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Life time of cemented carbide inserts with Ni-Fe binder in steel turning

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ABSTRACT

Health concerns associated with cobalt powder are a strong motivator for conducting research on alternative binders for cemented carbides. It has previously been shown possible to make cemented carbides with alternative binders, which offer good hardness and toughness. However, it is not fully known if these cemented carbides can be successfully used as metal cutting tools. In this study we have tested turning inserts from cemented carbide with a nickel-iron binder and compared these with cobalt based reference inserts in dry face turning of steel in a pairwise comparison. To facilitate relevant comparisons, both the alternative binder and the reference cemented carbide are gradient sintered and coated in the same way as commercial turning grades. It is found that the life time in this dry face turning test is only approximately 15% shorter with the nickel-iron binder than with the cobalt reference, which motivates further studies with this alternative binder. Flaking of the coating and thus less coating adhesion was identified as one reason for the shorter life time.

1. Introduction

Cemented carbides are used for applications that need a material with high hardness and high toughness. One of these applications is metal cutting, including steel turning, which is of great industrial importance [1]. The cemented carbides are composite materials of hard carbide grains, mainly tungsten carbide, WC, but sometimes also with cubic carbides and carbonitrides [2] as hard phases combined with a though metallic binder phase. The binder phase traditionally consists of cobalt [2]. Thus it is possible to design cemented carbides to have a hardness to toughness ratio suitable for metal cutting.

Cemented carbides are produced through a powder metallurgical route, and therefore carbide and metal powders need to be handled by the producers of cemented carbide tools and components. The possible health risks associated with inhaling cobalt powder have been investigated since the 1940 s [3] and suspicions were raised early on that cobalt powder was carcinogenic [4,5]. In 2013 an animal study by the National Toxicity Program showed that inhalation of cobalt powder increased the risks of lung cancer [6]. If it is possible to make cemented carbides with alternative binders having a performance matching those with cobalt binder the problems with cobalt powder could be eliminated or reduced.

Several alternative binders for tungsten carbide have been thoroughly investigated, including iron, nickel, alloys of the two and alloys of the two in combination with cobalt. These have been evaluated with respect to sinterability and basic mechanical properties, including hardness and toughness [7–11]. Many of these studies had metal cutting in mind as an application, but very few publications have actually tested hard metals with alternative binders in metal cutting [12–14]. The study presented in this work is an initial test on steel turning with alternative binder cemented carbides aimed at identifying important research areas for future work on replacing cobalt based cemented carbides.

Ceramic coatings were introduced on cemented carbide turning inserts in the late 1960s, resulting in substantially increased life times [1]. The coatings are typically Ti(C,N) and Al_2O_3 multilayers deposited by chemical vapor deposition, CVD. This technique allows stringent control over grain structure and crystal lattice orientation [15,16]. The purpose of the ceramic coating is to provide additional wear resistance. The Al_2O_3 acts as an inert barrier, preventing diffusion of carbon from the cemented carbide into the steel, which would otherwise cause diffusive wear [1]. It also acts as a thermal barrier, reducing the amount of heat conducted into the cemented carbide [1].

Modern turning grades contain cubic carbides and carbonitrides for increased wear resistance [2]. During sintering, a gradient of cubic carbides is formed [17,18]. The gradient consists of a depletion of cubic carbides and carbonitrides combined with an enrichment of binder phase in the surface zone [17–19]. This gives an increased toughness close to the surface, which prevents cracks from the coating to propagate into the cemented carbide, thereby avoiding crack growth and fracture [18]. Previous studies have

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Table 1
Composition of the two grades.

