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PROPERTY OF 9CR-3W-3CO-ND-B HEAT-RESISTANT STEEL SAVE12AD WELDED JOINT

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ABSTRACT

Developed 9Cr-3W-3Co-Nd-B heat-resistant steel SAVE12AD (Recently designated as ASME Grade 93) pipes and tubes have higher creep strength in both base metal and welded joints than conventional high Cr ferritic steels such as ASME Grades 91, 92 and 122. The welded joints of SAVE12AD tubes with commercial filler wire for W62-10CMWV-Co (Gr. 92) or Ni base filler wire ERNiCr-3 (Alloy82) also have much better creep rupture strength than those of conventional steels because of suppression of refining in the Heat-Affected-Zone (HAZ).

However, the creep rupture strength of weld metal of W62-10CMWV-Co was marginal. Additionally, the hot cracking susceptibility of weld metal using Ni base filler wire ERNiCr-3 was occasionally below the required level. Similar welding consumable for SAVE12AD has been developed to solve these problems. Optimization of nickel, neodymium and boron contents on similar welding consumable enables to obtain both the good long-term creep rupture strength and low enough hot cracking susceptibility of weld metal. Consequently, SAVE12AD welded joint is expected to be applied of piping and tubing above 600°C in USC power plants because of its good properties with similar welding consumable.

INTRODUCTION

High Cr ferritic steels such as ASME Grades 91, 92 and 122 have been used in ultra supercritical (USC) boilers for fossil power plants with a steam temperature up to about 600°C. As the degradation of long-term creep strength was found in these steels, the allowable tensile stresses were reevaluated and reviewed [1]. The degradation of creep rupture strength was considered mainly due to the inhomogeneous deformation around prior austenitic grain boundaries [2], the static recovery of lath structures [3], and the disappearance of MX precipitates with Z-phase precipitates [4]. Moreover, the Type IV fracture in the welded joints for high Cr ferritic steels is considered a significant issue [5].

9Cr-3W-3Co-Nd-B heat-resistant steel SAVE12AD has been developed as new high Cr ferritic steel that has improved creep rupture strength both in base metal and welded joints at elevated temperatures up to 600°C. Table 1 shows the alloy design of developed SAVE12AD base metal [6]. The welded joints of SAVE12AD tubes with commercial filler wire for W62-10CMWV-Co (Gr. 92) or Ni base filler wire ERNiCr-3 (Alloy82) also have much better creep rupture strength than those of conventional steels because of suppression of refining in the Heat-Affected-Zone (HAZ). However, the creep rupture strength with weld metal of W62-10CMWV-Co was marginal and the hot cracking susceptibility of weld metal with Ni base filler wire ERNiCr-3 was occasionally below the required level. Therefore, similar welding consumable for SAVE12AD which has good creep rupture strength and low enough hot cracking susceptibility is required.

In this paper, the properties of SAVE12AD welded joint with similar welding consumable are investigated.

Table 1 Alloy design of developed SAVE12AD base metal

Element	Target	Improvement
9Cr	・Long-term creep strength ・Solution strengthening	Creep strength of base metal
3W	・Laves phase precipitation strengtening	
0.01B	・Suppression of coarsening of $M_{23}C_6$ on grain boundary	
0.01N	・Suppression of Z-phase and BN precipitation	
0.02Nd	・Supression of S segregation	Creep ductility
3Co	・Stability of martensite	Toughness

EXPERIMENTAL PROCEDURE

Normalized and tempered laboratory melted plates, the product pipes and tubes of SAVE12AD were prepared, while welded joint tubes with the filler wires of W62-10CMWV-Co (Gr. 92) and Ni base filler wire ERNiCr-3 (Alloy82) were prepared. Table 2 shows the chemical composition of filler wires. In addition, a restraint weld cracking test was performed to evaluate solidification cracking susceptibility on 1st bead surface. Table 3 and Figure 1 show the welding conditions, illustration of test specimen and bevel configuration. Creep rupture tests were examined at 600°C and 650°C by using specimens taken from plates, pipes, tubes and welded joints.

