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DEVELOPMENT OF NEUTRON ABSORBER (MAXUS™) FOR HIGH BURN-UP SPENT NUCLEAR FUEL

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ABSTRACT

B-AL (Boron-Aluminium) plate is commonly used as a neutron absorption material for the basket plate of casks. For material property reasons, the boron carbide content (boron weight %) of the B-AL plates is commonly in the 15-40wt% range. Recently canister-based systems have been developed for long-term storage (60 years to 100 years) of high burn-up fuel, requiring higher neutron absorption. However, increasing the boron carbide content of conventionally produced plates reduces their ductility and thermal conductivity, and increases their cost. Therefore a new neutron absorber material (MAXUS™) with higher content of boron carbide was developed. The mechanical and physical properties and corrosion resistance of MAXUS™ plate containing 30-70wt% of natural boron carbide were measured.

MAXUS™ plate is produced using a powder metallurgy process. The plate has a sandwich structure with almost 100% dense MMC core and thin aluminum skins. The alloy skin improves the plate's mechanical properties and anti-corrosion resistance, and bonding during sintering. The sintering process was optimized to prevent occurrence of blisters. After sintering, the plates were hot and cold rolled to assure uniformity of the materials. Test samples were prepared containing 30,40,50,60, and 70wt% natural boron carbide materials.

Microstructure observations and mechanical, physical and corrosion testing have shown that the particles of boron carbide are distributed uniformly in MAXUS™ plate. Anti-blister tests also showed strong resistance to blistering. It has also been verified that MAXUS™ has reliable neutron absorption and mechanical and physical properties.

INTRODUCTION

Recently commercial nuclear reactors have begun using high burn-up fuel. Reprocessing or storage of the spent fuel introduces higher quantities of radionuclides, with high intensity and high heat output. To design the storage casks or canisters, materials with higher neutron absorption and thermal conductivity are required. Boron carbide is commonly used as the neutron absorbing material in casks and canisters. BORAL plate, manufactured by AAR Advanced Structures, is widely used for this purpose [1]. The material is a composite having a core of mixed aluminum and boron carbide particles with aluminum cladding on both sides. However, the material cannot be welded and, moreover, is subject to corrosion if the aluminum cladding is breached. Since the core is not fully dense, hydrogen gas can be generated rapidly in the presence of water, resulting in blistering of the skin/cladding layer [2]. An improved design uses plates mounted in racks [3]. To prevent blistering, melting technology was introduced as a Metal Matrix Composite [4]. The use of enriched borated aluminum alloy [5] and mixtures of uranium and aluminum oxide [6] have also been proposed. However, the complex process required to manufacture these materials increases the production cost. Therefore the new neutron absorbing material, MAXUS™, was developed to achieve higher boron carbide concentration. This paper reports experimental results for the material's mechanical, physical and thermal conductivity properties, and observations of its microstructure.

EXPERIMENTAL PROCEDURES

MAXUS™ plate is produced using a powder metallurgy process. The plate has a sandwich structure with almost 100% dense MMC core and thin aluminum skins. As in previously reported work [7], a pre-roll assembly is prepared for rolling. After packing an aluminum case with boron carbide powder and sintering, the case was hot and cold rolled to the 2.0 mm thickness. Samples were cut from the finish rolled sheet and annealed. Test samples were prepared containing 30, 40,50,60, and 70wt% natural boron carbide. Mechanical properties were measured in accordance with ASTM B-557. Bending tests were done to estimate the reliability under bending. The tests were done at 100 mm pitch and radius of the pressure head was 9 mm. Thermal conductivity of perpendicular to rolling direction was measured by the laser flash method. The thermal diffusivity specified by ASTM E-1461 was used to calculate the conductivity. The thermal expansion was measured from room temperature to 350 °C. The plate's anti-corrosion and anti-blistering properties were assessed by thermal shock tests. In these tests, samples were heated to 500 °C and then quickly quenched in water at the 20 °C. The procedure was repeated ten times and the samples were examined carefully. Also microstructures of the each sample were observed.

RESULTS

All mechanical and physical tests were done at room temperature. The results are summarized in the following figures.

Tensile Strength

Figure 1 shows the tensile strength. Tensile strength decreases with increasing concentration of boron carbide. This means bristle particles of the boron carbide cause fatigue crack during tensile testing.

