Coating as Micro-Structural System

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Abstract.

The paper provides the application of nanostructured TiAlN and nanocomposite structured TiAlSiN coatings on step drills. The analyses proved that the obtained tool lives are different despite the fact that the same tool geometry, coating, and PVD (physical vapour deposition) technology are used. This disproportion was experimentally tested focusing on surface condition using the pre and post treatment and on the chemical and structural coating composition.

Keywords: step drill, cutting edge, pre- and post-treatment, tool life, surface condition

1. Introduction

In present, the permanent requirement for higher productivity rates along with new/advanced workpiece, tool and coating materials and improvement of coating methods make this field for further research and development. The coatings as thin surface layers are not self-load carrying (Murčinková et al., 2017). Their preparation and production depends on many parameters, even on condition of substrate. The designing of coating as a micro-structural system with pre- and post- cutting edge preparation for individual applications is the complex and specific interdisciplinary engineering process.

Cutting operations are mainly characterized by large thermo-mechanical stress and strain, high interface temperatures in range 700-1200°C and high frictional forces. A significant portion of the supplied mechanical energy is consumed by frictional losses in range from 25-35% in the cutting zone (Vasilko, 2009; Murčinková et al., 2016). The low friction coatings can significantly decrease that loses. Among other benefits, the coatings have been observed to reduce cutting forces and provide longer tool life resulting in larger productivity (Vasilko & Murčinová, 2015). Since the early 1970's, when era of coatings begins, the large number with specific properties were developed. To apply suitable coating by suitable procedure for specific conditions is complex problem.

The presented case study involves the usage of new generation PVD-TiAlN, TiAlSiN coatings applied to cutting tools (drills) that are subjected mainly to normal forces acting at cutting edges comparing to forming tools that are subjected mainly the shear forces. However, the obtained tool lives can be different using the same geometry, coating and PVD procedure. This disproportion was experimentally tested.

2. Description of case study

2.1 Nanostructured coating TiAlN and surface condision

Fig. 1 shows the macroscopic geometry of tested sintered carbide step drill with double coolant holes. A new alternative to original AlCrN was goal to find, regarding the facts:

- to prolong tool life,
- coating containing the chromium is difficult to de-coated from tools by chemical way.
- when the de-coating is made, the de-coated waste is harmful for environment and need the special handling.

Figure 1: Macro-geometry of step drill

The selection of coating was influenced by machined material, hole depth, drill dimensions, "depth" of twisted surface for chip flow. The chosen coating for testing was TiAlN. Applying the TiAlN coating, the number of drilled components differs more than 300% comparing the coating procedure by producer B and C, Table 1. There is experience that the coatings quality from individual coating producers should not differ more than 20%. So, the individual steps of coating procedure were tested in detail.

Table 1 Comparison

Producer	Nanostructured coating	Number of drilled components
A	AlCrN	1200-1500
B	TiAlN	700-900
C	TiAlN	2000-2400

The parameters as placing of drill in tool holder table and holder cleanness in coating machine were considered the same for every coating batch. However, the double axis rotation of drill during deposition in coating machine used by producer C caused the larger coating thickness 3,5- 4 μm, comparing to triple axis rotation with 2,5 – 3 μm. Moreover, we focused on comparison of pre- and post-treatment of cutting edges and surfaces. In generally, the cutting edge/surface preparation operations are following:

- Pre-treatment: brushing, drag finishing for edge rounding, ball blasting, micro blasting to reduce the internal stress, polishing, magnet finishing, laser treatment.

- Post-treatment: polishing to decrease of final coating friction coefficient

The sequences of individual operations and parameters of pre- and post- treatment were tested to extend tool life in terms of minimizing the time for extra treatment operations. In Fig. 2, the cutting edges and surfaces of drills from producer C are shown to compare surface condition in individual steps. The following operations were made:

- the drill entered the coating section after sharpening by grinding, and the cutting edges and surfaces are of certain condition typical for grinding operation (Belán & Michalík, 2012; Vojtko et al., 2014),

- In Fig. 2, the cutting edges and drill surfaces were treated by drag finishing to deburr and round the cutting edge and to eliminate the roughness by polishing surfaces in special polishing abrasive media (OTEC); the parameters of that process were optimized as the cutting edges in step drills are at different drill diameters and thus their roundness is different after the drag finishing,

- After cleaning and decreasing, the process of PVD coating deposition in coating machine was made; in Fig. 3, the standard surface condition with coating is visible,

- In Fig. 4, the surface condition after polishing by brush (high productivity); the higher quality of surface polishing can be achieved by ball blasting or polishing in fine abrasive media, however, the damage of integrity of coating at the cutting edge can appear.

