End Plug Weld Properties of FMS Cladding Tube for SFR Fuel Fabrication

I Seul Ryu[1], Jung Won Lee[2*], Sung Ho Kim[2], Jeong Yong Park[2], Sun Ik Hong[1]
[1]*Nano Materials Engineering Department, Chungnam National University, Daejeon, Republic of Korea,*
Korea Atomic Energy Research Institute, 111,Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Republic of Korea
[*]*Corresponding author: jwlee3@kaeri.re.kr*

1. Introduction

A sodium-cooled fast reactor (SFR) system is one of the six systems selected for Gen-IV promising systems [1]. In Korea, the R&D on a SFR is actively underway as the national long-term nuclear R&D program. The operating environment of a SFR core is very severe. Thus, high chromium ferritic/martensitic (FM) steel such as HT9 has been used for SFR fuel cladding tube material because of the excellent irradiation characteristics. But the HT9 material is not enough to satisfy the discharge burnup goal due to the low creep resistance in high temperature environment over 500℃. In order to improve HT9 material properties, new FM steels, named FC92B and FC92N, were recently developed in KAERI, based on Gr92 material (9Cr-2W-Nb-V) [2,3]. But the end plug weld properties of new developed FC92B and FC92N material after welding are not reported yet. In this study, the post-welding mechanical properties of new FM steels were investigated and evaluated by microstructure observation, SEM, tensile test and micro-hardness test in comparison with HT9 material.

2. Experimental Details

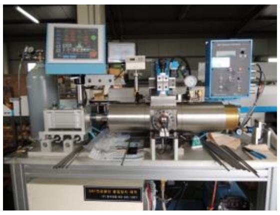
Table 1 shows the major chemical composition of the new FM steel cladding tube materials, FC92B and FC92N, used in this experiment. The weld specimens were prepared based on the SFR fuel rod dimensions.

Table 1. Major composition of FC92B and FC92N steels. (wt%)

	C	Cr	Mo	W	N	B
FC92B	0.07	9	0.5	2	0.08	<0.006
FC92N	0.07	9	0.5	2	0.02	0.015

The weld specimens were prepared by TIG (Tungsten Inert Arc) welding and PWHT (Post Weld Heat Treatment). TIG welding melts the weld joint by an electric arc generated between the tip of a tungsten electrode and the weld joint. The TIG welder for end plug welding was developed, as shown in Fig. 1(a).

End plug welding is carried out in a He gas atmosphere confined in a welding chamber. The welding chamber accommodates the weld joint and is evacuated to remove air gas, and is back filled with high purity (99.999%) He gas to fill the inner space of the fuel rod.




(a) TIG welder (b) PWHT furnace

Fig. 1. Photograph of the TIG welder and PWHT furnace.

A welding torch containing a welding electrode is located on top of the welding chamber. The weld joint is positioned directly under the welding electrode. The cladding tube plugged with an end plug is rotated and welding is conducted by the arc generated between the cladding tube and welding electrode. After end plug welding, PWHT is carried out in a vacuum atmosphere (over 10^{-4} torr) as shown in Fig. 1(b). Table 2 shows the experimental conditions for preparing the weld specimens.

Table 2. Experimental conditions for specimen preparation

	As-welded	300℃	500℃	700℃	900℃	
I.D No.	T1	T3	T5	T7	T9	HT9
	B1	B3	B5	B7	B9	FC92B
	N1	N3	N5	N7	N9	FC92N

The microstructures of specimens were observed by optical microscopy (OM) and scanning electron microscopy (SEM) to investigate the phase formation and precipitation in the weld part. Mechanical properties of specimens were also investigated by vickers micro-hardness test and tensile test to evaluate the weld integrity.

3. Results and Discussion

End plug welding was conducted at the normal weld conditions; weld current 30A and rotation speed 30 rpm [4]. After welding, PWHT was performed on the weld part according to the experimental conditions as shown in Table 2. Fig. 2 shows the weld specimens prepared for the experiment.

Fig. 2. Weld specimens prepared for the experiment.

3.1 Microstructures

The typical microstructures of end plug weld part are given in Fig. 3. Fig. 4 and Fig. 5 show the microstructures of FC92B and FC92N weld part. In these figures the weld metals solidify as ferrite in which the rapid diffusion allows considerable martensitic structure. It means that the transformation from ferrite to austenite and austenite to martensite occur in the solid state. But any differences are not observed in accordance with the chemical composition of FC92B and FC92N.

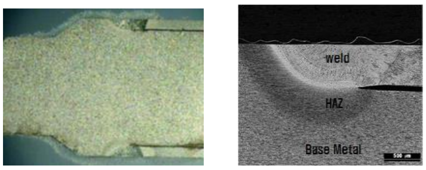


Fig. 3. Microstructures of end plug weld part.

