2017 Water Reactor Fuel Performance Meeting
September 10 (Sun) ~ 14 (Thu), 2017
Ramada Plaza Jeju • Jeju Island, Korea

B-10 Evaluation of BORAL Neutron Absorber

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ABSTRACT: *Neutron absorber materials are used in spent fuel pool(SFP) storage racks to increase the storage capacity of spent fuel. BORAL is the most commonly used neutron poison material to maintain criticality safety in SFP. But, some of the BORALs have experienced various levels of degradation like local blister on surface recently. This paper examines the performance of BORAL based on evaluation of surveillance coupons through neutron attenuation test. As the result of neutron attenuation test, we confirmed that all of surveillance coupons maintain B-10 area density even though they have some local blisters on surface. In other words, the areal density values demonstrated that there was no sign of boron loss.*

KEYWORDS: *Boral, Neutron Absorber, Blister, B4C, B10, Neutron Attenuation Test, Area Density, Surveillance Coupon.*

I. Introduction

Neutron absorber materials are used in spent fuel pool(SFP) storage racks to increase the storage capacity of spent fuel. BORAL is the most commonly used neutron poison material to maintain criticality safety in SFP. But, some of the BORALs have experienced various levels of degradation like local blister on surface recently. This paper examines the performance of BORAL based on evaluation of surveillance coupons through neutron attenuation test.

II. Neutron Attenuation Test

II.A. Blisters on surface of BORAL

BORAL is a boron carbide aluminum composite material. It is a material that has been widely used for criticality control in storage racks as well as storage and transportation casks for nuclear fuel. In these applications it is typically used in plate form with approximate dimensions of 5 to 8 inches width, 12 feet in length and up to 0.125 inches in thickness. The plate of BORAL is generally sealed within the rack structure and cannot readily be subjected to in-service inspection. So, when new fuel storage racks are installed, a series of surveillance coupons of the neutron absorber material are placed in the racks at that time. The coupons are housed in a specially designed assembly and placed in a storage cell surrounded by recently discharged spent fuel assemblies. And one or two coupons are removed from the assembly and sent to a laboratory for testing and inspection periodically. [1][2]

The plates of BORAL plate consists of a core material comprised of boron carbide in an 1100 aluminum matrix with a cladding of 1100 aluminum on each flat face as shown in Figure 1. The cladding is typically 0.010 inch thick. The core region is not 100% of theoretical density but contains varying degrees of porosity. As fabricated, the BORAL can have between 1% and 10% porosity in the core region. [3]

The blisters was detected on several of the coupons in one of KHNP units recently. BORAL blisters are voids that develop under the aluminum skin that covers the pressed boron carbide-containing composite that makes up the “meat” of the material. As part of an investigation as to the potential effect they may have on performance, KHNP performed the neutron attenuation test. It is important to confirm that B-10 content in BORAL keep in manufacturing because B-10 is used for criticality control in storage racks. [4]

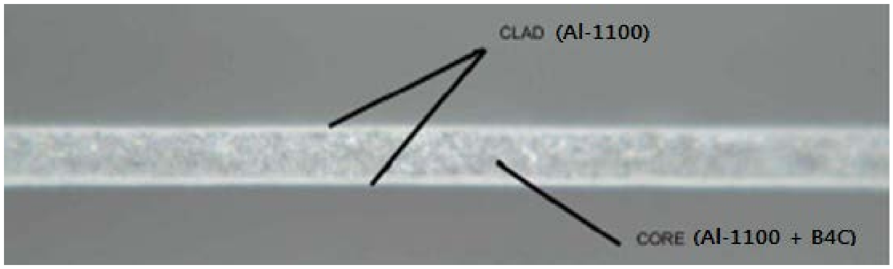


Fig. 1. Trimmed Edge of BORAL

II.B. Neutron Attenuation Test

Neutron attenuation test is to identify B-10 content in the neutron absorber. Neutron attenuation test facility used in this research generates about 60 thermal neutrons per second and irradiates thermal neutrons on the surface of a neutron absorber for 20 minutes. per one surveillance coupon.

