Int. Journal of Refractory Metals and Hard Materials 49 (2015) 212–218

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

journal homepage: www.elsevier.com/locate/IJRMHM

The use of niobium carbide (NbC) as cutting tools and for wear resistant tribosystems

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ARTICLE INFO

Article history:
Received 21 February 2014
Received in revised form 19 June 2014
Accepted 2 July 2014
Available online 8 July 2014

Keywords:
Sliding friction
Sliding wear
Ceramic
Oscillation
Coating
NbC
Niobium carbide
Hard metal
Cobalt

ABSTRACT

The tribological profile of alumina (99.7%) mated against rotating disks made in binder-less niobium carbide (NbC) and cobalt-bonded NbC were determined under unidirectional sliding tests (0.1 m/s to 8.0 m/s; 22 °C and 400 °C) as well as in oscillation tests (f = 20 Hz, Δx = 0.2 mm, 2/50/98% rel. humidity, n = $10^5/10^6$ cycles) under unlubricated (dry) conditions. In addition, the microstructure and mechanical properties of binderless NbC and NbC bonded with 8% cobalt were determined as well. The reason for testing hot-pressed NbC was to avoid side effects generated by sintering additives and/or second phases. The tribological data obtained were benchmarked with different ceramics, cermets and thermally sprayed coatings. NbC and cobalt-bonded NbC exhibited low wear rates under dry sliding associated with high load carrying capacity. The tribological profile established revealed a strong position of NbC bearing materials under tribological considerations and for closed tribo-systems against traditional references, such as WC, Cr_3C_2 and (Ti,Mo)(C,N).

1. Introduction

As refractory carbide, niobium carbide (NbC) is today still a forgotten carbide with hidden properties. The poor sintering ability may have represented one of the causes, which can today be overcome by either hot pressing, high-frequency induction heated sintering or by plasma-spark sintering. Ceramic composites containing niobium carbide suited for electrical discharge machining were elaborated.

Nevertheless, little data on the tribological profile on binderless or metal bonded niobium carbide are available. The tribological properties of NbC are unexplored, although NbC is a property-determining constituent in many steels and hard metals as well as in cast irons [1,2].

Densification of pure niobium carbide by hot pressing enables the determination ofthe fundamental (intrinsic) contribution of NbC to the tribological profile, including tribo-oxidation, without having side effects from binder metals or sintering aids. On the other hand, as shown in this paper, cobalt binder improves properties like toughness and strength as well as reduced the sintering and times and temperatures needed for densification.

Their most significant technical application until today has been reserved for tungsten carbide typically in the form of cemented carbides (hard metals). The applications of straight tungsten carbides range from metal cutting and wire drawing, as well as oil & gas drilling and mining, mineral and ground tools to rolling. For wear applications, hard metals are deposited as coatings by means of thermal spraying.

A significant increase in labor cost and taxes in China as well as in mining costs and increased domestic consumption escalated the prices for tungsten. Niobium represents a possibility in substitution and in supply to tungsten.

2. Experimental procedure

Different types of test pieces for tribological and mechanical testing were prepared by means of electrical discharge machining (See Fig. 1). The planar surfaces of the tribological samples were finished by lapping for HP–NbC to R_{pk} = 0.14 μm and R_{vk} = 0.84 μm and for NbC–8Co to R_{pk} = 0.213 μm and R_{vk} = 0.219 μm. Additionally, some NbC–8Co samples for oscillating dry sliding were polished to R_{pk} = 0.007 μm and R_{vk} = 0.009 μm.

2.1. Binderless niobium carbide

Niobium carbide was produced from a commercially available high purity niobium pentoxide (Nb_2O_5) powder (CBMM grade HP311). In this process lignite was blended with Nb_2O_5 powder and subsequently loaded into a furnace that was pre-heated to a temperature slightly

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http://dx.doi.org/10.1016/j.ijrmhm.2014.07.002
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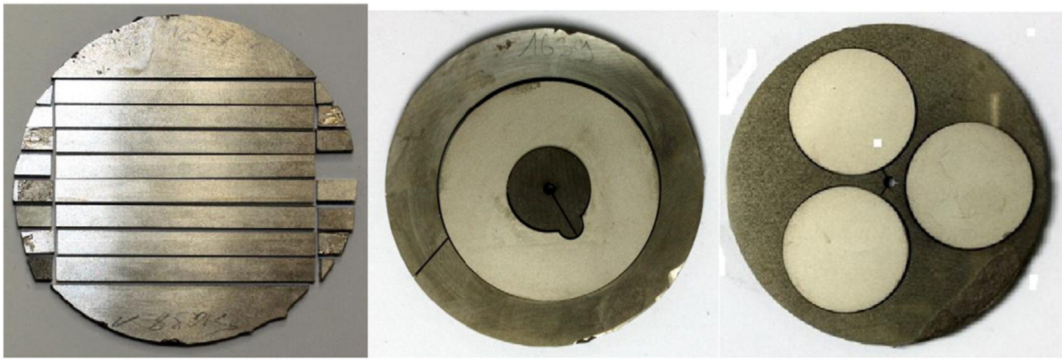

Fig. 1. Different samples machined by electro-discharge; machined from disks (bottom raw).

above 1200 °C under a mixture of $5\%H_2/95\%N_2$ as operating atmosphere. The granulometry of the NbC powder was $d_{50} = 3.86$ μm and $d_{90} = 18.12$ μm. The progress of the carburization reaction was monitored by measuring the CO(g)-concentration in the out-going gas. After completed carburization the sample material was moved into a cooling zone and held under a slightly reducing atmosphere consisting of N_2/H_2.

