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Mechanical Characterization of SA-508Gr3 and SS-304L Steel Weldments

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Abstract : *In order to utilize the hybrid structure and reduce the cost and weight of the components, the use of dissimilar metals is increasing day by day in most of the industries. Such metals are widely used in defense, aviation, automobile industries and power transmission sector as combination of these metals gives excellent mechanical properties such as high resistance to corrosion, high strength to weight ratio etc. Dissimilar materials of carbon steel SA-508Gr3 and stainless steel type SS304 L are widely used in nuclear power plants, petrochemicals, where the weldment are usually subjected to hot corrosion. This work deals with the assessment of mechanical properties of these bimetallic joints obtained by gas tungsten arc welding using SS308L and SS309L filler material. Hardness and tensile test were conducted to measure the micro hardness and tensile properties. The maximum hardness 37.5 and 27.5 were found in the weld joint for buttering and without buttering respectively, whereas ultimate tensile strength was found 547.67 MPa for buttering.*

Keywords: *Bimetallic Welding, Hardness, Ultimate Tensile Strength SA-508Gr3, SS-304L*

1. INTRODUCTION

The welding of 11–12%chromium steels is subject to the traditional concern with ferritic grain growth in the heat-affected zone of ferritic stainless steels. The grain growth could be inhibited if austenite on the ferrite grain boundaries could be stabilized at high temperatures. This article discusses the possibility that diffusion from the weld metal can increase the carbon or nitrogen content of the heat-affected zone, and consequently stabilize grain boundary austenite [1]. 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 [2-3]. 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, 5]. These investigations have shown that large thermal stresses arise in these joints during temperature fluctuations owing to the difference in thermal expansion coefficients [6]. Dissimilar metal welds composed of low alloy steel, Inconel 82/182weld, and stainless steel were prepared by gas tungsten arc welding and shielded metal arc welding techniques. Microstructures were observed using optical and electron microscopes. Typical dendrite structures were observed in Inconel 82/182 welds. Tensile tests using standard and mini-sized specimens and micro-hardness tests were conducted to measure the variation in strength along the thickness of the weld as well as across the weld. In addition, fracture toughness specimens were taken at the bottom, middle, and top of the welds and tested to evaluate the spatial variation along the thickness. It was found that while the strength is about 50–70MPa greater at the bottom of the weld than at the top of the weld, fracture toughness values at the top of the weld are about 70% greater than those at the bottom of the weld [7]. Residual stresses present in the weld joint are one of the main factors, which cause failures in dissimilar weld joints. A typical dissimilar pipe weld joint, representing a joint used in an Indian Fast Breeder Test Reactor (FBTR) was fabricated between 2.25Cr–1Mo ferritic steel and AISI type316 stainless steel with and without Inconel-82 buttering on the ferritic steel side. Residual stress profiles across these weld joints were determined using the X-ray diffraction (XRD) technique. The Inconel-82 buttering layer employed in the dissimilar weld joint is useful in reducing the residual stresses in the HAZ of the ferritic steel and thus the buttering will be beneficial to avoid/minimize residual stress related failures of dissimilar weld joints [8]. The study of structural changes in laboratory welds of 6Cr-Mo-V 8-3-2 (T25) and X12Cr-Mo-V-Nb 10-1 (P91) steels annealed at temperatures from 600° to 900°C(1112°to 1652°F). Carbon redistribution measurements by the EPMA method were complemented with detailed structural analyses aimed at the phase and chemical compositions of coexisting carbides and carbon nitrides. The results of experimental work were compared with thermodynamic and kinetic calculations using the Thermo-Calc and DICTRA software. A very good agreement between the calculations and the experiments was obtained, in particular for the phase composition of individual areas of the weld joints [9]. Power station pipelines and other structural fabrications operating at high temperature are predominantly made of creep-resistant steels. These steels may become martensitic even if the cooling medium was air due to their relatively high Cr, Mo, and V content, which can retard the Bai nitic transformations. These steels must, therefore, be preheated, and filler materials must be carefully selected. In heterogeneous joints, substantial diffusion takes place during high-temperature service conditions. This paper describes the layered formation in the heterogeneous welded joint and reports on the investigation of the consequences of such diffusion. The principal goal of this investigation was to reduce the probability of cracking during service [10]. 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 [11-13] or in laboratory test programs [14- 15] have been in the ferritic alloy close to the weld. The carbon migration takes place from SA 516 gr. 65 to weld metal when the bimetallic weld samples subjected to thermal loading at temperature 625^0C. The ultimate tensile strength and hardness of samples increases by increasing the pre-stress [16, 17].Thermal cycling in power plant operation during the numerous startups and shut-downs thus plays a major role in premature service failure of these joints [18-19]. These cyclic stresses superimposed on the residual welding stresses, external loads and internal steam pressures cause the ultimate service failure of the dissimilar joint [22, 23]. At high temperature carbon migration takes place from higher concentration to lower concentration. This carbon migration is also responsible for bimetallic weld join failure [24].

