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Properties of "MAXUS®" Aluminum Matrix Composite

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"Dry storage casks" which store spent nuclear fuel require thermal neutron-absorbing materials such as aluminum alloy plates containing boron in order to prevent criticality. The MAXUS® plate has been developed specifically for that material. The plate is an Al-B_4C metal matrix composite clad with an aluminum alloy produced via a powder metallurgy and a rolling process. The advantages of MAXUS® are higher concentration limit of B_4C and more uniform distribution of B_4C particles in the aluminum matrix, in comparison with a material by an ingot metallurgy process. Microstructure, density, tensile strength and thermal conductivity of the MAXUS® plates containing 10-60 volume%B_4C were examined. Tensile properties and microstructure changes during annealing were also investigated for the MAXUS® plate containing 30 volume%B_4C. Density, tensile strength and thermal conductivity were revealed and discussed from a view point of microstructure. The tensile properties not deteriorated after annealing is explained to be due to absence of large constituents of several micrometers in the composite.

Keywords: *Cask, Spent nuclear fuel, Thermal neutron, Neutron absorber, Boron, Boron carbide, B_4C, Aluminum, Aluminum alloy, Metal matrix composites, Powder metallurgy, Microstructure, Density, Thermal conductivity, Constituent, Recrystallization*

1. Introduction

"Dry storage casks" which store spent nuclear fuel require thermal neutron-absorbing materials such as aluminum alloy plates containing boron in order to prevent criticality [1]. The MAXUS® plate has been developed specifically for that material [2]. The plate is an Al-B_4C metal matrix composite clad with an aluminum alloy produced via a powder metallurgy and rolling process. The advantages of MAXUS® are higher concentration limit of B_4C and more uniform distribution of B_4C particles in the aluminum matrix, in comparison with a material by an ingot metallurgy process.

The purpose of this paper is to examine microstructure, density, tensile strength and thermal conductivity of the MAXUS® plates containing 10-60 volume%B_4C. Tensile properties and microstructure changes during annealing were investigated for the MAXUS® plate containing 30 volume%B_4C.

2. Experimental Procedure

Aluminum and boron carbide powders were mixed using a V-type blender. Six kinds of mixed powders containing B_4C of 10, 20, 30, 40, 50 and 60% (% represents volume %) were prepared. The 5052 alloy boxes were filled with each mixed powder, and sintered in a vacuum. Subsequently, those boxes were subjected to hot rolling to plates and annealing. The MAXUS® plate then consists of an Al-B_4C composite clad with a 5052 alloy.

Microstructure, density, tensile strength and thermal conductivity were examined. The density was measured by means of Archimedes method. Tensile test pieces (shape No.14B in JIS Z 2201) were taken in the transverse direction and tensile tests were conducted at room temperature in accordance with JIS Z 2241. Thermal conductivity was calculated using the results of thermal diffusivity and specific heat measured by laser flash method at room temperature.

3. Results and Discussion

3.1. Microstructure

Optical microstructures of the composite region of the MAXUS® plates are shown in Fig. 1. It indicates that B_4C particle sizes are almost the same as those before mixing, namely the particles have not been broken into pieces during rolling. The B_4C particles are distributed being isolated in an aluminum matrix of an Al-10% B_4C composite, and some particles are in touch with each other in the composites of higher B_4C contents. Voids indicated with arrows are also observed between B_4C particles in those higher-B_4C composites.

3.2. Density and void

Density of the MAXUS® plates and area fraction of voids are shown in Fig. 2 with a theoretical density. The density of the MAXUS® plates is lower than the theoretical one due to the voids.

