Comparison of Properties of Super 304H Tube Welded by Manual and Semiautomatic Hot Wire GTAW

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ABSTRACT - Super 304H austenitic stainless steel with 3% of copper possess excellent creep strength and corrosion resistance, which is mainly used in heat exchanger tubing of the boiler. Heat exchangers are used in nuclear power plants and marine vehicles which are intended to operate chloride environment at moderately high temperature sections of Advanced Ultra Super Critical (AUSC) boilers, welding of austenitic steels is inevitable owing to economic aspects of boiler. Super 304H austenitic stainless steel tubes are welded by manual and semiautomatic hot wire gas tungsten arc welding. Radiograph test is carried out on manual and semiautomatic hot wire weld in which ensure the soundness of weld joints if there is no defects. Micro examination of manual and semiautomatic weld shows no defects present in weld metal, HAZ and base metal. Microstructure of manual weld contains mostly austenitic (ɣ) grain of columnar dendritic and equiaxed dendritic structure. The microstructure of semiautomatic weld reveals austenitic grain structure which has copious equiaxed dendritic structure in weld metal region.

Semiautomatic hot wire weld joint has yield strength, ultimate tensile strength, percentage of elongation, percentage of elongation greater than manual weld joint of Super 304H austenitic stainless steel tube. Microharness of semiautomatic hot wire weld joint is greater than manual weld joint of Super 304H austenitic stainless steel tube. SEM analysis is ensure presence of austenitic (ɣ) grain in which has finer columnar dendritic and equiaxed dendritic structure and small amount oxide present in weld region of manual weld. It is also reveals fully austenitic (ɣ) grain in which equiaxed dendritic structure in weld metal region in semiautomatic hot wire weld.

1.1 INTRODUCTION

1.2 MANUAL TIG WELDING

Manual gas tungsten arc welding is a relatively difficult welding method, due to the coordination required by the welder. Similar to torch welding, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other. Maintaining a short arc length, while preventing contact between the electrode and the workpiece, is also important. To strike the welding arc, a high frequency generator provides an electric spark. This spark is a conductive path for the welding current through the shielding gas and allows the arc to be initiated while the electrode and the workpiece are separated, typically about 1.5–3 mm apart. Once the arc is struck, the welder moves the torch in a small circle to create a welding pool, the size of which depends on the size of the electrode and the amount of current. Filler metal is added manually to the front end of the weld pool as it is needed. The filler rod is withdrawn from the weld pool each time the electrode advances, but it is always kept inside the gas shield to prevent oxidation of its surface and contamination of the weld. In this welding, tungsten electrode is 2.4mm, filler rod size 2.4mm,interpass temperature at 216°C, shielding gas and purging gas flow rate 20lpm and 6lpm As shown in fig 1.1 Manual GTAW Machine.

Fig 1.1 Manual GTAW Machine

1.3 SEMIAUTOMATIC HOT WIRE GTAW EWM MACHINE

Hot wire GTAW is resistance heated closer to melting point which fed continuously to the weld puddle 1G,(or) downhand welding on plate, (or) welding pipe when pipe can be rotated, followed by 2G. As the filler wire is pre-heated, the weld deposition efficiency of HW-GTAW process is higher when compared to the conventional GTAW process.

Hot wire gas tungsten arc welding (HW-GTAW) process is the one where the filler wire is preheated close to its melting point before it is fed in to the arc. The effect of HW-GTAW parameters such as welding current, hot wire current and the wire feed rate during welding of super ASS 304H stainless steel tubes were evaluated in terms of heat input, voltage-current (V-I) characteristics and weld bead characteristics such as bead weight and geometry. As the existing information on this process is limited, it is imperative to study the individual and synergistic effect of HW-GTAW process variables such as welding current, hot wire current and wire feed rate on the weld quality. In the current work, the effect of the aforementioned process variables of HW-GTAW of super 304H stainless steel tube used for boiler manufacturing has been evaluated by characterising the welding process and joint for heat input, V-I characteristics, weight of the metal deposited and bead geometry described in terms of bead width, depth of penetration, area of fusion and deposit, toe angle. TIG welding machines are mainly used for welding clean and safe seams in forced positions and root passes. With DC TIG welding machines, that can work with almost any material, from alloyed steel to copper, while EWM's AC/DC welding machines are the ideal partner for welding stainless steel. Hot wire gas tungsten arc welding is used to weld the Super 304H austenitic stainless steel tube with appropriated welding current and arc voltage and hot wire current which make a soundness of weld joint. Argon is used as a shielding gas which is under pressure of 100bar and the rate of flow 20 liter per minute. In this welding, the tungsten is used as a tungsten electrode in 3.2mm diameter and 1.2mm fire wire size so that is suitable for welding of similar material Super 304H tube austenitic stainless steel. As shown in fig 1.3 Semiautomatic Hot Wire Welding Machine.