Table 2 Chemical composition of filler wires (mass%)

Filler wire	C	Si	Mn	P	S	Co	Ni	Cr	Mo	W	V	Nb	Ti	N
W62-10CMWV-Co	0.07	0.31	0.78	0.003	0.003	0.98	0.47	10.04	0.34	1.46	0.21	0.036	-	0.04
ERNiCr-3	0.03	0.19	2.99	0.003	0.002	-	75	18.4	-	-	-	2.7	0.39	-

Table 3 Welding conditions

Welding process	Automatic GTAW
Filler wire	1.2mmφ spool
Pass	1-8
Curent (A)	100-130
Voltage (V)	13-14
Traveling speed (mm/s)	1.67
Heat input (kJ/mm)	0.8-1.1
Preheating	None
Interpass temp.	150°C max.
PWHT	740°C for 30min.

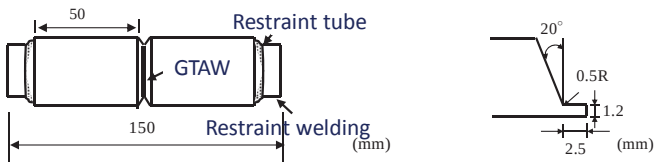

Figure 1 Illustration of restraint weld cracking test specimen and bevel configuration

Next, SM400 plate was welded with SAVE12AD candidate similar welding consumable. The candidate chemical composition of similar welding consumable is shown in table 4. Cobalt, nickel, boron and neodymium content is changed to investigate the effect on the creep rupture strength, hot cracking susceptibility and toughness. Table 5 and figure 2 shows welding condition and illustration of welding test specimen. The test specimen of creep rupture strength and sharpy impact test was cut from all deposit weld metal. The creep rupture strength was examined at 650°C. The sharpy impact test was conducted at 0 and 20°C using 10 mm x 10mm V notch test specimen.

Table 4 Chemical composition of candidate similar welding consumable (mass%)

Similar welding consumable	C	Si	Mn	Cr	Co	Ni	W	N	B	Nd
9Cr-3Co-3W-0.1Ni-0.01B-Nd	0.08	0.28	0.51	9.01	2.94	0.09	2.99	0.01	0.01	0.04
9Cr-3Co-3W-0.8Ni	0.08	0.28	0.50	9.13	3.00	0.82	3.06	0.01	-	-
9Cr-5Co-3W-0.8Ni	0.08	0.29	0.52	9.05	5.01	0.84	3.10	0.01	-	-
9Cr-3Co-3W-0.4Ni-0.01B	0.08	0.33	0.53	9.05	2.92	0.40	2.99	0.01	0.01	-
9Cr-3Co-3W-0.5Ni-0.01B	0.08	0.31	0.51	8.98	3.14	0.50	3.05	0.01	0.01	-
9Cr-3Co-3W-0.8Ni-0.01B	0.09	0.31	0.51	8.96	2.98	0.81	3.05	0.01	0.01	-

Table 5 Welding conditions

Welding process	Manual GTAW
Filler wire	2.4mmφ
Heat input (kJ/mm)	0.9-1.2
Preheating	None
Interpass temp.	150°C max.
PWHT	740°C for 30min.

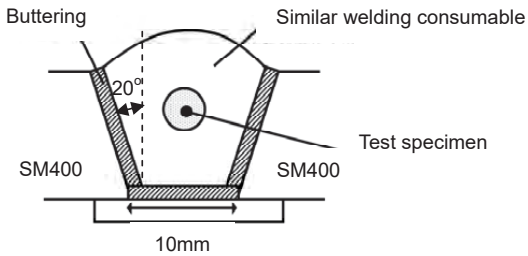

Figure 2 Illustration of welding test specimen

Finally, SAVE12AD welded joint was prepared with similar welding consumable. Table 6 shows welding conditions and bevel configuration was used as shown in figure 1. The tensile strength on the cross section was evaluated at room temperature, 600 and 650 ºC. The Vickers hardness measurements were made on the cross section, using a Vickers indenter with 10kgf. The creep rupture strength was examined at 600°C and 650°C. Bending test was conducted and its angle was 180º, preparing the sample of the cross section perpendicular to the welding direction to evaluate hot cracking susceptibility.

