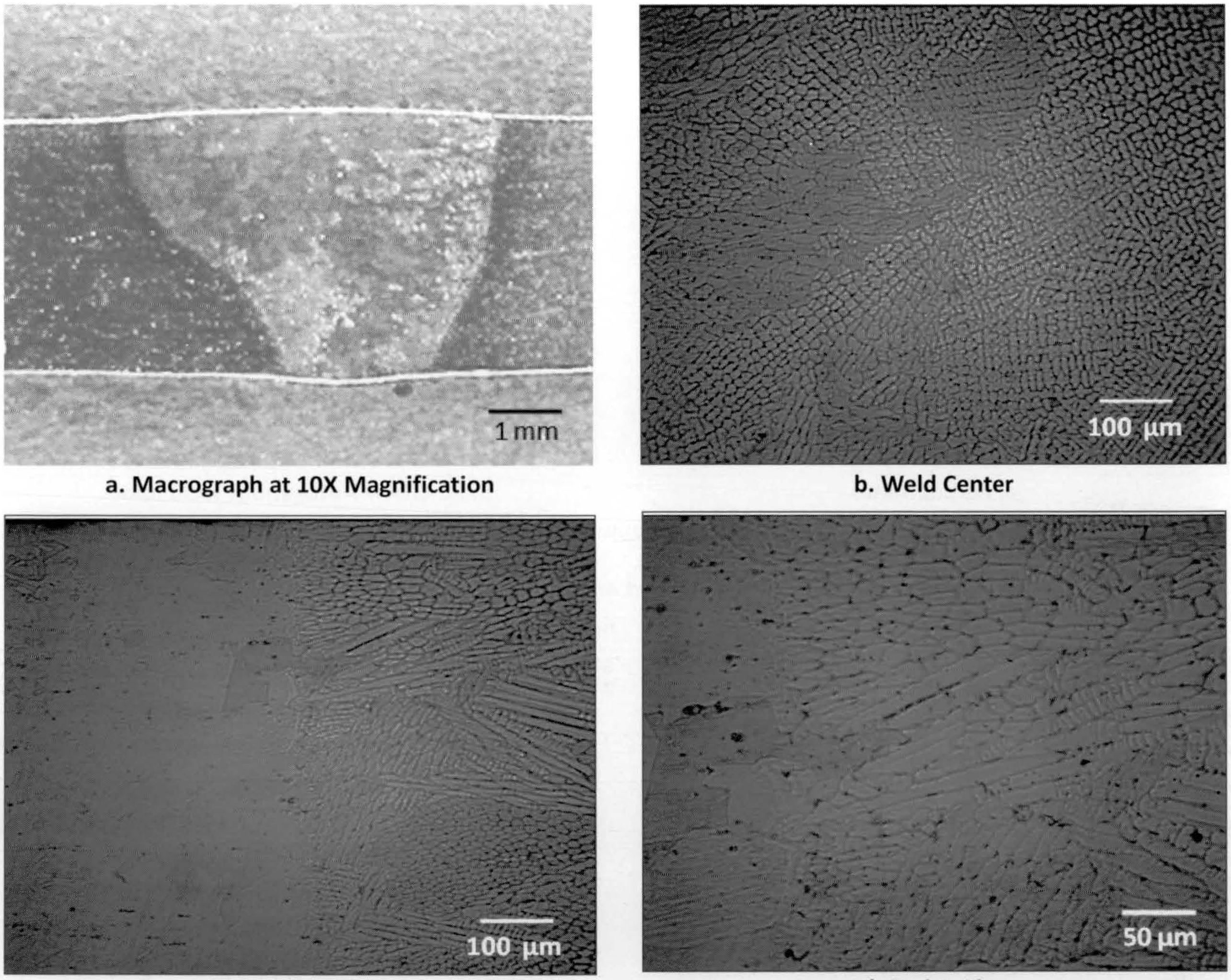
Peak current (A)	110
Base current (A)	66
% on time	75
Frequency (Hz)	10
Voltage (V)	11
Welding speed (mm/min)	70
Heat input (kJ/mm)	**0.933**

of autogenously welded PC-GTAW super 304HCu austenitic stainless steel joints.

