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MECHANICAL PROPERTIES AND MICROSTRUCTURE ANALYSIS OF SUPER304 HCu JOINTS USING FRICTION WELDING

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Abstract: Austenitic stainless steels are more complex in nature than ferritic and martensitic steels, as they have at least four major alloying elements such as Fe, C, Cr, & Ni. Super 304H is widely used in super heater and reheater tubes of power plants. The addition of 3% (wt) Cu to Super 304H, aimed at reducing the recycling cost, has been found to increase the elevated temperature strength of the austenitic steels, especially their creep performance in the temperature range of 650-750°C. In fusion welding, a number of weldability problems will encounter, if proper precautions are not taken. Weld solidification and liquation cracking may occur depending on the base and filler material used. Embrittlement due to sigma phase and carbide formation may also occur. The high carbon content increases the susceptibility to sensitization, Stress corrosion cracking and Intergranular corrosion. To overcome these problems a solid state welding process known as Friction welding has proved itself to be a reliable and economical way of producing high quality, defect free weld joints by elimination fusion related problems. The weld joints have to be in service temperatures of greater than 600° C for the entire design life of the power plant. The integrity and the life of the power plant depends on the performance of these weld joints at elevated temperature. Hence in this investigation it is planned to study the microstructure evolution and tensile properties of the friction welded joints of AISI304HCu after exposing at 650° C for different time period such as 10, 50 and 100 hours. The results are presented and discussed in detail.

Key Words*:* Austenitic stainless steel; Friction welding; Heat treatment; Tensile properties; Microstructure; Micro hardness.

1.0 Introduction

Austenitic stainless steel is an alloy, which is iron based and contains major elements Cr and Ni to give it characteristics suitable for a wide range of applications. SUPER 304H austenitic stainless steel is used for boiler plant heat exchanger tubes to increase the efficiency that contain minimum of 17-19% chromium and 7.5-10.5% nickel. SUPER 304 stainless steel is used in chemical, petrochemical and fertilizer industries and as equipment in dairy, food processing, cryogenic vessels and as heat exchanger tubes. In the various materials for the heat exchanger tubes , the SUS 304H austenitic steel has shown considerable promise due primarily to its high oxidation, corrosion and creep resistances, and relatively low processing cost. Further enhancements in the efficiency of power plants can be achieved by operating at higher steam temperatures, which in turn requires higher creep resistant alloys. In this context, the addition of 3.08 wt.% Cu to SUS 304H, aimed at reducing the recycling cost, has been found to increase the elevated temperature strength of the austenitic steels, especially their creep performance in the temperature range of 650–750 ◦C [1–10]. The exact mechanism and role of Cu in enhancing the creep strength is yet to be identified and is under investigation [11–13]. However, it has been proposed that Cu, which gets dissolved in the austenitic matrix, while exposed the welded joints in the temperature range of 650c-750c, which forms precipitates during service, as coherent nano-sized particles. Cu-rich phase within the matrix [6]. Cheng et al. [13] have revealed that the addition of Cu up to 3–4 wt. % is optimum as it leads to Cu-rich phase that has an ideal combination of size, number as well as spacing. They have also reported that the effect of Cu in enhancing the creep performance of steel accelerates with ageing. It is particularly important to examine if such precipitation adversely affects the ductility of the alloy. This is because any such degradation could lead to sudden failure of the components, which is highly undesirable. Therefore, the effect of exposing at 650 ◦C and the mechanical properties of the3.08 wt.% Cu added SUS 304H austenitic steels was studied in this work .Friction welding has been successfully applied for welding high ductility to join by non- fusion welding technique. In particular, friction welding can be used successfully to join a much broader spectrum of similar and dissimilar materials than fusion welding. Hence, there is a need to develop highly efficient joining methods which enables one to achieve higher strength and quality more consistently than with the fusion welding process. Friction welding is a solid state joining process that produces coalescence by the heat generated between two surfaces by a mechanically induced rubbing motion.

2.0 Materials and experiments

The parent material used in the investigation was SUS 304HCuaustenitic stainless steel in tube form of outer diameter 57.1 mm and wall thickness 3.5 mm. The chemical composition of the parent material is given in Table 1and the tensile properties of the parent material are given in Table 2.

Table 1

Chemical composition (wt %) of SUS 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	0.95	3.08	0.045	0.0039	.01

Table 2

Tensile properties of SUS 304HCu tube.

