MECHANICAL PROPERTIES OF TiB_2-NiAl COMPOSITE MATERIALS FABRICATED BY SPARC PLASMA SINTERING

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Abstract

Titanium diboride added with NiAl of up to 80wt% has been sintered using spark plasma sintering (SPS) at temperature between 1273K and 1673K. By the x-ray diffraction measurements it has been shown that TiB_2 and NiAl co-exist in equilibrium at the temperature up to 1673K. By the SEM observation it has been shown that NiAl fills the space between TiB_2 grains and dense samples are obtained. The grain size of TiB_2 is around several microns which is the same as that of the starting TiB_2 powders. The highest Vickers hardness of 1600Hv has been obtained for TiB_2-40wt%NiAl, which has bending strength of as high as 730MPa. The highest bending strength of 990MPa has been obtained for TiB_2-80wt%NiAl. On the other hand, the bending strength of monolithic NiAl and TiB_2 sintered at 1573K is as low as 370MPa and 250MPa, respectively.

1. Introduction

Titanium diboride (TiB_2) has many desirable properties such as high hardness (Hv=3400), high melting point (3000K), low density, high electrical resistivity and good corrosion resistance.[1] It is a promising candidate for cutting tools, wear proof parts, aircraft propulsion systems, space vehicle thermal protection and so on. However, a high sintering temperature above 2000K is required to obtain TiB_2 of high quality, which limits its application [2]. We have shown that the addition of Al_3Ti up to 30wt% improves the mechanical properties of sintered TiB_2. The Hv of 2100 and bending strength of 600MPa has been obtained for TiB_2-30wt%Al_3Ti sintered at 1473K. [3,4]

The intermetallic compound NiAl displays a number of favourable properties such as high melting temperature (1800K), low density ($5.86x10^3 kg/m^3$) and excellent oxidation resistance. It has been shown that the addition of TiB_2 to NiAl up to 30% significantly improves the high-temperature compressive strength of NIAl. [5,6] Guo et al have reported that the tensile strength of NiAl is improved by the addition of 15 wt% TiB_2.[6] However, the mechanical properties of the TiB_2-NiAl composite of TiB_2-rich composition range have not been reported. In the present study we have investigated the mechanical properties of the TiB_2-NiAl composite in the entire composition range of TiB_2 and NiAl.

2. Experimental method

The raw materials were commercially available TiB_2 powders of 99.9% purity, Al powders of 99.9% purity and Ni powders of 99.9% purity (all powders by Furuuchi Chemical Corp.). The diameter of TiB_2 powder particles was a few microns and those of Al and Ni powders were around 10 microns. NiAl has the CsCl type lattice structure for the atomic ratio of Ni between 50 % and 60%. In the present study, the ratio of Ni in NiAl is fixed to 55atomic%.

A graphite die, having an internal diameter of 20mm and a wall thickness of 10mm was filled with 5g of the mixed powders of TiB_2-NiAl, sealed by two graphite punches and mounted on the equipment, SPS-1050 fabricated by Sumitomo Coal Mining Ltd. The mixed powders were heated to a definite temperature between 1273K and 1673K with the rate of 50K/min, kept for 10 minutes, and then furnace cooled to room temperature. The temperature was measured using the infrared radiation thermometer IR-AHS0 fabricated by Chino Corporation. Sintering was performed in a vacuum with a residual pressure of 50Pa. A uniaxial pressure of 20MPa was applied during the sintering.

Density of the samples was calculated from the volume and the mass of the samples. SEM observation was performed using a Hitachi H-3300 instrument. X-ray diffraction patterns were measured using Rigaku X-ray diffractmeter with Cu-kα radiation source. Vickers hardness was measured using a Shimadzu HMV-2 micro hardness tester with the load of 19.6N and pressing time of 15 seconds. To perform the bending test, rectangular shape samples with the size of 2x3x20 mm^3 were cut by the electric discharge. Three point bending tests were performed using a Shimadzu AGS-J test machine with the crosshead speed of 0.5mm/min and the span of 15mm.

3. Results and discussion

Figure 1 shows the X-ray diffraction pattern of the polished surface of TiB_2-40wt%NiAl and TiB_2-80wt%NiAl specimens sintered at 1673K. As shown in Fig. 1, in the X-ray diffraction patterns of both two specimens, peaks from TiB_2 of hexagonal AlB_2 type and NiAl of cubic CsCl type lattice structures have been observed. These results show that NiAl and TiB_2 co-exist in equilibrium at 1673K.