II.B.1. Test Facility

Fig. 1 is the neutron attenuation test facility. It consists of graphite layer, SP^9-He^3 detector, and a neutron source. Graphite layer is to moderate fast neutrons in order to generate thermal neutrons and the detector is to measure neutrons. Neutron source is Am^{241}-Be(α,n). Neutrons that is generated in test facility are epithermal and thermal neutrons. So we measure neutrons pervious to Cd filter in order to exclude epithermal neutron from total neutrons. Fig. 2 shows the neutron spectrum with Maxwell-Boltzman distribution.

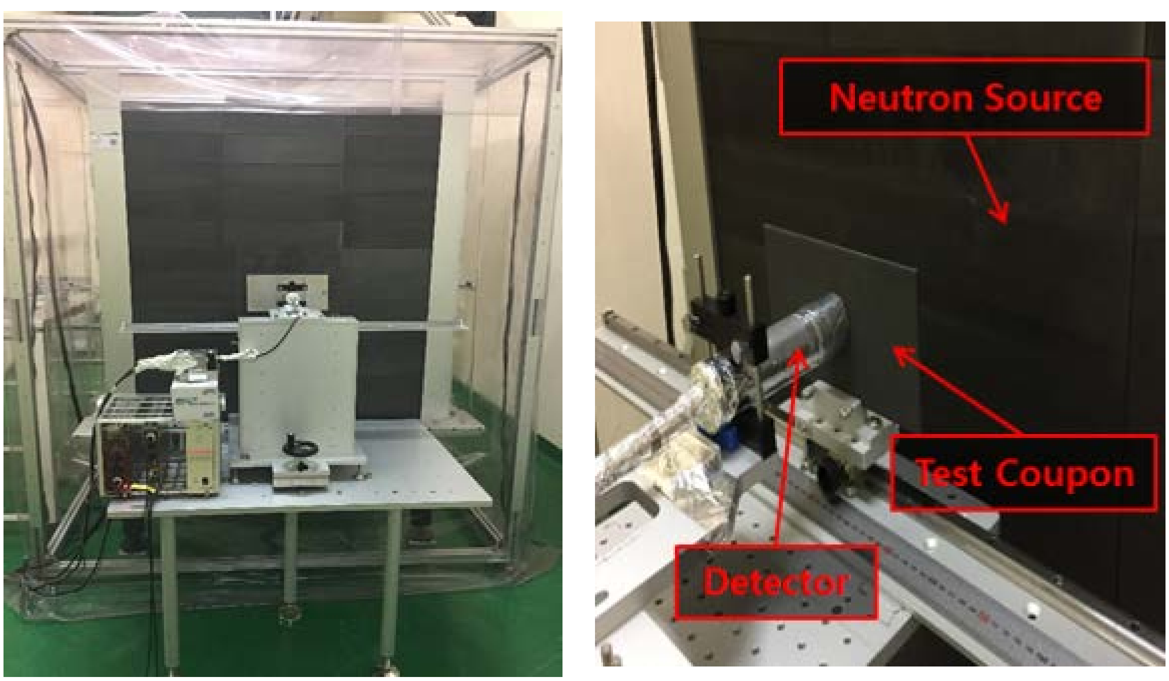


Fig. 1 Neutron Attenuation Test Facility

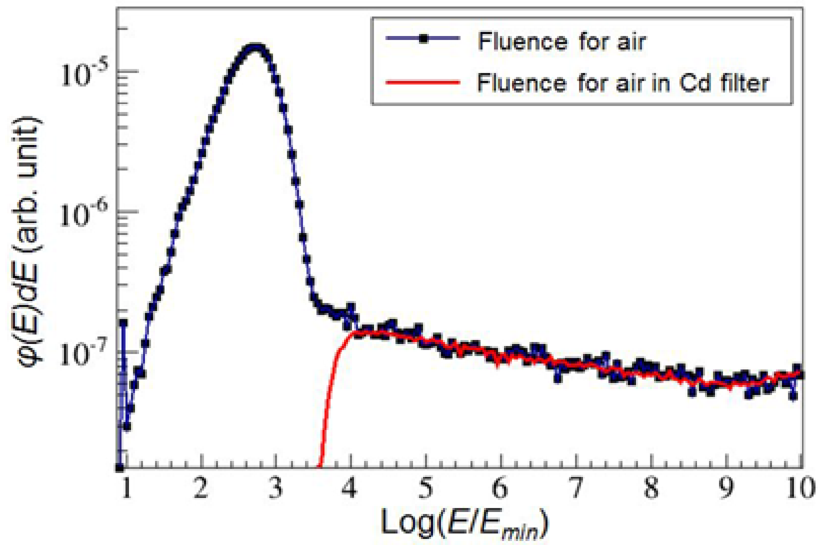


Fig. 2 Neutron Spectrum

II.B.2. Test Procedure

The procedure of Neutron attenuation test is below.

① SP^9-He^3 detector is set within thermal neutron field and shielded by the Cd cover(thickness : 0.6mm). Then, the detector measure the count rate that is defined as Re. Re is the count rate of epithermal neutrons over 0.6eV.
② The count rate measured after removing Cd cover is defined as Rt. Rt is total count rate.
③ The difference of Rt and Re is the count rate of epithermal neutrons. It is defined as Rth. Rth = Rt - Re
④ Surveillance coupon is set in the test facility, and the count rate(St) is measured in condition without Cd cover.
⑤ The count rate(Se) is measured in condition with Cd cover.
⑥ The difference of St and Se is the count rate of epithermal neutron of surveillance coupon. It is defined as Sth. (Sth = St- Se)
⑦ The transmission rate of a surveillance coupon is defined as P. (P = Sth/Rth = (St-Se)/(Rt-Re)

II.B.3. Surveillance Coupon for Test

Surveillance coupons (total of 8 coupons) were extracted from KHNP units and analyzed. They set in spent fuel pool in 1997. 3 coupons of them have several blisters and the others is normal coupons. Fig. 3 shows them. The conditions of spent fuel pool are below.

◦ Water Temperature : less than 50 ºC
◦ Boron Density : over than 2,000 ppm
◦ Pressure : less than 2bar

Fig. 4 shows five test locations on the surface of a coupon in a typical test. Five locations are center, b1, b2, b3 and b4. Additionally, Neutron attenuation test is performed at the locations with blisters and it is in Fig. 3.