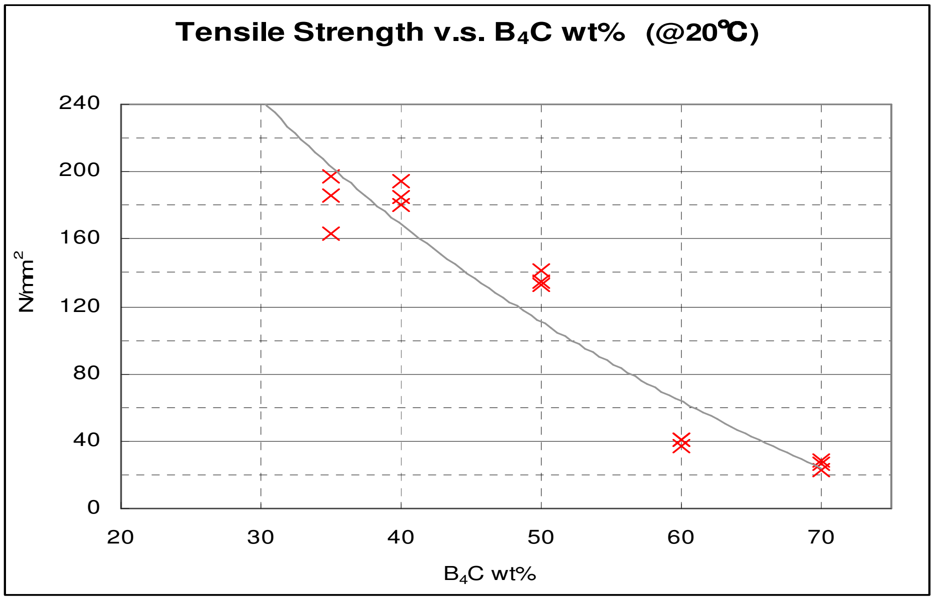

Figure 1. Tensile Strength v.s. wt% of Boron Carbide

Bending Strength

The bending force for each sample is shown in Figure 2. Although the bending force decreases with increasing concentration of boron carbide, the decrease is smaller than expected, probably due to the presence of the aluminum skins. The effect of skin thickness on bending strength is currently being investigated. Nonetheless, the current results strongly indicate that MAXUS™ plate would be suitable for design applications involving non-planar shapes.

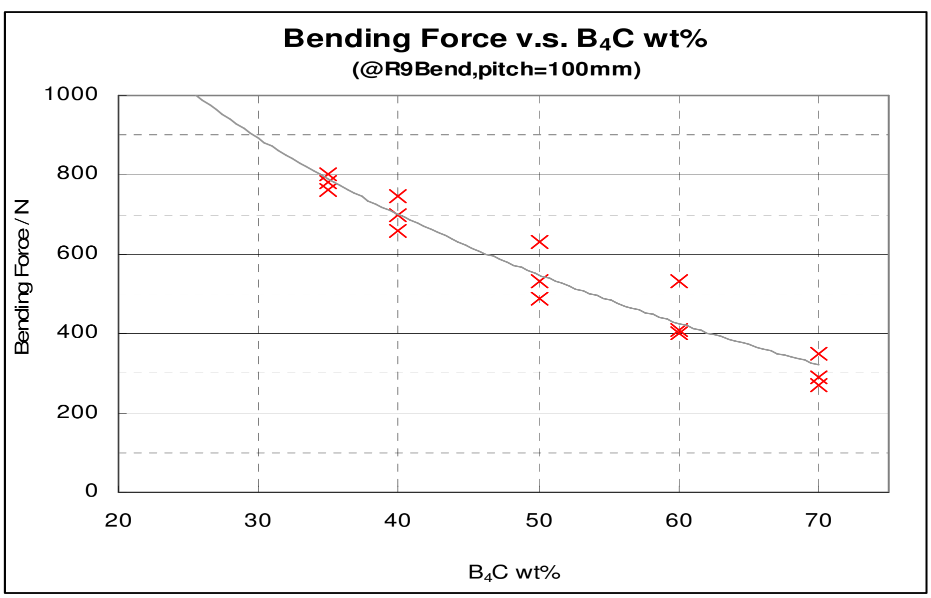

Figure 2. Bending Strength

Thermal Conductivity

Thermal conductivity is as shown Figure 3. The measured data deviate significantly from the theoretical curve at more than 50wt% concentration. Development is ongoing to increase the thermal conductivity at these higher concentrations.