Fraunhofer IKTS (Dresden, Germany) manufactured disks with a diameter of 60 mm and a height of 6 mm. Hot-pressing was performed without the use of sintering additives at 2150 °C under 50 MPa (4 h, 10 K/min) reaching an average density of 7.68 g/cm^3. Entirely cubic NbC corresponding to JCPDS 38-1364 was identified by XRD in the hot-pressed disks. The microstructure (see Fig. 2) analyzed by FESEM (Field Emission SEM) revealed dense sintering along the NbC grain boundaries. The micro-hardness over the disk height and the diameter in the middle of the height was uniform and averaged to 1681 ± 92 HV0.2. The binderless HP–NbC1 did not however reach the theoretical density, due to a reaction between the Nb_2O_5 present on the surfaces of the NbC grains with NbC. This grain porosity shown in Fig. 2 is also responsible for the reduced micro-hardness as compared to literature data.

2.2. Cobalt bonded niobium carbide

Commercially available NbC powder (Treibacher 100, FSSS = 1.18 μm, Austria) and cobalt powder (Umicore grade Co-HMP, Belgium) were used for realizing the NbC–8Co with a cobalt content

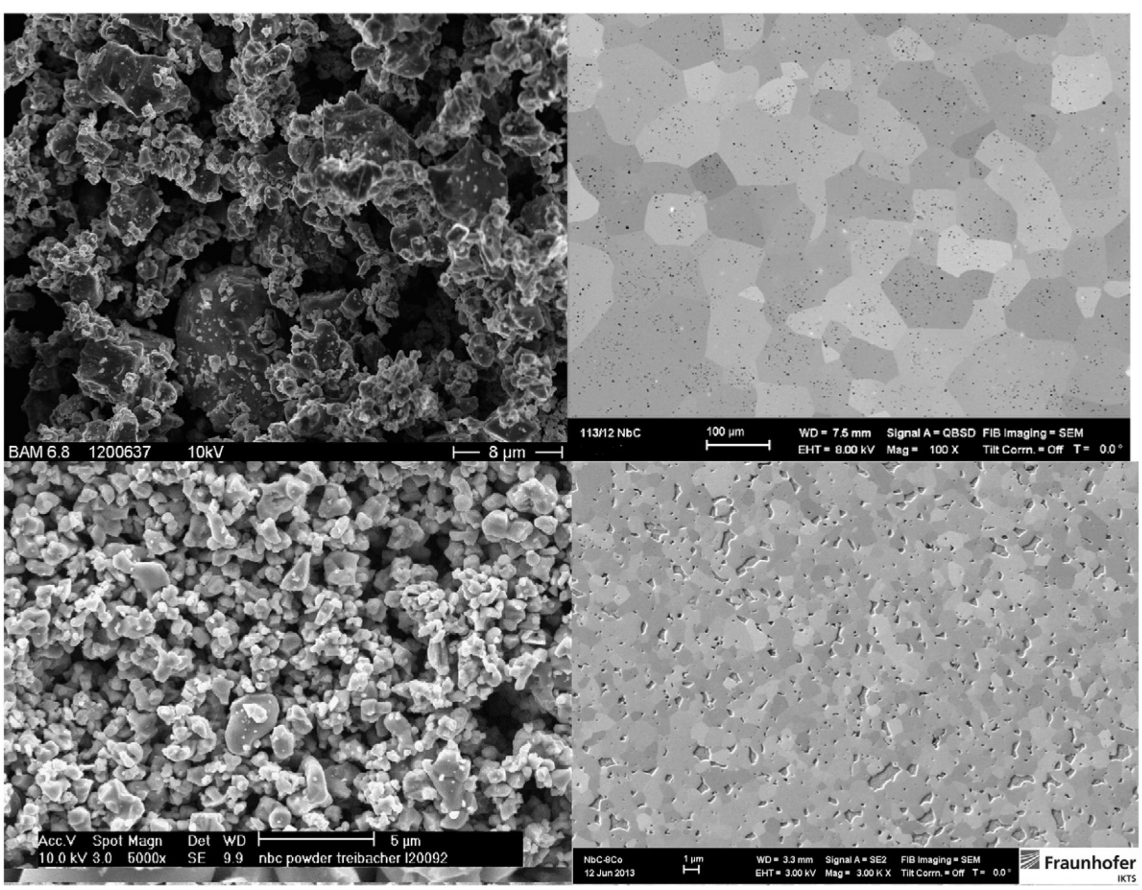

Fig. 2. Morphology of powder (left) and microstructure of sintered samples (FESEM, right). Hot-pressed and binderless NbC1 (top, [14]) and SPS sintered NbC–8Co (bottom).