HARD MACHINING TEST USING END MILLS WITH TiSiN, AlCrN AND TiAlN THIN FILMS

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Abstract

The article presents the results of the milling tests - "hard machining" - on the processed (hardened and tempered) material X37CrMoV5-1 (ČSN 19552). At the beginning, the hardness tests of the machined material block were carried out using the Rockwell method. Machining tests were focused on the evaluation of hard machining efficiency and were performed under comparable conditions. At the first stage thin films TiSiN and AlCrN were optimized as a part of a project solution for machining highly and medium hardened materials. Original coating TiAlN was also used for comparison in the second stage. As a result, the flank wear documentation of thin films TiSiN, AlCrN and TiAlN was processed with the same tooling time being set. The flank wear VB and the effectiveness of using the coatings from other perspectives were also evaluated.

Keywords: Metallurgy, steel, applications, tools, thin film, flank wear

1. INTRODUCTION

PILSEN TOOLS builds upon a long-standing tradition of the ŠKODA Pilsen company that dates back to the 19th century. PILSEN TOOLS ltd. is engaged in the production of tools, gauges, machinery and moulds and performs their heat treatment, alkaline blackening and other technological operations during the production activities. One part of the company is the Centre of Progressive Machining and the Heat Treatment Centre. The Centre of Progressive Machining has modern milling and turning machines and other modern equipment. The Heat Treatment Centre has a SECO WARWICK vacuum hardening furnace and other equipment needed to carry out heat treatment of metals. Within these centres the evaluation and optimization of metal machining and processing and other innovation activities are carried out. In its production, PILSEN TOOLS uses hardened and heat-treated tool steels and these materials are machined in relatively large quantities. Therefore, the aim of this work was to optimize the cutting process and conditions and to select a suitable thin film for the milling of the processed material.

2. GENERAL INFORMATION ABOUT HARD MACHINING.

Hard machining involves machining of materials with hardness of 50-60 HRC. Not long time ago, the work pieces of such material have been only grinded, but today the development of cutting tools and coatings has made it possible to perform conventional chip machining without sufficient problems [1]. When machining hard materials are widely used cemented carbide (milling, drilling operations, especially while machining hardened steels), cubic boron nitride (turning of hardened steels and cast irons) and cutting ceramics (turning of grey, malleable cast iron, heat resistant, refractory materials and hardened steels). The basic problems that arise when machining hard materials:

- Hard materials cause high specific cutting force while machining which produce large, variable sized cutting forces that negatively affect the cutting edge of the tool and can cause a brittle fracture to the tool or rapid damage of the workpiece;
- Hard martensitic grains in machined material result in high abrasive wear of the tool and therefore relatively rapid flank wear VB according to standard ISO 3685 [2];

- Large amount of heat is generated during machining, at relatively lower cutting speeds (up to 100 m/min). The general rule that can be applied is: the lower are cutting conditions, the greater proportion of heat is transferred into the tool. This creates the problem of effective cooling;

Considering the problems described above, the selection of a suitable cutting tool and the thin film must provide high surface hardness of the tool, high abrasion resistance, good friction properties and thermal barrier between the cutting zone and the substrate material of the tool.

When choosing the appropriate thin film technology, it is important, on the one hand, to choose a suitable technological process of deposition and, on the other hand, suitable structuring of the formed thin film system. Deposition technologies include CVD, PVD, and low-temperature CVD. The CVD technology has the advantage of relatively high adhesion due to more considerable diffusion processes in layer formation due to the high deposition temperature, which is, however, could be too high for some cutting tools as they can undergo tempering. The PVD technology has the advantages of the lower deposition temperature and the greater variability of the formed types of deposited films as well as the better control of the process possibilities of creating a different layer composition. A low-temperature CVD such as PA CVD allows the CVD process temperatures to be lowered, but this reduces the possibility of creating a more stable diffusive connection. With PVD technology, there is a choice between magnetron dusting and arc evaporation in a vacuum. The choice of the thin-film system is determined also by the desired additional properties mentioned above (heat resistance, friction characteristics etc.). Properties apart from process parameters are given by structuring the thin-film system. The increase in hardness can be achieved due to grain size reduction in the structure of substrate. Considering all the requirements, mentioned above, the two most appropriate PVD thin films for hard materials machining were selected for testing - TiSiN-based thin film “A” and AlCrN-based thin film “B”.