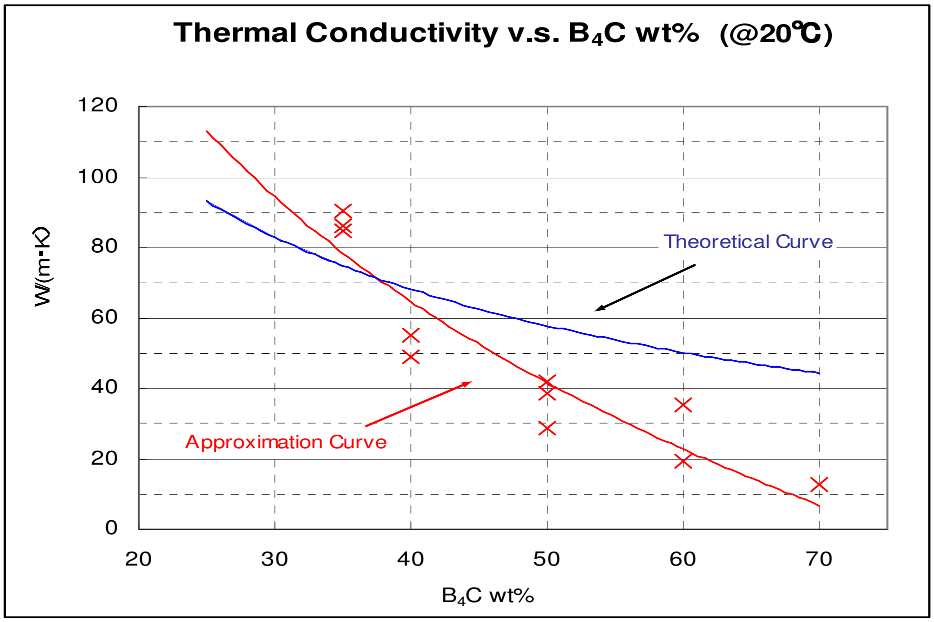

Figure 3. Thermal Conductivity

Thermal Expansion

Figure 4 shows the thermal expansion. Thermal expansion is close to the theoretical curve. The discrepancy between the theoretical and fitted curves at 30wt% to 40wt% is characteristic of metal matrix composites. Boron carbide particles apparently restrain the expansion of the aluminum structure.

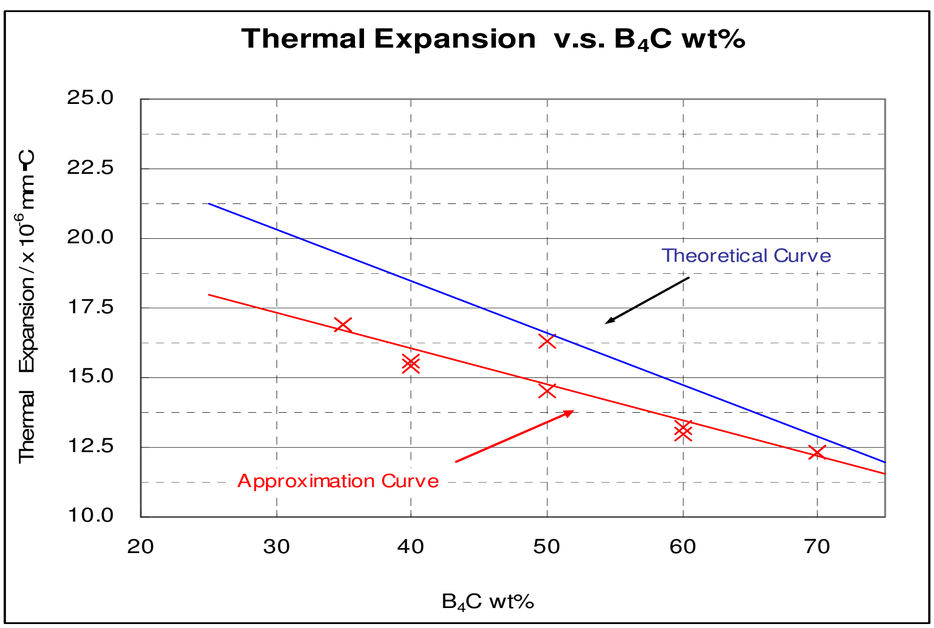

Figure 4. Thermal Expansion

Thermal Shock

Photographs of the samples after the thermal shock test are shown in Figure 5. There are no visible blistering, flaking, dividing, or swelling.

