MECHANICAL PROPERTIES OF BIMETALLIC WELD JOINT BETWEEN SA 516 GRADE 65 CARBON STEEL AND SS 304 L FOR STEAM GENERATOR APPLICATION

Manoj Saini[1], Navneet Arora[2], Chandan Pandey[3], Husain Mehdi[4]

[1]*Assistant Professor, MED, Meerut Institute of Technology Meerut-250002 (U.P) /India*
[2]*Professor, MIED, IIT Roorkee (U.K), 247667 /India*
[2]*Research Scholar, MIED, IIT Roorkee (U.K), 247667 /India*
[3]*Assistant Professor, MED, Meerut Institute of Technology Meerut-250002 (U.P) /India*

Abstract

For a long time now, bimetallic welds (BMWs) have been a necessity within the pressurized water reactors (PWR) and boiling water reactor (BWR) designs, where the heavy section low alloy steel components are usually connected to stainless steel (SS) primary piping systems. For PWRs, the BMWs, which are of particular interest, are those attaching the systems to the various nozzles of the reactor pressure vessel (RPV), steam generators (SG) and pressuriser.

The scope of this paper is to study of mechanical behavior in bimetallic welds used in nuclear power plant. We intended to summarize the understanding of weld behavior that may be applicable in the design of welded components for nuclear power plant systems.

Keywords: *Bimetallic joints, Buttering, SA 516 gr. 65 carbon steel; SS 304 L; SS 308 L.*

--***--

1. INTRODUCTION

Dissimilar metal joints between austenitic stainless steels and carbon steels containing low amounts of carbon are being extensively utilized in many high-temperature applications in energy conversion systems. In steam generating power stations, the parts of boilers that are subjected to lower temperatures as in the primary boiler tubes and heat exchangers are made of ferritic steel for economic reasons. Other parts, such as the final stages of the super heaters and repeaters operating at higher temperatures where increased creep strength and resistance to oxidation are required, are constructed with austenitic stainless steels. Therefore, transition welds are needed between the two classes of materials [1-3].

There have been several studies on the welding of carbon steels and stainless steels because the failure in bimetallic joints can occur before the components reach their design life [4,8].

These investigations have shown that large thermal stresses arise in these joints during temperature fluctuations owing to the difference in thermal expansion coefficients [1-5].

The highest risk zone in the joints is the interfacial region between the weld metal and carbon steel and all of the austenitic-ferritic dissimilar alloy weld failures that have occurred in service [6-9] or in laboratory test programs [10-11] have been in the ferritic alloy close to the weld. Thermal cycling in power plant operation during the numerous start-ups and shut-downs thus plays a major role in premature service failure of these joints [12-13]. These cyclic stresses superimposed on the residual welding stresses, external loads and internal steam pressures cause the ultimate service failure of the dissimilar joint [13, 19, 20]. The service life of the joint can be improved by reducing the magnitude of cyclic thermal stresses through a gradual change in thermal expansion coefficients of the joint components. One approach in this direction is to use a filler material having a coefficient of thermal expansion (CTE) intermediate between those of the carbon steel and the stainless steels [9]
At high temperature carbon migration takes place from higher concentration to lower concentration. This carbon migration is also responsible for bimetallic weld join failure [16, 17]. To avoid carbon migration buttering layer is to be deposit on carbon steel [4].
This paper discusses the effect of buttering layer on carbon steel on mechanical properties of bimetallic weld joint.

2. EXPERIMENTAL DETAILS

2.1 Base Materials

Bimetallic weld joints between austenitic stainless steels and carbon steels are being extensively utilized in many high-temperature applications in energy conversion systems. In steam generating power stations, the parts of boilers that are subjected to lower temperatures as in the primary boiler tubes and heat exchangers are made of carbon steels for economic reasons. Other parts, such as the final stages of the super heaters and reheaters operating at higher temperatures where increased creep strength and resistance to oxidation

are required, are constructed with austenitic stainless steels[4].
The materials used are carbon steel SA 516 grade 65 that is used in reactor pressure vessel[1,2,18] and stainless steel type 304 L that is used in primary boiler tubes[4,7,8]. These steels were received in the form of rectangular block.