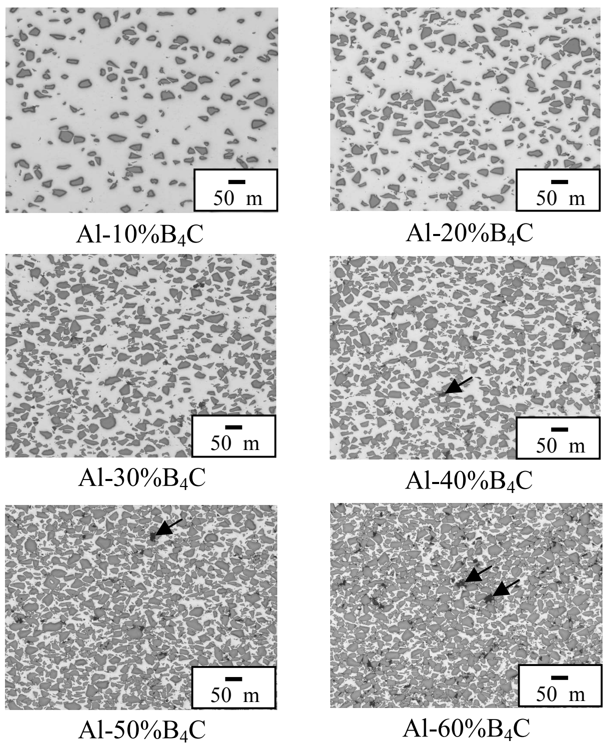


Fig. 1 Optical microstructures of the composite region of the MAXUS® plates. Arrows indicate some examples of voids.

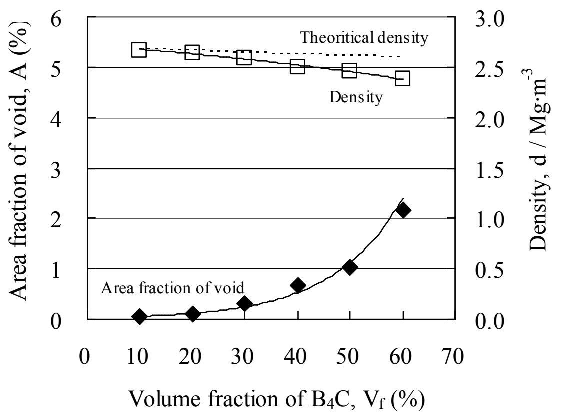


Fig. 2 Relationship between area fraction of void or density and volume fraction of B_4C.

3.3. Tensile strength

The relationship between tensile strength and volume fraction of B_4C is shown in Fig. 3. The higher B_4C content is, the weaker tensile strength becomes, although B_4C particles are much harder than an aluminum matrix. This is because failure arises from coalescence of voids during elastic deformation for the MAXUS® plates of higher B_4C contents.

3.4. Thermal conductivity

Thermal conductivity is shown in Fig. 4. Calculated values by a rule of mixtures are also shown. Thermal conductivity of the MAXUS® plates of 50 and 60%B_4C is lower than the theoretical values. This is assumed to be caused by voids.

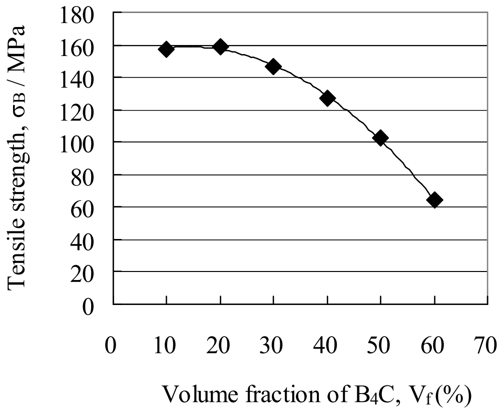


Fig. 3 Relationship between tensile strength and volume fraction of B_4C.

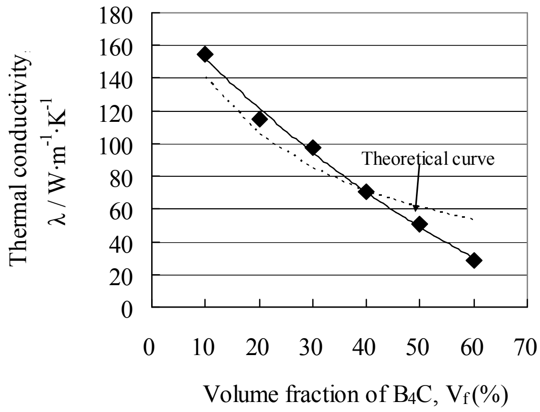


Fig. 4 Relationship between thermal conductivity and volume fraction of B_4C.