2. EXPERIMENTAL PROCEDURE

2.1 Base Materials

Carbon steel SA-508Gr3 and stainless steel SS304L are used in pressure vessel and primary boiler tubes respectively.

2.2 Buttering and Filler Materials

Buttering was done on SA 508 Gr3 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.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 intergranular 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.

2.3 Chemical Composition

Chemical composition of carbon steel SA 508 Gr3 and stainless steels are given in table 1and 2 respectively.

Table 1. Chemical composition of SA-508Gr3 Steel

Steel	C	Mn	P	S	Si
SA-508Gr3	0.19	1.2-1.5	0.006	0.002	0.07-0.1

Table 2. Chemical composition of Stainless steel [6]

Stainless Steel	C	Mn	Si	Cr	Ni	P	S
304L (Base Material)	.03	2	1	18-20	8-12	.045	.03
308L(Filler Material)	.03	2	1	19-21	10-12	.045	.03
309L (Buttering)	.03	2	1	22-24	12-15	.045	.03

2.4 Mechanical and Physical Properties

Mechanical and physical properties of carbon steel SA 508 Gr3 and stainless steels are given in table 3.

Table 3. Mechanical and physical properties of SS and carbon steel SA 508 Gr3 [6]

Types of Steel	*Tensile Strength (MPa)*	*Yield Strength (MPa)*	*Elastic Constant (GPa)*	*Thermal Coefficient $10^{-6}m/m^0C$*	*Density Kg/m^3*
SA-508Gr3	450	240	200	11.7	7.8
304L	480	210	193	17.2-18.4	7.8-8.0
308L	618	450	190	17.2-18.4	7.7-8.0
309L	644	489	190	15-17.2	7.7-8.0

2.5 Designing of Test Specimen

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 4

Table 4:- Tensile Test Dimension

Material	L_i	w^i	t^i	L^f	w^f	t^f	A^i	A^f	%RA	%EL
Without Buttering	115	19.8	10.3	120	19	10	203.94	*190*	*6.83*	*4.34*
With Buttering	115	19.5	10.3	122	18.6	9.8	200.85	*182.28*	*9.24*	*6.08*

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

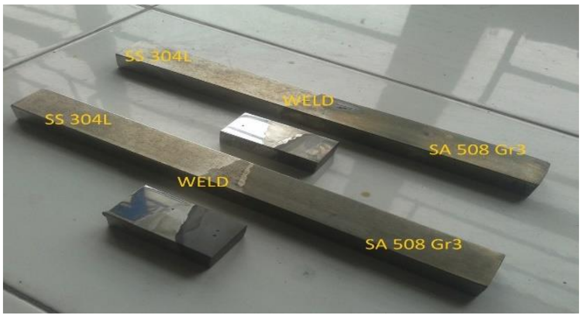


Figure 1:- Unfinished tensile test specimen

2.6 Welding Procedure

2.6.1 Gas tungsten arc welding

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas (usually an inert gas such as argon), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma.

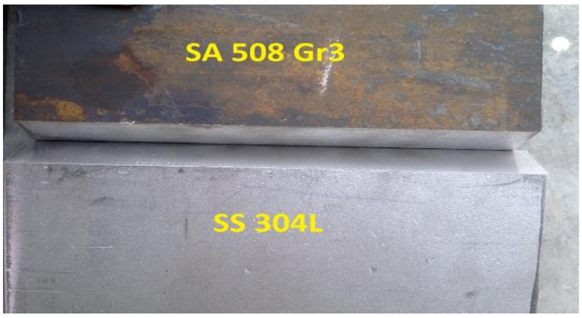
2.6.2 Processing parameter

Table 5: Processing Parameters

Types	*Current*	*Voltage*	*Wire feed (cm/min)*	*Gas Flow rate(Lit/min)*
Buttering	190-200	12-15	40	10
Without Buttering	230-270	12-15	40	10

2.7 Sample Preparation

A 25 mm thick plate of SS 304 was welded to a 25 mm thick plate of SA 508 Gr3 by using GTAW process. The plate was shaped to a thickness of 10 mm. The specimen's blanks 150 mm x 20 mm x 10 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. The samples before Post weld heat treatment and after Post weld heat treatment are shown in below figures 2-3.