2.2 Buttering and Filler Materials

Buttering was done on SA 516 grade 65 by depositing SS 309L. SS 309L is a highly alloyed austenitic stainless steel used for its excellent oxidation resistance, high temperature strength and creep resistance. The lower nickel content of SS 309L improves resistance to sulphur attach at high temperatures. It is tough and ductile and can be readily fabricated and machined[1,4].

Filler material was used SS 308 L. Weld filler SS 308L has the same composition as type SS 308 except the carbon content has been held to a maximum of 0.30% to reduce the possibility of inter granular carbide precipitation. SS 308L is ideal for welding types 304, 321 and 347 stainless steels. This is a suitable wire for application at cryogenic temperatures[4,14,15].

2.3 Chemical Composition

Chemical composition of carbon steel SA 516 grade 65 and stainless steels are given in table 1 and 2 respectively.

Table 1:- Chemical composition of SA 516 grade 65 steel [1,2]

Type of Carbon steel	C	Mn	P	S	Si
SA 516 steel Grade 65	0.24	0.85–1.20	0.025	0.025	0.15–0.40

Table 2:- Chemical composition of Stainless steel [5]

Type of Stainless steel	C	Mn	Si	Cr	Ni	P	S
304L (base material)	0.03	2.0	1.0	18.0-20.0	8.0-12.0	0.045	0.03
308L (filler material)	0.03	2.0	1.0	19.0-21.0	10.0-12.0	0.045	0.03
309 L (buttering material)	0.03	2.0	1.0	22.0-24.0	12.0- 15.0	0.045	0.03

2.4 Mechanical and Physical Properties

Mechanical and physical properties of carbon steel SA 516 grade 65 and stainless steels are given in table 3

Table 3:- Mechanical and physical properties of SS and carbon steel SA 516 gr. 65 [1,2,5]

Type of steel	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)	Thermal coeff. (10^{-6} m/m°C)	Density (Mg/m^3)
SA 516 gr.65	450–585	240	200	11.7	7.8
304L	480	170	193-200	17.2-18.4	7.8-8.0
308L	618	448-460	190-210	17.2-18.4	7.7-8.03
309L	644	489	190-210	15.0-17.2	7.7-8.03

2.5 Shielding Gas

The shielding gas used was commercially available argon (99.97 pure) gas flow rate of 10 liter per minute was chosen after taking trails on a test plate. This particular value was chosen since good weld characteristic were obtained at this gas flow rate[5].

2.6 Wire Feed System

The filler wire was fed in the weld pool using a push type wire fed system. This system consists of two drive rollers, which can be adjusted according to the wire electrode diameter in order to provide a smooth feed. The fed rate 40 cm/mint was used for both welding and buttering.

2.7 Groove Preparation

Both 304 L and SA 516 grade 65 steel plates of 32 mm thickness as available in departmental store were shaped into 20 mm thickness by using shaper machine and cut into 200 x 150 x 20 mm^3 each plate. A single v groove of an angle 45^0 was made between these two plates[4,7]. A base plate of mild steel was welded to hold both SS and SA 516 grade 65 in proper relation so after welding the effect of distortion will be minimized. The SA 516 grade 65 plate was fully machined then after applying buttering layer of 4-5 mm; it is again machined to obtain the required geometr[4].

2.8 Sample Preparation

A 20 mm thick plate of SS 304 was welded to a 20 mm thick plate of SA 516 by using GTAW process. The plate was shaped to a thickness of 6.5 mm. The specimen's blanks 150 mm x 12.5 mm x 6.5 mm were cut from the welded plate; the weld was in the center of the blank. Total 4 numbers of blanks were obtained from the welded plate. These samples subjected to a Post weld heat treatment for reducing residual stress. After that these the samples are prepared for tensile test, charpy test and hardness test to find out these properties. For tensile test the flat tensile specimen are made and for microstructure and hardness samples are cut from the center contained base metal of both material i.e. carbon steel SA 516 grade 65 and SS 304L and weld metal at the centre.