3.5. Strength and microstructure after annealing

Tensile properties after annealing were examined in detail for the MAXUS® plate of 30%B_4C (Fig. 5). The result for a 1050 aluminum plate is also shown in this figure which has been prepared via an ingot metallurgy process. Tensile strength and 0.2% proof stress deteriorate around at 300°C for both the MAXUS® and 1050 aluminum plates. The deterioration of the strengths for the MAXUS® plates was less than 1050 aluminum plates.

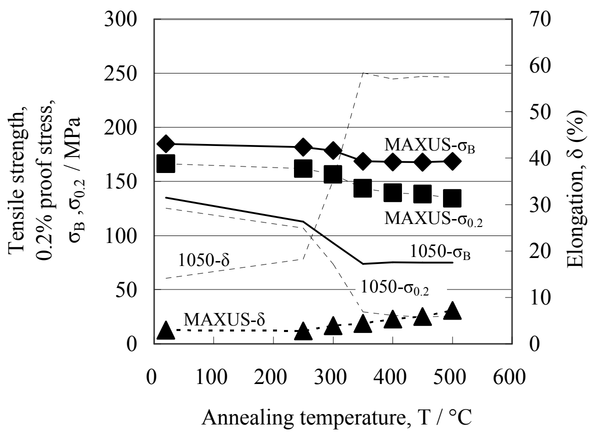


Fig. 5 Relationship between tensile properties and annealing temperature of the MAXUS® plate of 30%B_4C.

For separating strengths of a composite from those of the MAXUS® plate, tensile properties of a 5052 alloy and a composite were examined (Figs. 6-7). The 5052 alloy plate has been prepared via an ingot metallurgy process, and the composite after scalping skins of the MAXUS® plate. The composite does not show an obvious deterioration of strengths (Fig. 7), although the 5052 alloy does (Fig. 6) as well as the 1050 aluminum in Fig. 5. From observation of microstructure (Figs. 8-9), deterioration of the strengths for the 5052 alloy is due to recrystallization during annealing (Fig. 8b), but recrystallization has not been occurred in the composite (Fig. 9b). Therefore, it is assumed that the deterioration of the strengths for the MAXUS® plate around at 300°C was caused by the 5052 alloy skins.

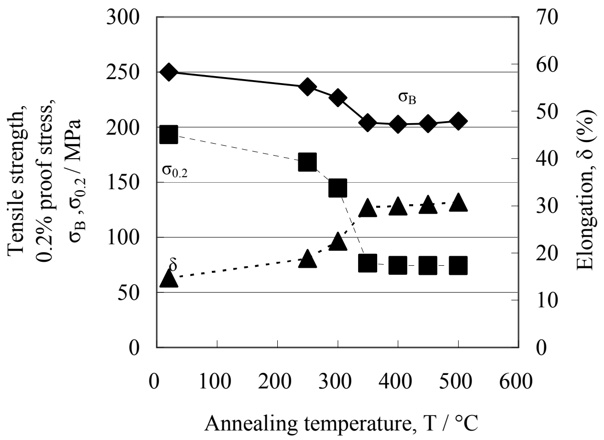


Fig. 6 Relationship between tensile properties and annealing temperature of the 5052 alloy.

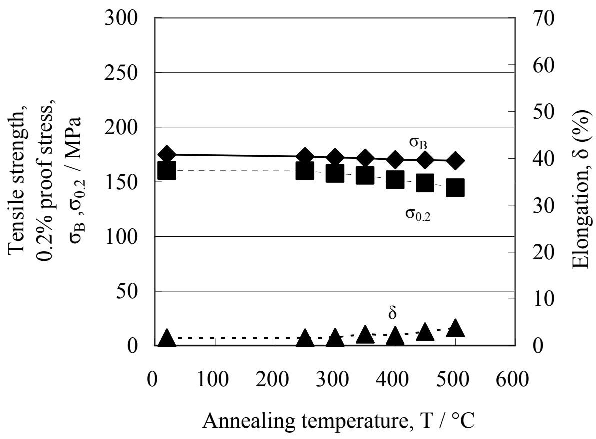
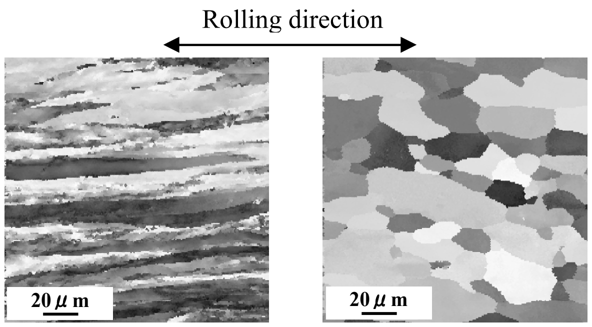
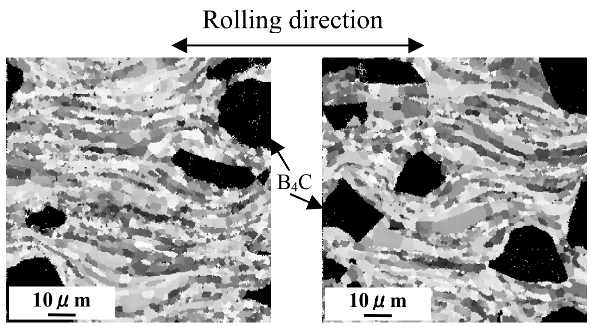