Table 6 Welding conditions

Welding process	Manual GTAW				
Filler wire	2.4mmφ				
Welding condition	Pass	Curent (A)	Voltage (V)	Traveling speed (mm/s)	Heat input (kJ/mm)
	1st	100	12	1.67	0.72
	2nd-	120-140	14	1.67	1.01-1.18
Preheating	None				
Interpass temp.	150°C max.				
PWHT	740°C for 30min.				

RESULTS

PROPERTIES OF WELDED JOINT WITH COMMERCIAL FILLER WIRE

Figure 3 shows a creep rupture strength of SAVE12AD welded joint with W62-10CMWV-Co (Gr. 92) and Ni base filler wire ERNiCr-3 (Alloy82). The creep rupture strength of welded joint with W62-10CMWV-Co filler wire is lower than that of base metal.

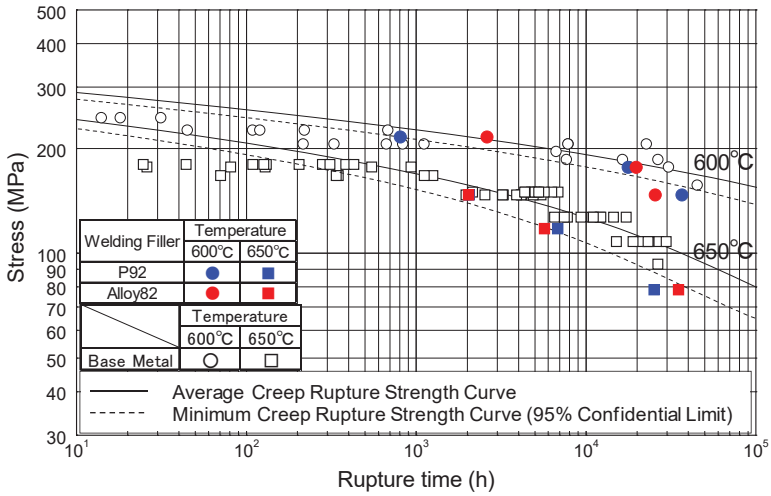

Figure 3 Creep rupture strength of SAVE12AD welded joint with W62-10CMWV-Co and ERNiCr-3 filler wire

Figure 4 shows an appearance on 1st bead surface of restraint welded joint using ERNiCr-3 filler wire after penetration test. A cracking is generated on 1st bead surface and the test results indicate that the hot cracking susceptibility with Ni base filler wire was occasionally below the required level. Therefore, the similar welding consumable for SAVE12AD which has good creep rupture strength and low enough hot cracking susceptibility is required.

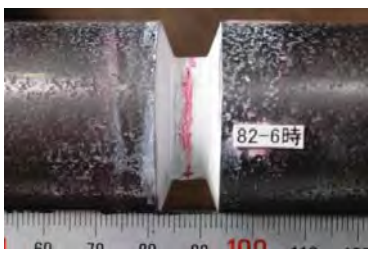

Figure 4 Appearance of 1st bead surface of restraint welded joint with ERNiCr-3 filler wire after penetration test.

PROPERTIES OF WELD METAL WITH CANDIDATE SIMILAR WELDING CONSUMABLE

Figure 5 shows a creep rupture strength of weld metal at 650°C with SAVE12AD candidate similar welding consumable. 0.01% boron content for similar welding consumable is essential to achieve the creep rupture strength which is equivalent to the base metal.