Fig 1.3 Semiautomatic Hot Wire Welding Machine

1.4 MATERAILS

Super 304H is an austenitic stainless steel which utilized for ultra super critical boiler and pressure vessel. Increasing temperature and pressure demands placed by the ultra supercritical technologies in pulverized-coal power generation plants have necessitated the need for the development of new high performance alloys. The recently developed SUS 304HCu austenitic steel has shown considerable promise, primarily due to its high oxidation resistance, corrosion resistance and creep resistance, at a relatively low processing cost. The addition of 3 wt. % Cu to SUS 304HCu, aimed at increasing the corrosion resistance has found to increase the elevated temperature strength and the creep strength in the temperature range of 650°C-750°C. The exact mechanism and role of Cu in enhancing the creep strength is yet to be identified and is under investigation. The addition of Cu to steels can have adverse effects on the mechanical properties of the fusion welded joint, as it can form low temperature eutectic phases that preferentially segregate to the grain boundaries and embrittle the alloy.

The Super 304H Austenite stainless steel tubes material. SS 304 H is a fully austenitic stainless steel having fcc crystal structure from room temperature to melting point and does not involve any solid state phase change up to melting. Hence the only way to modify its property and microstructure is by hot or cold rolling, followed subsequently by suitable annealing. The

SUS 304H austenitic steels have shown promise as they offer excellent high temperature properties (high oxidation, corrosion and creep resistance) at relatively lower materials cost combined with easy recycling processing. These alloys contain 18 wt.% Cr, 9 wt.% Ni and 0.4 wt.% Nb with no other high temperature elements such as Mo, V,W, Ta that are generally added to impart high stability to the microstructure at elevated temperatures. It has shown that the addition of small amounts of Cu, which leads to nano-particle precipitation, can significantly improve the creep strength of the SUS304H austenitic steel, which in turn makes the alloy suitable for use in the temperature range of 650–750 ◦C. However, the exact mechanism and role of Cu in improving the creep strength is yet to be identified and is under investigation. Note that Cu, which forms low temperature eutectic phases that preferentially segregate to the grain boundaries, is known to cause grain boundary embrittlement in steels. Therefore, a critical assessment of the role of dilute amounts of Cu on fatigue and fracture characteristics of SUS 304H stainless steel is essential. As shown in table 1.1 Chemical composition Super 304H Austenite stainless steel tubes.

Table 1.1 Chemical composition Super 304H Austenite stainless steel tubes and filler material (ER304H cu)

Material	**C**	**Si**	**Mn**	**Cr**	**Ni**	**Cu**	**Ti +V+Nb**	**N**	**P**	**S**	**Mo**	**B**	**Others**
Super 304H	**0.08**	**0.22**	**0.79**	**17.74**	**8.58**	**2.68**	**0.62**	**0.11**	**0.015**	**<0.01**	**0.35**	**<0.001**	**Fe**
ER304H Cu	**0.06**	**0.28**	**3.2**	**17.27**	**16.47**	**2.74**	**0.2**	**0.14**	**<0.01**	**<0.01**	**0.94**	**<0.001**	**Fe**

1.5 FILLER ROD

TIG welding is an electric welding process that uses a non-consumed tungsten electrode to provide heat, with the filler rod added manually. There are two different size of filler rods are used for manual and semiautomatic hot wire TIG welding process. The size of filler rods are 2.4mm and 1.4mm in manual welding and semiautomatic welding respectively. In manual welding, filler rod is feed into arc during welding so as feed rate under control manually by welder. As shown in Table 1.1 chemical composition of filler material (ER304H cu).

1.6 Preparation of Similar materials (SUPER304H –SUPER 304H)

As shown in figure 3.1 geometric size of super 304H tube of similar material. The joints with single 'V' butt preparation was welded using GTAW process.

