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Assessing mechanical properties of the dissimilar metal welding between P92 steels and alloy 617 at high temperature †

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Abstract

In this study, a new welding technology of dissimilar materials, Cr-based P92 steels and Ni-based Alloy 617 is introduced and demonstrated to investigate its reliability. Firstly, multi-pass dissimilar metal welding between P92 steel and Alloy 617 was performed using DCEN TIG welding technology, buttering welding technique and a narrow gap groove. After welding, in order to understand characteristics of the dissimilar metal welds, metallurgical micro-structures analysis by optical observation and static tensile strength assessment of the dissimilar welded joints were conducted at 700°C.

Keywords: Dissimilar metal welding; Buttering welding; Narrow gap; P92 steels; Alloy 617; The hardness; Micro-structure; High temperature strength

1. Introduction

The most currently global issue for mitigating environmental pollution is to increase the generative efficiency of thermal power plants. The core technology for increasing the efficiency is to improve the performance of steam turbines. In order to improve the performance of steam turbines, the power plant requires high temperature steam, and thus it is important to develop the material, which can tolerate high temperature and has both durability and reliability under extreme environment [1, 2].

Among the materials developed so far, Ni-based super alloys and P92 steels have been considered as candidate materials for thermal power plants [3]. However, welding between different metals is more vulnerable than the similar welding. Hence, in order to apply these Ni-based alloys and P92 steels to the rotor of a steam turbine, it is necessary to develop the welding technology considering properties of materials [4, 5]. Previous studies on Alloy 617 and P92 steels mainly were limited to the mechanical properties of similar welding procedure [6, 7]. And each study on Alloy 617 and P92 steels focused on the dissimilar metal welding other materials without buttering welding procedure [8]. In this study, dissimilar metal welding between P92 steel and Alloy 617, which are heat-resistant materials, was performed and investigated by using buttering welding technology. Static tensile strength, fatigue strength at R.T and elevated temperature, hardness distribution, and metallurgical microstructures of the dissimilar metal welds were assessed.

2. Dissimilar metal welding between P92 steel and Alloy 617

2.1 Welding procedure

Tables 1 and 2 indicate the chemical composition of P92 and Alloy 617. DCEN TIG welding technology is basically a combination of buttering welding and multi-pass welding using Thyssen 617, served as the filler metal. The welding specimen was designed in U-shape groove for narrow-gap. Before a dissimilar metal welding process of P92 steel and Alloy 617, the buttering welding was previously performed on P92 steel side with Thyssen 617 filler-metal. The cycle of buttering welding and dissimilar metal welding was repeated seven times. The welding conditions of dissimilar metal welding are given in Table 3. As above, the optimum welding condition was determined by repetitively performing preliminary welding with a variety of welding conditions as well as shield gas composition and flow by using a welding process and real time monitoring technique [9].

In order to prevent thermal distortion which is formidably caused by welding heat during the welding process, both ends

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Table 1. Chemical composition of P92 steels (wt. %).

Ni	Cr	Co	Mo	Al	C	W
0.18	9.11	12.5	0.47	0.001	0.10	1.710
Mn	Si	S	Nb	B	Fe	
0.48	0.22	0.006	0.056	0.004	Bal.	

Table 2. Chemical composition of Alloy 617 (wt. %).

Ni	Cr	Co	Mo	Al	C	Ti
44.5	22.0	12.5	9.0	1.2	0.07	0.3
Mn	Si	S	Cu	Fe		
0.5	0.5	0.008	0.2	1.5		

Table 3. Conditions of dissimilar metal welding.

Pass	Shield gas	Current (A)	Voltage (V)	Welding speed (cpm)	Freq. (Hz)	Weaving width (mm)
Buttering	Mixed gas ($Ar+2.5\%H_2$) 1.5L/min	150	10	10	0.5	3
1		150	10	10	0.5	3
2		150	13	10	0.5	3
3		150	16	10	0.5	3
4		150	16	10	0.5	3
5		150	16	10	0.5	4
6		150	16	10	0.5	5
7		150	16	10	0.5	5

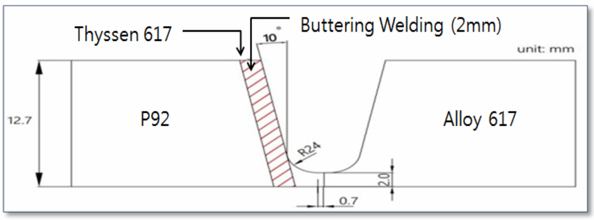


Fig. 1. Schematic diagram of buttering and dissimilar metal welding.

of base metal were fixed with welding jigs. Fig. 1 shows the schematic diagram of dissimilar metal welding procedure between P92 steel and Alloy 617.

