Sintering, microstructure and properties of WC-FeAl-B and WC-Ni3Al-B composite materials

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Chapter 6 Conclusions

Uniaxial hot pressing of WC-FeAl-B, WC-Ni_3Al-B and WC-Co composites at optimum temperature of 1500 °C (higher than the melting points of FeAl and Ni_3Al alloys) under inert atmosphere was carried out and the conclusions are as follows:

1. Based on XRD, TEM, TEM-EDS and electron diffraction investigations no new phases were detected in the WC-40vol%(FeAl-B) and WC-40vol%(Ni_3Al-B) composites at 1500 °C with boron additions of up to 0.1 wt%. This indicates that with increasing amount of boron up to 0.1wt%, WC and aluminides are stable in the WC-FeAl-B and WC-Ni_3Al-B systems. One reason for absence of new phases could be due to much lower present boron concentration below the boron solubility limit in the particular aluminides.

2. Tungsten was dissolved in FeAl (0.7 at%) and Ni_3Al (1.2 at%) binders at the sintering temperature 1500 °C. The W solubility in FeAl and Ni_3Al binders increased to around 2.7 at% and 3.5 at %, respectively by increasing the amount of boron up to 0.1 wt%. This is could be because dissolved boron decreases the melting points of the particular aluminides.

3. The microstructures of WC-40vol%(FeAl-B) and WC-40vol%(Ni_3Al-B) composites contained faceted WC particles with sharp edges surrounded by the binders with no voids presence at the WC/binder interfaces. The microstructure was similar to those of WC-40vol%Co and commercial WC-10wt%Co (H10F) hardmetals.

4. The contiguity of WC particles (WC/WC contact) and the aluminide grain sizes decreased and the WC faceting increased in both WC-FeAl-B and WC-Ni_3Al-B composites with increasing the amount of boron in the binders. It is believed that the increase in the WC faceting with increasing boron content is related to increasing WC solubility in the aluminide binders with increasing boron.

5. The hardness of WC composites depended upon the hardness of the binder. WC-40vol%(FeAl-B) exhibited the highest hardness (1580 HV) followed by WC-40vol%(Ni_3Al-B) (1310 HV) and WC-40vol%Co (1200 HV). This is a

consequence of the higher hardness of FeAl-B than Ni_3Al-B followed by Co. Increasing the amount of boron in aluminide binders had no significant effect on the hardness of the WC-FeAl-B and WC-Ni_3Al-B composites. This may be explained by the observations that increases in boron content had no significant effect on the bulk hardness of both FeAl-B and Ni_3Al-B alloys.

6. The fracture toughness of the WC-40vol%Ni_3Al was higher than that of WC-40vol%FeAl and similar to that of WC-40vol%Co. This is due to the significantly lower ductility of FeAl compared with those of Ni_3Al and Co. The abrasive wear resistance of WC-FeAl was higher than that of WC-Ni_3Al, while the wear resistance of WC-Ni_3Al was comparable to that of WC-Co.

7. Increasing the boron content from 0 to 0.5wt% in WC-FeAl-B and WC-Ni_3Al-B resulted in significant improvements in both fracture toughness (42% and 38% respectively) and abrasion wear resistance (24% and 14% respectively). However, further increasing the boron content from 0.05% to 0.1wt% had no significant additional effect on these properties. WC-40vol%(Ni_3Al-0.05%B) and WC-40vol%(FeAl-0.05%B) composites exhibited higher and similar fracture toughnesses compared with that of WC-40vol%Co, respectively. The excellent wear resistance exhibited by the WC-FeAl-B and WC-Ni_3Al-B with minimum boron content of 0.05 wt% hardmetal is due to their unique combination of high hardness and fracture toughness. The beneficial effect of boron on increasing the fracture toughness and wear resistance of the intermetallic matrix composites is not only due to increasing the ductility, toughness and strength of the aluminide alloys but also importantly due to increases in WC solubility in the aluminide binders.

8. Abrasive wear testing results of the boron doped aluminide matrix WC and WC-Co composites exhibited similar morphologies in their worn surfaces. The surfaces were abraded by a combination of ductile processes including microploughing and microcutting, and brittle processes including pull-out of particular phases and cracking of the carbide particles. Increasing the amount of boron in the aluminide binders resulted in decreasing of surface abrasion via brittle processes as a result of the increasing the fracture toughness with increasing boron content.

Finally, it is suggested that FeAl-B and Ni_3Al-B alloys can be considered as significant potential alternative binders in WC composites. They have suitable wettability with WC, significant solubility of WC, are non-carbide formers, have thermodynamic stability, melt at not too high temperatures, and have higher hardness, toughness and wear resistance than Co. The higher cost of synthesis of the intermetallic matrix WC composites by hot pressing under controlled atmosphere compared with the production of conventional WC-Co seems the main drawback to commercial production of these hardmetals. However, this research showed that WC composites based on boron doped FeAl or Ni_3Al binders demonstrate excellent combinations of high hardness, fracture toughness and abrasion wear resistance compared with that of WC-Co hardmetals. Moreover, recently a limited number of studies showed that WC-FeAl and WC-Ni_3Al hardmetals have superior corrosion resistance compared with WC-Co, and also that their strength increases with increasing temperature up to about 800 °C. Therefore, WC-FeAl-B and WC-Ni_3Al-B hardmetals could provide superior performance in particular applications that require high hardness and fracture toughness (especially WC-Ni_3Al-B composites), wear resistance (especially WC-FeAl-B composites), corrosion resistance and high strength at high temperatures.

Suggestions for Further Work

1. Based on the review of the literature it is well established that boron segregates to aluminide grain boundaries. Aluminide binders (or ligaments) between WC particles act as single crystals, it is thus expected that boron could be segregated on the WC/aluminide interfaces. This segregation could be investigated by atom probe ion microscopy.

2. Boron addition to FeAl and Ni_3Al alloys results in a decrease in their melting points. The lower melting point of the binder in hardmetals leads to lower sintering temperature and consequently lower liquid phase sintering process cost. It is, therefore, suggested that hot pressing of the WC composites base on the boron doped aluminide binders should be carried out at the lower temperature and much longer sintering time than those used in this research work to study their densification behavior.