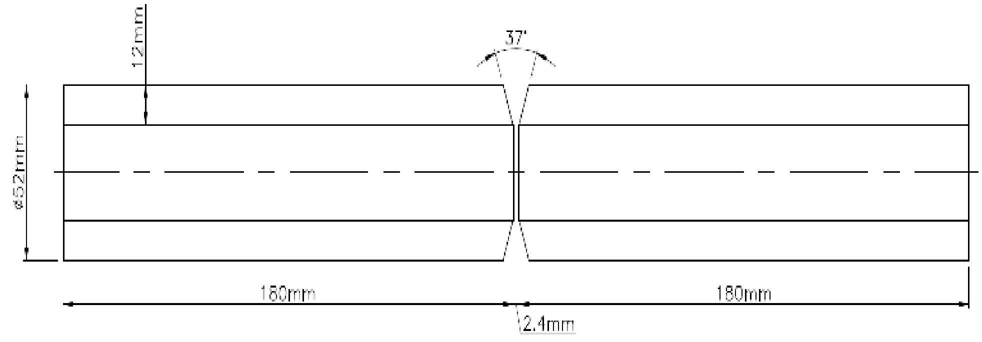


Fig 1.4 Geometric size of super 304H tube of similar material

The job identified by 304M and 304S that are represented by manual and semiautomatic hot wire weld.

Fig 1.5 Welded samples of similar joint of super 304H tube

2.1 RESULT AND DISCUSSSION

2.1 RADIOGRAPH TESTING

The super 304H is an austenitic stainless steel in tube form which is welded by manual and semiautomatic hot wire gas tungsten arc welding. These welds are firstly visually examined and show the weld indicated good quality of welding. Secondly these weld joints are examined by radiography test (RT) which ensured the soundness of weld if there is no defects on both process weld.

2.2TENSILE TEST RESULT

Super 304H transverse weld tensile specimen which is carried out tensile test according to standard test AWS B4.0. The tension test is completely conducted at room temperature 29^0C

Table 2.1 Tensile test result

Identification	Specimen Size in mm	Y.S in Mpa	U.T.S in Mpa	% Elongation (G.L =50mm)	% RA	Position Of Fracture
SUS 304H M	12.98x 8.96	397	624	23	40	Weld
SUS 304H SA	12.98x 8.96	398	657	38	61	Base metal

Semiautomatic welded super 304H tube similar joint has greater yield strength, ultimate tensile strength, percentage of elongation, percentage of reduction than manual weld. The fracture is occurred in welded portion of super 304H manual weld so as it not consider to be weld failure when the value is compared with base material. These tensile test value of manual weld sample is greater than the base material super 304H so as it not weld failure. Base material tensile test values as shown in table 4.2.

Table 2.2 Super 304H austenitic stainless steel tensile test value

Super 304H base material	Y.S in Mpa	U.T.S in Mpa	Elongation
values	350	590	30

The tensile tested samples of manual and semiautomatic welded as shown in fig 2.1.

Fig 2.1 Tensile test of manual and semiautomatic welded sample

2.3 MACRO EXAMINATION

For Manual weld and Semiautomatic weld of Super 304H steel tube

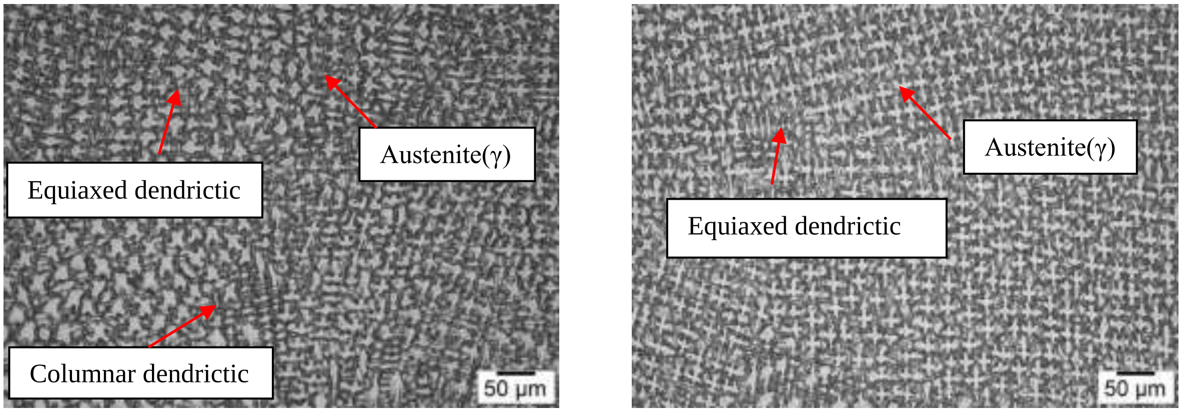
Manual weld **Semiautomatic weld**

Fig 2.2 Macro image for Manual and Semiautomatic weld of SUS 304H tube

The macro image of manual and Semiautomatic hot wire weld of SUS 304H tube is as shown in fig 2.2. The macro image shows that macro defects are not present in base metal, HAZ and weld region.

