Proceedings of the International Conference on Manufacturing Systems – ICMaS
Vol. 4, 2009, ISSN 1842-3183
University POLITEHNICA of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania

ABOUT THE WEAR CRITERION FOR CUTTING TOOLS

Mircea LOBONȚIU, Vlad DICIUC, Vasile NĂSUI

Abstract: *The current paper deals with the concept of tool wear and aspects derived from its connection to different input or output factors of the cutting process. Subsequent to a series of experiments on various cutting systems, a concept of wear criterion in the cutting system is to be proposed and substantiated by theoretical premises as well as by the experimental data.*

Key words: *tool life, wear criteria, ball nose end mill.*

1. INTRODUCTION

The approach of a cutting tribosystem requires a detailed analisys of the phenomena which limits the values of the cutting data on the one hand, and, on the other hand, the time of tool usage at its entire cutting capacity.

The wear of a any tool type – be it single point, multipoint, or abrasive one, is an outcome of the wide range of phenomena which take place at the tool – workpiece contact, blade(s) – workpiece contact and grain – workpiece contact respectively.

There is no doubt that a persistent stress of the tool triggers its quick wear by local energetic overcharge at the contact level, in the chip forming area. These phenomena exert an energetic impact over the tool and the workpiece altogether, as they cause sudden and rapid temperature rises, followed by sudden and rapid drops in temperature.

Bringing up the restrictive elements of tool usage in a cutting process where a reference wear or a normal type of wear occur, would mean staying set on the concept of tool life criterion defined according to ISO 3685 [6], ISO 8688 [7] and other reference standards on tool life testing. This tool life is defined as a predetermined value of certain measurements relevant to tool deterioration or the onset of a specified phenomenon. It's obvious that this specified phenomenon must exist; it must be set as a limit. Moreover, these phenomena must be clearly stated and clarified with scientific rigour.

In this frame regarding the tool wear, it is necessary to tackle the restriction criteria on tool usage, the so-called tool wear criteria, which cannot stick only to the tool life specifications. In many cutting situations a cutting capacity of the tool might still be present but either the surface quality is diminished, or the shape of the cut surface changes due to tool wear.

According to norms mentioned by current standards related to tool life testing, it is required to define the tool life criterion as predetermined values of certain measurements with regard to tool deterioration. At this point we will take into account some preset values of measurements or the onset of a specified phenomenon. This type of approach leaves room to ambiguity, as the specified phenomena can be no other than the accuracy of the machined surface, the surface quality, the process energy balance, the acoustic emissions and vibrations. Consequently, these are nothing but restrictive elements that take us to wear criterion / criteria.

Thus, it may be convenient to give a general outline to the wear criterion accepted through series of "restrictions" or "limits" conditioning the cutting process. The limitation could be accomplished through the nature of tool wear – catastrophic failure, the loss of cutting capacity which is registered energetically up to a certain value, the sound pressure, vibrations, shocks, certain features of the machined surface, or the failure in ensuring shape accuracy and dimensional accuracy of the piece, depending on the type of the cutting process (kinematic meshing in the case of gears, by using profiling tools through mutual wrapping, or, in the case of machining by direct cutting, the surface shape being generated as a result of a technologic capability of the machine-tool-device-piece system).

There can be other limits like those rendered by the energy criteria which should lead to the concept of energy charge limit of the tool. It is under the attempt of being defined as the energy charge capability up to the onset of some drawbacks triggered by high energy consumption – severe deformation (flow) of the tool tip / bringing the tool tip in an advanced stage of plastic strain / reaching certain limit temperatures between the tool and the workpiece. These energetic aspects occurring at the tool – workpiece contact may lead to tool wear as a result of high energetic impact. It may also lead to changes in the quality of the piece surface, as well as to limits related to the machine resistance or cutting ability, especially in those cases where the tools can withstand higher cutting regimes than the machine.

In this context it can be said that the “specified phenomena” according to ISO's definition of the tool life criteria, might be: wear criterion, energetic criterion and machined surface precision.

This general approach will obviously imply specific peculiarities depending on the tool type (single point/multipoint cutting tool, abrasive, profiling tool), depending on the type of process (direct cutting, kinematic meshing, etc.) on the tool's material – workpiece

