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Progress in development of coated indexable cemented carbide inserts for machining of iron based work piece materials

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Abstract. Increasing demands on material properties of iron based work piece materials, e.g. for the turbine industry, complicate the machining process and reduce the lifetime of the cutting tools. Therefore, improved tool solutions, adapted to the requirements of the desired application have to be developed. Especially, the interplay of macro- and micro geometry, substrate material, coating and post treatment processes is crucial for the durability of modern high performance tool solutions. Improved and novel analytical methods allow a detailed understanding of material properties responsible for the wear behaviour of the tools. Those support the knowledge based development of tailored cutting materials for selected applications. One important factor for such a solution is the proper choice of coating material, which can be synthesized by physical or chemical vapor deposition techniques. Within this work an overview of state-of-the-art coated carbide grades is presented and application examples are shown to demonstrate their high efficiency. Machining processes for a material range from cast iron, low carbon steels to high alloyed steels are covered.

1. Introduction

The introduction of cemented carbide as tool material changed the chip forming machining industry significant in the beginning of the last century. With the introduction of exchangeable tips in the mid of the last century, this progress moved further on. A further milestone was reached around 1969 when the first coated cemented carbide inserts came to the market. These first TiC coatings synthesized via chemical vapor deposition (CVD) extended the lifetime of the tools by factors of 6 to 10. Rapidly the progress moved on by using multilayer coatings of CVD TiCN-TiC to meet the required material properties for metal cutting, which are mainly wear resistivity and toughness. In the 70ies of the last century CVD Al_2O_3 as an additional coating material could be synthesized in production scale. Especially the high temperature properties like hardness at elevated temperatures and low thermal conductivity showed big improvements in steel and cast iron turning operations. In the further decades, the CVD TiCN-Al_2O_3 multilayer systems where upgraded in detail, which means deposition technology and microstructure. To increase the toughness of the tools in cutting operation and avoid the brittle eta-phase in the cemented carbide-coating interface, the deposition process was changed to a medium temperature process using CH_3CN instead of CH_4 as carbon feed. In parallel, the post treatment of such coatings was improved to decrease the surface roughness as well as to adjust the residual stresses. [1-6]

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Beside the synthesis of hard and wear resistant coatings using CVD, the physical vapor deposition (PVD) raised significantly for cemented carbide cutting tools with the introduction of TiAlN coatings at the end of the last century. Despite the huge variety of PVD coating systems used for solid carbide tools, TiAlN based coatings are still dominant when indexable inserts are used. [7-9]

The major proportion of cutting applications using indexable inserts can be covered using the CVD TiCN-Al_2O_3 and PVD TiAlN based coatings, in tailored coating thickness. For some special applications like milling of stainless austenitic steels and titanium alloys an outstanding coating system is CVD TiB_2 which is covered within this work. [10, 11]

The further development of steels in high demanding applications like gas turbines regarding high temperature strength and creep resistivity, lead to difficult du machine materials with high demands on the cutting tool. Beside the machining strategy, macro and micro geometry of the tool as well as machining conditions, the proper choice of insert grade is crucial. An all-in-one solution suitable for every purpose is usually not possible, so the aim of this paper is to point out the strengths of the different systems in the high demanding machining of turbine blades.

2. Experimental

2.1. Cutting test

To compare the machining performance of cemented carbide inserts a helirough 5-axis machining process was chosen. Therefore a martensitic stainless steel X22CrMoV12-1 (1.4923) and an austenitic stainless steel X12CrNiWTi16-13 (1.4962) in the dimensions 100×60×400 mm were selected. The cutting parameters for both materials were: cutting speed v_c = 280 m/min, feed per tooth f_z = 0.3 mm, engagement ae = 25.88 mm and maximum depth of cut $a_{p,max}$ = 3 mm. All cutting tests were carried out without coolant. A Ceratizit MaxiMill A251.40.R.04-12-RS tool holder with four bottom type cutting inserts in RPHX1204MOSN in F50 and M50 geometry, shown in Figure 1, was used. One "entry" describes the material removal around the turbine blade at one longitudinal position. The lifetime criteria is a maximum flank wear $v_{B\,max}$ = 0.5 mm or insert breakage.