2. EXPERIMENTAL DETAILS

Super 304HCu austenitic stainless steel tubes of outer diameter 57.1 mm and wall thickness of 3.5 mm were used for this investigation. The chemical composition of the tubes in as-received condition was given in Table 1.

The joints with square butt edge preparation was welded using PC-GTAW with Argon as the shielding and purging gas with flow rate of 12



a. Macrograph at 10X Magnification

b. Weld Center

c. Heat Affected Zone

d. Fusion Line

Fig 2. Optical Micrograph of Autogenous PC-GTA Weld Joints

and 10 liters per minute respectively to prevent oxidation of the weld. The welding parameters used for this investigation is shown in Table 2.

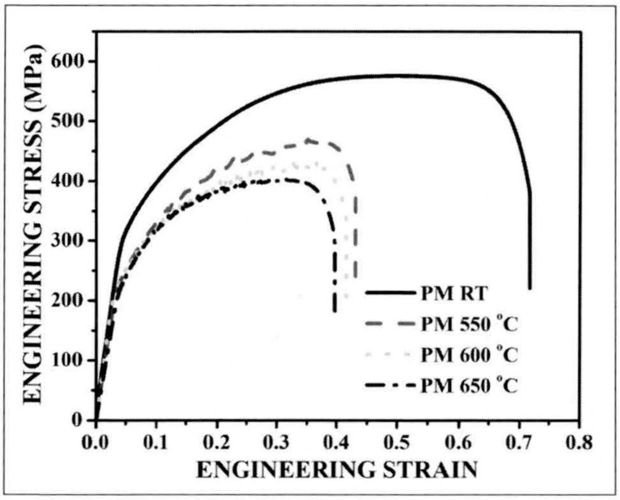
The joints inspected for full penetration and specimens were extracted from the weld joints using wire-cut electric discharge machining. The photograph of the joint welded by PC-GTAW was shown in Fig. 1a. The dimensions of hot tensile specimen were shown in Fig. 1b. Tensile test was carried out as per ASTM E21 standard in Instron make universal testing machine (UTM), at a nominal strain rate of $1x10^{-3}$ S^{-1} at test temperatures of room temperature (RT), 550°C, 600°C, and 650°C. The UTM system was equipped with a three-zone resistance heating furnace for high temperature tests and a computer with data acquisition system for obtaining digital load-elongation data. The photographs of PC-GTAW tensile specimens before and after test were shown in Fig. 1c and Fig. 1d respectively.

The specimen for microstructural examination were prepared using standard metallographic techniques and etched with 3 parts HCL and 1 part HNo_3 for 5-10s to reveal the microstructural features. The microstructural examination was carried out using light optical microscope (OM) and scanning electron microscope (SEM). Ferrite measurement in the weld metal was carried out using (make: Fischer), ferritescope. The micro hardness measurements were carried out using Vickers microhardness tester with a load of 500g and dwell time of 15s. The fracture surfaces of the tensile specimens were studied using SEM to reveal the modes of fracture.

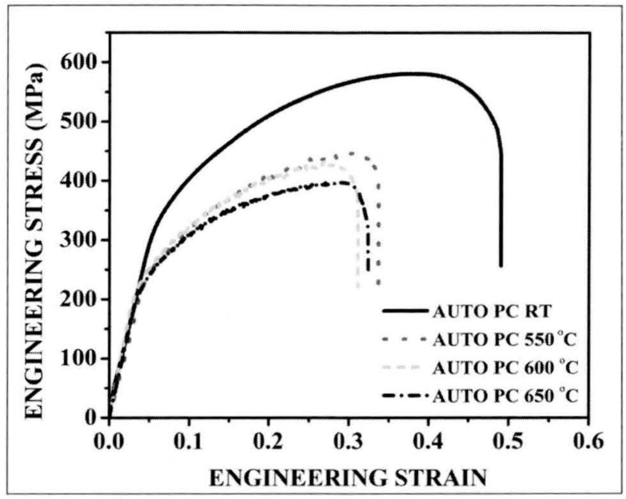
3. RESULTS

3.1 Microstructure

The macrograph of PC-GTAW joints were shown in Fig. 2a show complete penetration through the full thickness of the joint without any



