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Abrasive wear of WC–FeAl–B and WC–Ni_3Al–B composites

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Abstract

The abrasion resistance of WC–40vol%(FeAl–B), WC–40vol%(Ni_3Al–B), and WC–40vol%Co, prepared from ultra fine precursor powders and processed by uniaxial hot pressing, has been investigated using a pin-on-drum tester. Intermetallic binders, with different amount of boron including 0, 250, 500, 750, and 1000 ppm B, were prepared in ultrafine form under controlled atmosphere using ring grinding, blended with submicron (0.8 μm) WC powder and then uniaxially hot pressed at 1500 °C under a pressure of 20 MPa for 4 min in 10^{-2} MPa argon atmosphere. In an additional investigation, wear results were compared with that of commercial H10F (WC–10wt%Co, WC particle size of 0.7 μm). It was found that the wear resistance of WC–FeAl–B and WC–Ni_3Al–B increased with the increasing amount of boron. WC–40vol%FeAl–B showed the highest abrasion resistance, close to that for WC–10wt%Co (H10F) composite, followed by WC–40vol%Ni_3Al–B and WC–40vol%Co.

Keywords: Sliding wear; Intermetallic matrix composites; Hardmetals; WC composites; Aluminides

1. Introduction

Cemented carbides are generally considered to be highly resistant to abrasive wear due to their unique combination of high hardness and moderate levels of fracture toughness. This is one of the important reasons for the selection of these materials for a large number of applications in cutting tools, drilling and mining equipment [1,2].

The abrasion resistance of the WC–Co composites has been found to depend on hardness, toughness, and microstructural parameters such as binder mean free path and WC grain size [3,4]. Larsen-Basse [5] pointed out that ductile binders in WC hardmetals with a good bonding to the carbide grains could result in the optimum performance but the hardness of the binders is another property which will affect abrasion resistance. The aluminides have many attributes necessary for superior wear resistance such as high hardness, high elastic modulus and good environmental resistance and these are therefore specially promising tribological materials need in aggressive environment at elevated temperatures [6]. Johnson et al. [7] reported that iron aluminides are very resistant to abrasive wear and erosion, and they have significantly greater abrasive wear resistance compared with the nickel aluminides and 304 stainless steel at high temperatures. Alloys based on the ordered intermetallic compounds Ni_3Al and Fe_3Al are also being investigated as alternative materials for more several abrasive wear and erosion applications [7]. The area of intermetallic composites is relatively new and it is important to note that while many potential applications are being pursued, but it seems that currently no intermetallic composite components are in use in industrial applications [8]. In intermetallic/ceramic systems, an important requirement for high interface strength between matrix and particles is thermodynamic stability and compatibility. If thermodynamic stability is not ensured, reaction

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products at the intermetallic/ceramic interface may adversely affect interfacial bonding [9]. Thermodynamic calculation carried out by Misra [10] show that FeAl is chemically compatible at 1273 K with a wide range of ceramics such as carbides, borides, oxides, and nitrides. Thermodynamically, WC has sufficient wettability with FeAl [11] and Ni_3Al [12] and the possibility of forming compacts of WC–FeAl and WC–Ni_3Al have been reported by Mosbah et al. [13] and Tumanov et al. [12], respectively. The former produced the WC–FeAl composites with high density by the liquid phase sintering technique with uniaxial pressure. Recently, Ahmadian et al. [14] observed the beneficial effect of boron in hot pressed WC–FeAl–B and WC–Ni_3Al–B composites. They found that the minor addition of B resulted in higher toughness and inhibited WC grain growth comparable to conventional WC–Co composites.

The present paper reports the sliding wear behavior of WC–FeAl–B, WC–Ni_3Al–B, and WC–Co sintered compacts processed under similar processing conditions with different boron levels. The phase compositions and surface morphologies of the wear testing were examined, and characterised by means of X-ray diffraction and scanning electron microscopy with incorporated energy dispersive spectrometry.

2. Experimental procedure

2.1. Intermetallic compounds and composites processing

WC–40vol%(FeAl–B) and WC–40vol%(Ni_3Al–B) composites with an average grain size of carbide 0.69 μm have been investigated. To compare the results of these composites to that of tungsten carbide hardmetals based on cobalt, WC–10wt%Co (H10F) with WC grain size of 0.8 μm, manufactured by Sandvik Hardmaterials and WC–40vol%Co were also investigated. WC–40vol%Co composite with grain size of carbide 0.69 μm was produced under processing conditions similar to that used for the intermetallic matrix composites. Binder alloys, Fe–40at%Al (FeAl) and Ni_3Al, doped with different amount of boron, 0, 250, 500, 750, and 1000 ppm B, were produced using vacuum arc melting and chill casting. The commercially elemental ingredients of 99.9% or above purity were used. Ingot melting, cutting, turning and mixing was repeated several times to ensure homogeneity of boron. Intermetallic ultrafine powders were produced in controlled atmosphere ring grinding using a stainless steel ring grinding vessel under helium inert atmosphere. Blending of intermetallic and cobalt powders with WC powder of average grain size of 0.69 μm was carried out by cylindrical mill under helium atmosphere. Samples with near full density were prepared for wear testing by uniaxial hot pressing using graphite dies with 6.35 mm internal diameter. Induction heating was carried out under the controlled atmosphere and constant load of 20 MPa. All the cermets were sintered using a uniaxial hot press at 1500 °C for 4 min under a partial Argon atmosphere of about 10^{-2} Pa. Vickers hardness of the sintered materials was determined from polished specimens using an Indentec hardness tester with loads of 10, 20 and 30 kg. The densities of the specimens were determined by immersion in water using Archimedes' principle. Details on the composite fabrication can be found elsewhere [14].

2.2. Abrasion wear testing

Abrasive wear performance of the intermetallic matrix composites and the WC–Co hardmetals was evaluated using a pin-on-drum apparatus at ambient conditions, as per ASTM G 132 standard, under a 100 N load and a sliding speed of 0.04 m/s. The pin-on-drum wear test involves high-stress, two-body abrasion, in which one end of the specimen (cylindrical pin, 6.35 mm in diameter by 20–30 mm in length) is moved over an abrasive sheet which is attached to the drum using an adhesive. The composite pin samples were abraded against 150 grit silicon carbide, with a nominal abrasive particle size of 105 μm and hardness of 24.0 GPa. The drum was rotated at 60 rpm and the wear path was maintained 6 m. After testing, specimens rinsed in alcohol, cleaned ultrasonically, dried and weighted to within ±0.0001 g. Typically, 10 separate tests were performed on each sample and the mass loss for each specimen from the individual wear tests was averaged and the standard deviation calculated. The wear rate was expressed in terms of mass loss (which is the difference between the specimen weight before and after the test). Wear surface microstructures of the abraded pins were examined by SEM.

3. Results and discussion

3.1. Wear behavior of WC composites based on intermetallic binders

Values of hardness for these composites are listed in Table 1. Hot pressing resulted in dense materials with densities ranging from 94% to 98% theoretical density. However, the results showing that the hardnesses of WC–FeAl–B composites are higher than those of WC–Ni_3Al–B composites.

The mass losses of WC–40vol%(Ni_3Al–B) and WC–40vol%(FeAl–B) composites as a function of boron content are shown in Fig. 1.

It can be seen that the mass loss of WC–40vol%-(Ni_3Al–B) and WC–40vol%(FeAl–B) decrease with the increases in boron level. This is more pronounced when boron is present in quantum of less than 500 ppm, and