2.4 MICRO EXAMINATION

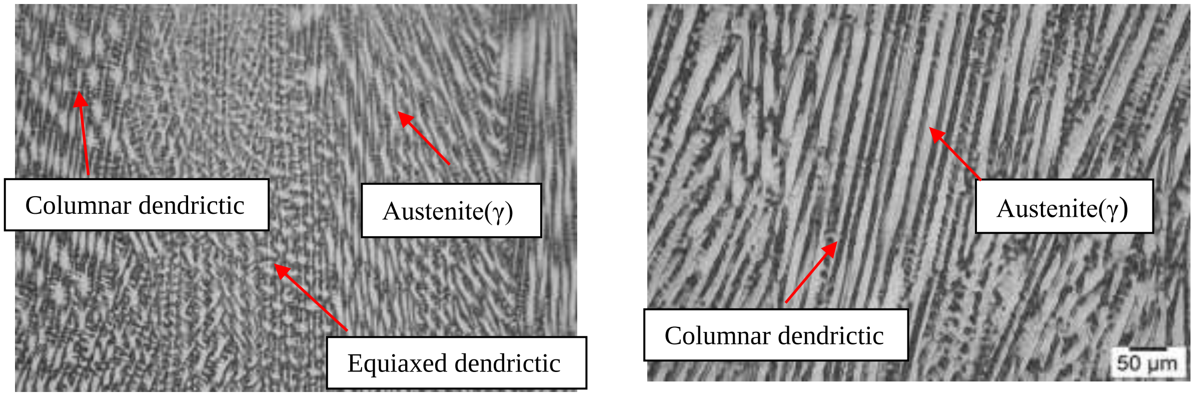
The optical microstructure of SS304H showed equiaxed grains with the copious presence of typical austenitic stainless steel. The microstructural variation across the joints of manual and semiautomatic weld is shown in Fig.2.3.



200X 200X

Fig 2.3 Manual and Semiautomatic weld top portion of Super 304H tube

The WM microstructure of manual and semiautomatic weld joints which reveals the presence of fully austenitic equiaxed dendritic structure. However, it consists of finer interdendritic and grain boundary precipitates weld metal. Microstructure of manual weld metal shows columnar dendritic and equiaxed dendritic structure under these welding current 130A and arc voltage 18V with maintain the interpass temperature at 216°C for 30mins. Semiautomatic Hot wire weld metal shows fully austenitic equiaxed dendritic structure which takes place under these welding current 141A, arc voltage 12V and hot wire current 40A with maintain the interpass temperature 160°C for 5mins. As shown in fig Manual and Semiautomatic variation of weld joint in middle portion of Super 304H tube.



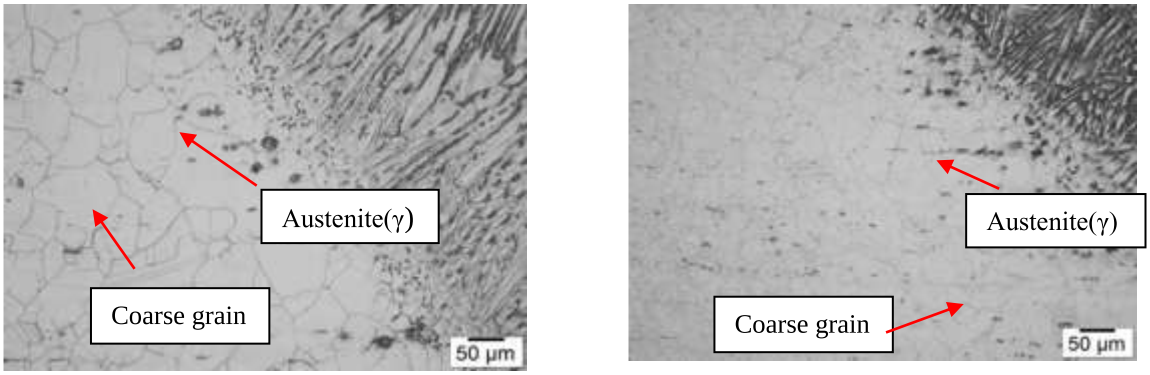
200X

200X

Fig 2.4 Manual and Semiautomatic weld middle portion of Super 304H tube

The microstructure manual weld of SUS 304H tube joint is reveals austenitic columnar dendritic side of weld and equiaxed dendritic structure at center of weld. These structures appears in middle portion of weld that undergone following parameters welding current 149A and arc voltage 18V with maintain an interpass temperature at 216°C for 30mins.