Figure 1. Ceratizit MaxiMill A251.40.R.04-12-RS tool holder for turbine blade machining and the helirough machined turbine blade in the background.

2.2. Cemented carbide substrate materials

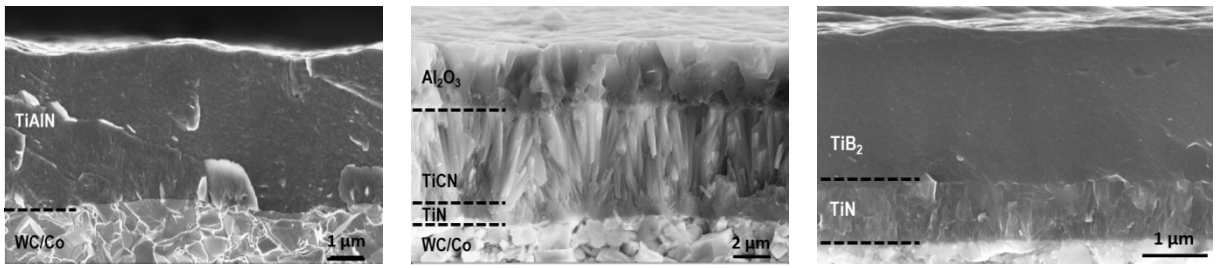
To evaluate the cutting performance within a wide range of material properties, cemented carbide grades with varying composition from ISO P20 to P45 were used and combined with CVD TiCN-Al_2O_3, PVD TiAlN and CVD TiB_2 coatings. An overview of the used combinations is given in Table 1.

Table 1. Carbide grades and coatings used in the tooling tests

ISO	Cobalt content	HV30	Coating	Ceratizit Grade
P20	8 %	1500	CVD TiCN-Al_2O_3	CTCP220
P20	8 %	1500	PVD TiAlN	CTPP225
P30	10.5 %	1400	CVD TiCN-Al_2O_3	CTCP230
P30	10.5 %	1400	PVD TiAlN	CTCP235
P40	12.5 %	1380	CVD TiCN-Al_2O_3	CTCM235
P40	12.5 %	1380	PVD TiAlN	CTPM240
P45	10 %	1330	CVD TiCN-Al_2O_3	experimental
P45	10 %	1330	PVD TiAlN	experimental
P45	10 %	1330	CVD TiB_2	experimental

2.3. Investigated coating systems

The coatings where synthesized in industrial scale ARC-PVD and thermal CVD devices. The PVD TiAlN coatings were alloyed with Ta as described elsewhere [12, 13]. The CVD TiCN coatings consists of a TiN interlayer (0.7 µm), a medium temperature TiCN layer (5.8 µm) [14], a bonding layer and corundum type α-Al_2O_3 layer in 0001 texture (3.5 µm). The CVD TiB_2 coating is deposited on a 1 µm TiN interlayer and shows despite most CVD coatings residual compressive stresses [10]. The microstructure of the coatings is shown in Figure 2.



a) b) c)

Figure 2. Scanning electron microscope cross sections of the investigated a) PVD TiAlN ,b) CVD TiCN-Al_2O_3 and c) CVD TiN-TiB_2 coatings.

Due to the fact, that metal cutting operation takes place at elevated temperatures, the temperature dependent hardness of the outermost layer is important. Therefore, the coating hardness in the as deposited state as well as the hot hardness at 500 °C are given together with the corresponding coating thickness in

Table 2. The CVD TiCN-Al_2O_3 and PVD TiAlN coatings were post-treated in order to reduce the surface roughness and tailor the stresses in the CVD coating.

Table 2. Overview of coating properties

Deposition method	Coating materials	Total thickness	Hardness RT	Hardness 500 °C
CVD	TiCN-Al_2O_3	10 µm	26 GPa [15]	16 GPa [15]
PVD	TiAlN	5 µm	28 GPa [15]	9 GPa [15]
CVD	TiB_2	3.5 µm	44 GPa [10]	-

3. Results

The lifetime of the selected carbide and coating combinations is given as number of entries of the helirough process. The Figure 3 and Figure 4 showed the lifetime with increasing toughness of the cemented carbide substrate from ISO P20 toP45 for CVD TiCN-Al_2O_3 and PVD TiAlN, respectively.