a. Parent metal



b. PC-GTAW Autogenous weld joint

Fig 3. Engineering Stress Strain Curves of Weld Joints of Super 304HCu at Different Test Temperature

Table 3: Hot Tensile Properties of Parent Metal and Autogenous PC-GTAW Weld Joints of Super 304HCu

Joint	Test temperature °C	0.2% Yield strength MPa	Ultimate tensile strength MPa	Elongation (%)	Failure Location
Parent metal (PM)	RT	284.2	575.8	71.8	-
	550	205.5	465.8	43.0	-
	600	193.0	431.8	41.7	-
	650	204.3	401.8	39.6	-
PC-GTAW	RT	322.9	570.4	39.2	Weld metal
	550	218.1	443.7	38.6	Weld metal
	600	174.8	425.4	35.1	Weld metal
	650	182.3	394.8	39.4	Weld metal

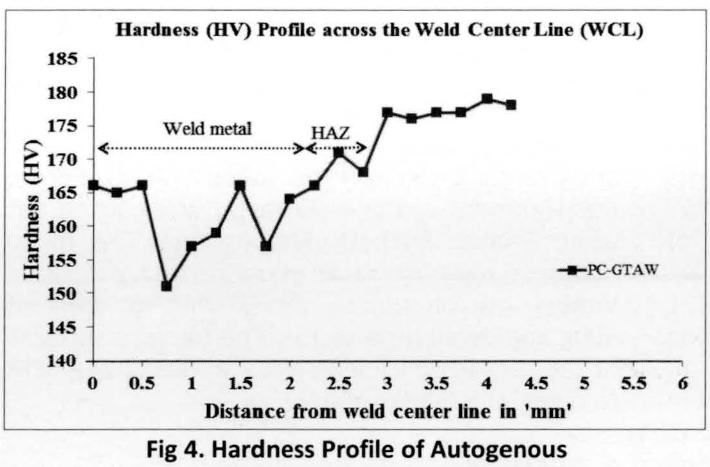


Fig 4. Hardness Profile of Autogenous PC-GTAW Joints of Super 304HCu

macro level defect. The optical micrograph of PC-GTAW joint weld center is shown in Fig. 2b which consists of randomly oriented austenite grains of cellular morphology. The Fig. 2c and 2d shows the HAZ and fusion line of the PC-GTAW joint, the HAZ reveal the grain coarsening occurred in this region during welding. The fusion line of PC-GTAW joints reveals that the solidification, started by epitaxial growth, followed by planar solidification and transforming to cellular mode of solidification towards the weld center. Fig. 2d reveals the non-continuous stringers of inter-dendritic delta ferrite (dark phase) between the coarse columnar grains. The average volume % of delta ferrite in PC-GTAW joint is found to be 0.78 % by the ferritoscope measurement.

3.2 Tensile Properties

The engineering stress-strain curves of parent metal and autogenous PC-GTAW joint of super 304HCu at various test temperatures are shown in Fig. 3a and 3b respectively, and their values are presented in Table 3. The autogenous

PC-GTAW joint exhibited lesser tensile strength than the parent metal at all test temperatures, with failure at the weld metal. The strength and elongation of both parent metal and weld joints decreased with increase in test temperature. The tensile strength decreases by 30 % for parent metal and by 31 % for autogenous PC-GTAW weld joint with increase in test temperature from RT to 650 °C.