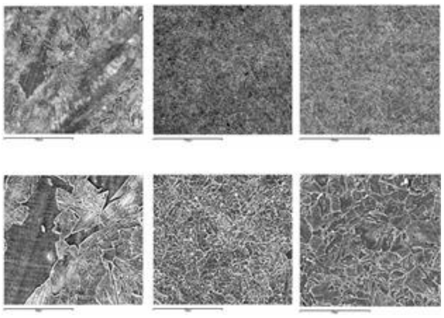


Fig. 4. Microstructures of FC92B weld part.
(a)Weld (x500), (b)HAZ(x500), (c)Base(x500),
(d)Weld (x1500), (e)HAZ(x1500), (f)Base(x1500)

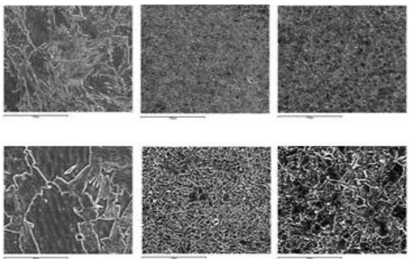


Fig. 5. Microstructures of FC92B weld part.
(a)Weld (x500), (b)HAZ(x500), (c)Base(x500),
(d)Weld (x1500), (e)HAZ(x1500),(f)Base(x1500)

3.2 Micro hardness

In order to compare the effects of the different PWHT temperature, the vickers micro-hardness on the weld part was measured. The hardness distributions across the weld part along with PWHT temperature are given in Fig. 6. The as-welded hardness is higher than that of the PWHT treated specimens. The hardness in the fusion zone is also higher than that of heat affected zone (HAZ) and base metal, which means the material structure has been transformed to martensite. And the hardness in the fusion is decreased as the temperature is increased.

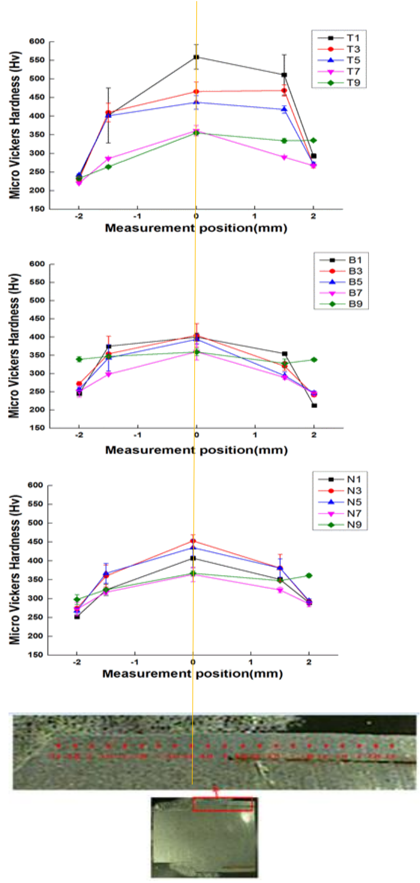


Fig. 6. Hardness distributions of the weld part.
(a)HT9, (b)FC92B, (c)FC92N

Fig. 7. Tensile test results
(a)HT9, (b)FC92B, (c)FC92N

3.3 Tensile Test

The results of tensile tests are shown in Fig. 7. The yield strength and UTS in the weld part are not able to measure because all the tensile specimens were fractured in the cladding tube, not weld part, as shown in the figure. It means that the yield strength and UTS in the weld part are higher than that of base part of the cladding tube, which means the mechanical integrity of the weld part is confirmed.

4. Conclusions

As a result of this study, it is confirmed that the transformation from ferrite to austenite and austenite to martensite occur in the weld part during welding. But any differences are not observed in accordance with the chemical composition of FC92B and FC92N. And also the mechanical properties of the FC92B and FC92N weld part are superior to the base metal of the cladding tube.

ACKNOWLEDGEMENTS

This work has been carried out under the Nuclear Research and Development Program supported by the Ministry of Science, Ict and Future Planning in the Republic of Korea.

REFERENCES

[1] GIF Symposium Proceedings, Global 2009, Sep. 9-10, 2009, Paris, France

[2] J. H. Kim, J. M. Kim, S. H. Kim, C. B. Lee, Microstructural and Mechanical Property Evaluation of the Ferritic-Martensitic Steel under Liquid Sodium Environment, Kor. J. Met. Mater., Vol.48, No.10, pp.914-921(2010)

[3] S. H. Kim, B. J. Song, S. D. Park, I. H. Kuk, W. S. Ryu, Microstructure and Mechanical Properties in HT9 and HT9M Steels for Nuclear Power Plant, J. Kor. Inst. Met. & Mater., Vol.37, No.12, pp.1487-1493(1999)

[4] J. W. Lee, Y. M. Woo, H. T. Kim, K. H. Kim, S. H. Kim, End Plug Welding of New FM Cladding Tube for SFR Metallic Fuel Rod, 2015 KNS Autumn meeting, Oct. 29-30, 2015, Gyeongju Korea