	Target binder phase composition [wt%]			Powder composition [wt%]							
	Co	Fe	Ni	Co	Fe	Ni	Ti	Ta	Nb	N	WC
Reference binder (R)	100	0	0	7.2	0	0	1.8	2.7	0.41	0.09	Balance
Ni-Fe binder (A)	0	14	86	0	1.1	6.5	1.8	2.7	0.44	0.17	Balance

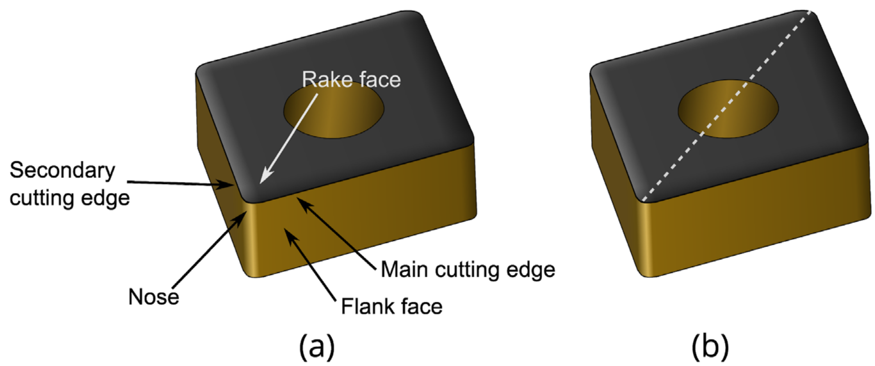

Fig. 1. Simplified drawing of the insert geometry. Note that the real inserts include a chip breaker not shown in this drawing a) The names of the different parts of the cutting edge. b) Dashed line representing the placement of cross sections.

shown that it is possible to achieve a similar gradient also with alternative binders [20,21].

Turning operations usually involve high forces and the temperature in the cutting zone can be as high as 1000 °C [1]. These conditions lead to macroscopic plastic deformation of the cemented carbide, which in some applications can limit the tool life [22]. The thermal barrier of Al_2O_3 enables turning at higher speeds without substantial thermal softening of the cemented carbide substrate [23]. The plastic deformation of the insert nose changes the geometry of the cutting edge and will eventually require replacement of the insert.

To the best knowledge of the authors, this is the first work where gradient sintered multilayer coated alternative binder cemented carbide inserts, made according to state of the art techniques, are tested in steel turning while carefully monitoring their performance and wear.

2. Method and materials

This study presents a pairwise comparison of a nickel-iron binder phase cemented carbide and a cobalt binder cemented carbide as a reference. The study was conducted to get information on if it was at all possible to use these alternative binder cemented carbides in steel turning, and what possible reasons there could be for differences in performance.

In order to be able to do a fair comparison both alternative binder and cobalt based cutting inserts were made to mimic the microstructural features in state of the art cutting inserts with cobalt binder. Thus, the alternative binder grades in this study are gradient sintered and coated following the same coating procedure used for the cobalt based reference.

2.1. Making of the inserts

A powder metallurgical route was used for producing the inserts, including mixing of metal and ceramic powders with polymer and ethanol, milling of the mixture, spray drying to remove the milling liquid, pressing into the ISO standard geometry CNMG-120408-PM and sintering in vacuum at 1450 °C for 1 h. After sintering, the inserts were edge treated to get a final edge radius of 50 μm. The details are given elsewhere [21].

The grades were designed with 12.4 vol% binder phase and 11.2 vol% cubic carbonitrides. The target binder phase compositions and the distribution of elements are given in Table 1. The target gradient thickness was 25 μm.

The inserts were CVD coated with a commercial multilayer coating of TiN, Ti(C,N), Al_2O_3, TiN. All inserts in this study were coated in the same batch. Prior to coating, the inserts were cleaned in ethanol. In a final step the TiN was removed from the rake face by blasting. Texture analysis of the coatings is outside the scope of this work but was done in a separate study by XRD and Harrie's formula [24]. It was found that while the reference had typical strong texturing of the Ti(C,N) and Al_2O_3 in line with the turning grade GC4325 [25], the Ni-Fe binder insert displayed a more random Ti(C,N) and Al_2O_3 orientation, despite being coated in the same batch.

The specific names of the different parts of the cutting edge are shown in Fig. 1.

2.2. Turning test

The two different grades were tested in a pairwise comparison in dry face turning. Cutting parameters can be found in Table 2.

Table 2
Cutting parameters in turning test.

Turning operation	Face (radial) turning
Cutting velocity	200 m/min
Feed	0.35 mm/rev
Length of one cut	59 mm
Cutting depth	2 mm
Coolant	None
Work piece material	SS2541
Work piece geometry	Cylindrical
Lathe	Mazak machining center