3.3 Microhardness

The micro hardness profile of autogenous PC-GTAW joints across the weld center line was given in Fig. 4. The lowest hardness (151 HV) in the weld joint was recorded in the weld metal region, where the failure of the joint occurred. The HAZ of PC-GTAW joint exhibited higher hardness valve than the weld metal region. The variation in hardness value within the weld metal region was attributed to the inhomogeneous microstructure observed in this region.

3.4 Fracture Surface

The SEM fractographs of the parent metal and autogenous PC-GTAW tensile specimens tested at RT and 600 ºC was shown in Fig. 5. The fracture surface of parent metal tested at RT reveals the presence of fine dimples which is attributed to the prominent ductile mode of failure. The fracture surface of autogenous PC-GTAW joint tested at RT reveals coarse dimples with size closely confirm to the dendritic size of the weld metal, which evidence the reduced ductility associated with the weld joint. The fracture surface of parent metal tested at 600°C (Fig. 5c) reveals larger voids surrounded by finer dimples and some featureless flat region, attributed to the reduced ductility of the weld joints at higher temperatures. Similar observations, with more flat regions in the fracture surface of weld joints, evidencing the more brittle nature of failure involved with the autogenous PC-GTAW joints at high temperatures.

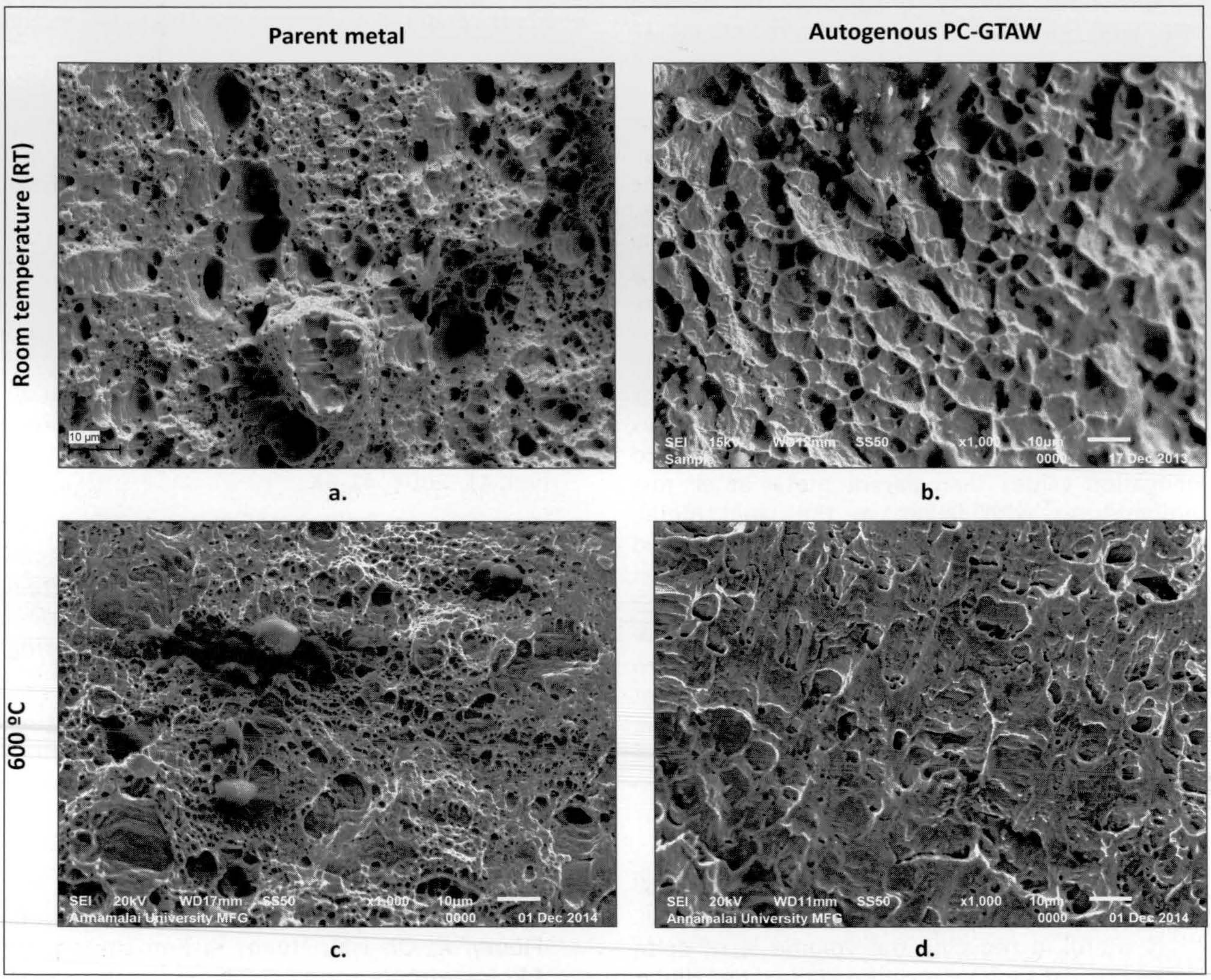


Fig 5. SEM Fracture Surface of Tensile Specimens

4. DISCUSSION

The microstructure of autogenous PC-GTA weld metal shown in 2b reveals primary austenite type solidification, which is evident from the cellular morphology of the austenitic grains. The presence of segregated delta ferrite phase in the intercellular regions of the austenitic grains (Fig. 2d) is due to segregation of ferrite forming elements in the advancing liquid for solidification in the weld metal. The volume fraction of delta ferrite in the columnar grains of weld metal region near the fusion line is higher than the weld center region due to the rapid cooling aided by the epitaxy, the weld structure could solidify far away from equilibrium [11]. The pulsing current in PC-GTAW helped in reduction of delta ferrite and segregation