3. Strength assessment of dissimilar metal welds between P92 steels and Alloy 617

3.1 Specimen

Specimens to assess tensile and fatigue strength of dissimilar metal welds between P92 and Alloy 617 were fabricated in accordance with recommended ASTM standard E8M [10]. Weld metal, HAZ and both base metal of P92 steel and Alloy 617 are included within the range of the gage length of the specimens as shown in Fig. 2, Fig. 3 shows the actual specimen.

3.2 Test procedure

Tensile strength of the dissimilar metal welds was assessed

Table 4. Conditions of fatigue test.

	R.T		
	P_{max} (MPa)	Load ratio	Freq. (Hz)
Loading condition	$0.9\sigma_u = 660$	R = 0.1	10
	$0.8\sigma_u = 588$		
	$0.7\sigma_u = 515$		
	$0.6\sigma_u = 441$		
	$0.5\sigma_u = 368$		

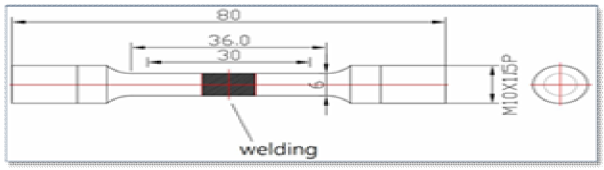


Fig. 2. Configuration of test specimen.

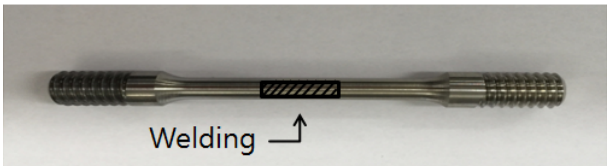


Fig. 3. Actual test specimen.

using INSTRON 8801 tester at room temperature (R.T) and temperatures of 300°C, 500°C and 700°C.

In the tensile test, loading process was controlled by displacement of 1 mm/min. In order to evaluate tensile strength at increased temperatures, the testing temperature was controlled by high-frequency induction heater and infrared thermal sensor. After tensile test, fracture surfaces of failed specimens depending on different temperatures were investigated by SEM observation.

The fatigue test was conducted by using the load decreasing method, the test load by 10% on the basis of the static tensile strength as indicated in Table 4. The frequency of fatigue loading was 10 Hz in sine wave, load ratio was 0.1 and the fatigue limit was 10^6 cycles.

Micro-hardness measurements were performed across the dissimilar metal welds to secure each hardness distribution in the weld including the base metal, HAZ and the weld metal. A hydraulic micro Vickers hardness tester was used for the hardness test. Hardness distribution at weld was measured at 200 g press-fit load. The cross section of dissimilar metal welds was divided into top, middle and bottom to compare hardness distribution.

For micro-structure observation on the failed surface, specimen was fabricated from the cross section of the tensile test specimens. The specimens were polished using SiC papers, and finished with 5 μm and 1 μm paste diamonds. After polishing, in case of P92, base metal and HAZ parts were etched with 5 mL of HCl + 1 g of picric acid + 100 mL of ethyl alcohol. And in case of Alloy 617, base metal, HAZ and weld

Table 5. Tensile strengths of the dissimilar metal welds.

	Alloy 617	P92	Alloy 617 +P92
Yield strength (MPa)	443	573	487
Tensile strength (MPa)	675	773	736

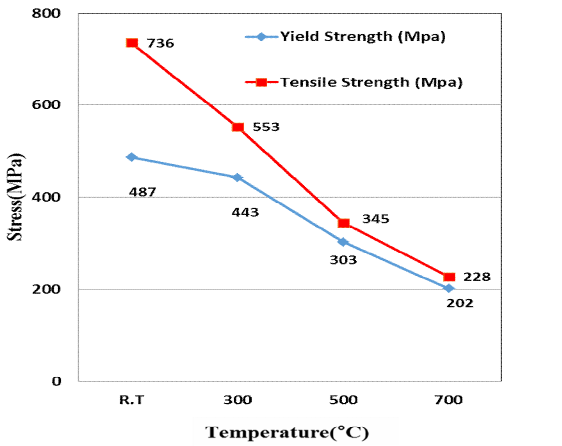


Fig. 4. Results of tensile test at elevated temperature.

metal parts were etched with 10 mL HNO_3 + 20 mL HCl + 30 mL distilled water [11]. The microstructures were investigated by using an optical microscope.