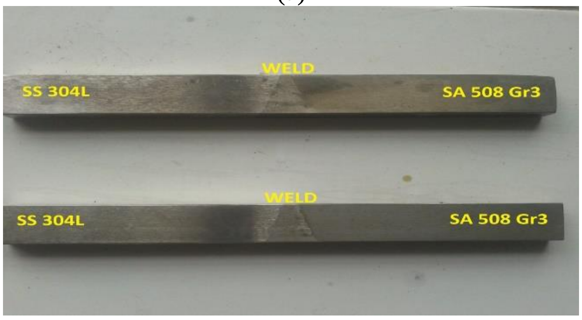


(a)

(b)

Figure 2: (a) plate before welding (200 x 100 x 25 mm), (b) Welded plate (200 x 100 x 25 mm)

(a)



(b)

Figure 3: bimetallic weld samples (150x20x10 mm^3) (a) with buttering, (b) without buttering

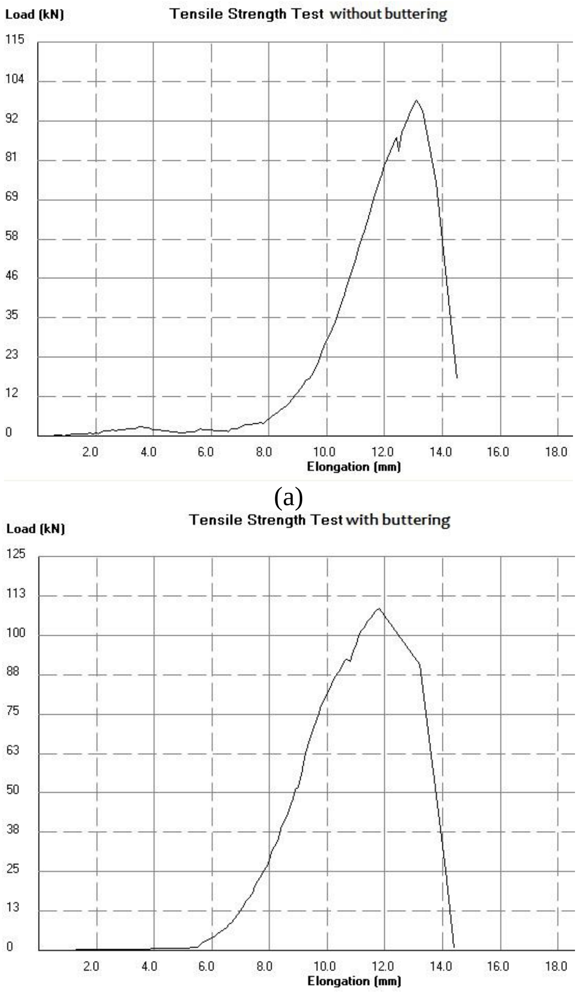
After that these samples are prepared for hardness and tensile test to find out these properties. For hardness test, samples are cut from the center contained base metal of both material i.e. carbon steel SA-508Gr3 and SS 304L.

3. RESULTS AND DISCUSSIONS

3.1 Tensile Test

Table 6:- Mechanical Properties of weld metal

Weld Types	*Yield Strength (Mpa)*	*Tensile Strength (MPa)*	*HRC (Weld Metal)*	*%EL*	*%RA*
Without Buttering	424.4	470.73	37.5	4.34	6.83
With Buttering	458.05	547.67	27.5	6.08	9.24



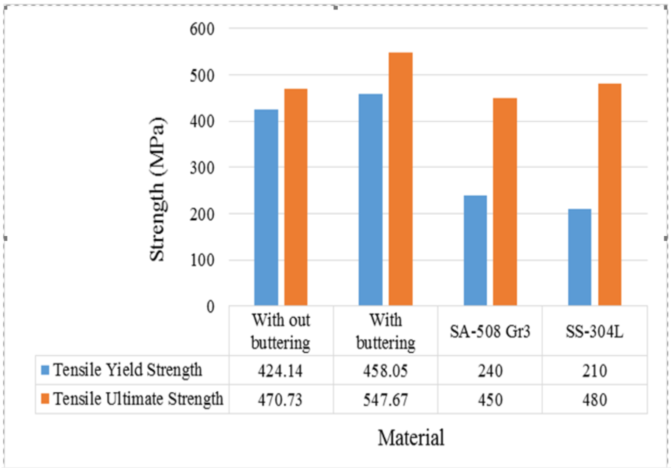
(a)

(b)

Figure 4: Load displacement diagram (a) without buttering, (b) with buttering

A tensile test was performed on the carbon steel SA-508Gr3 and stainless steel type SS304 bimetallic sheet. Tensile test specimens were fabricated according to the dimensions shown in table 4. The load-displacement curves were obtained from the tensile test. Figure 4 summarizes the variation patterns of the tensile force and the elongation percentage of the bimetallic sheet in the direction sheet thickness.