3. MATERIAL PREPARATION AND EVALUATION

As one of the most commonly used materials in the hardened state in PILSEN TOOLS ltd. is the material X37CrMoV5-1 (ČSN 19552), which is often used in manufacturing of dies, molds, etc. This material has been hardened to a hardness of 50 ± 2 HRC. The chemical composition is shown in **Table 1**.

Table 1 Chemical analysis of X37CrMoV5-1 (ČSN 19552) (wt%)

C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	V	W	Co
0.379	0.970	0.370	0.012	0.001	5.280	0.000	1.320	0.000	0.000	0.360	0.000	0.000

Because the block of the evaluated material is of relatively larger dimensions, cooling of the surface runs faster than inner part while hardening. That causes irregular hardness distribution through the material. To evaluate and minimize that influence, hardness tests were carried out at the beginning on each side of the cube-shaped test material at 5 points on each side as shown in **Figure 1**. Each side was labeled 1 through 6. The aim of this measurement was to find such a position of the material block in machine vices, that the difference of hardness for each level should be minimal. A large difference in hardness could cause an uneven load on the tool and thus inaccurate results.

After carrying out hardness tests on all 6 sides, the hardness level was evaluated. Three main ways of machining were considered (see **Figure 1**):

- Direction of machine spindle normal to side 6 (or 1)
- Direction of machine spindle normal to side 5 (or 2)
- Direction of machine spindle normal to side 4 (or 3)

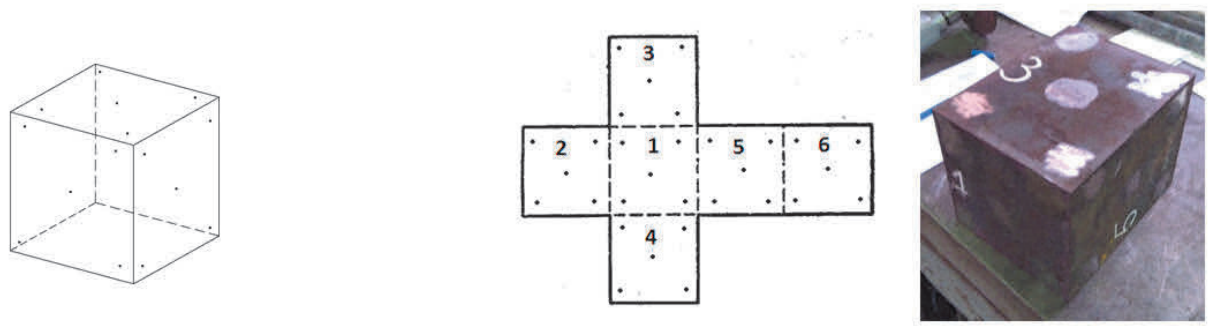

Figure 1 Hardness tests points on material block

The results are shown in the tables of measured values.

Table 2 Average hardness on levels [HRC]

Levels description	upper side	1 level	2 level	3 level	bottom side
from 6 to 1 normally	44.4	48.6	48.2	48.9	47.4
from 2 to 5 normally	48.2	47.5	46.9	47.5	48.7
from 4 to 3 normally	49.3	47.0	46.8	47.6	48.4

Table 3 Hardness rages (max. minus min. values) on levels [HRC]

Levels description	upper side	1 level	2 level	3 level	bottom side	Levels description
from 6 to 1 normally	3.2	3.5	2.9	3.7	4.1	3.5
from 2 to 5 normally	2.1	8	6.4	5.7	2.9	5.0
from 4 to 3 normally	3.4	5.7	5.1	6.9	3.9	5.0

The smallest calculated average value of the hardness is at level 6-1, and therefore the most suitable method of machining is from side 6 to 1. Using this way of clamping of block the load on the tool is more even than it would be using the other ways. The cube was clamped so that side 1 was upside and 6 downside. Therefore, the perimeter dimensions of the block were 215 x 215 mm.