Figures 2 (a) and (b) show the SEM images of the polished surface of the TiB_2-80wt%NiAl and TiB_2-40wt%NiAl specimens sintered at 1673K. In Fig. 2 (a) and (b), it is found that NiAl fills the space between TiB_2 grains and a dense specimen is obtained showing good wetting property of TiB_2 and NiAl. The size of TiB_2 particle is several microns which is

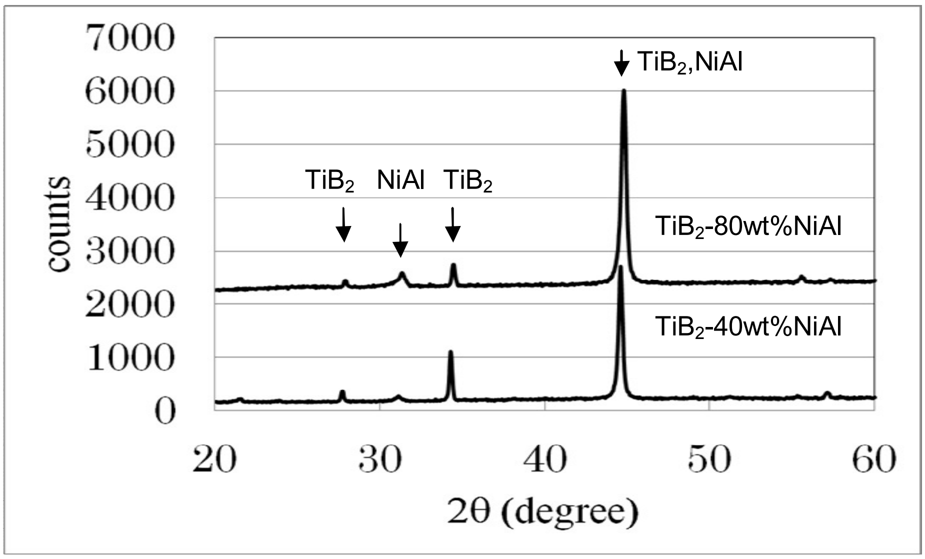

Figure 1. X-ray diffraction pattern from TiB_2-40wt% NiAl and TiB_2-80wt% NiAl sintered at 1673K