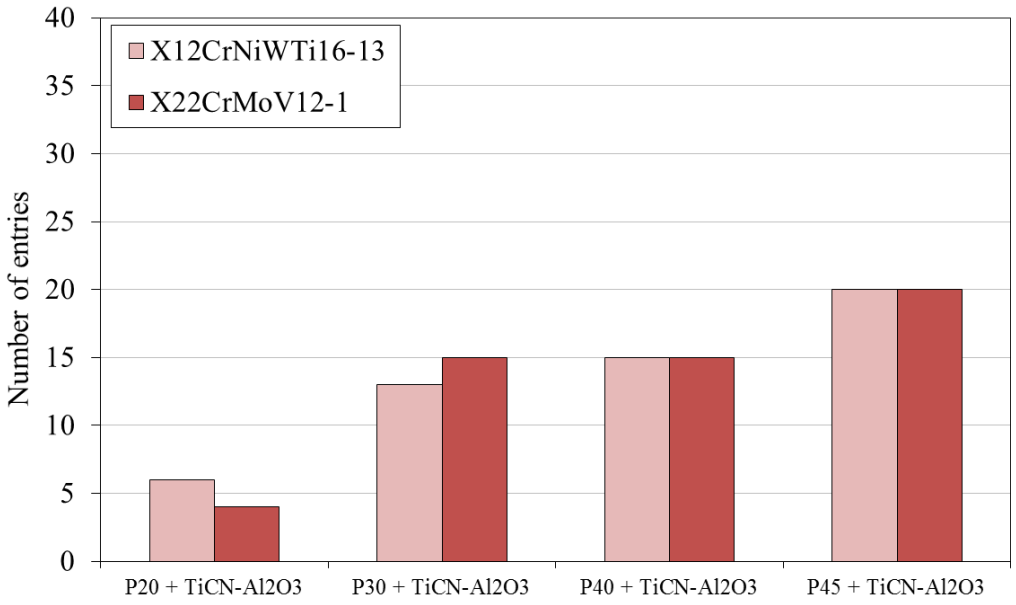


Figure 3. Lifetime of the cutting inserts with CVD TiCN-Al_2O_3 coatings, with increasing toughness of the cemented carbide from ISO P20 to P45 using F50 chipbreaker.

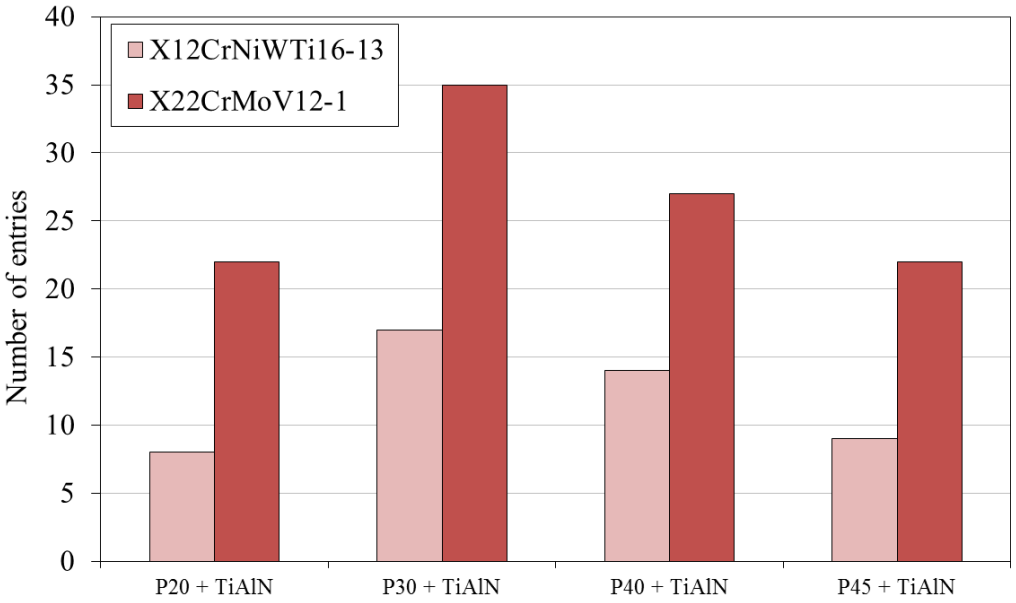


Figure 4. Lifetime of the cutting inserts with PVD TiAlN coatings, with increasing toughness of the cemented carbide from ISO P20 to P45 using F50 chipbreaker.