Figure 2. Surface condition after drag finishing

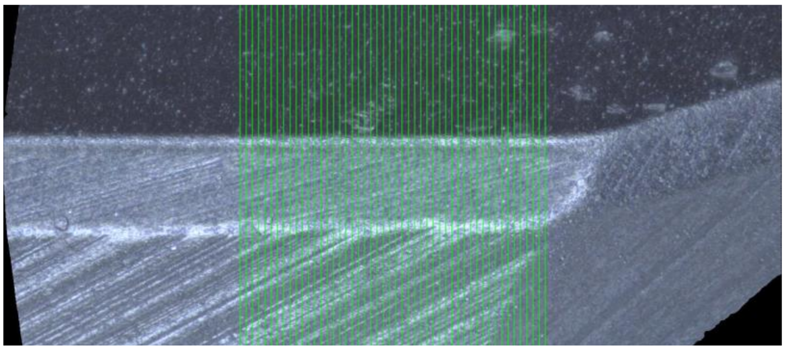


Figure 3. Surface condition after coating

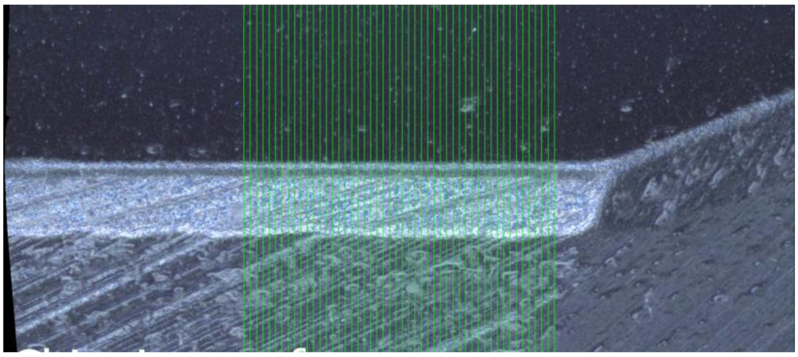
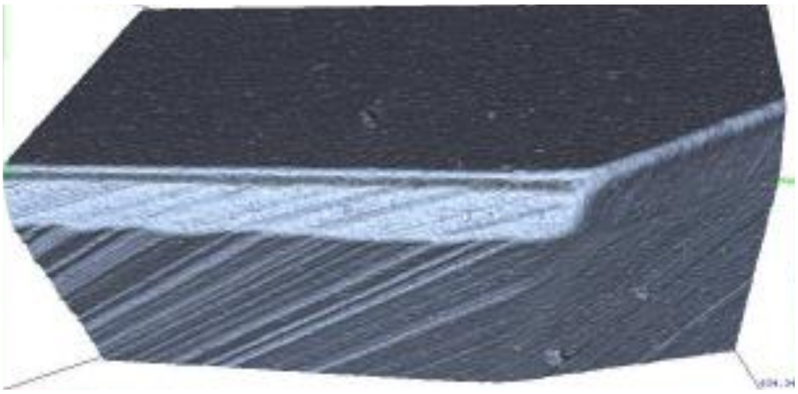


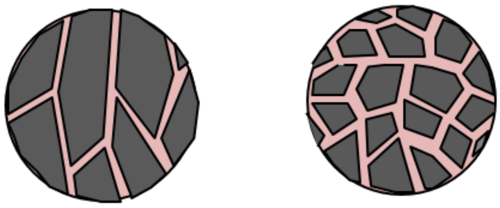
Figure 4. Surface condition post-coating polishing



3. Nanocomposite structured TiAlSiN

Using the mentioned nanostructured TiAlN coating with mentioned pre- and post- treatment was not sufficient for deep hole drilling, i.e. depth of drilling is more as 8-times larger than drill diameter. The drill is subjected to high temperature while the deep drilling. The composite structured coating TiAlSiN was applied as the coating chemical composition involves silicium Si that improve thermal stability and heat resistance. The coatings containing non-metalic elements are called the composite coatings. When depositing nanocomposites, the hard nanocrystaline grains TiAlN become embedded in amorphous Si_3N_4 matrix. Two phases are not mixed completely and the nanocomposite structure is developed. Fig. 5 presents schematically nanocomposite structure. The addition of Si changes the microstructure from "columnar" to "isotropic".

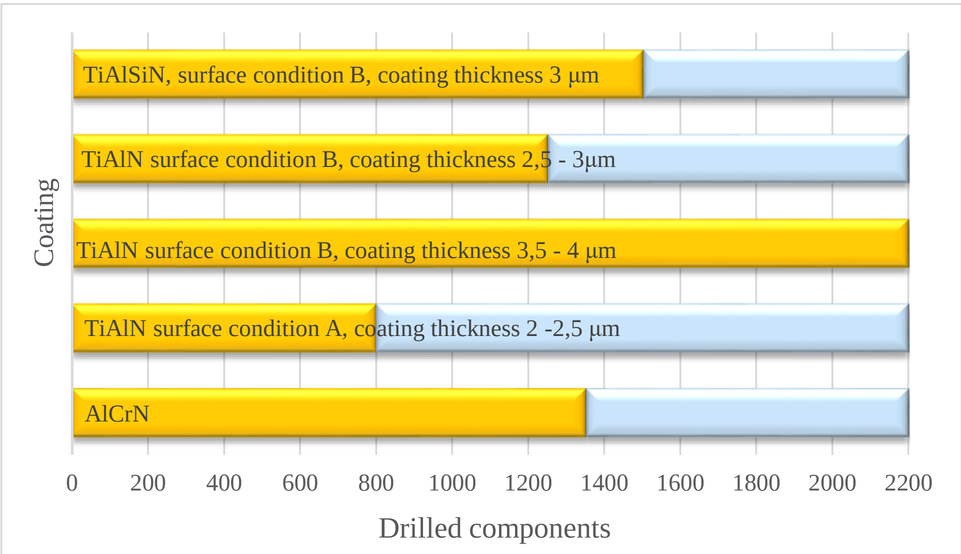
Figure 5. TiAlN – columnar nanostructure (left), TiAlSiN – "isotropic" nanocomposite structure