0.2%Yield strength in MPa	Ultimate tensile strength in MPa	Elongation in gauge length of 50mm(%)
308	613	43.2

2.1 Friction welding process

A special mandrel was made to hold the tube that have to be friction weld .The specimen is hold in the mandrel and tack welded around the periphery at 120°.The welding was carried on a continuous drive friction welding machine which has a capacity of 3kN.The specimen welded at a speed of 2400 rpm. In the continuous drive friction welding process a stationary member is pressed against a rotating member with an axial pressure(optimum condition).

The optimum condition was selected according to the various trial runs. The experimental design matrix is tabulated in table 3.To arrive at suitable parameter as employed for ferrite –ferrite and austenitic stainless steel. Few more trails are carried out to set defect free welds. The main parameter employed is friction force and burn off (length loss during friction /forge stage). The relative motion generates frictional heat which causes the material to deformed plastically. After a preset displacement (known as burn-off) has occurred the machine is rapidly braked and the pressure is increased to generate a high quality solid state welding. The specimen before and after welding is shown in the photograph. The 3 factors which were varied are rotational speed (N), friction time (F) and forging time(D). The friction pressure and forging pressure were kept constant as 60 MPa and 90 MPa respectively. Optimum friction welding parameters yielded maximum tensile strength of the joint

Fig.1

Fig.2

Table 3

	Rotational speed 'R' (RPM)	Friction pressure (MPa)	Forging pressure (MPa)	Friction time 'F' (s)	Forging time 'D' (s)
Predicted by response surface methodology	2232.23	60	90	23	55
Experimental	2110	60	90	23	55.61

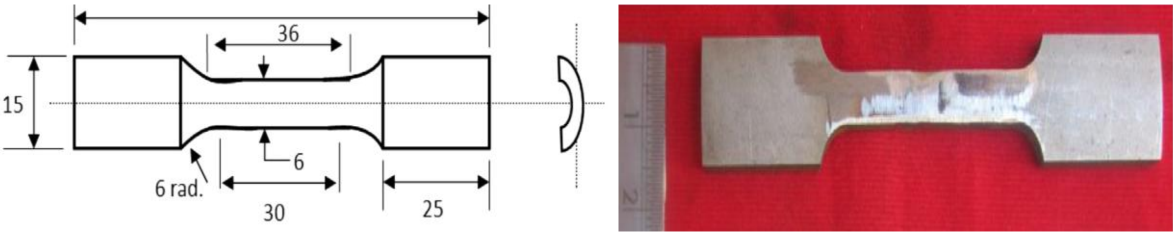

Fig.3 tensile specimen

Table 4

Tensile properties of the friction welded joint using optimized parameters.

0.2% Yield strength in MPa	Ultimate tensile strength in MPa	Elongation in gauge length of 30 mm (%)
286	599	25

3.0 HEAT TREATMENT

The specimens were exposed to a temperature of 650◦c in the resistance furnace for the time periods of 10, 50 and 100hrs and cooled in atmospheric air to expose the actual practical applications. Also the grain size of austenite at heat treatment temperature largely controls the mechanical properties .The heat treatment gives considerable growth of grains. The mechanical properties can be altered by varying the grain size. Grain refinement is the only way to improve the strength and ductility. Also coarse grains have high hardenability than fine grains.

3.1 Mechanical testing

The tensile specimens were extracted by wire cut electric discharge machining, transverse to the weld joint as shown in Fig. 3. The schematic representation and the photograph of the tensile specimen before and after test are shown in Fig. 5 and 6. The tensile tests were carried out in accordance with the ASTM E 8M-04 standard in a 100 kN, electro-mechanical controlled universal testing machine. The hardness measurement was carried out across the weld joint along the mid thickness using Vickers micro hardness testing machine with a load of 0.5 kg and dwell time of 15s at a distance of 0.25mm

Fig.4

Fig.5

Fig.6

3.2 Metallography

Base metal microstructure: Initially the specimen part is cut from the parent metal by abrasion cutting machine. The specimen is polished to a mirror finish polish i.e crack free surface. This achieved by followed as per standards .Etching: The polished specimen is etched by an etchant which is a mixture of Hcl and HNo_3 in ratio of 3:1.The etching time is maintained up to 50 seconds and washed in the running water. Micro structure of base metal is studied under low magnification 100X .In this structure major morphology of austenite phase with equiaxed grains are revealed.