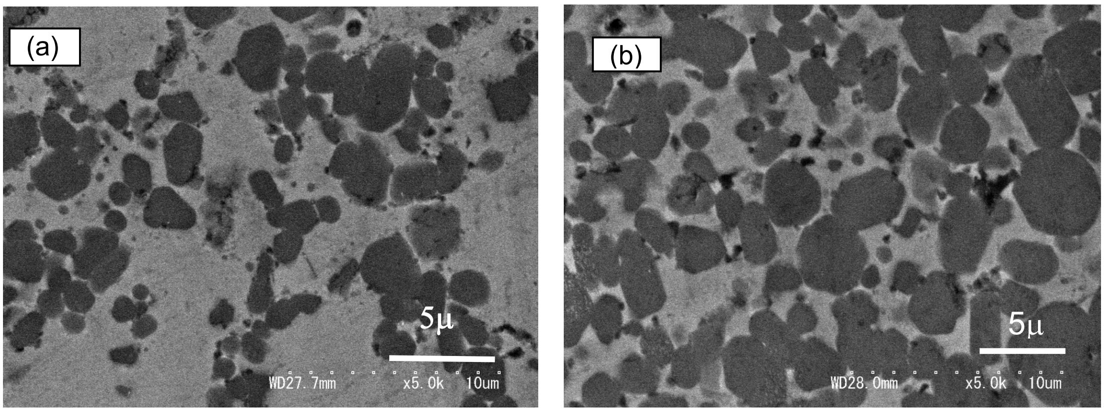

Figure 2. SEM image of TiB_2-80%NiAl (a) and TiB_2-40%NiAl (b) sintered at 1673K

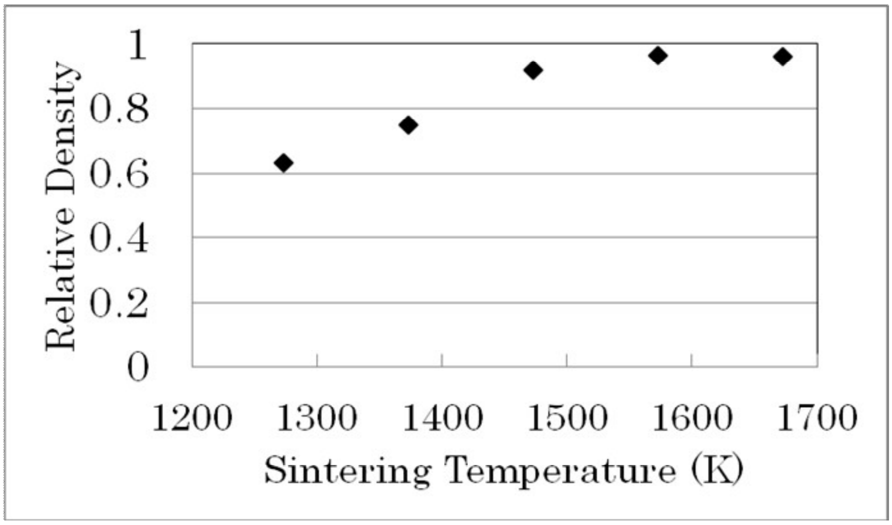

Figure 3. Dependence on the sintering temperature of the Relative density of TiB_2-40wt%NiAl

the same as that of the starting particles.

In Figure 3 is shown the relative densities of TiB_2-40wt%NiAl specimens sintered between 1273K and 1673K. The density of TiB_2-40wt%NiAl increases as the sintering temperature increases up to 1573K. The relative density of TiB_2-40wt%NiAl sintered at 1573K is 96% (density 4800kg/m^3).

In order to investigate the mechanical properties of TiB_2-NiAl composite specimens, the Vickers hardness measurements and the three point bending tests were performed. Figure 4 shows the dependence on the amount of NiAl of the Vickers hardness, Hv, of the TiB_2-NiAl composite sintered at 1573K. The Hv value of TiB_2 sintered at 1573K without NiAl is as low as 750 Hv. The Hv increases rapidly with the addition of NiAl. The Hv value of the TiB_2-NiAl composite reaches the maximum value of 1600 Hv for 40wt% NiAl. Increasing the content of NiAl beyond 40% leads to a decrease of Hv. This is because the Hv value of monolithic NiAl is as low as 380MPa. This behavior of the Vickers hardness of the TiB_2-NiAl system is similar to that of the TiB_2-Al_3Ti systems, even though the highest Hv value of the TiB_2- NiAl composite is smaller than that of the TiB_2-Al_3Ti composite (The highest Vickers hardness for TiB_2-Al_3Ti composite system is 2100Hv for TiB_2-30wt%Al_3Ti [3]).

Figure 5 shows the dependence on the amount of NiAl of the bending strength of the TiB_2-NiAl composite sintered at 1573K. The bending strength of TiB_2 sintered at 1573K is 250MPa, which increases gradually as the amount of NiAl increases. The bending strength of TiB_2-60wt%NiAl which has the highest Vickers hardness is 730MPa. The highest bending

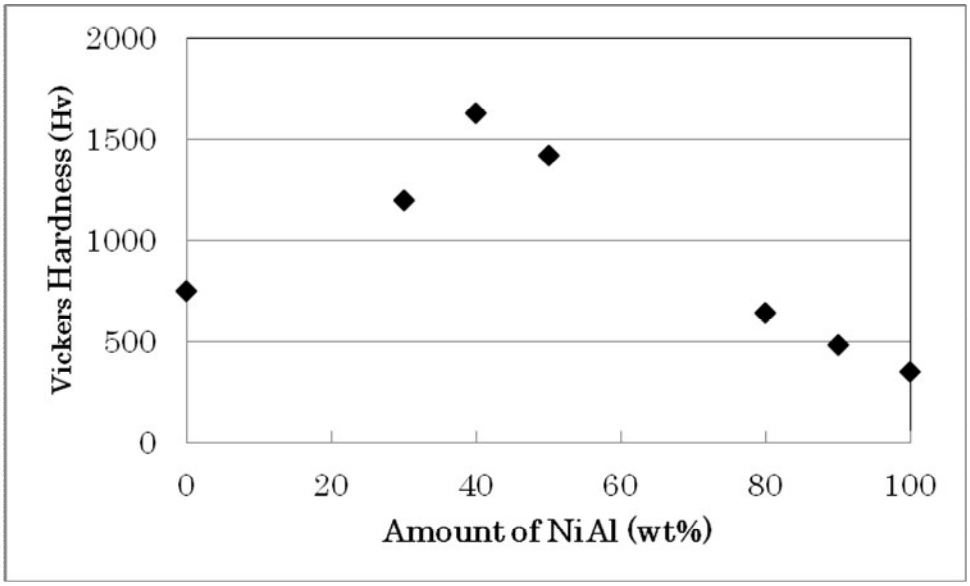

Figure 4 Dependence on the amount of TiB_2 of the Vickers hardness, Hv, of the TiB_2-NiAl composite sintered at 1573K