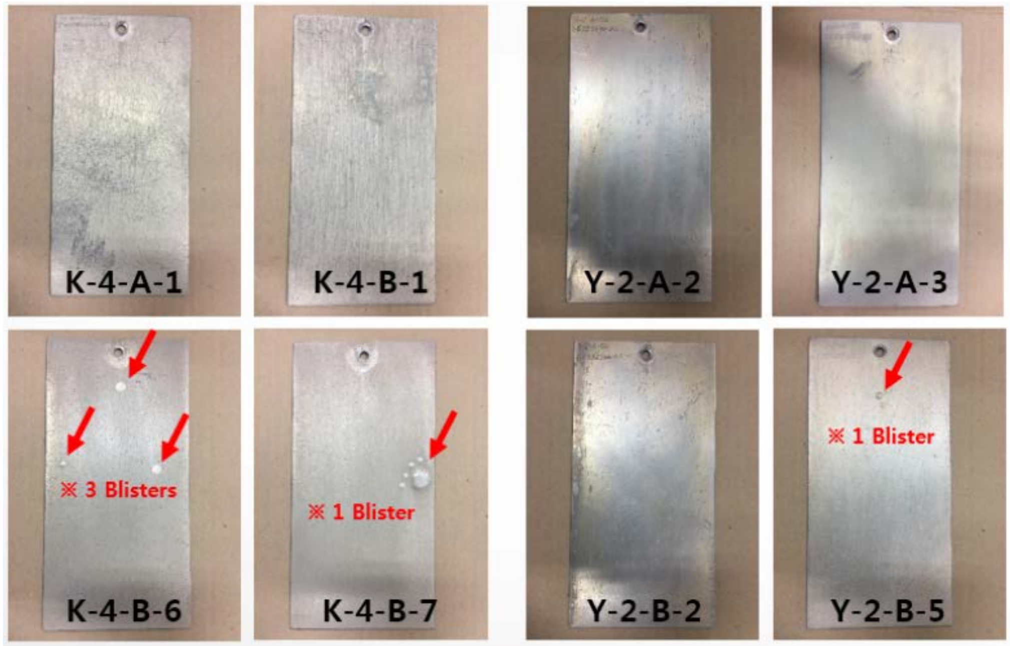


Fig. 3 Surveillance Coupons for Neutron Attenuation Test

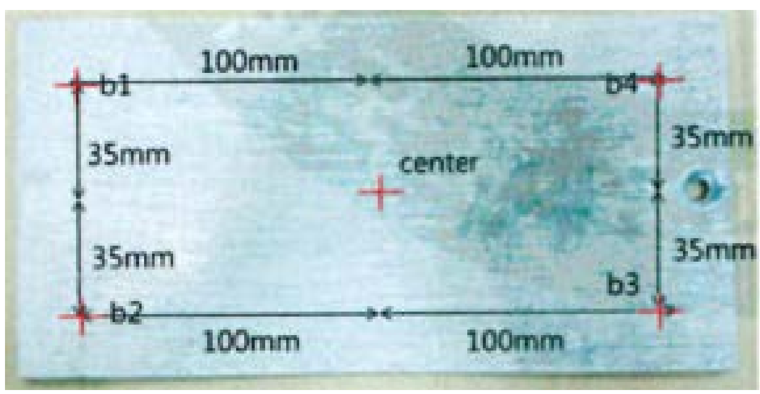


Fig. 4 Typical 5 Test Locations

II.C. Test Result

Neutron attenuation test was performed in order to measure B-10 area density at 5 locations in normal surveillance coupons (K-4-A-1, K-4-B-1, Y-2-A-2, Y-2-B-2, Y-2-A-3), and at additional blister locations (K-4-B-6, K-4-A-7, Y-2-B-5). With this approach, a thermal neutron beam is transmitted through a neutron absorber surveillance coupons and compared to the manufacture value to determine the effective B-10 area density.

Table I is the result of neutron attenuation test for surveillance coupons. As the result of neutron attenuation test, we confirmed that all of surveillance coupons maintain B-10 area density even though they have some local blisters on surface. In other words, the areal density values demonstrated that there was no sign of boron loss. The uncertainty of the transmission rate is ±0.035%.

TABLE I. Result of Neutron Attenuation Test (1/2)

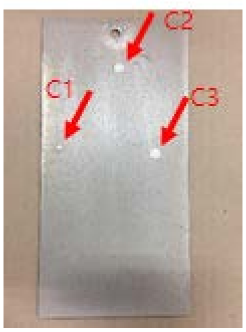
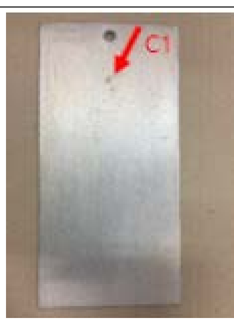
Coupons	Test Location	P (%)	B-10 Area Density (g B_{10}/㎠)	
			Measured	Manufacture
 K-4-A-1	center	1.85	0.02294	0.0214 ~ 0.0217
	b1	1.98	0.02245	
	b2	1.80	0.02313	
	b3	2.07	0.02215	
	b4	1.99	0.02242	
	average	1.94	0.02260	
 K-4-B-1	center	1.87	0.02287	
	b1	1.56	0.02414	
	b2	2.01	0.02235	
	b3	1.99	0.02242	
	b4	2.06	0.02219	
	average	1.90	0.02275	
 K-4-B-6	center	2.29	0.02143	
	b1	2.37	0.02120	
	b2	2.27	0.02150	
	b3	2.32	0.02135	
	b4	2.26	0.02153	
	average	2.30	0.02140	
	C1	2.28	0.02146	
	C2	2.34	0.02129	
	C3	2.22	0.02166	
 K-4-A-7	center	2.12	0.02199	
	b1	2.26	0.02153	
	b2	2.13	0.02196	
	b3	1.99	0.02242	
	b4	2.08	0.02212	
	average	2.12	0.02199	
	C1	1.97	0.02249	