3. RESULTS AND DISCUSSION

3.1 Hardness Survey

We use ASTM E92 – macro Vickers hardness test at a load of 5 Kg. The hardness distributions across the carbon steel base metal, weld metal and SS base metal.

The Vickers hardness of bimetallic weld samples with buttering and without buttering shown in the following tables. In first sample were no buttering was used there is a hardness drop near the SA 516 gr. 65 and weld interface because of carbon migration. In carbon migration the carbon migrates from high concentration of carbon to low concentration of carbon because the concentration of carbon is high as compare to SS 304 L so the carbon migration takes place from SA 516 gr. 65 to SS 304 L. This carbon migration can be prevented by applying a layer of 5 to 6 mm thickness of buttering on SA 516 gr. 65.

3.2 Tensile Test Survey

The tensile test conducted as per ASTM E-8 std. on bimetallic weld samples. The initial and final dimensions of these samples are given in following table no. 4 and mechanical properties are given in table no5.

Table 4:- Tensile test results

Type	l^i	w^i	t^i	l^f	w^f	t^f	A^i	A^f	% RA	% El
Without buttering	50	12.5	6.5	56	11	5.5	81.25	60.5	25.50	12
With buttering	50	12.5	6.5	60	8.5	4	81.25	34.0	58.15	20

Where:
l^i = initial gauge length in mm, w^i = initial width in mm, t^i = initial thickness in mm, l^f = final gauge length in mm, w^f = final width in mm, t^f = final thickness in mm, % RA = percentage reduction in cross-section area in mm^2, %EL = percentage change in length

Table 5:- Mechanical Properties

Type	Yield strength (MPa)	Ultimate tensile strength (MPa)	VHN (weld metal)	% EL	% RA
Without buttering	222	497.23	310	12	25.50
With buttering	288	504.61	288	20	58.15

3.3 Charpy Impact Test

The Charpy impact test conducted as on bimetallic weld samples. The results are shown in following table no.6

Table 6:- Charpy impact test Result

Type	dimensions	Energy in jules
Without buttering	55x10x10	150
With buttering	55x10x10	200

4. CONCLUSIONS

The mechanical properties of bimetallic weld joint between SA 516 gr 65 and SS 304 L without buttering and with buttering are find out.

- The carbon migration takes place from SA 516 gr. 65 to weld metal when the bimetallic weld samples subjected to thermal loading at temperature 625°C.
- Due to carbon migration the soft zone forms near the interface of SA 516 gr. 65 and weld metal also the hard zone form near the interface of weld metal and SS 304 L. these soft zone is responsible for hardness drop near interface of SA 516 gr. 65 and these hard zone for hardness increase near the interface of weld metal and SS 394 L.
- To prevent carbon migration the temperature should not be high and also can be prevent by the increasing the thickness of buttering layer on carbon steel.

REFERENCES

[1]. John F. Harvey., "Pressure Vessel Design: Nuclear and Chemical Applications", D. Van Nostrand Company, Inc, Princetion, New Jersey, Affiliated East-West Press Pvt. Ltd, New Delhi, 1969.