Microstructure of semiautomatic weld shows columnar and dendritic structure at center of weld which take place under these welding current 141A, arc voltage 12V and hot wire current 40A with maintain the interpass temperature 160°C for 5mins. Smaller dendrites generally lead to higher ductility. As shown in fig 2.4 HAZ of manual and semiautomatic weld

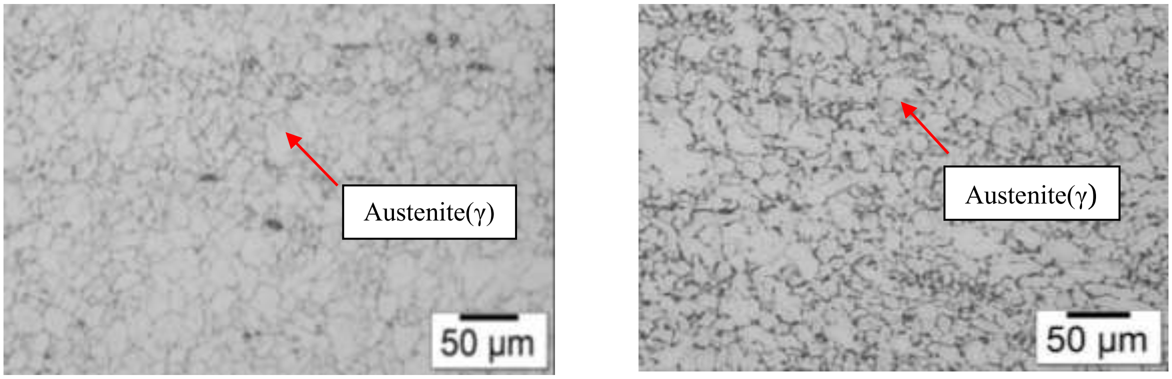


HAZ 200X

HAZ 200X

Fig 2.5 HAZ of manual and semiautomatic weld

The fusion line of filler-added joint is shown in Fig 4.7, which reveals the partially melted zone with epitaxial growth of austenitic grains towards the weld center. The microstructure of HAZ shows coarse grain in manual and semiautomatic weld of Super 304H steel tube.



BM 200X BM 200X

Fig 2.6 Microstructure of Super 304H austenitic stainless steel tube

2.5 MICROHARDNESS TEST

Hardness is measure of resistance of the material against indentation. The hardness value obtained in a particular test serves only as a comparison between materials. There are 70 number of indentation is carried out on manual and semiautomatic weld. The micro hardness value is represented in graph form. As shown in fig 4.9 graph of hardness value Super 304H Welded by Manual weld.

