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Dynamic hardness of cemented tungsten carbides

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ABSTRACT

Cemented tungsten carbides are composed of a hard tungsten carbide (WC) phase held together by a soft, ductile binder phase, typically cobalt (Co). This study examines the role of the binder composition and content on the Knoop hardness at quasi-static and dynamic strain rates. Seven different tungsten carbide materials were tested: four WC-Co systems containing 10%, 15%, 20% and 25% cobalt, two with a chromium-nickel alloy binder phase, and one “binderless” tungsten carbide. Quasi-static Knoop hardness testing was performed at strain rates of $10^{-3}\,s^{-1}$ and at indentation loads between 300 and 30,000 g using a Wilson Tukon 2100 unit. Dynamic Knoop hardness testing was conducted at strain rates of $10^{3}\,s^{-1}$ using a Dynamic Indentation Hardness Tester over a range of indentation loads. All of the materials exhibited a rate-dependent Knoop hardness, with the hardness increasing by up to 60% with increasing strain rate.

1. Introduction

Hardness is a measure of the resistance of a material to permanent deformation under an applied load. The problem with determining the hardness of ceramic materials is that ceramics are inherently brittle and exhibit minimal, if any, plastic deformation during the indentation process. This can lead to hardness indentations with excessive cracking and spalling, which complicates the hardness determination. The use of the Knoop hardness method has proven to be the most effective method of determining the hardness of many advanced ceramics over a broad range of indentation loads [1]. In the Knoop hardness method, a load is applied to an elongated, symmetric pyramidal diamond indenter, which is placed in contact with the material to be tested. This process causes deformation of the material leaving a permanent impression that is used to determine the hardness. The geometry of the Knoop indenter is such that the ratio of the long and short diagonals is approximately 1:7, while the ratio of the resulting long diagonal to the indentation depth is approximately 1:30, making the Knoop geometry useful for materials with a high likelihood of spallation and crack formation occurring during the indentation process.

Dynamic testing at high strain rates (10^{2}–$10^{4}\,s^{-1}$) bridges the gap between the quasi-static laboratory testing and the very high strain rates (10^{5}–$10^{6}\,s^{-1}$) experienced during high-speed machining [2] and ballistic impact events [3]. Rough bounds for these strain rate testing regimes are illustrated in Fig. 1. Many materials exhibit rate-dependent properties. Thus high strain rate testing is necessary to fully characterize and evaluate a material that may be exposed to such conditions. Previous work has established that many metals [4–8] and ceramics [4,6,9,10] exhibit a higher hardness during high-strain-rate indentation testing when compared to quasi-static hardness values.

Cemented tungsten carbide materials have high strength, hardness, and fracture toughness; these properties are desirable for many engineering applications, including cutting tools for material machining and mining as well as military applications in armor-piercing projectiles. Binder content and tungsten carbide grain size can be used to tailor the hardness and fracture toughness for the intended application. Cobalt is the traditional binder material due to its ability to wet and dissolve the WC without forming a third phase [11]. However, the US Department of Health and Human Services' National Toxicology Program has listed Co as reasonably anticipated to be a human carcinogen [12]. These health concerns, combined with the fluctuation of global cobalt prices and availability due to economic and political instability in many of the countries [13–15] with cobalt deposits, have led to the exploration of alternative binder materials as replacements for cobalt.

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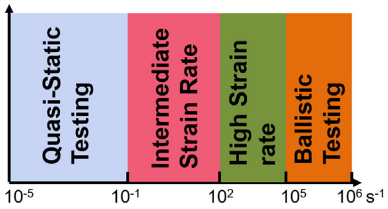

Fig. 1. Strain rate domains ranging from normal quasi-static laboratory testing to very high strain rates in the ballistic realm.

Table 1
Properties of WC materials.

Material	Binder	Binder wt%	Average WC Grain Size (μm)
Cercom WC[a]	N/A	≈0%	0.4
Kennametal S105	Co	10%	0.6
MPI 15	Co	15%	1.7
MPI 20	Co	20%	1.1
MPI 25	Co	25%	1.5
Kennametal KFY	$CrNi_3$	10%	0.6
Kennametal BFY	$CrNi_3$	10%	0.9

[a] This is considered binderless; however, it does contain trace amounts of Co and V.

