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Testing a method for evaluating the performance of coatings on end mills in semi-industrial conditions

T. Leemet[1,*], J. Allas[1], M. Madissoo[1], E. Adoberg[2] and R. Saar[3]

[1]Institute of Technology, Estonian University of Life Sciences, Kreutzwaldi 56, EE51014 Tartu, Estonia; [*]Correspondence: Tonu.Leemet@emu.ee
[2] Institute of Physics, University of Tartu, Riia 142, EE51014 Tartu, Estonia
[3]Department of Materials Engineering, Faculty of Mechanical Engineering, Tallinn University of Technology, Ehitajate tee 5, EE19086 Tallinn, Estonia

Abstract. Milling remains as one of the most versatile machining operation in manufacturing. Machine tools with several axis of movement and precise numerical controls are able to manufacture complex geometries for medical implants, parts needed in space technology etc. The quality of the workpiece and the cost of manufacturing are influenced by many factors, tool selection being one with considerable impact. Depending on the specific type of milling operation and the material of the billet, the coating of the cutting tool can have a significant influence to quality and cost of the process.
In this study an attempt is made to develop a methodology for relatively simple but effective means for evaluating the suitability of a coating for a particular milling operation. Flank wear width is generally recognized as the key indicator for tool life criteria. Relatively complex geometry of the end mill makes the flank wear measurements somewhat difficult. In practice several other indication of tool wear are used: changes in the spectra and volume level of the sound emitted from the cutting process, shape and color of the chips, quality of the manufactured surface and the presence of the burrs. In this work the flank wear measurements by optical measurements are analyzed and reasoned, additional information is found by scanning electron microscopy. Three industrial PVD coatings – TiAlN, naCo and nACro were tested.

Key words: PVD coatings, milling, tool life, cutting tool wear phenomenon.

INTRODUCTION

Depending of the particular manufacturing situations several choices for the cutting tool selection can be made. Finding the optimal, i.e. most cost-effective solution is not a straightforward task. Machining is a complex phenomenon consisting of many potentially influential parameters. For instance, the overall stiffness of the machine tool is the first parameter to consider when choosing between high speed steel or carbide tools, the former having higher toughness should be the preferred choice for machine tools with lower stiffness. Carbide tools, although harder and therefore having superior wear resistance, are more fragile, thus more prone to fracturing when used on machine tools with low stiffness. Leaving other factors constant on acceptable level carbide tools are known to have higher material removal rate at the same tool life. Implementation of dedicated hard coating on the tool amplifies it even further. Tool geometry and machining parameters are additionally among the key factors to be considered in the machining process.

There are numerous different coatings available on the market today. The industry segment is constantly in search and development of new coatings with enhanced properties. Tool manufactures give general recommendations about coating selection and usage conditions depending on the material to be machined. Still in many practical cases the choice of the cutting tool and coating remains as a matter of subjective preference based on limited experience. One purpose of the current research is an attempt to develop method suitable for evaluating the suitability of specific coatings for milling of chosen material.

The essential task of the coating is to modify the contact conditions in the cutting region between the different wear surfaces reducing wear intensity, prolonging tool life and assuring the quality of the finished surface. Benefits of the coating arise from its higher hardness and wear resistance at elevated temperature, accompanied with lower friction coefficient between contacting surfaces and good chemical and thermal stability (Sarwara et al., 2008). Reports have been published about tool life of coated tools being three times higher than the one for uncoated tools (Trent, 1996). Coatings are usually up to 5 microns in thickness and deposited either via physical or chemical vapor depositions technology.

Considerable amount of scientific papers have been published in the field of tool life or tool quality investigations in general. It can be seen from literature that great number of coating – workpiece material combinations with in depth analyses of wear mechanism have been studied and published (Filice et al., 2007). In this work, an alternative approach is taken with focus on manufacturing aspect instead of tribology.

The emphasis of the current work is on two key concepts of interest to the scientific community today (Odelros 2012): 1. Developing and implementing the methodology for fast and reliable evaluation of cutting tool quality in industry like situation. To fulfil this aim the testing routine based on ISO 8688 International Standard has been developed. Coating choice for particular coating – workpiece material combination has been investigated and discussed; 2. Determining the best choice from three coatings (TiAlN, nACro and nACo) qualitatively for milling HYDAX 25 steel.

MATERIALS AND METHODS

HYDAX 25 was chosen as test material due to its widespread usage and relatively good machinability characteristics. In principle it is a derivative of the S355 construction steel with higher manganese content for achieving elevated machinability due to the relatively hard manganese particles in the matrix leading to extended chip breakage, thus elevating automated cutting operation capabilities. Material was used in as-received state, hot-rolled bars with rectangular cross-section of 105 mm in side length, test billets were cut into pieces of 300 mm in length. The nominal chemical composition and values of mechanical properties are given in Table 1.