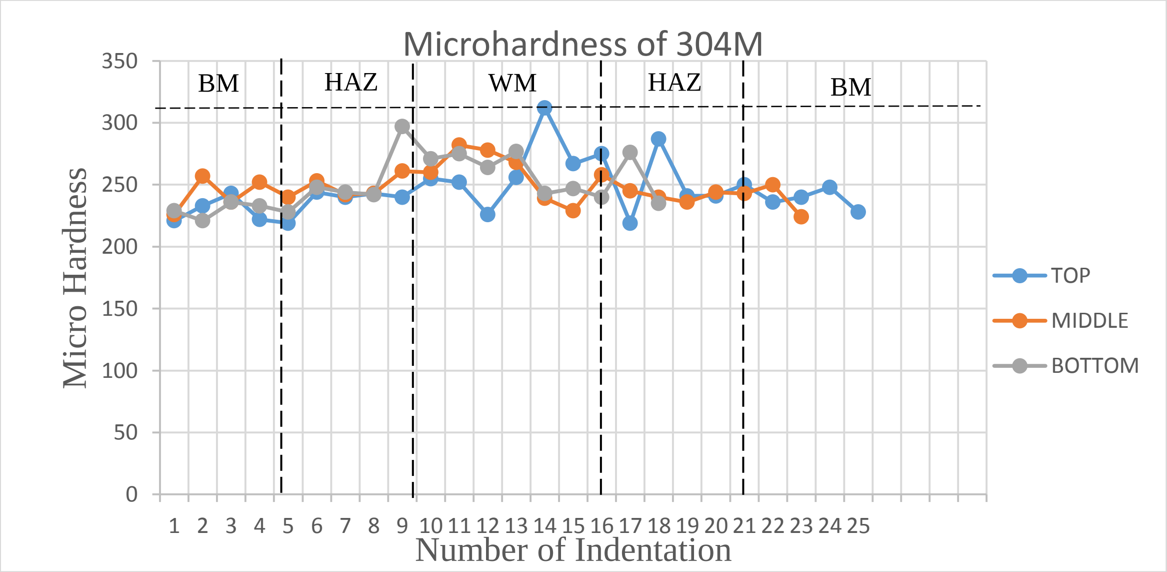


Fig 2.7 Graph for hardness value Super 304H Welded by Manual weld

The maximum micro hardness value of weld metal (319HV) is greater than HAZ (277HV) and base material (258HV). A graph is represented micro hardness peak value and lower value of weld metal, HAZ, and base metal. As shown in fig 4.11 Graph for hardness value Super 304H Welded by Semiautomatic weld.

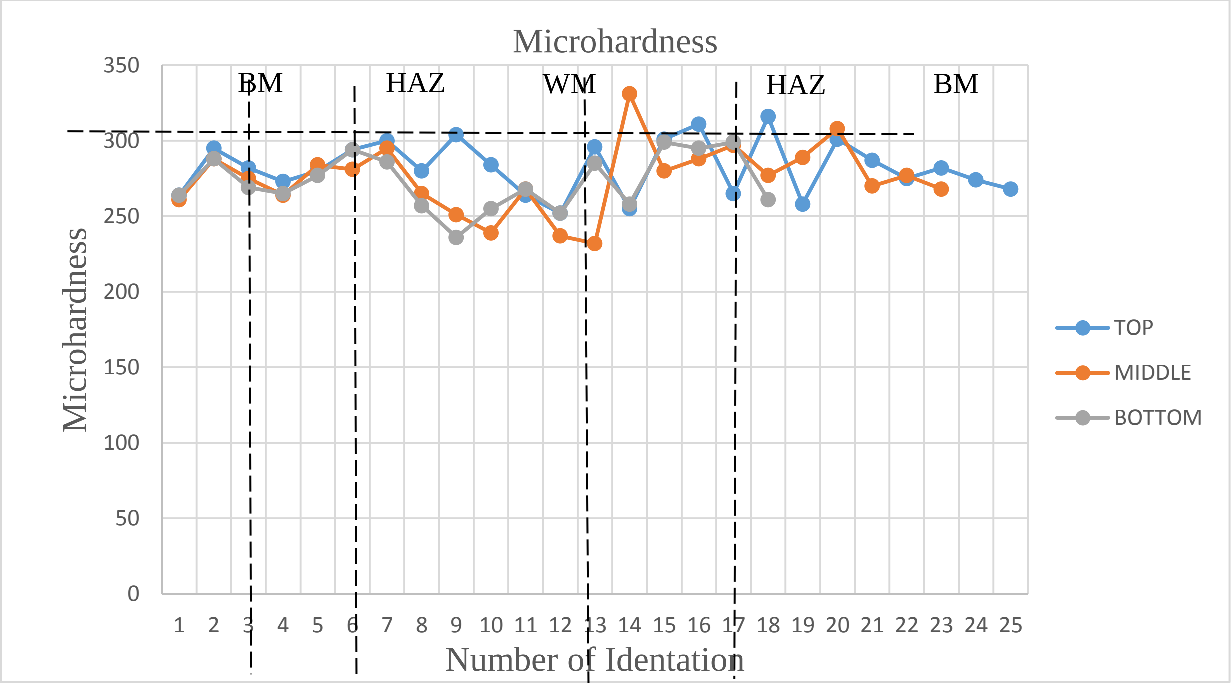
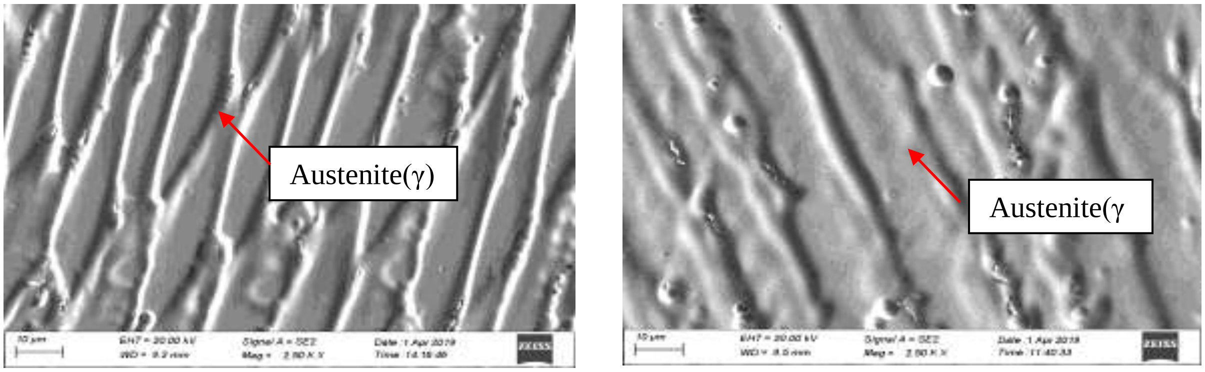