The CVD TiCN-Al_2O_3 coated substrates showed comparable lifetime for both work piece materials, which increases with increasing toughness of the carbide. The PVD TiAlN coated grades showed a maximum of performance for the P30 carbide and a similar trend for both work piece materials. The lifetime when machining martensitic X22CrMoV12-1 is approximately doubled compared to austenitic X12CrNiWTi16-13 work piece material.

The comparison of the lifetime of PVD TiAlN, CVD TiCN-Al_2O_3 and CVD TiB_2 coated P45 carbide is shown in Figure 5. The CVD TiB_2 coating could outperform the other coating materials on martensitic X22CrMoV12-1 work piece material, but not on austenitic X12CrNiWTi16-13.

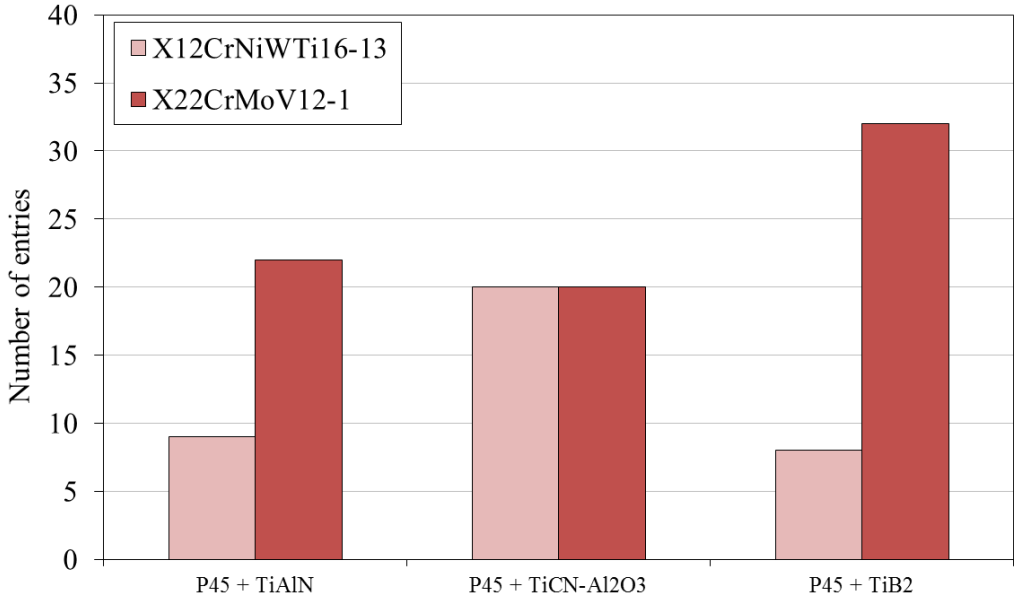


Figure 5. Lifetime of the cutting inserts with P45 carbide and varying coating material using F50 chipbreaker.

For the best performing carbide an coating combination on each work piece material, which means P45 carbide with CVD TiCN-Al_2O_3 coating on austenitic X12CrNiWTi16-13 and P30 carbide with PVD TiAlN coating on martensitic X22CrMoV12-1 the test was repeated using a more stable M50 chip breaker geometry, in comparison to the above used F50. The comparison of the number of entries is shown in Figure 6. A slight increase in lifetime could be reached for the CVD TiCN-Al_2O_3 coatings on both workpiece materials and for PVD TiAlN on austenitic X12CrNiWTi16-13. On martensitic X22CrMoV12-1 the F50 geometry with P30 carbide and PVD TiAlN coating showed the pest performance.