Three coatings were chosen to be tested, all of which were deposited on end mills with exactly the same geometry. Platit π 80 arc ion plating PVD unit at Tallinn University of Technology, Estonia, was used for deposition of hard coatings (Gregor, 2010). Substrate material was the same at all instances – solid carbide, WC/Co. All cutting edges were inspected prior to testing. An average acceptable level of coating quality was verified and assured. The cutting edges of all instruments tested looked sharp with no burrs or coating flaking. Summary with cutting tool overview and information about used coatings is presented in Table 2.

Table 1. Nominal workpiece composition and mechanical properties, HYDAX 25

Cast analyses		Tensile test	
MPa	wt. %	Parameter	MPa
340	0.21	$R_{p0.2}$	340
552	0.20	R_m	552
26.4	1.04	A_5, %	26.4
56	0.012	Z, %	56
144.7	0.106	HBW	144.7

Table 2. Cutting tool parameters and properties of coatings

Type of mill	Shank form	Coating	Diameter	Flute angle	Coating thickness	Adhesion*
HPC endmill	cylinder	nACo	8 mm	35°/38°	1.40 μm	HF 3
HPC endmill	cylinder	TiAlN	8 mm	35°/38°	1.71 μm	HF 3
HPC endmill	cylinder	nACro	8 mm	35°/38°	2.01 μm	HF 3

*Daimler–Benz adhesion method

Milling experiment was designed in a way which ensured and retained constant cutting conditions throughout testing. HAAS SMM-HE vertical CNC machining center was used. Material was cut by layers with thickness of 4 mm, toolpath with climb-milling passage moving along spiral cutting path was programmed by MasterCam X6 CAM software. As high speed machining is becoming more and more popular in everyday machining practice, the cutting parameters for testing were chosen according to guidelines suggested for high speed machining with dry air blast cooling as machining environment. Cutting parameters are presented in Table 3.

Table 3. Cutting parameters used in milling experiments

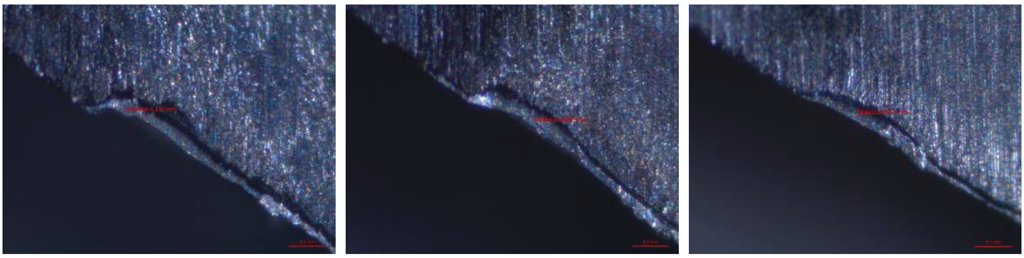
Cutting speed v_C , m min^{-1}	238
Width of cut, a_E , mm	1.6
Depth of cut, a_P , mm	4
Feed per tooth, mm Z^{-1}	0.08
Material removal rate, cm^3 min^{-1}	19.2
Coolant	Dry air blast

Tested tools were periodically observed and tool wear recorded after cutting two layers of material. The volume of the material removed by cutting one layer was 113.5 cm^3, the tool wear was recorded periodically after cutting of 227 cm^3 of material, which corresponds to 36 m of cutting length. For the estimation of the tool wear, i.e. system composed of cutter and its coating, an optical ZEISS Discovery V12 stereomicroscope with software ZEN was utilized. For performing the flank wear quantitative measurements the near vicinity of the region between worn and un-worn segments of the flank face was used for observations. Every end mill was tested for 252 m of cutting length (1,589 cm^3 of removed material).

Focusing on flank wear and notch wear on the flank face has been justified following numerous research papers published on the subject (Lim et al, 1999; Ezugwu et al, 2001; Ezugwu et al, 2005).