Fig 2.8 Graph for hardness value Super 304H Welded by Semiautomatic weld

The maximum micro hardness value of weld metal (331HV) is greater than HAZ (301HV) and base material (308HV). A graph is represented micro hardness peak value and lower value of weld metal, HAZ, and base metal. Micro hardness value approximately equal to base metal and HAZ of semiautomatic hot wire weld of Super 304H austenitic stainless steel tube. Thus, the micro hardness value of semiautomatic hot wire weld is greater than manual weld of Super 304H austenitic stainless steel tube.

4.5 SEM

Scanning Electron Microscopy (SEM) is a test process that scans a sample with an electron beam to produce a magnified image for analysis. The method is also known as SEM analysis and SEM microscopy, and is used very effectively in microanalysis of solid inorganic materials. Electron microscopy is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects.

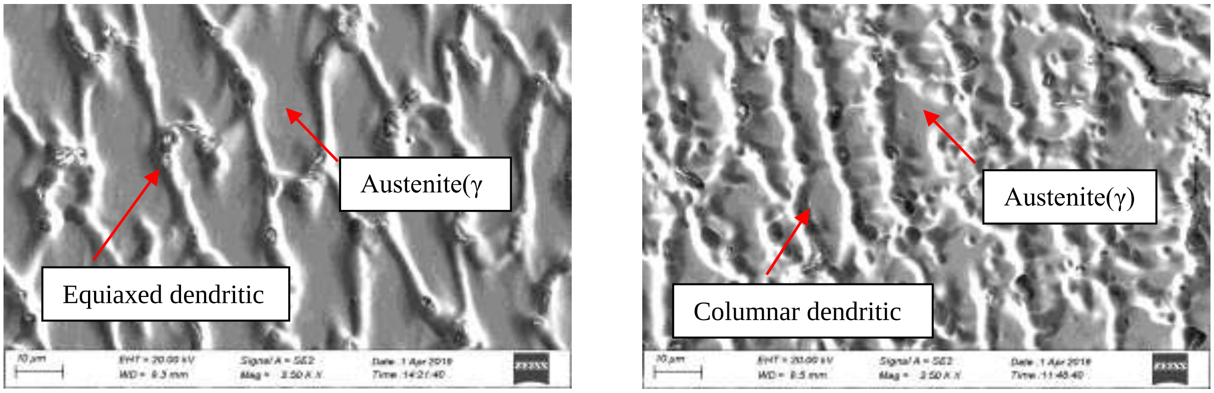


(A) 2500X

(B) 2500X

Fig 4.13 SEM Image for SUS 304H M and SUS 304H SA weld metal

SEM micrographs of the filler-added weld joint are reveals randomly oriented fully austenitic dendritic grains. The SEM image was taken at middle portion of bottom process. The SEM Image of SUS 304H tube joint is reveals austenitic columnar dendritic at side and equiaxed dendritic structure at center of weld. These structures appears in middle portion of weld that undergone following parameters welding current 149A and arc voltage 18V with maintain an interpass temperature at 216°C for 30mins. The SEM Image of semiautomatic weld shows columnar and dendritic structure at center of weld which take place under these welding current 141A, arc voltage 12V and hot wire current 40A with maintain the interpass temperature 160°C for 5mins. Smaller dendrites generally lead to higher ductility.