Fig.7

The micro structural features of the friction welded SUS 304HCu joint after thermal exposure at 650c in various time periods of 10,50&100hrs were characterized using optical microscopy. The specimens for microstructural study were prepared by following standard metallography procedures and then etched with a solution of ferric chloride, con. HCl and con. HNO_3 to reveal the microstructural features. The microstructure of the various regions of the welded joint were analyzed using a light microscope and fracture surface of the tensile specimen was studied using scanning electron microscope

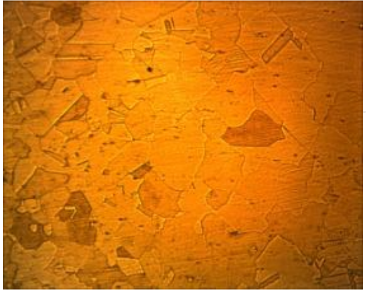

Fig.8 Haz10hrs

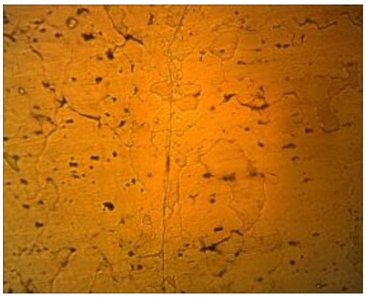

Fig.9 weld centre

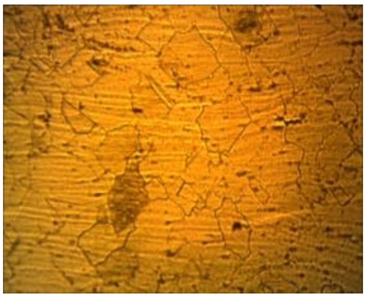

Fig.10 50hrs HAZ

Fig.11 weld centre

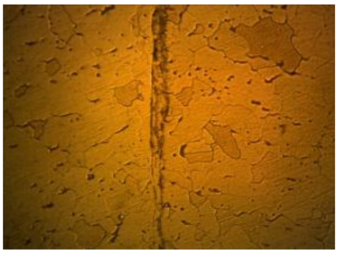

Fig.12 100hrs HAZ

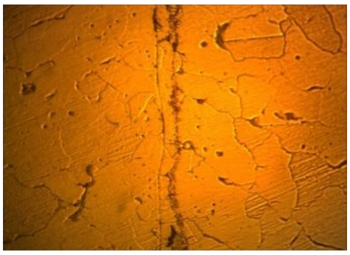

Fig.13 weld centre

4.0 Results

Table 5

Sample	0.2%Yield strength In (MPa)	UltimateTensile strength in(MPa)	Elongation in gauge length of 36 mm (%)	Joint Efficiency in %
PM	308	613	43.2	
AW	286	599	25	96
10hrs	342	425	24.6	69.3
50hrs	376	470	13.4	76.7
100hrs	319	399	10.2	61.1

Fig.15 shows the microstructure of the various regions of the friction welded SUS 304HCu tube. Fig. 7 represents the parent material microstructure which consists of fine equiaxed structure with annealing twins. Fig. 14 shows the macrograph of the friction welded joint, which reveals the clear bonding of the joint without any macro level defects and the flash formation during friction welding. Fig. 9,11,13 represents the low magnification image of the centre of the weld joint which was exposed at 650◦c in 10,50,100hrs reveals the grain growth of specimen as the distance from the centre increases [19]. The micro structural changes are divided into 4 regions for convenience and named as i. Dynamically Recrystallized Zone (DRX), ii. Fully Plasticized Zone (FPZ), iii. Partially Plasticized Zone (PPZ) iv. Unaffected Parent Material (UPM). The DRX zone consists of very fine grain which has recrystallized during the friction welding process.

4.1 Tensile properties

The tensile properties of the friction welded joints after thermal exposed at 650c in various time periods are presented in Table 4. The yield strength and tensile strength of the weld joints showed a decrease of 30% and 20% respectively in comparison with parent material strength values. The strength value of the weldjoint is appreciably higher than the minimum requirement of theparent material which means that the SUS 304HCu tubes can be fabricated using friction welding. The failure of the weld joint has occurred at/close to the weld interface with elongation of 25%exhibiting a shear like failure.