RESULTS AND DISCUSSION

Experimental results are summarized on micrographs by stereomicroscopy at Fig. 1 where flank faces of different end-mills with different coatings are aligned in a row.



a) b) c)

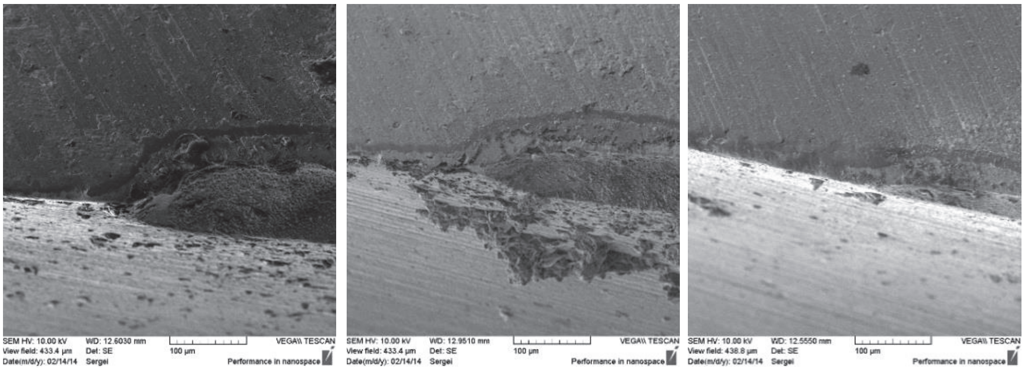
Figure 1. Flank wear on clearance face on three end mills, x63: a) nACo; b) TiAlN and c) nACro.

It is evident from the figures that tools with different coatings bare non-similar resistance to wear. This can be concluded visually from the micrographs of Fig. 1. Adhesive wear composed on abrasive wear results in notch wear mark at the depth of cut line, 4 mm from the tip of the end mill along the shank centerline. Quantitative measurements of overall flank wear lead to results concluded in Table 4, from where it is justified to state that nACro coating has the highest wear resistance in the studied machining situation.

Table 4. Flank wear width values after cutting 252 m

Specific coating on end mill	Flank wear land width, mm
nACo	0.120
TiAlN	0.087
nACro	0.067

For additional information about the current state of features on tested end mills, SEM micrographs were taken, Fig. 2. Same spot as with optical microscopy was under inspection. Angle of view has been tilted to reveal rake face, flank face and the cutting edge in between. From here it is seen that nACo and TiAlN coatings have developed a degree of adhered debris on the rake face. Whereas the planes on nACro coated end mill are relatively clean.



a) b) c)

Figure 2. SEM micrographs of the end mill cutting edge: a) nACo; b) TiAlN and c) nACro.

CONCLUSIONS

1. Methodology for cutting wear determinations has been proposed and tested. Three coatings, nACo, TiAlN and nACro on end mills were used to machine HYDAX 25 construction steel. Within constant conditions end mill with nACro coating has the least amount of wearing.

2. Major wear mechanism in action is abrasion. Notch wear due to adhesive wear is also clearly evident. No mentionable signs of built up edge, thermal cracking, edge chipping or plastic deformation was reported.

3. Following the outcome of the performed research it suffices to say that the proposed method as such has some potential shortcomings. Suitability of a particular coating based only on the estimation of the overall flank wear value is potentially overlooking other important and influential parameters. Quality of the finished surface and actual dimensions of the feature being machined together with in-situ cutting force measurements are considered for inclusion for future investigations.

4. Wear on rake face of the tool i.e. crater wear was left out from considerations. Future work should also include chemical wear mechanism as a component affecting tool life.

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REFERENCES

Astakhov, V.P. 2006. *Tribology of Metal Cutting*. Elsevier, 425 pp.

Sarwara, M., Haider, J., Perssonb, M. & Hellberghb, H. 2008. Evaluating the performance of TiN coating on a PM HSS milling cutter used in manufacturing of bandsaws. Available at: Open Access repositories (http://core.kmi.open.ac.uk)

Lim, C.Y.H., Lim, S.C. & Lee, K.S. 1999. Evaluation of the performance of CBN tools when turning Ti–6Al–4V alloy with high pressure coolant supplies. *Tribology International* **32**, 393–398.

Ezugwu, E.O., Da Silva, R.B., Bonney J. & Machado, Á.R. 2005. The performance of TiN-coated high speed steel tool inserts in turning. *Int. J. Mach. Tool Manu.* **45**, 1009–1014.
Ezugwu, E.O. & Okeke, C.I. 2001. Tool life and wear mechanisms of TiN coated tools in an intermittent cutting operation. *J. Mat. Process. Tech.* **116**, 10–15.
Trent, E.M. 1996. *Metal Cutting, 3rd Edition*, Butterworth/Heinman.
Odelros, S. 2012. *Tool wear in titanium machining*, Uppsala Universitet, 63 pp.
Filice, L., Micari, F., Settineri, L. & Umbrello, D. 2007. Wear modelling in mild steel orthogonal cutting when using uncoated carbide tools. *Wear* **262**, 545–554.
Gregor, A. 2010. *Hard PVD Coatings for Tooling*. Tallinn University of Technology, 140 pp.
Davim, J.P. *ed.:* 2007. *Machining*, Springer, 358 pp.