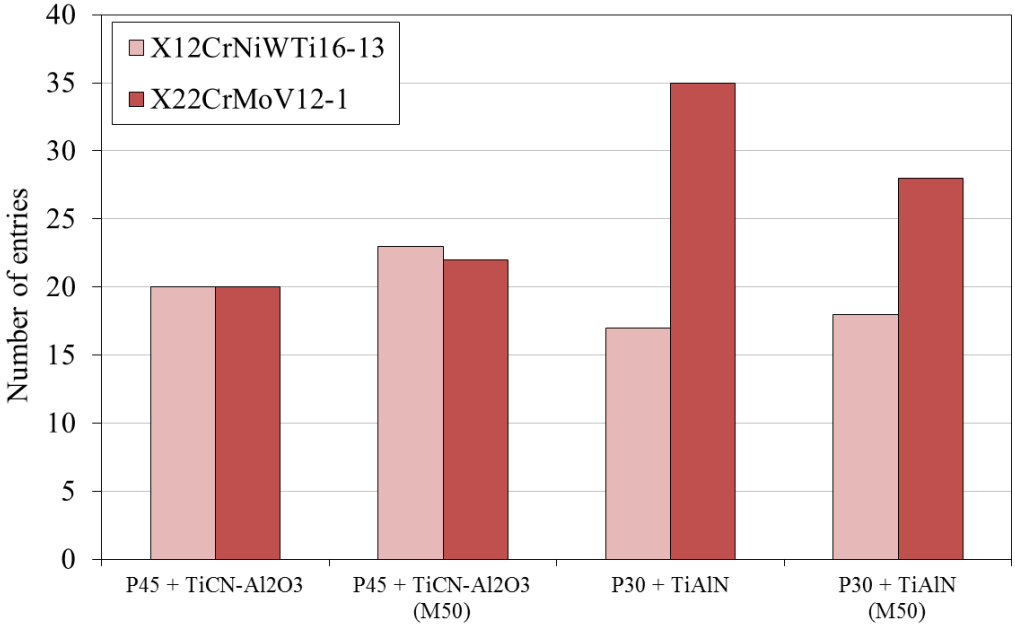


Figure 6. Lifetime of the cutting inserts with best performance P45 carbide and CVD TiCN-Al_2O_3 coating and P30 carbide with PVD TiAlN coating. Both where tested in F50 and M50 chip breaker geometry.

4. Discussion

The cutting performance of several carbide and coating combinations for machining turbine blade materials of high alloyed steels was compared. For a dry helirough process on martensitic X22CrMoV12-1 the combination P30 carbide with PVD TiAlN coating and F50 chip breaker showed the best performance of 35 entries. The second best combination was the P45 substrate with CVD TiB_2 coating with 32 entries. This result showed that the martensitic steels are more abrasive and the coatings with the highest hardness at room temperature showed the lowest wear rate.

When machining austenitic X12CrNiWTi16-13 the combination of P45 carbide and CVD TiCN-Al_2O_3 in M50 chip breaker geometry outperformed all other combinations with 23 entries. The second best version was P30 carbide with PVD TiAlN in M50 geometry, but showed with 18 entries only 78 % of the lifetime. The thermal load on the cutting tool seems to be much higher when machining austenitic work piece material, therefore a more stable geometry is necessary to avoid plastic deformation at the cutting edge, which could lead to coating delamination. For this application the insulation of the Al_2O_3 coating and its high temperature wear resistivity are crucial.

To gain a fundamental understanding of cutting operations and tool wear, the interaction of work piece material, cutting parameter, tool geometry and tool materials including carbide and coating has to be investigated more in detail. Especially the mechanical and thermal loads during application have to be determined, to set the right boundary conditions for the choice of cutting materials and their further development. An all-in-one solution suitable for every purpose is not possible when highest performance is desired.

5. Conclusion

For the best cutting performance on dedicated applications and work piece materials, the right choice of insert grade, which means the combination of carbide grade and coating, is crucial. As it turned out for different types of high alloyed stainless steels different insert grades have to be used. It could be demonstrated that …

- P30 carbide with PVD TiAlN coating (CTPP235) in F50 geometry showed the best result on martensitic X22CrMoV12-1 work piece material and the best overall performance. This should be the first choice.
- P45 carbide with CVD TiCN-Al_2O_3 (experimental) in M50 geometry outperformed other combinations on austenitic X12CrNiWTi16-13 work piece material. The width of machining parameters is narrower, but in the optimum the difference in lifetime is significant.
- CVD TiB_2 coatings could be an alternative when machining abrasive materials with moderate thermal load.

A further optimization to improve the wear resistivity and especially the high temperature material properties is crucial to meet the requirements of future machining demands. Therefore detailed investigations and measurement methods have to be developed.

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