Zirconium and Vanadium Composite as Inter-diffusion barrier between Metallic Fuel and Clad Material

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1. Introduction

Sodium-cooled Fast Reactor (SFR) has been applauded as a next generation nuclear reactor due to its performance over recycling of a nuclear spent fuel as pyro-processing [1]. Moreover, a uranium and zirconium metal fuel in a nuclear reactor shows better performances than other nuclear fuel type, in terms of easy manufacturing of the fuel rod, high heat transfer capacity and excellent resistance of the sodium. Nuclear cladding occurred due to the inter-diffusion between metallic fuel and the cladding material above the nuclear reactor operating temperature. The thickness of the cladding increasingly reduces during the nuclear reactor operation. During the fusion reaction, various rare earth elements such as Nd, Ce, La, Sm and Pr arises from the U-Zr nuclear fuel.

As mention above, nuclear cladding is needed to prevent inter-diffusion. In this study, we controlled diffusion behavior in order to prevent this thickness decrease of the cladding. Effective alternative method is inserting a barrier in between cladding and metal fuel. Zirconium (Zr) and vanadium (V) are one of the promising candidates as barrier material which shows better performance than other barrier material to improve durability of the cladding. Even though Zr and V materials carried out significant role, it cannot act as a perfect diffusion barrier. In this study a composite of Zr and V as different micro structure of diffusion barrier in between 420J2(Fe based 12Cr steel) and misch metal (MM) was attempted [4]. The Zr/V thin films were deposited by radio frequency (r.f) magnetron sputtering system. These results indicated that a multi-layer of the Cr/V-Zr/Cr/V-Zr thin film act as a better shielding for inter-diffusion.

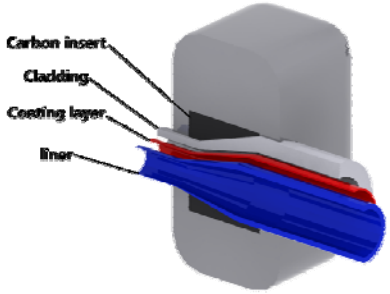

Fig.1. Applied interlayer on liner for the nuclear cladding

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 nuclear fuel and cladding material to conduct diffusion tests. A diffusion couple test between MM (70Ce-30La) and 420J2 steel at 660 °C was conducted. The diameter and thickness of the 420J2 disks were 8 and 1.5 mm. Before the deposition of vanadium, the 420J2 disks were polished with fine SiC paper. The Zr/V deposition layer was fabricated by co-sputtering pure Zr and V (99.99%) targets on a 420J2 substrate, using a RF sputtering system at room temperature. The Zr and V target was sputtered using a radio frequency magnetron ((a) V 80 W (b) V 80 W - Zr 80 W (c) Cr 60 W / V 80 W - Zr 80 W /Cr 60 W / V 80 W - Zr 80 W). The substrate holder was rotated at a speed of 30 rpm in order to minimize the biased growth of the deposition layer. The film was deposited after a base pressure of 4.5×10^{-6} Torr and working pressure of 4.5×10^{-3} Torr. Argon as react gas was purged (purity 99.999 %) at 40 sccm.

2.2 Diffusion couple test

The diffusion couple test was carried out to find out inter-diffusion between the MM and the 420J2,. Prepared sample was inserted into the jig and then it was tightened firmly. After clamping, it was put into a vacuum furnace. The diffusion tests were performed at 660 °C for 24 h. The 660 °C was chosen based on the general operation temperature of an SFR. After the heat treatment, specimens were cooled under air. SEM and EDS analysis were conducted to investigate the inter-diffusion.