4. Results and discussion

4.1 Tensile strength and fatigue strength

The static tensile strengths of the dissimilar metal welds are shown in Table 5 which is including the properties of the two base materials. It can be seen that the dissimilar metal welds have enough strength in comparison to the strength of two base materials

Most of specimens at elevated temperatures were failed at HAZ of the P92 side. Showing this result is due to the fact that HAZ is the most vulnerable part by high welding residual stress and metallurgical change from the welding heat input. Both yield strength and tensile strength decreased while temperature increased as illustrated in Fig. 4. This is because the material softens at the elevated temperature, and thus failure type was shown in ductile.

Fig. 5 shows S-N curves to evaluate the fatigue strength of the dissimilar metal welds at room temperature. The fatigue limit was evaluated to be 368 MPa which is 50% of the tensile strength of the dissimilar metal welds.

Fig. 6 shows microstructures of the failed surface at the elevated temperature. According to temperature increase, as shown in Fig. 6, the size and number of dimple increase. As mentioned above, this behavior can be explained due to ductile failure at the high temperature.

4.2 Hardness distribution at the dissimilar metal welds

The micro-hardness distributions across the welds for P92

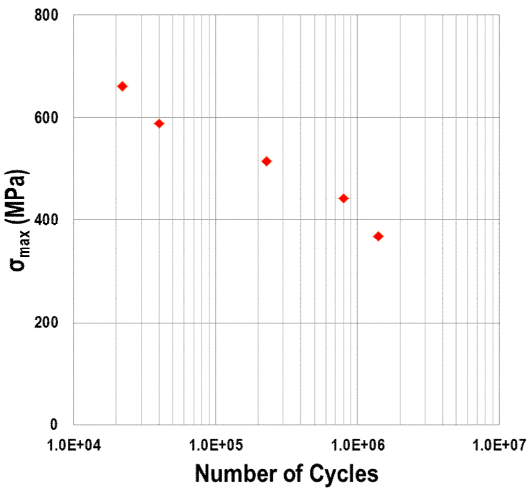


Fig. 5. S-N curve of dissimilar metal welds.

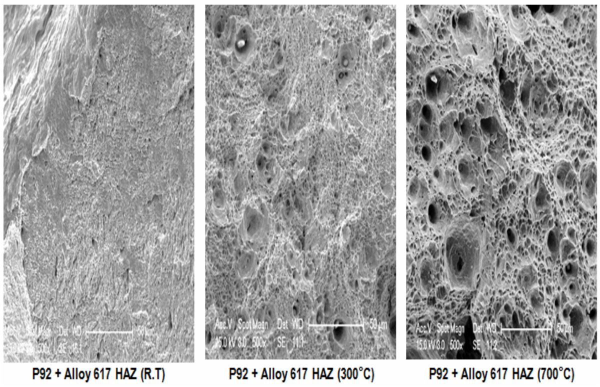


Fig. 6. Fracto-graphy on the fracture surface.

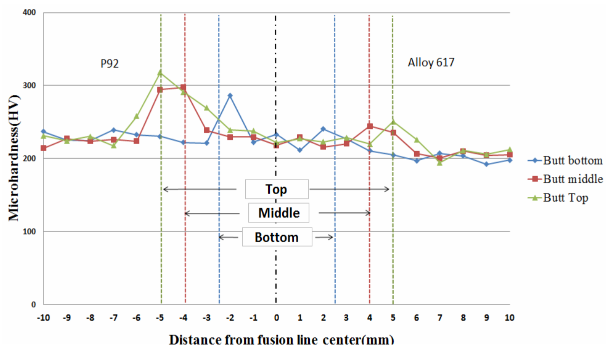


Fig. 7. The micro-hardness distribution at the dissimilar metal welds.

and Alloy 617 are shown in Fig. 7. After cross section of the weld was divided into top, middle and bottom, the micro-hardness was measured by 1 mm for three times. In Fig. 7, the plotted graphs are in the average range for each part. Both sides of HAZ of the weld showed high hardness distributions. Especially, the hardness distribution at the HAZ of the P92 is higher than that of Alloy 617. The reason why P92 shows the higher hardness distribution is because the micro-structure of P92 is martensite and Alloy 617 is austenite. And the micro-

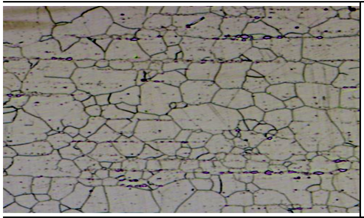
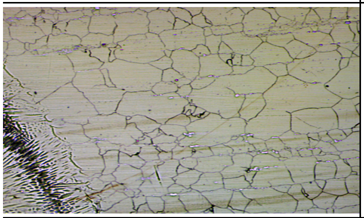
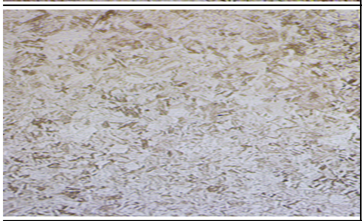
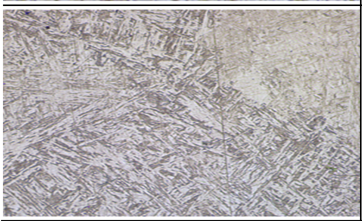
	Base metal (Alloy617)
	HAZ (Alloy 617)
	Weld metal
	HAZ (P92)
	Base metal (P92)