4.2. Hardness

The hardness profile of the friction welded joint joints after thermal exposed at 650c in various time periods are presented in the graph along the mid thickness in transverse direction to the weld is shown in Fig.16. TheDRX region in the centre of the weld joint showed an high hardness value of 289 VHN, between the parent material hardness and FPZ hardness value. The lowest hardness of 212VHN was recorded in the FPZ due to the coarse grain structure formed in this region during friction welding. The hardness has got a gradual rise from the PPZ region to the UPM region with decrease in grain size.

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5.0. Discussion

Annealing twins formation in parent material microstructure is reported to be the characteristic of austenitic steels and other face centered cubic (FCC) metals and alloys having low stacking fault energies, which have been subjected to an annealing treatment after a plastic deformation process [14]. The formation of DRX zone on both sides of the interface of the joint is due to the low temperature and high strain rate involved with this region, which aids the dynamic recrystallization in the narrow DRX zone during friction welding. The high forging pressure (90 MPa) applied to the weld interface during the forging time (55 s) causes the material to flow plastically, which induces high strain rate in this region causing dynamic recrystallization along the interface of the weld. This phenomenon in this zone has restricted the grain growth and assisted the nucleation of new sub grains and thereby resulted in a finer sub-grain structure in the DRX zone [15]. The region next to the DRX zone is the FPZ the rapid grain growth in the FPZ region is due to the low strain rate and high temperature involved in this region during friction welding. The increase of hardness in the DRX region in comparison to other regions of the weld joint is due to the dynamically recrystallized finer grain structure. The region next to the DRX region is the FPZ region with higher hardness of 289 HV which is attributed to the coarse grains formed in this region. Similar increase and decreased hardness value shows the variation in grain size.

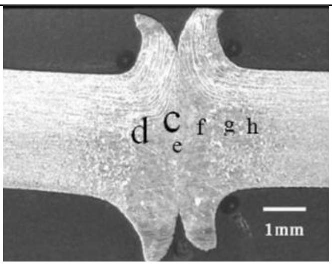

Fig.14 Macro view

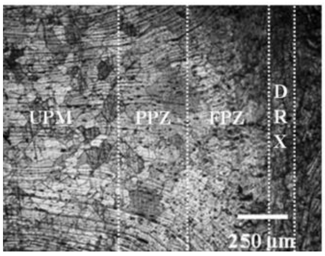

fig.15 various regions

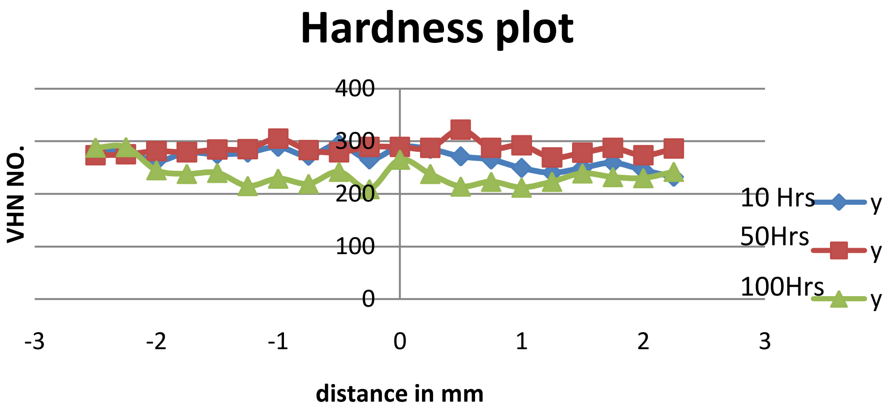

Fig. 16

Conclusions

1. The SUS 304HCu tubes can be successfully welded using continuous drive friction welding process, without any micro or macro level defects.
2. The friction welded joint of SUS 304HCu exhibited good mechanical and metallurgical properties. The joint exhibited an ultimate tensile strength of 96% and 76% after thermal exposed of the parent material’s strength.
3. The formation of dynamically recrystallized region (DRX) at the interface of the joint is due to the high strain rate involved with this region.
4. In the tensile specimen, the failure occurred at/near to the weld interface with shear like fracture
5. The specimens were exposed at various time perids of 10,50.and 100hrs
6. tensile properties, microstructure of various regions and micro hardness were compared. The results show the grain growth, considerably lower ductility and increase in hardness.

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