in the weld by enhancing the fluid motion in the weld pool. In pulsed current mode the surface of the molten liquid is sufficiently under cooled during the background current time thereby enhancing the cooling rate and homogenization of the weld metal. The homogenization of weld metal has resulted in microstructure with less delta ferrite and segregation [12,13], although segregation was not completely avoided by current pulsing. A small amount of delta ferrite in austenitic weld metal is essential to prevent hot cracking. However, the presence of delta ferrite will enhance the creep rate during exposure to creep condition, as the delta ferrite-austenite interface will act as effective path for diffusion [14] and hence delta ferrite to be avoided in the microstructure of weld metal for high temperature applications. Autogenous PC-GTAW joint exhibited lower strength and elongation values than parent metal at all test temperatures with failure at the weld metal, where the lowest hardness was recorded (refer Fig. 4). The strength and elongation decreases with increase in test temperature for both parent metal and autogenous PC-GTAW joints. The decrease in elongation and strength values at elevated temperature of both parent metal and weld joints are attributed to the annihilation of dislocation.

5. CONCLUSIONS

1. The current pulsing in autogenous PC-GTAW of super 304HCu austenitic stainless steel, is useful in reducing the volume % of delta ferrite and alloy segregation in the intercellular regions, but was not eliminated completely.
2. The autogenous PC-GTAW joint of super 304HCu exhibited lower tensile strength and elongation than the parent metal at all test temperature, with the failure of the weld joint located in the weld metal.
3. Although, the autogenous welding of super 304HCu can produce defect free weld joints, the lower strength values and segregation of alloying elements in weld metal does not provide the required properties for high temperature applications in USC boilers.

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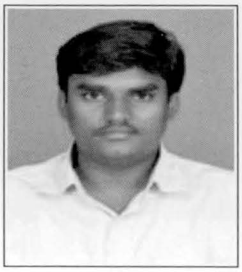

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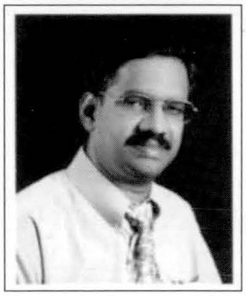

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