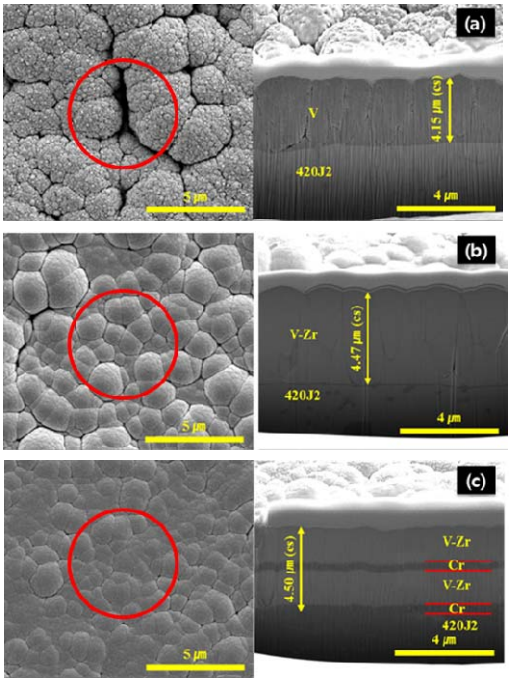

Fig.2. surface and cross-sectional image by focused ion beam (FIB) of (a) V 80 W (b) V 80 W - Zr 80 W (c) Cr 60 W / V 80 W - Zr 80 W /Cr 60 W / V 80 W - Zr 80 W.

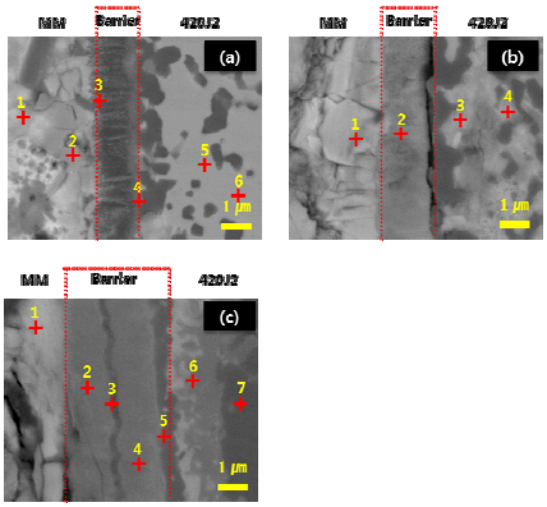

Fig. 3. Cross sectional SEM image after diffusion couple test (a) V 80 W (b) V 80 W - Zr 80 W (c) Cr 60 W / V 80 W - Zr 80 W /Cr 60 W / V 80 W - Zr 80 W.

3. Results

Fig. 2 shows cross-sectional and surface images of the thin film diffusion barrier. With addition of Zr by co-sputtering, the structure of thin film as barrier enhances preventing the inter-diffusion due to the increase of the thin film density as shown in Fig. 3.

After the diffusion couple test at 660 °C, all specimens were formed in inter-diffusion between MM and 420J2. However, inter-diffusion was decreased in specimens as shown in Fig. 3 (c) because the more dense structure than (a) and (b) as confirmed by Fig. 2.

Table. 1 (c) at point 7 shows no inter-diffusion of Ce and La element but other specimens allowed inter-diffusion.

Table. 1. Atomic percent of EDX from the Fig. 3.

	Point	Elements	Atomic %
(a)	1	La L	32.00
		Ce L	68.00
	2	La L	18.23
		Ce L	81.77
	3	V K	75.96
		Cr K	10.82
		Fe K	13.22
	4	V K	12.76
		Cr K	43.65
		Fe K	43.59
	5	Fe K	65.28
		Ce L	34.72
	6	Fe K	65.60
		Ce L	34.40

	Point	Elements	Atomic %
(b)	1	La L	31.43
		Ce L	68.57
	2	V K	25.79
		Zr L	74.21
	3	La L	30.80
		Ce L	69.20
	4	Cr K	22.35
		Fe K	6.36
		La L	23.81
		Ce L	47.48

	Point	Elements	Atomic %
(c)	1	La L	17.03
		Ce L	82.97
	2	V K	31.57
		Zr L	65.43
	3	V K	15.07
		Cr K	41.19
		Fe K	16.58
		Zr L	23.87
	4	V K	32.64
		Cr K	3.59
		Fe K	6.13
		Zr L	57.64
	5	V K	9.33
		Cr K	34.97
		Fe K	48.08
	6	Zr L	7.61
		V K	2.13
		Cr K	20.73
		Fe K	65.68
		Ce L	11.46
	7	Cr K	13.38
		Fe K	86.62

4. Conclusions

To prevent the inter-diffusion between the nuclear cladding and nuclear fuel, vapor deposited multi-component as thin film barrier has been studied. As can be observed from the SEM and EDS analysis total prevention of inter-diffusion cannot be achieved by Cr/Zr-V/Cr/Zr-V multi-layer, although it decreases inter-diffusion to an acceptable extent. These results indicate that this multi-component system has the potential to be used as nuclear cladding barrier material.

REFERENCES

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