(A) 2500X (B) 2500X

Fig 4.14 SEM Image for SUS 304H M and SUS 304H SA weld metal

The SEM Image is taken from the bottom portion of weld at higher magnification of 2500X. The SEM image of manual weld is reveals fully austenitic equiaxed dendritic structure at bottom portion of weld which is takes place under these welding current 130A and arc voltage 18V with maintain the interpass temperature at 216°C for 30mins. Then it is also shows small amount of oxide in weld metal region.

The SEM Image of semiautomatic hot wire weld metal shows columnar and equiaxed dendritic structure at bottom portion of weld which takes place under these welding current 121A, arc voltage 11V and hot wire current 40A with maintain the interpass temperature 160°C for 5mins. Therefore, the finer equiaxed dendritic structure is present in semiautomatic weld would rather than manual weld of Super 304H steel tube. As shown in Fig 4.14 SEM Image for HAZ of SUS 304H M and SUS 304H SA weld metal.

CONCLUSIONS

In this present work, Super 304H austenitic stainless steel in tube form which is welded by manual and semiautomatic hot wire gas tungsten arc welding (GTAW) process. After welding NDT, mechanical and metallurgical testing are carried out to check the soundness of weld.

1. Radiography test is carried out on manual and semiautomatic weld joint of Super 304H tube which ensure the soundness of weld if there is no defects.
2. Semiautomatic hot wire weld joint has yield strength, ultimate tensile strength, percentage of elongation, percentage of elongation greater than manual weld joint of Super 304H austenitic stainless steel tube.
3. Microstructure of manual weld joint reveals fully austenitic (ɣ) grain structure. It consists of columnar dendritic and equiaxed dendritic structure in weld metal region. The microstructure of semiautomatic weld joint reveals austenitic grain structure which has copious equiaxed dendritic structure in weld metal region.
4. Microharness of semiautomatic hot wire weld joint is greater than manual weld joint of Super 304H austenitic stainless steel tube.
5. The SEM is ensure presence of austenitic (ɣ) grain in which has finer columnar dendritic and equiaxed dendritic structure and small amount oxide present in weld region of manual weld. It is also reveals fully austenitic (ɣ) grain in which equiaxed dendritic structure in weld metal region in semiautomatic hot wire weld.

REFERENCE

1) A.H.V. Pavan, K.S.N. Vikrant , R. Ravibharath , Kulvir Singh (2015) “Development and evaluation of SUS 304H-IN 617 welds for advanced ultra supercritical boiler applications”. International Journal of Iron and Steel Research.
2) M. Vinoth Kumar, V. Balasubramanian and A. Gourav Rao (2016) “Effect of filler addition on solidification behaviour and hot tensile properties of GTA-welded tube joints of Super 304H austenitic stainless steel”. International Journal of Iron and Steel Research.
3) TAN Shu-Ping' , WANG Zhen-Hua , CHENG Shi-Chang , LIU Zheng-Dong HAN Jie-Cai, FU Wan-Tangz (2010) “Effect of Cu Content on Aging Precipitation Behaviors of Cu-Rich Phase in Fe-Cr-Ni Alloy”. International Journal of Iron and Steel Research.
4) M. Vinoth Kumar, V. Balasubramanian, S. Rajakumar, Shaju K. Albert (2015) “Stress corrosion cracking behaviour of gas tungsten arc welded super austenitic stainless steel joints. International Journal of Material Science and Engineering.
5) Indrani Sena, E. Amankwaha,b, N.S. Kumara, E. Fleuryc, K. Oh-ishid, K. Honod, U. Ramamurtya,(2011) “Microstructure and mechanical properties of annealed SUS 304H austenitic stainless steel with copper”. International Journal of Material Science and Engineering.
6) B. Prabha, P. Sundaramoorthy, S. Suresh, S. Manimozhi, and B. Ravishankar, (2008) “Studies on Stress Corrosion Cracking of Super 304H Austenitic Stainless Steel”. International Journal of Material Science and Engineering.
7) K.K. Alanemea,b, S.M. Hongc, Indrani Sena, E. Fleuryc, U. Ramamurtya,(2009) “Effect of copper addition on the fracture and fatigue crack growth behavior of solution heat-treated SUS 304H austenitic steel”. International Journal of Material Science and Engineering.
8) A Study on Process Characteristics and Performance of Hot Wire Gas Tungsten Arc Welding Process for High Temperature Materials refers by International Journal of Material Science and Engineering.
9) Effect of post weld heat treatment on microstructure and mechanical properties of Hot Wire GTA welded joints of SA213 T91 steel refers by International Journal of Material Science and Engineering.