4. MACHINING TESTS

4.1. 1st part of the machining test

At the first part of the test were used uncoated solid carbide mills manufactured by SCT Tools with further coating with appropriate thin film. At the beginning the sample 1 was coated and tested with TiSiN-based "A" thin film. When the feed rate was about 800 mm/min. the cutter held 750 mm (or about 6.45min) and cracked. Further, in the preparatory phase of the tests with TiSiN-based thin film "A" and AlCrN-based thin film "B" mills were subjected to working conditions optimization - feed and cutting speed. After optimization, the feed rate v_f was chosen at value 400 mm/min and cutting speed v_c at value 78.5 m/min. Also, the flank wear on optimized samples was measured and these values were used as the initial wear for the test continuation. Optimized working conditions were used for subsequent tests. The flank wear VB was measured at each of the 4 blades. The results were averaged and are shown in the **Table 4** and on the **Figures 2 - 3**. With each mill 5 rounds of total distance 215 x 5 = 1075 mm were carried out during one lap of test. At the end of each lap, flank wear measurement VB was performed on every tool using measuring microscope MULTICHECK PS500.

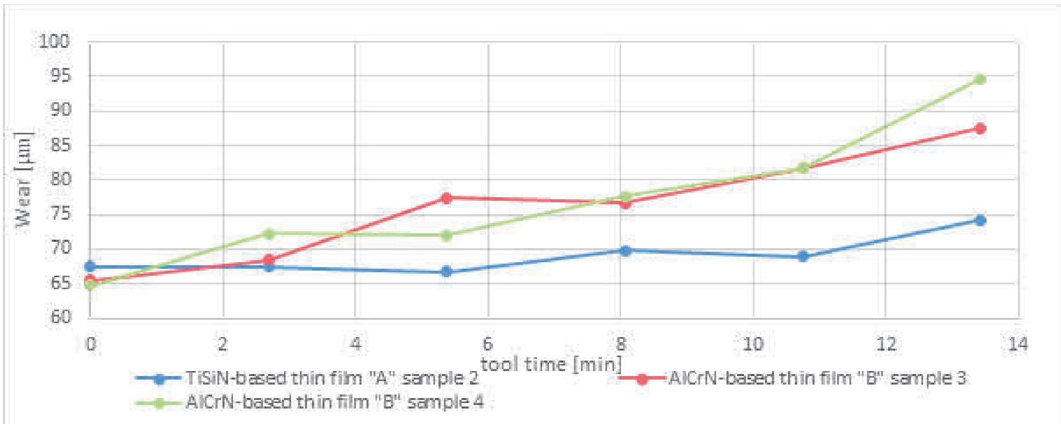

Figure 2 The course of flank wear of tools with TiSiN-based "A" and AlCrN-based "B" thin films

Table 4 The course of flank wear of tools with TiSiN-based "A" and AlCrN-based "B" thin films [µm]

Tool time [min] distance of machining [mm]	Initial tool wear	2.69 1075	5.38 2150	8.06 3225	10.75 4300	13.44 5375
thin film TiSiN-based "A" sample 2	68	68	67	70	69	74
thin film AlCrN-based "B" sample 3	66	69	78	77	82	88
thin film AlCrN-based "B" sample 4	65	72	72	78	82	95

