Vanadium as barrier to Prevent Inter-diffusion between Metallic Fuel and Clad Material

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1. Introduction

Sodium-cooled Fast Reactor (SFR) has been considered as next generation nuclear reactor because of its ability of recycling nuclear fuel [1]. Specially, U-Zr metal fuel in nuclear reactor has advantages such as ease of fabrication, high thermal conductivity, proliferation resistance and a good stability for sodium which have proven efficient in extending the fusion possibility. In spite of advantages, metal fuel can be inconvenient to use cladding. Actinide elements cause a FCCI (Fuel Clad Chemical Interaction) and eutectic reaction with Fe as nuclear cladding components at just above 650 ℃ [2]. Since nuclear cladding thickness is decreased during the combusting U-Zr metal fuel, the interaction place in the cladding is brittle and less strength. It was reported that the eutectic melting between U–Pu–Zr and Fe occurs above 650 ℃ [3]. For such reasons, liner related materials and process have been studied by many research groups. In order to apply this nuclear cladding liner, Zr and V metals show better properties to preventing FCCI. Although liner materials prevent FCCI to an extent, it cannot block it perfectly. In this study, we attempt a combination of vanadium (V) and vanadium foil double layer in between a 420J2(Fe based 12Cr steel) and misch metal [4]. The V thin film was deposited with various RF-power. The results of diffusion couple tests at 660 ℃ for 25 hours showed that a combination of the V thin films and foil exhibited a better shielding for FCCI.

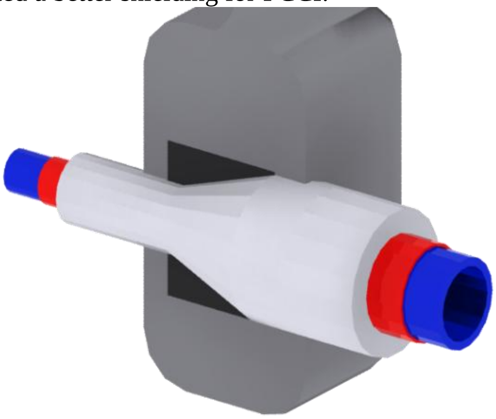

Fig.1. Applied interlayer on liner for the nuclear cladding

2. Methods and Results

2.1 Specimen preparation

420J2 steel (C 0.26~0.40 /Si ≤1.00 /Mn ≤1.00 /P ≤0.040 /S≤0.030 /Ni≤0.60 /Cr 12.00~14.00) disks were used as fuel and cladding material to conduct diffusion tests. A diffusion couple test between Misch metal (70Ce-30La) and 420J2 steel at 660 ℃ was conducted. The diameter and thickness of the 420J2 disks were 8 and 1.5 mm. Before the deposition vanadium, the 420J2 disks were polished with fine SiC paper. The V deposition layer was fabricated by sputtering pure V (99.99%) targets onto a 420J2 substrate, using a RF sputtering system at room temperature. The V target was sputtered using a radio frequency magnetron (60 W 7 h/ 80 W 7 h). V foil of thickness 0.025 mm with 99.7 % purity has been used. The substrate holder was rotated at a speed of 20 rpm in order to minimize the biased growth of the deposition layer. The film was deposited after a base pressure of $5x10^{-6}$ Torr and working pressure $5x10^{-3}$ Torr. Argon was purged (purity 99.999 %) at 40 SCCM.

2.2 Diffusion couple test

To find out inter diffusion between the Misch metal and the 420J2, the diffusion couple test was carried out. Fig.2 shows the schematic illustration of the diffusion test jig. Prepared sample was inserted into jig and then it was tightened firmly. After clamping, it was into vacuum furnace. The diffusion tests were performed at 660 ℃ for 24 h. The 660 ℃ was chosen based on the general operation temperature of an SFR. After the heat treatment, specimens were cooled under air. SEM and EDAX analysis were conducted to investigate diffusion.

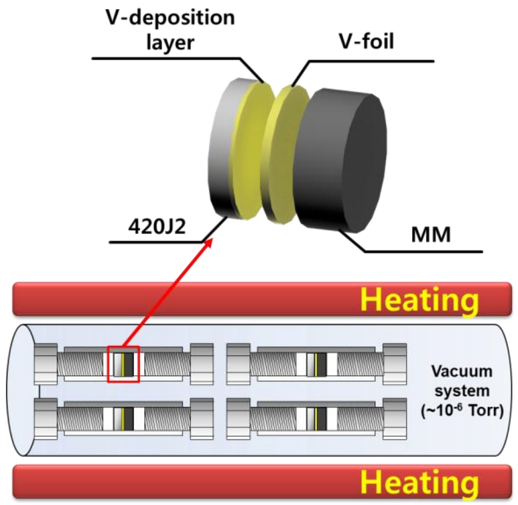

Fig. 2. Schematic illustration of the diffusion couple test.