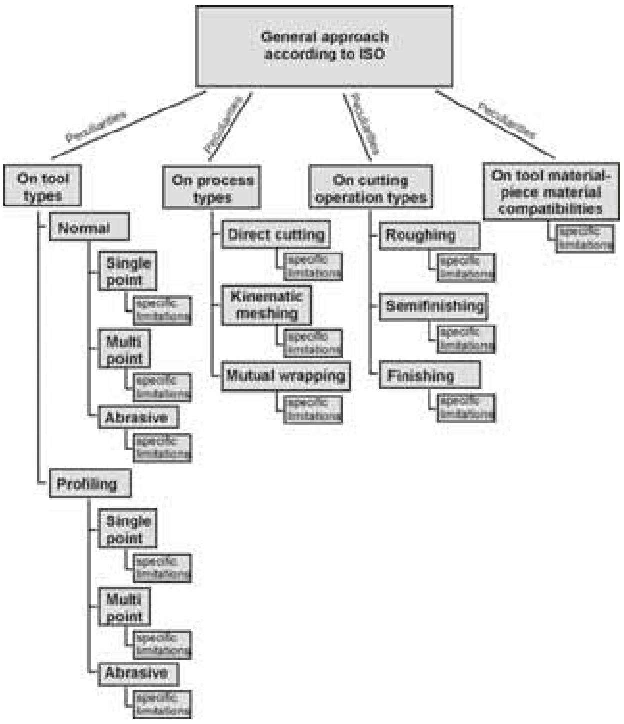

Fig. 1. Suggested approach on specific limitations.

material compatibility, as well as on cutting operation type i.e. roughing, semi-roughing, semi-finishing, finishing, etc. We hereby propose specific limitations; these limitations will have to be named and included in a complete map like the one presented in Fig. 1.

Transforming these concepts into a hypothesis, an experiment was carried out, consisting in the milling of a flat surface using ball-end nose mills vertically positioned. The tool wear was analyzed both through classical means (optical microscope) and through the output of the cutting process: the surface quality, the surface texture, acoustic pressure and electrical power consumption.

The experiments were housed by the Research Centre of RAMIRA S.A., Baia Mare, in an industrial working environment.

The purpose of the study was to assess the possibility of tool wear detection using acoustic emissions, to find a possible influence of tool wear over the electrical power consumption and to monitor the wear phenomenon while milling flat surfaces with this type of tool in a vertical position.

2. EXPERIMENTAL SETUP

The cutting was performed on a C45 workpiece Table1, annealed, according to the recommendations set by ISO 8688–2/1989 Tool life testing in milling [7]. The average hardness of this material was 170 HB.

Table 1

Chemical composition for C45

C	0.420	**S**	0.009	**Cu**	0.010
Si	0.240	**Al**	0.002	**Ni**	0.015
Mn	0.640	**As**	0.004	**Cr**	0.020
P	0.019	**Ti**	0.003	**Mo**	0.009

Table 2

Tool specifications

Tool Tail Code	MM12-20095.3-3027
Insert Code	MM12-14014-B120PF-M03, F15M $z = 2$ teeth, $D = 14$ mm
Insert Coating	TiC, TiN and Al_2O_3 Multilayer

The tool used was purchased from SECO TOOLS manufacturer – Table 2**.** The milling operation was performed in the presence of cutting fluid.

The insert was selected according to the material to be machined and the type of machining (finishing). The following milling conditions were applied: $a_a = 0.3$ mm, $a_r = 0.3$ mm, $V_f = 1452$ mm/min, $f_z = 0.07$ mm/tooth, $n = 10\,368$ rev/min.

The machine tool was a 5-axis OKUMA MU-400VA with 30 kW engine. The milling operation was performed on a workpiece measuring 95×95×245 mm, in 15 minute-rounds, a number of 4 rounds being completed until the "cleaning" of the surface with another Ø120 end mill, in order to remove the previously machined surface. This is done before advancing with another stepdown on the Z axis in order not to alter the outcome of the cutting process. The tool life criterion was chosen to be the roughness level, that is, the cutting operation was carried out up to 4 times the initial value of the roughness. The cutting was performed in the presence of the cutting liquid. The surface roughness level and the surface profile were monitored by means of a portable TR200 roughness tester provided by Micro Photonics Inc. The device used for the tool wear testing was an optical stereoscope supplied by I.O.R. manufacturer, having a 20× – 80× magnifying power and a Nikon Coolpix S1 camera. The quality of the surface/surface texture was recorded by means of a digital camera as part of a CV-HB100-type Brinell hardness testing device supplied by CV Instruments Europe BV, having a magnifying power of 30×. The acoustic emissions were monitored with the help of a Bruel&Kjaer 2250 sound meter, provided with a free-field microphone with 0° angle of incidence. The acoustic emissions were recorded every 15 minutes during cutting, applying a 5-second averaging sample and using the A weighting curve as main and the C weighting curve as a second, the peaks being recorded on the A curve. The emission frequency of the cutting tool was observed, its value being determined by the formula (1):

$$F = \frac{n \cdot z}{60}, \qquad (1)$$

where *n* stands for revolutions and *z* stands for the number of tool's teeth.

Replacing the values in rel. (1), we get rel. (2):

$$F = \frac{10368 \cdot 2}{60} = 345.6\ \text{Hz}\,. \qquad (2)$$

The electrical power consumption was monitored with a FLUKE 435 measuring device. The experiments were conducted in an environment having 20°C temperature and 45.2% humidity.