Fig. 8. Micro-structures of dissimilar metal welds.

hardness distributions of top are higher than those of bottom. Bauschinger effect is the explanation because the bottom experienced repetitive cycles of cooling and heating rather than the top.

4.3 Analysis of microstructure

Fig. 8 shows the micro-structures of the dissimilar metal welds, divided into base metal, HAZ and weld metal. The micro-structures of base metal and HAZ of Alloy 617 show typical austenite crystal. However, the micro-structures of HAZ are a little larger than those of base metal. And the micro-structure of weld metal shows dendrite crystal. The micro-structure of P92 base metal shows lath tempered martensite crystal. In HAZ of P92, the micro-structure shows tempered martensite crystal which was collapsed by welding heat input. It is assumed that changes of metallurgical microstructures by welding heat input caused hardness difference, that is, hardness distribution on the P92 side is higher than that on Alloy 617 side.

5. Conclusions

This study aims to demonstrate reliability of the dissimilar metal welds of P92 and Alloy 617 through assessing the mechanical characteristics and the micro-structures.

The results of experiments are summarized as:

(1) All tensile specimens were failed at the HAZ. Tensile strengths were evaluated by 736 MPa at R.T and 228 MPa at 700°C, and thus both yield strength and tensile strength decreased along with increase of the temperature. The fatigue limit was evaluated to be 368 Mpa which is 50% of the tensile strength.

(2) It is shown that the hardness distribution at HAZ of the weld is high. Especially, the hardness distribution at the HAZ on the P92 is higher than that of Alloy 617.

(3) The micro-structures of base metal and HAZ of Alloy 617 show typical austenite, and weld metal shows dendrite grain. The micro-structure of P92 base metal shows lath tempered martensite. In HAZ of P92, the micro-structure shows tempered martensite which was collapsed by welding heat input.

References

[1] J. S. Ahn, S. H. Lee, S. K. Cho, G. J. Lee, C. H. Lee and S. J. Moon, Study on the improvement of weld-joint reliability in water wall tubes of the ultra supercritical coal fired boiler, *The Korean Welding and Joining Society*, 28 (1) (2010) 41-46.

[2] B. Vitalis, Overview of oxy-combution technology for utility coal-fired boilers, *Advances in Materials Technology for Fossil Power Plants* (2008) 968-981.

[3] J. Cao, Y. Gong, K. Zhu, Z.-G. Yang, X.-M. Luo and F.-M. Gu, Microstructure and mechanical properties of dissimilar materials joints between T92 martensitic and S304H austenitic steels, *Materials and Design,* 32 (2011) 2763-2770.

[4] J. A. Francis, H. K. D. H. Bhadeshia and P. J. Withers, Welding residual stresses in ferritic power plant steels, *Mater Sci. Technol.,* 23 (9) (2007) 1009-1020.

[5] W. L. Mankins, J. C. Hosier and T. H. Bassford, Microstructure and phase stability of inconel alloy 617, *Metallurgical and Material Transaction* (1974) 2579-2590.

[6] Y. S. Park and D. H. Bae, Assessment of fracture mechanical characteristics including welding residual stress at the weld of Ni-base Super Alloy 617, *19th European Conference on Fracture* (2012) 163-170.

[7] R. Kannan, V. Sankar, T. Sandhya and M. D. Mathew, Comparative evaluation of the low cycle fatigue behaviours of P91 and P92 steels*, Procedia Engineering,* 55 (2013) 149-153.

[8] K. G. Kumar, K. D. Ramkumar and N. Arivazhagan, Characterization of metallurgical and mechanical properties on the multi-pass welding of Inconel 625 and AISI 316L, *Journal of Mechanical Science and Technology*, 29 (3) (2015) 1039-1047.

[9] Y. S. Park, H. S. Ham, S. M. Cho and D. H. Bae, An assessment of the mechanical characteristics and optimum welding condition of Ni-based super alloy, *Procedia Engineering,* 10 (2011) 2645-2650.
[10] Standard test method for tension testing of metallic materials, *ASTM E8M* (2004).
[11] Standard Practice for Micro-etching Metals and Alloys, *ASTM E407* (2004).

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