4. Discussion and conclusions

Many parameters influence the tool life and performance. In generally, the typical parameters of cutting tools are geometry and material both the substrate and the coating. That parameters can be recognized as macroscopic. Moreover, the macroscopic parameters are not a sufficient condition for required tool performance and tool life. Other important parameters are sharpening quality and its accuracy.

Figure 6. Comparison of number of drilled components by one drill



The case study showed effect of pre- and post- treatment (reconditioning), coating thickness and effect of the structure and chemical composition resulting in different material arrangement. Different coating thickness is caused by either double or triple rotation of tool holder.

In Fig. 6, the tool life of original AlCrN coating was approximately 1350 drilled components.

The TiAlN coating, surface condition A, was made by other producer. The source of the drill failure was too sharp (low roundness) cutting edge resulting in the coating peel-off on cutting edge and its rapid damage (tool life 800 drilled components).

The surface condition B and thickness of coating TiAlN 3,5-4 μm provided the maximum number of drilled components by one drill (approximately 2200). The same pre- and post-treatment (surface condition B), but lower thickness of coating (2,5-3 μm) caused decrease of tool life up to 43% (1250 drilled components).

Only the drill surface conditions (TiAlN surface condition A and B, thickness 2,5 μm) due to treatment influenced the tool life up to 56%. Comparing TiAlN, surface condition B, thickness 3,5-4 μm, i.e. maximum tool life to original AlCrN coating the number of drilled components by one drill increased up to 63%.

Comparing TiAlSiN coating and TiAlN of same surface condition and thickness, the tool life is extended up to 20%, recall that drill with TiAlSiN coating is subjected to high temperature appearing in deep drilling. The presence of the heat resistance silicium is evident.

When the drill (cutting tool) is cutting, the coating behaves as micro-structural system. It come into interaction with machined material, cutting fluid and temperature under specified cutting conditions and many interactions and effects are examined, e.g.

- adhesion improved by pre-treatment,
- roundness of cutting edge,
- roughness of substrate surfaces,
- cutting edge roughness in longitudinal and transverse direction,
- grinded micro-geometry,
- subsurface stress state after grinding (sharpening),
- friction coefficient along with temperature, etc.

To create suitable micro-structural system providing the longest tool life, we need to find the suitable combination of many parameters obtained by various technological taking into account also the conditions of cutting.

The appropriate micro-structural system of coating should be effective in terms of economy of manufacturing process. Although the requirement on pre- and post- treatment slightly increase the price, time and difficulty for operators of coating procedure, it provides other indirect savings, such as savings on transport, de-coating and re-coating. Using the coatings TiAlN and TiAlSiN without chromium, the process become more ecologic by its elimination from process.

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References

[1] Murčinková, Z., Baron, P., Tiňo, L., Pollák, M. and Murčinko, J. (2017) Research and analysis of stress distribution in multilayers of coated tools. International Journal of Materials Research, 108(6), pp.495-506.

[2] Vasilko, K. (2009) Teória a prax trieskového obrábania (in Slovak), Theory and practice of machining, 565 p., Technical university of Košice.

[3] Murčinková, Z., Vasilko, K. and Murčinko, J. (2016) Analysis of wide-range dependence of cutting parameters and the coating impact in deformation zone. Indian Journal of Engineering and Materials Sciences. Vol. 23, no. 4, p. 254-260.

[4] Vasilko, K. and Murčinová, Z. (2015) Question of Optimal Cutting Speed for Machining by Conventional and Coated Cutting Tools. Manufacturing Technology, 15(3), pp.483-490.

[5] Belán, M. and Michalík, P. (2012) The durability and wear of coated mills from HSS-PM in stainless steel cutting without cutting fluid. In 23th DAAAM International Symposium on Intelligent Manufacturing and Automation (pp. 2304-1380).

[6] Vojtko, I., Simkulet, V., Baron, P. and Orlovský, I. (2014) Microstructural characteristics investigation of the chip-making process after machining. In Applied Mechanics and Materials (Vol. 616, pp. 344-350). Trans Tech Publications.