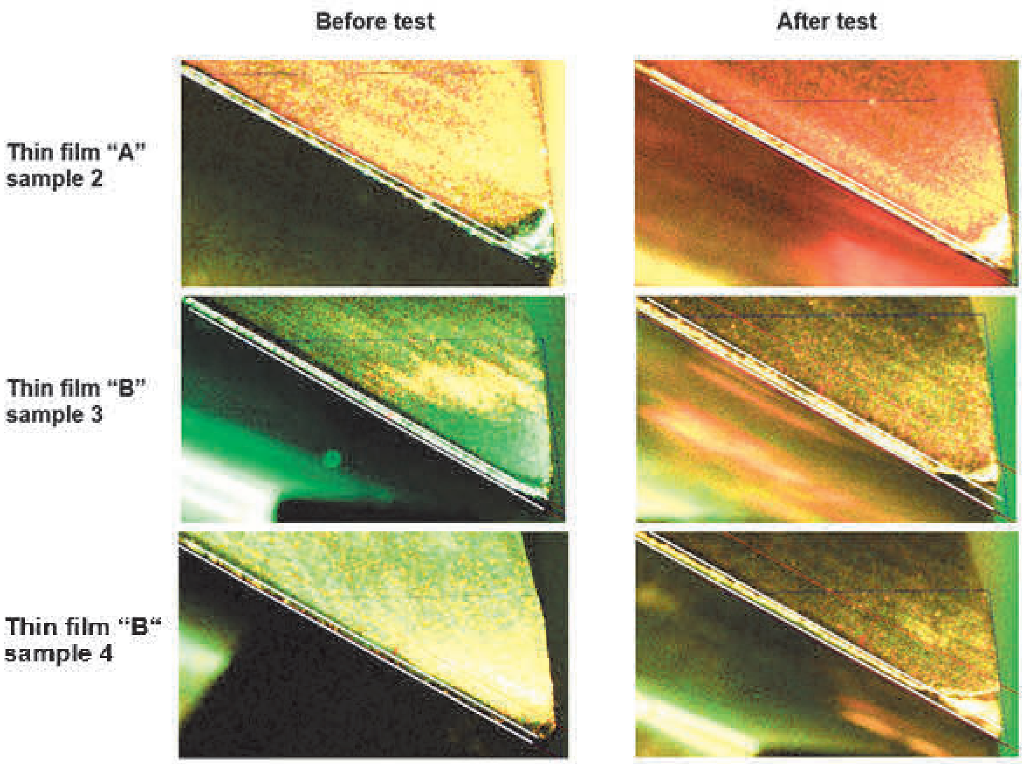

Figure 3 Flank wear before and after machining tests

4.2. Conclusion of 1st part of the machining test

As a result of hard machining tests, it was found that under the same operating conditions (v_f = 400 mm/min and v_c = 78.5 m/min) TiSiN-based thin film "A" exhibits about 19% less flank wear than thin film "B".

4.3. 2nd part of the machining test

For second part of the test were used the same solid carbide mills manufactured by SCT Tools [3], but one sample was with an original coating TiAlN. The other uncoated mill was used with TiSiN-based thin film “A” as a comparison. Working conditions were taken from first part of the test (feed rate v_f = 400 mm/min at cutting speed vc = 78.5 m/min). Again, with each mill 5 rounds of total distance 215 x 5 = 1075 mm each were carried out. At the end of each lap flank wear measurements (VB) were performed. The results were averaged and listed in the **Table 5** and on the **Figures 4 - 5**.

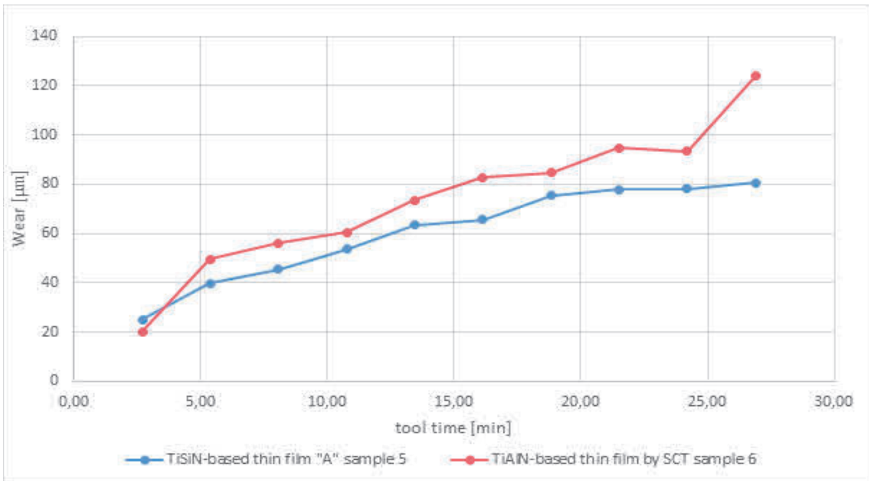

Figure 4 The course of flank wear of tools with TiSiN-based “A” and TiAlN thin films