Fig. 7 Relationship between tensile properties and annealing temperature of the MAXUS® plate of 30%B_4C without skins.



(a) As rolled (b) Annealed at 500°C

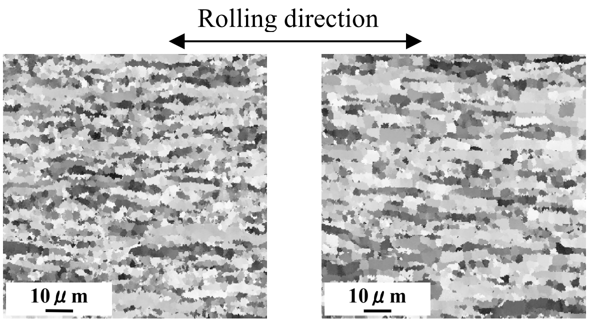
Fig. 8 EBSD microstructure of the 5052 alloy.



(a) As rolled (b) Annealed at 500°C

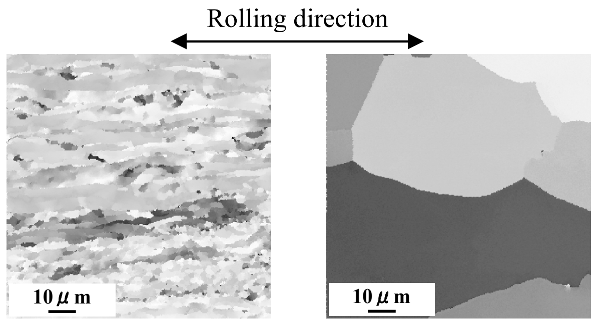
Fig. 9 EBSD microstructure of the MAXUS® plate of 30%B_4C.

In order to clarify the reason why the composite did not show recrystallization, the MAXUS® plate without B_4C were produced and microstructures before and after annealing were observed (Fig. 10). It was found that recrystallization does not occur after annealing even if the B_4C powder does not exist. The EBSD observation revealed that both the center part of the MAXUS® plate without B_4C (Fig. 10a) and the 1050 aluminum (Fig.11a) show sub-grained structures and that only the 1050 aluminum has been recrystallized (Fig. 11b). This microstructure difference is explained from iron-containing constituent sizes (Fig. 12), namely the constituents in the center part of the MAXUS® plate are smaller to be sub-micrometers and that those in the 1050 aluminum several micrometers. The TEM observation was then conducted and it was found that dislocations are not dense around the constituents in the MAXUS® plate (Fig. 13a), but are dense in the 1050 aluminum (Fig. 13b) resulting in recrystallization as shown in Fig. 14 [3, 4]. The reason why the constituents in the MAXUS® plate are smaller is that solidification rate in producing aluminum powders is higher comparing that of the sheet ingots.



(a) As rolled (b) Annealed at 500°C

Fig. 10 EBSD microstructure of the center part of the MAXUS® plate without B_4C.



(a) As rolled (b) Annealed at 500°C

Fig. 11 EBSD microstructure of the 1050 Aluminum.