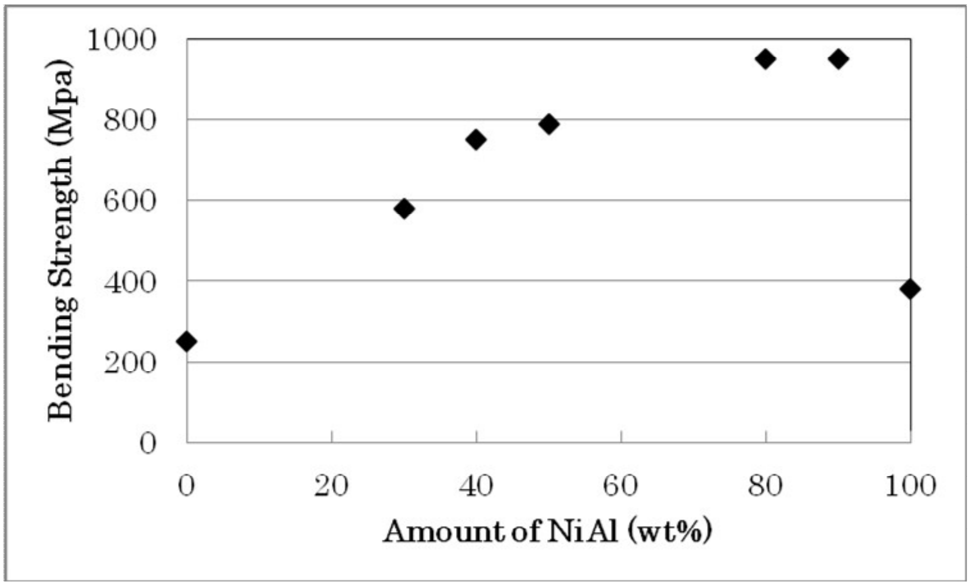

Figure 5 Dependence on the amount of TiB_2 of the bending strength of the TiB_2-NiAl composite sintered at 1573K

strength of the TiB_2-NiAl composite is as high as 950MPa for 80wt% NiAl specimen. The bending strength of the TiB_2-NiAl composite is larger than that of the TiB_2-Al_3Ti composite (the highest bending strength for TiB_2-Al_3Ti composite is 660MPa for TiB_2-30wt%Al_3Ti [4]). The bending strength of the TiB_2-NiAl composite decreases rapidly as the amount of NiAl increases above 90%.

4. Conclusion

TiB_2-NiAl composite specimens have been sintered using spark plasma sintering at temperature between 1273K and 1673K. By the x-ray diffraction measurements it has been shown that TiB_2 and NiAl co-exist in equilibrium at the temperature up to 1673K. By the

SEM observation it has been shown that NiAl fills the space between TiB_2 grains and dense samples are obtained. The highest Vickers hardness of 1600Hv has been obtained for TiB_2-40wt%NiAl, which has bending strength of as high as 730MPa. The highest bending strength of 950MPa has been obtained for TiB_2-80wt%NiAl. The bending strength of the TiB_2-NiAl composite system is larger than that of the TiB_2-Al_3Ti composite system for wide composition range between 10wt% and 70 wt%, while the highest Vickers hardness of the TiB_2-NiAl composite is 1600Hv, which is smaller than that of the TiB_2-Al_3Ti composite, 2100Hv.

References

[1] R. A. Cultuler, Engineering Materials Handbook, Vol. 4, pp787-811, ASME International, 1991.

[2] W. Wang, Z. Fu, H. Wang and R. Yuan, Influence of hot pressing sintering temperature and time on microstructure and mechanical properties of TiB2 ceramics, J. European Ceramic Society, Vol. 22, pp1045-1049, 2002.

[3] M. Yoshida, Materials Transaction, “Influence of Sintering Temperature on the Microstructure of TiB_2 Sintered with Al_3Ti Additive”, vol 53, pp1648-1651, 2012.

[4] M. Yoshida and T. Yumitate, “Mechanical Properties of TiB_2-Al_3Ti and TiB_2-$(Al,Ni)_3Ti$ Composites”, Material Transaction, vol 53, pp1933-1937, 2012.

[5] J. D. Whittenberger, R. K. Viswanadham, S. K. Mannan and B. Sprissler, “Elevated temperature slow plastic deformation of NiAl-TiB_2 particulate composites at 1200 and 1300K”, J. Materials Science, vol 25, pp35-44, 1990.

[6] J. T. Guo, D. T. Jiang, Z. P. Xing, G. S. Li, “Tensile properties and microstructures of NiAl-20TiB_2 and NiAl-20TiC in situ composites”, Materials and Design, vol 18, Nos. 4/6, pp357-360, 1997.