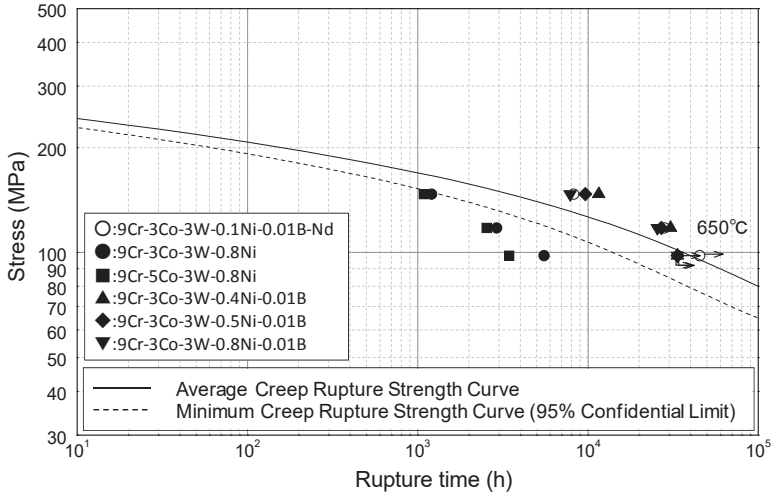

Figure 5 Creep rupture strength of SAVE12AD similar weld metal

Figure 6 shows an effect of boron content on the toughness of weld metal. 0.01% boron content deteriorates the toughness. In order to improve the toughness, the nickel content is increased and high temperature for PWHT is investigated. The superior nickel content is 0.4% because the creep rupture strength of 0.5% and 0.8% nickel similar weld metal at 650°C x 147MPa and 118MPa is slightly lower than that of 0.4%Ni as shown in Figure 5. Table 7 shows the toughness of SAVE12AD similar weld metal 9Cr-3W-3Co-0.4Ni-0.01B-Nd less after 740 and 760°C x 30min PWHT. The toughness is improved after the high temperature for PWHT.

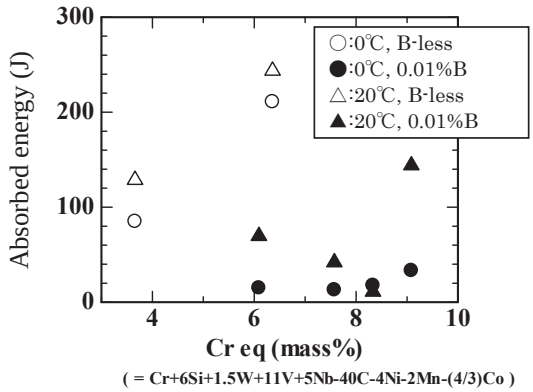

Figure 6 Effect of boron content on toughness of SAVE12AD candidate similar weld metal

Table 7 Toughness of SAVE12AD similar weld metal after each PWHT

PWHT	Temperature (°C)	Absorbed energy Ave.(J)
740°C x 30min	0	36
760°C x 30min	0	55
740°C x 30min	20	42
760°C x 30min	20	97

PROPERTIES OF WELDED JOINT WITH SIMILAR WELDING CONSUMABLE

Table 8 shows tensile property of SAVE12AD similar welded joint with similar welding consumable 9Cr-3W-3Co-0.4Ni-0.01B-Nd less. Figure 7 and 8 shows a hardness distribution and creep rupture strength of SAVE12AD similar welded joint. The hardness of weld metal has higher than that of base metal and creep rupture strength is equivalent to the base metal. The test results clarify that SAVE12AD similar welded joint has good mechanical property. Figure 9 shows an appearance of SAVE12AD similar welded joint after side bending test. No cracking is observed and similar welded joint has resistance to hot cracking susceptibility.

Table 8 Tensile property of SAVE12AD similar welded joint

Temperature (°C)	Tensile strength (MPa)	Reduction (%)	Fractured position
RT	734	73.4	Base metal
	733	73.4	Base metal
600	333	91.0	Base metal
	339	91.0	Base metal
650	263	93.8	Base metal
	266	93.8	Base metal