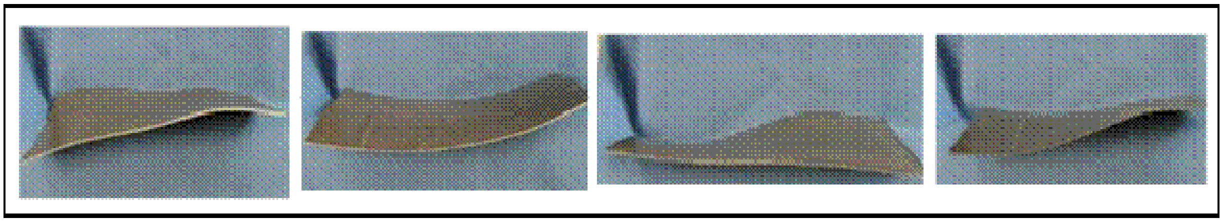

Figure 5. Thermal Shock Test

Microstructure

(1) Microstructure of each sample is shown in Figure 6. Microstructure shows uniform distribution of the boron carbide.

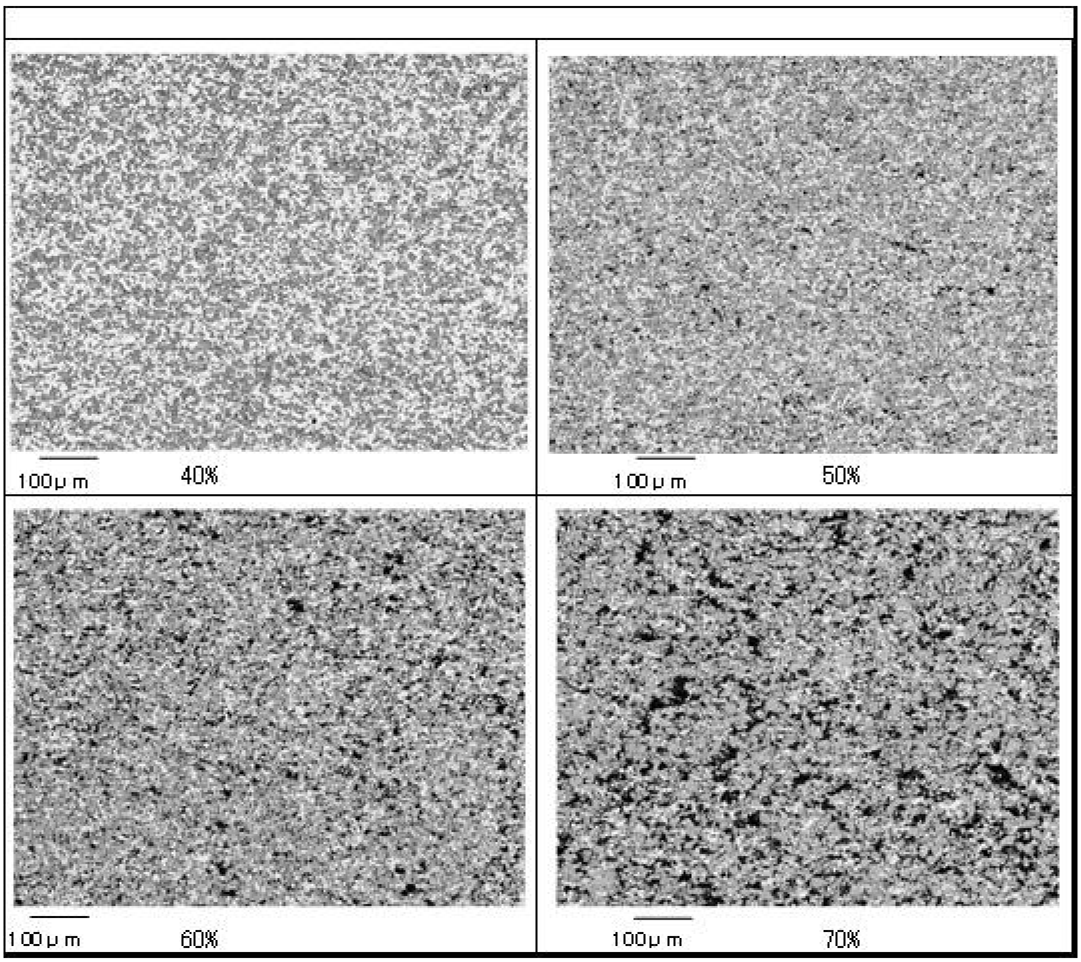

Figure 6. Microstructure

CONCLUSIONS

The properties of the MAXUS™ plate containing 40-70wt% natural boron carbide were measured. In these tests,

(2) Mechanical and physical properties decrease with increasing concentration of boron carbide.
(3) Thermal shock test shows no blistering.
(4) Microstructure shows uniform distribution of the boron carbide.

Based on these test results, MAXUS™ can be used as a neutron absorbing material in casks and canisters for the high burn-up spent fuel.

ACKNOWLEDGMENTS

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