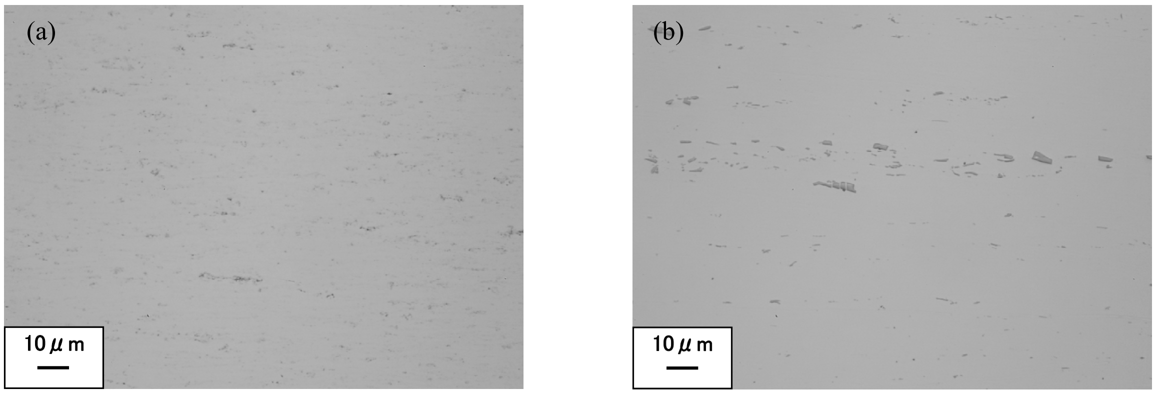


Fig. 12 Optical microstructure of (a) the center part of the MAXUS® plate without B_4C and (b) the AA1050 alloy after rolling.

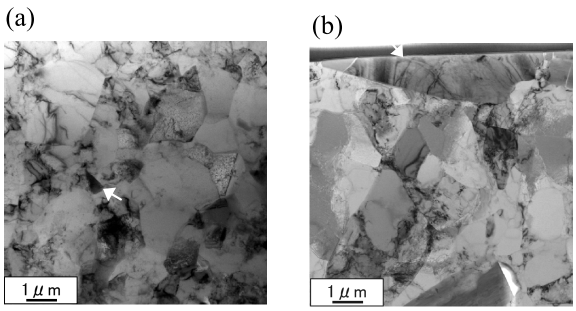


Fig. 13 TEM microstructure around constituents in (a) the MAXUS® plate without B_4C and (b) the AA1050 alloy. Arrows indicate constituents.

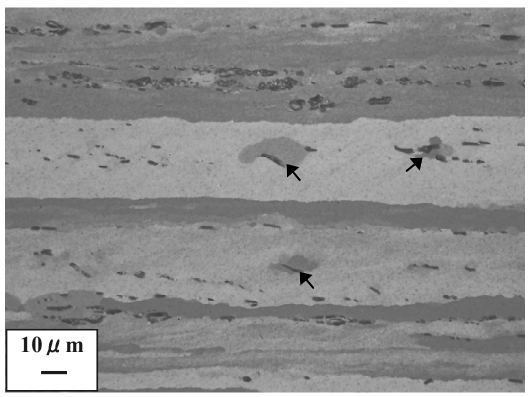


Fig. 14 Optical microstructure of the 1050 aluminum during annealing. Arrows indicate recrystallized grains initiating on constituents.

4. Summary

Microstructure, density, tensile strength and thermal conductivity of the MAXUS® plate containing 10-60%B_4C were examined and following conclusions were obtained:

The B_4C particles are distributed being isolated in an aluminum matrix of an Al-10% B_4C composite, and some particles are in touch with each other in the composites of higher B_4C contents. Voids are also observed between B_4C particles in those higher-B_4C composites. The density of the MAXUS® plates is lower than the theoretical one due to the voids. The higher B_4C content is, the weaker tensile strength becomes, although B_4C particles are much harder than an aluminum matrix. This is because failure arises from coalescence of voids during elastic deformation for the MAXUS® plates of higher B_4C contents. Thermal conductivity of the MAXUS® plates of 50 and 60%B_4C is lower than the theoretical values due to existence of voids. The composite part of the MAXUS® plates contains constituents of sub-micrometers and dislocations are not dense around the constituents, resulting in the fact that recrystallization does not occur during annealing.

References

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