Table 5 The course of flank wear of tools with TiSiN-based “A” and TiAlN thin films [μm]

Tool time [min]	**2.69**	**5.38**	**8.06**	**10.76**	**13.45**	**16.14**	**18.83**	**21.52**	**24.21**	**26.90**
Machining distance [mm]	**1075**	**2150**	**3225**	**4300**	**5375**	**6450**	**7525**	**8600**	**9675**	**10750**
TiSiN-based thin film “A” sample 5	25	40	46	54	64	66	76	78	78	81
Thin film TiAlN by SCT sample 6	20	50	56	61	74	83	85	95	94	124

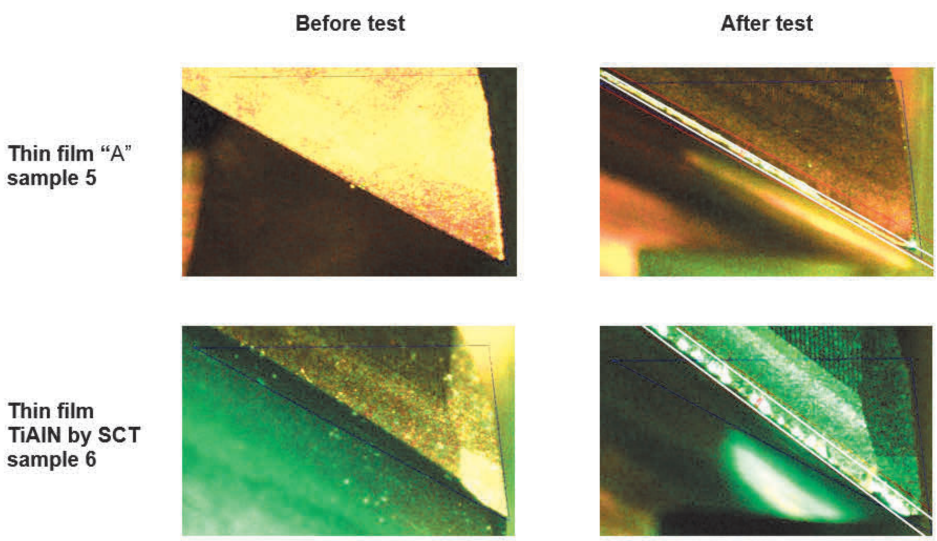

Figure 5 Flank wear before and after machining tests

4.4. Conclusion of 2nd part of the machining test

In the case of second part of hard the machining tests it was determined that under the same operating conditions (v_f = 400 mm/min and v_c = 78.5 m/min) TiSiN-based thin film “A” exhibits 35% less flank wear on the than the original coating TiAlN by SCT Tools manufacturer.

5. GENERAL CONCLUSION

AlCrN. TiAlN and TiSiN-based films have been tested within the survey. Comparing TiSiN-based thin film “A”, AlCrN-based thin film “B” and the original TiAlN thin film of the tool manufacturer. At the both experiments the least flank wear had a mill with TiSiN-based thin film “A”. This thin film has the highest micro hardness and higher abrasion resistance, which favorably affects its properties concerning machining hard materials.

To improve surface strength, low-voltage reactive vacuum evaporation technologies from different manufacturers were tested. Thin films based on nitrides are available and can be Ti-based with a combination of other elements such as Al. Cr. Si. etc. The thermal load is also important while choosing the microstructure. In the case of TiSiN, higher hardness (up to HV 0.02 3800) and stability can be expected, as well as a higher resistance to spreading of the cracks due to the fine structure of the surface layer. Further improvements could be achieved by selecting not ternary but quadratic thin layers (e.g. TiAlSiN) and structuring by layering, i.e. by interleaving with other types of thin film layers in a multilayer system (e.g. Al_2O_3. TiN etc.).

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