

Mechanical, Microstructural and Corrosion Characterization of Low Binder Containing WC-Co Grades Using a Binderjet Process

Krutibas Panda
Halliburton Energy Services
300 N. Sam Houston Pkwy. E.
Houston, Tx 77032
USA

Reece Goldsberry
Halliburton Energy Services
300 N. Sam Houston Pkwy. E.
Houston, Tx 77032
USA

Paul Prichard
Kennametal Inc
1600 Technology Way
Latrobe, PA 15650
USA

Ed Rusnica
Kennametal Inc
1600 Technology Way
Latrobe, PA 15650
USA

Jerry Domingue
Kennametal Inc
1600 Technology Way
Latrobe, PA 15650
USA

Zhuqing Wang
Kennametal Inc
1600 Technology Way
Latrobe, PA 15650
USA

ABSTRACT

Cemented Tungsten carbides (WC-X) have been a mainstay for wear components across many different industries including oil & gas. These ceramic-metal (cermet) systems can be widely tailored to optimize their wear resistance, corrosion resistance and toughness properties to suit their functional requirements. Conventional powder metallurgy has been the process of choice for these cermets whereby tungsten carbide powder along with a choice of metallic binder (cobalt, nickel, or alloyed binder) are pressed into a desired shape and subsequently sintered. There are manufacturing limitations to traditional powder metallurgy for parts containing high geometric complexity. In addition, secondary processing required to create complex features on press-sintered parts such as electro discharge machining (EDM) can sometime lead to micro cracking in the re-cast layer, which subsequently leads to part failure during operation. Additive manufacturing (AM) can produce cemented carbides with complex part geometry, significant weight reduction, and elimination of subsequent secondary processing to these parts. Although several AM methods have been investigated to additively manufacture cemented carbides, the present study utilized a binderjet process to manufacture two relatively low binder containing WC-Co

grades; WC-17%Co and WC-13.5%(Co+Ni+Cr+Mo). The corrosion, wear, and mechanical properties of AM cemented carbides grades were characterized in the present study. Corrosion properties of the AM grades as well as their equivalent grades fabricated using conventional PM route were compared using linear polarization resistance and cyclic potentiodynamic polarization following methods outlined in ASTM G59 and ASTM G61, respectively, in neutral 3.5% NaCl solutions. Mechanical characterization was performed using fracture toughness testing per ASTM B771 as well as transverse rupture toughness testing per ASTM B406 on these grades. Wear properties were examined according to ASTM G65 and B611. Optical and scanning electron microscopic techniques were further utilized to characterize and compare the microstructures of the samples manufactured using these two processing routes. The effect of microstructure on the resulting mechanical properties of the AM parts is also addressed in this study.

Key words: Additive Manufacturing, WC-Co, Binderjet Process

INTRODUCTION

Cemented carbides have been widely used to make parts for wear applications due to the excellent combination of hardness and toughness. Cemented carbides represent a group of composite materials containing hard metal carbides, such as tungsten carbide (WC), bonded by ductile metallic binder agents, such as cobalt (Co), nickel (Ni), or iron (Fe).¹ By varying WC grain size, weight fraction of metallic binder, and processing parameters, a wider range of microstructure and mechanical properties can be achieved.

Cemented carbide products are fabricated through a series of complex powder metallurgy (PM) processes. In conventional method, green compacts are prepared by pressing, extruding, or molding loose powders to desired shapes and sintered to final geometries.² In recent years, additive manufacturing (AM) has been viewed as an alternative approach to fabricate cemented carbides. AM allows for the fabrication of 3-dimensional components in a layer-by-layer fashion. Compared to conventional subtractive manufacturing, AM has significant design freedom and economic advantages. AM is able to make parts with complex geometries and internal channels, minimize post machining by printing near net shape geometries, reduce new product development cycles from design to finish, and recycle un-used powders to reduce the waste of raw materials