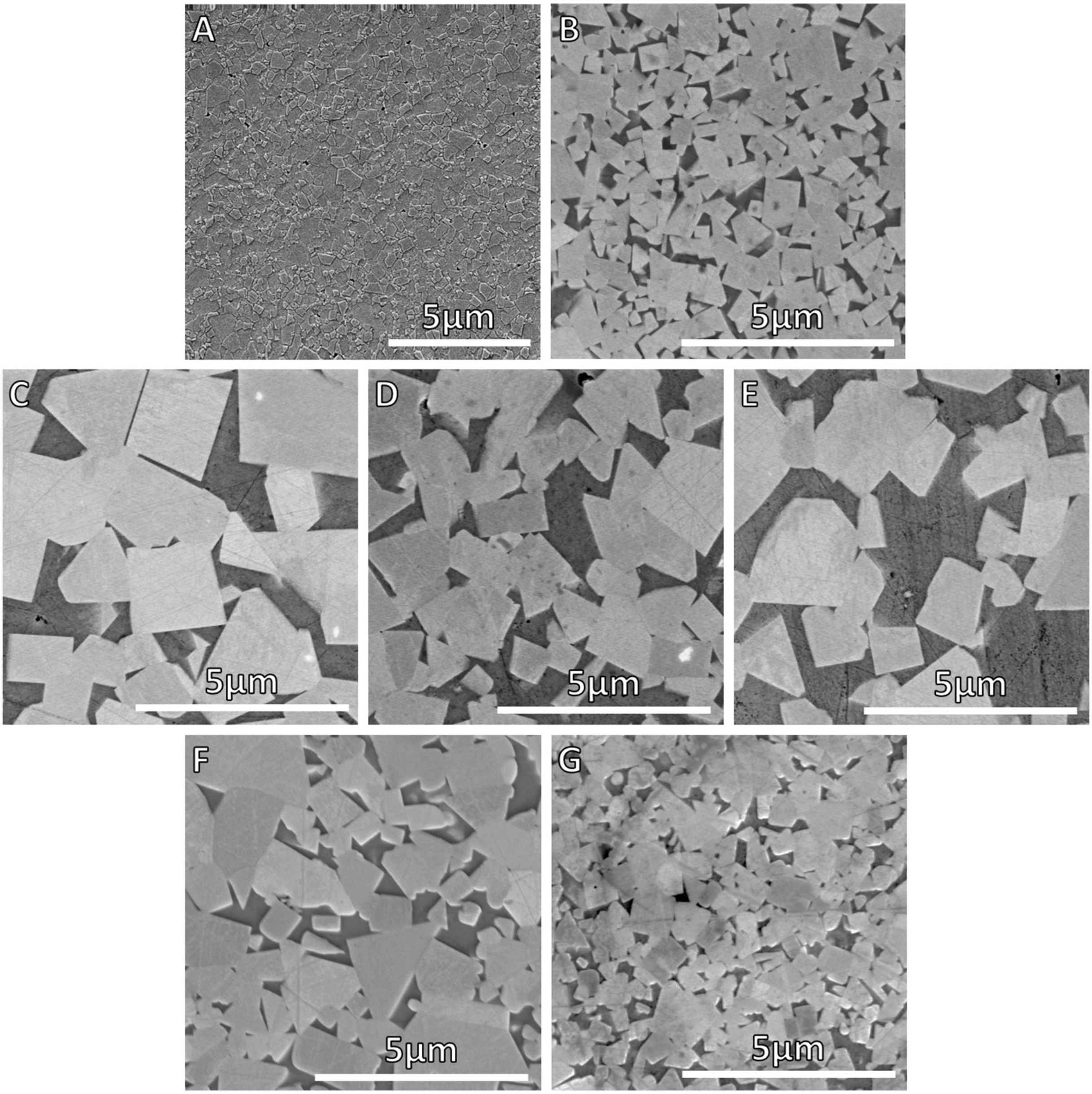

Fig. 2. Scanning electron microscopy (SEM) images of material microstructures: A) Cercom binderless WC, B) Kennametal S105 10% Co, C) MPI 15% Co, D) MPI 20% Co, E) MPI 25% Co, F) Kennametal BFY 10% Cr—Ni alloy, and G) Kennametal KFY 10% Cr—Ni alloy.