The tensile strength of the weldment with buttering and without buttering were found to be 547.67 MPa and 470.73 MPa respectively, whereas the corresponding value for parent material SA-508Gr3 and SS 304L were 450 MPa and 480 MPa. It was noticed that the tensile strength of buttering weldment has the greater value as compared to that of



material as well as without buttering weldment.

Figure 5: Comparision of tensile strength of weldment (buttering and without buttering) and parent materials

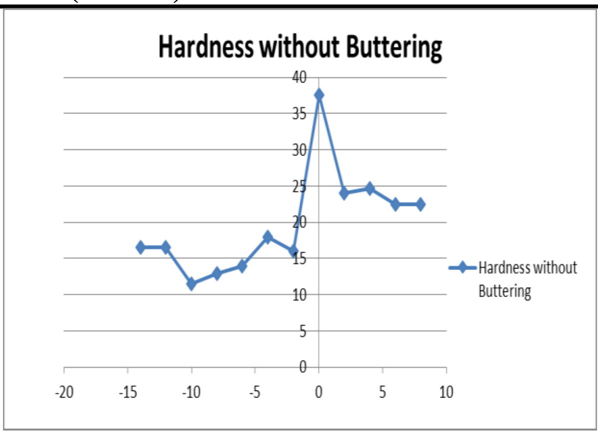
3.2 Hardness Survey

We use ASTM E18 – Standard methods for Rockwell hardness of metallic materials. The hardness distributions across the carbon steel base metal, weld metal and SS base metal are shown in table 7.

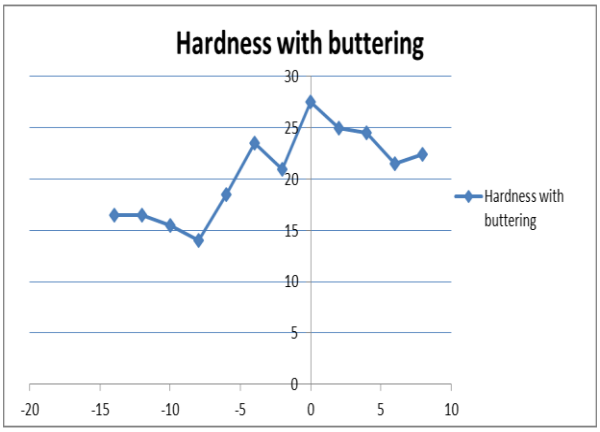
Table 7: Rockwell hardness result

Position (mm)	Hardness without Buttering	Hardness with Buttering
-14(SA 508 Gr3)	16.5	16.5
-12	16.5	16.5
-10	11.5	15.5
-8	12.9	14
-6(HAZ)	14	18.5
-4 (HAZ)	18	23.5
-2(Interface)	16	21
0 (weld)	37.5	24.5
2 (Interface)	24	25

4	24.7	24.5
6	22.5	21.5
8(SS-304L)	22.5	22.4



(a)



(b)

Figure 6: (a) Hardness without buttering, (b) Hardness with buttering

The micro hardness profile of the joint across the weld region is an important factor which decides the mechanical properties of the joints. The hardness survey was conducted across the SA-508Gr3 to SS-304L joints interface covering base material and abutting weld material affected by friction heat as demonstrated in figure 6. The micro hardness of bimetallic weld samples with buttering and without buttering as shown in the tables 7. In first sample when no buttering was used, hardness was maximum at the center and various fluctuations in the hardness were observed as shown in figure 6. Carbon migrations were the main cause of the fluctuations. In carbon migration, the carbon migrates from high carbon concentration to low carbon concentration, because the concentration of carbon is high as compared to SS 304 L so the carbon migration takes place from SA 508 Gr3 to SS 304 L. This carbon migration can be prevented by applying a thick layer of buttering (5 to 6 mm) on SA 508 Gr3. The maximum hardness of 37.5 and 27.5 were observed in the weld joint for buttering and without buttering respectively.

4. CONCLUSIONS

In this work, dissimilar materials i.e. carbon steel SA 508 Gr3 and stainless steel type SS304 L was used. Buttering was carried out for improving the properties with the help of filler material of stainless steel (Grade-SS309L and Grade-SS308L).

- ➢ The carbon migration takes place from SA 508 Gr3 to weld metal at 625^{0}C.
- ➢ Due to carbon migration the soft zone formed near the interface of SA 508 Gr3 and weld metal and hard zone formed near the interface of weld metal and SS 304 L.
- ➢ The soft zone results in hardness drop near interface of SA 508 Gr3 while hard zone increases the hardness near the interface of weld metal and SS 304 L.
- ➢ Carbon migration can be prevented by the increasing the thickness of buttering layer on carbon steel.
- ➢ The maximum hardness of 37.5 and 27.5 were observed in the weld joint for buttering and without buttering respectively.

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