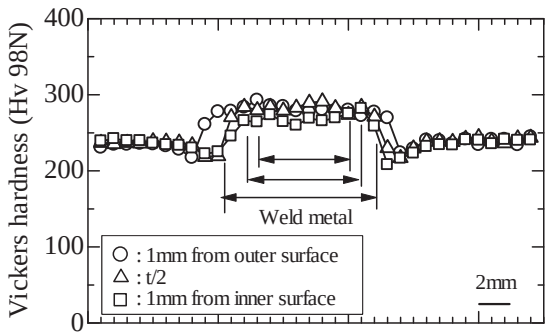

Figure 7 Hardness of SAVE12AD similar welded joint

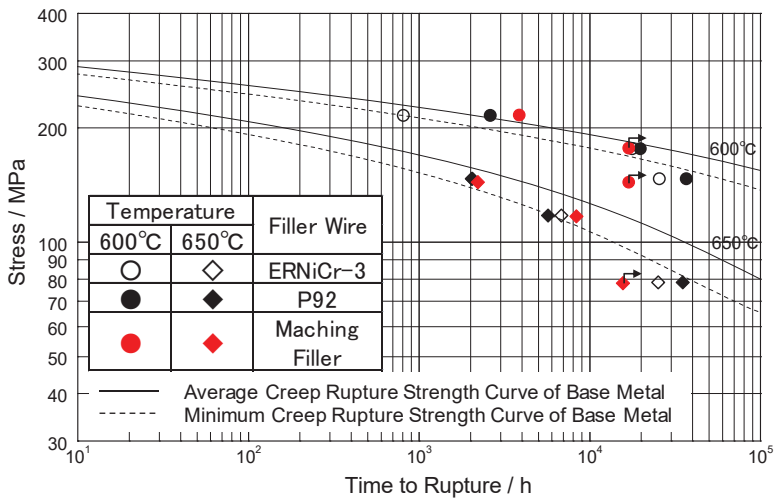

Figure 8 Creep rupture strength of SAVE12AD similar welded joint

Figure 9 Appearance of SAVE12AD similar welded joint after bending test

DISCUSSION

SAVE12AD base metal has good creep rupture strength, ductility and toughness because it contains 9% chromium, 3% tungsten, 3% cobalt, neodymium and boron. In order to keep the good creep rupture strength and ductility, chromium, tungsten, cobalt and boron content of similar welding consumable is equivalent to that of base metal. Especially, boron content also has effect to suppress forming the fine grain on HAZ and is essential to improve creep rupture strength [7-10]. On the other hand, boron content deteriorates the toughness of weld metal. In order to improve the toughness, nickel content is increased as an austenitic former element. Generally, the δ-ferrite would be remained on weld metal of high Cr ferritic steels due to high cooling rate after welding. The content of austenitic former element is effective to improve the toughness. The long-term creep rupture test results indicates that 0.4% nickel content is suitable because over 0.4% nickel content deteriorates the creep rupture strength. In addition, high temperature for PWHT accelerates a recovery of microstructure on weld metal and it enables to improve the toughness.

Neodymium content has been reported that the toughness on HAZ deteriorates because the Neodymium has affinity for oxygen and excessive oxidation is easily occurred during welding. The similar welding consumable doesn't contain neodymium for good toughness.

Therefore, the chemical composition of SAVE12AD similar welding consumable is 9Cr-3W-3Co-0.4Ni-0.01B-Nd less as shown in table 9.

Table 9 Alloy design of developed SAVE12AD similar welding consumable

Base metal	Similar welding consumable	Target	Improvement
0.01B	0.01B	Suppression of forming fine grain on HAZ	Creep rupture strength of welded joint
0.02Nd	Nd-less	Suppression of excessive oxidation	Improve toughness
0.1Ni	0.4Ni	Increasing of austenitic former element	Improve toughness

CONCLUSION

The properties of SAVE12AD welded joint using similar welding consumable were investigated.

The creep rupture strength of SAVE12AD welded joint using W62-10CMWV-Co was marginal and the hot cracking susceptibility of welded joint using Ni base filler wire ERNiCr-3 was occasionally below the required level. On the other hand, SAVE12AD welded joint using similar welding consumable 9Cr-3W-3Co-0.4Ni-0.01B-Nd less has better creep rupture strength and low enough hot cracking susceptibility than welded joint using commercial filler wire.

Consequently, SAVE12AD welded joint is expected to be applied of piping and tubing above 600°C in USC power plants because of its good long-term creep rupture strength and low enough hot cracking susceptibility by using the similar

welding consumable.

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