TABLE I. Result of Neutron Attenuation Test (2/2)

<table>
<tr><th rowspan="2">Coupons</th><th rowspan="2">Test Location</th><th rowspan="2">P (%)</th><th colspan="2">B-10 Area Density (g B_{10}/㎠)</th></tr>
<tr><th>Measured</th><th>Manufacture</th></tr>
<tr><td rowspan="6">
Y-2-A-2</td><td>center</td><td>2.14</td><td>0.02192</td><td rowspan="25">0.0214
~
0.0217</td></tr>
<tr><td>b1</td><td>2.28</td><td>0.02146</td></tr>
<tr><td>b2</td><td>2.18</td><td>0.02179</td></tr>
<tr><td>b3</td><td>2.34</td><td>0.02129</td></tr>
<tr><td>b4</td><td>2.46</td><td>0.02095</td></tr>
<tr><td>average</td><td>2.28</td><td>0.02146</td></tr>
<tr><td rowspan="6">
Y-2-B-2</td><td>center</td><td>1.84</td><td>0.02298</td></tr>
<tr><td>b1</td><td>1.94</td><td>0.02260</td></tr>
<tr><td>b2</td><td>2.11</td><td>0.02202</td></tr>
<tr><td>b3</td><td>2.12</td><td>0.02199</td></tr>
<tr><td>b4</td><td>1.97</td><td>0.02249</td></tr>
<tr><td>average</td><td>2.00</td><td>0.02239</td></tr>
<tr><td rowspan="6">
Y-2-A-3</td><td>center</td><td>1.67</td><td>0.02365</td></tr>
<tr><td>b1</td><td>1.68</td><td>0.02360</td></tr>
<tr><td>b2</td><td>1.78</td><td>0.02321</td></tr>
<tr><td>b3</td><td>1.82</td><td>0.02306</td></tr>
<tr><td>b4</td><td>1.83</td><td>0.02302</td></tr>
<tr><td>average</td><td>1.76</td><td>0.02328</td></tr>
<tr><td rowspan="7">

Y-2-B-5</td><td>center</td><td>2.21</td><td>0.02169</td></tr>
<tr><td>b1</td><td>2.13</td><td>0.02196</td></tr>
<tr><td>b2</td><td>2.25</td><td>0.02156</td></tr>
<tr><td>b3</td><td>2.32</td><td>0.02135</td></tr>
<tr><td>b4</td><td>2.32</td><td>0.02135</td></tr>
<tr><td>average</td><td>2.25</td><td>0.02156</td></tr>
<tr><td>C1</td><td>2.1</td><td>0.02206</td></tr>
</table>

III. CONCLUSIONS

KHNP(Korea Hydro & Nuclear Power Co., Ltd.) is the largest electric power company which generates approximately 31.5% of the total electric power generated in South Korea. It operates 25 nuclear power plants and hydroelectric plants. KHNP recently performed the test to verify the performance of BORAL coupons in spent fuel pool. So, The coupons were harvested from spent fuel pools of KHNP units and B-10 area density was measured by neutron attenuation test. With this approach, a thermal neutron beam is transmitted through a neutron absorber surveillance coupons and compared to the manufacture value to determine the effective B-10 area density. Eight surveillance coupons were harvested and three coupons of them have several local blisters on the surface.

As the result of neutron attenuation test, we confirmed that all of surveillance coupons maintain B-10 area density even though they have some local blisters on surface. In other words, the areal density values demonstrated that there was no sign of boron loss. We have a plan to perform the neutron attenuation test for METAMIC surveillance coupons soon.

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