A variety of AM processes have been investigated to produce cemented carbide components. In beam-based processes, such as powder bed fusion, directed energy deposition, and electron beam melting, WC remains solid and liquid sintering occurs when metallic binder is melted by laser or electron beam. Due to high melting point of WC and rapid heating and cooling cycles in the processes, cemented carbide components usually have low densities, inhomogeneous microstructure, micro cracks, and brittle intermetallic phases.³⁻¹⁵ In sintering-based processes^{4,6,7,10,13,14}, such as binder jetting, a layer of powder is spread across the powder bed and a liquid polymer agent from an inkjet print head is selectively deposited to bond powder particles to form a green compact, as schematically shown in Figure 1.¹⁶ After the print, the green part is cured to improve green strength, depowdered to remove unbound powder, debound to remove the polymer binder, and sintered to reach full density.

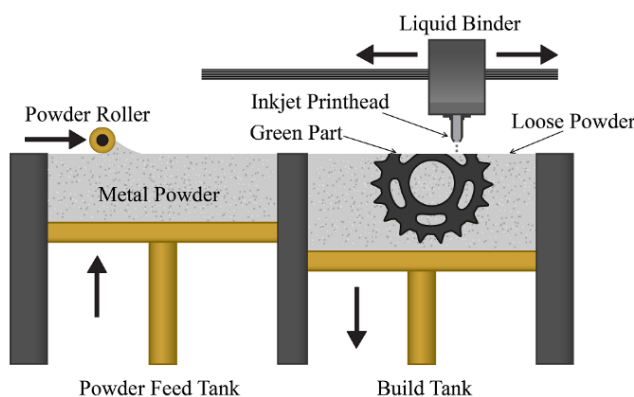


Figure 1. Schematic of binder jetting process.¹⁶

Ideal microstructure of cemented carbides is fully dense with WC grains uniformly distributed in metallic binder matrix. However, in parts made by binder jetting, inhomogeneous microstructure and defects are often observed, especially in carbides with low metallic binder contents, due to low green density after printing and inappropriate post heat treatment cycles.¹⁷⁻²⁰ Inhomogeneous microstructure includes a mixture of coarse and fine grains and patches of Co. Defects include porosity, $\text{Co}_x\text{W}_y\text{C}_z$ phase or eta phase, and graphite or C-porosity. The porosity and defect evaluation is performed in accordance with the ASTM B276²¹, ASTM B657²² and ASTM B930²³. These defects will act as stress concentration sites and largely reduce material performance.

The present study focuses on investigating microstructure and properties of two WC grades with relatively low metallic binder contents: 17 wt.% Co and 13.5 wt.% Co+Ni+Cr+Mo), made using binder jetting. Optical microscopy was applied to characterize porosity level and WC grains. Fracture toughness, transverse rupture strength, wear resistance, and corrosion properties were measured and compared to the properties from equivalent grades made using conventional PM method. The effect of microstructure on resulting mechanical, wear, and corrosion properties were also discussed.

EXPERIMENTAL PROCEDURE

Materials

In this study, two Kennametal[†] proprietary WC grades designed for binder jetting were used. KAC89-AM-K[†] designated as AM-1 is a mixture of WC grains in Co matrix and it is designed to have good wear resistance in abrasive and erosive environments. KAR85-AM-K[†] designated as AM-2 contains WC grains distributed in a lower amount of metallic binder. The additions of Ni, Cr, and Mo in Co increase the corrosion resistance, so this grade has better performance in abrasive and corrosive environment. Table 1 shows the nominal compositions for the two grades as well as their conventional equivalent grades, KHC88[†] (CE-1) and CN13S[†] (CE-2). AM test coupons were printed in ExOne machine[†] with a commercial water-based binder.

Table 1. Chemical compositions of AM-1, AM-2, CE-1, and CE-2.

Wt.%	AM-1	AM-2	CE-1	CE-2
Co	17	-	16	-
Co+Ni+Cr+Mo	-	13.5	-	13.5
WC	Balance	Balance	Balance	Balance

[†]Trade Name