[2]. Dennis R. Moss, "Pressure Vessel Design Manual", Gulf Professional Publishing, Elsevier 3rd Edition, ISBN: 0-7506-7740-6, 2004.
[3]. Manoj Saini, Chandan Pandey, Navneet Arora, "Thermal Cycling of Bimetallic Weld Joints between SA 516 Grade 65 Carbon Steel and SS304 L for Steam Generator Application", MIT International Journal of Mechanical Engineering, Vol. 4, No. 1, January 2014, pp. 37–40 ISSN 2230-7680 © MIT Publications
[4]. R. Chhibber, N. Arora, S. R. Gupta, and B. K. Dutta, "Use of bimetallic welds in nuclear reactors: associated problems and structural integrity assessment issues", Proc. IMechE Vol. 220 Part C: J. Mechanical Engineering Science, DOI: 10.1243/09544062 JMES13E 2006.
[5]. "Metals and their Weldabi1ity" American Welding Society Welding Handbook Seventh Edition, vol. 4, International Standard Book Number: 0-87171-218-0, 1982.
[6]. A. M. Clayton, "Thermal shock in nuclear reactors", Progress in Nuclear Energy, Vol. 12 No. 1, pp. 57 83, 1983
[7]. M. Sireesha, Shaju K. Albert, S. Sundaresan, " Thermal Cycling of Transition Joints Between Modified 9cr-1mo steel and alloy 800 for steam Generator application", International journal of pressure vessels and piping 79,2002, 819-827.
[8]. R. L. Klueh and J.F. King, "Austenitic Stainless steel-Ferritic steel weld joint failures", Welding research supplement September 1982, 302s-310s.
[9]. J. W. Elmer, D. L. Olson and D. K. Matlock, "The thermal expansion characteristics of stainless steel weld metal", Welding research supplement September 1982, 293s-301s.
[10]. C. Sudha, V. Thomas Paul, L. E. Terrance, S. Saroja, and M. Vijayalakshmi, "Microstructure and microchemistry of hard zone in dissimilar weldments of Cr-Mo steels" Supplement to the welding journal, April 2006, 71s-80s.
[11]. A. K. Bhaduri, S. Venkadesan, P. Rodriguez, "Transition metal Joints For steam generators", Int. J. Pres. Ves. & Piping 58, 19942, 51-265
[12]. Z. Abdulaliyev, S. Ataoglu, and D. Guney, "Thermal Stresses in Butt-Jointed Thick Plates from Different Materials", Welding Journal, July 2007, vol. 86, 201s-204s
[13]. A. Joseph, Sanjai K. Rai, T. Jayakumar, N. Murugan, "Evaluation of residual stresses in dissimilar weld joints". International Journal of Pressure Vessels and Piping 82, 2005, 700–705.
[14]. J. N. Dupont and C. S. Kusko, "Technical Note: Martensite Formation in Austenitic/Ferritic Dissimilar Alloy Welds", Welding Journal, February 2007, 51s-54s.
[15]. J.A. Self, D.K. Matlock and D.L. Olson, "An Evaluation Of Austenitic Fe-Mn-Ni Weld Metal For Dissimilar Metal Welding", Welding Research Supplement September 1984, 282s-288s.
[16]. Mitchell, M. D., Offer, H. P. & King, P. J., "Carbon migration in transition joint welds." Report GEFR-00398, General Electric Co., USA, 1978.
[17]. Christoffel, R. J. & Curran, R. M., "Carbon migration in welded joints at elevated temperatures"., Weld J., 35, 1956, 457s-469s.
[18]. "Requirements for post weld heat treatment. Boiler and Pressure Vessels Code", Section I, Part PW-39, ASME, New York, 1989.
[19]. R. Foret, B. Zlamal, and J. Sopousek, "Structural Stability of Dissimilar Weld between Two Cr-Mo-V Steels", Welding Journal, October 2006, 211s-217s.
[20]. L. Béres, A. Balogh, W. Irmer, and C. S. Kirk., "Behavior of Welded Joints of Creep- Resistant Steels at Service Temperature", Welding Journal 331 –S.
[21]. A. M. Meyer and M. Du toit, "Interstitial Diffusion of Carbon and Nitrogen into Heat-Affected Zones of 11–12% Chromium Steel Welds", Welding Journal, December 2001.
[22]. D. J. Koteckia, "Martensite Boundary on the WRC-1992 Diagram", Welding Research Supplement MAY 1999, 181-S.
[23]. Klueh RL, King LF, Griffith JL, "A simple test for dissimilar metal welds", Welding J 1983¸62:154s–9s.