3. Results

In the fig.3 the microstructure of the specimens after the diffusion couple test at 660 ℃ has shown. From the fig. 3 (a), (b), (d) it can be conclude that an interface diffusion layer has been formed. However, this inter diffusion has winded down in specimens as shown in fig. 3 (b) due to the presence of a V layer. In order to prevent v foil of inter diffusion with the V layer is introduced and it is found to be efficient as shown in fig. 3 (c) and (e).

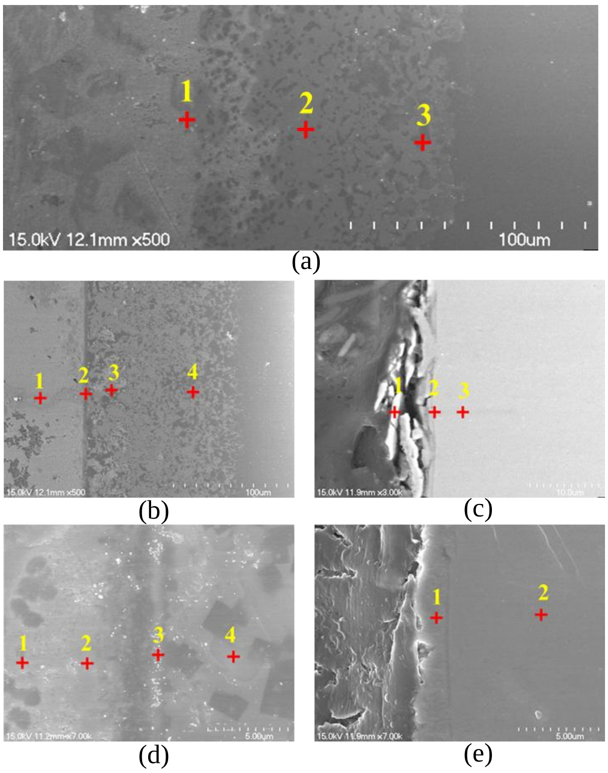

Fig. 3 SEM and EDX analysis of (a) as received 420J2, (b) applied power 60 W, 7 h (c)60 W, 7 h with V foil (d) 80 W, 7h and (e) 80 W, 7h with V foil

Table.1. Concentration table of Fe, Cr, La and Ce across the reaction region of EDX analysis point.

No.	Element	Atomic%
1	La L	42.62
	Ce L	57.38
2	Cr K	16.35
	Fe K	7.35
	La L	33.08
	Ce L	43.22
3	Cr K	16.36
	Fe K	83.64

(a)

No.	Element	Atomic%
1	La L	21.21
	Ce L	78.79
2	V K	61.44
	Cr K	11.59
	La L	6.86
	Ce L	20.10
3	Cr K	31.02
	Fe K	64.84
	La L	1.23
	Ce L	2.91
4	Cr K	21.77
	Fe K	65.51
	Ce L	12.72

(b)

No.	Element	Atomic%
1	V K	95.40
	Cr K	0.73
	Fe K	3.87
2	Cr K	11.60
	Fe K	88.40
3	V K	1.20
	Cr K	11.92
	Fe K	86.88

(c)

No.	Element	Atomic%
1	La L	25.69
	Ce L	74.31
2	La L	28.69
	Ce L	71.31
3	V K	58.77
	Cr K	17.01
	La L	5.88
	Ce L	18.35
4	La L	31.86
	Ce L	68.14

(d)

No.	Element	Atomic%
1	V K	91.50
	Fe K	2.32
	La L	2.42
	Ce L	3.75
2	C K	46.27
	Cr K	7.69
	Fe K	46.04

(e)

4. Conclusions

In this work, an improved method to prevent FCCI between 420J2 and misch metal was reported.

From the SEM and EDX analysis it can be concluded that although, a vanadium layer was able to prevent the FCCI to an extent, better results were shown by the combination of a vanadium foil with the deposited vanadium layer surface of the 420J2. These results from the ability of vanadium foil to prevent inter diffusion, effectively.

Acknowledgements

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