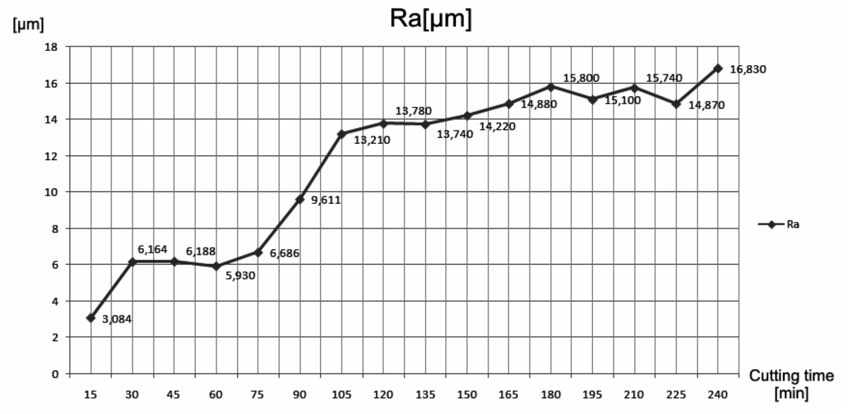

Fig. 2. Machined surface roughness over time.

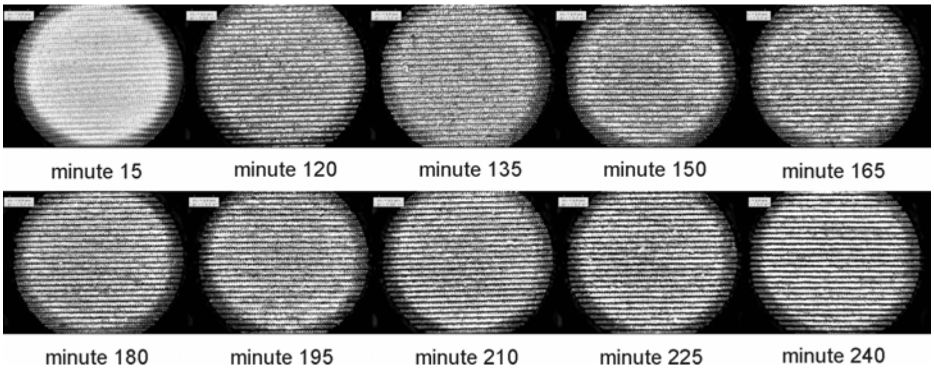

Fig. 3. Photos of the machined **s**urface texture taken on different moments in time.

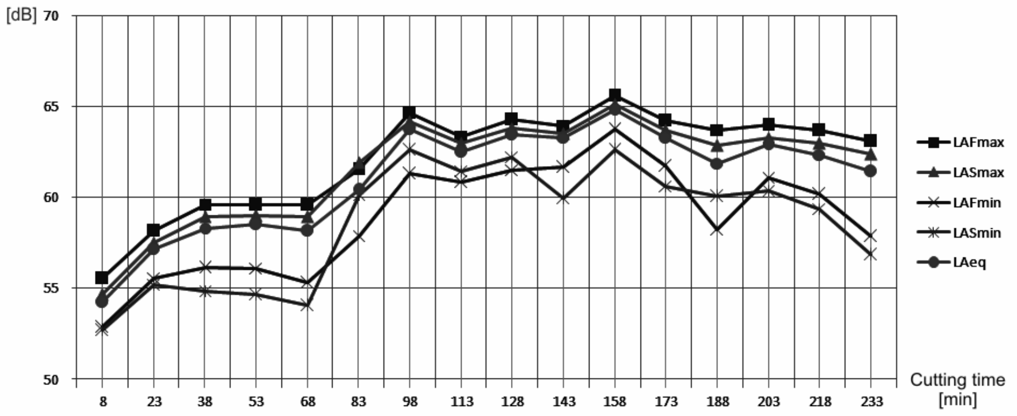

Fig. 4. Sound levels for the cutting process
(LAFmax – maximum time-weighted sound levels on the *A* fast weighting curve, LASmax – maximum time-weighted sound levels on the *A* slow weighting curve, LAFmin – minimum time-weighted sound levels on the *A* fast weighting curve, LASmin – minimum time-weighted sound levels on the *A* slow weighting curve, LAeq – the equivalent continuous sound levels on the *A* curve).

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The wear criterion chosen for this experiment was the rise in the surface roughness, subsequent to the processing, namely 4 times greater compared to the roughness registered after machining the same surface with a new tool. It was named wear criterion, because when this criterion was reached, the tool hadn't been changed (taken out of order), as it would have been, according to the definition, in the case of dealing with a tool life criterion set through this roughness limit. After attaining this wear criterion (minute 120) the cutting process was carried on, the tool showing a stable cutting behavior, both in what regards the roughness of the machined surface and from the perspective of acoustic emissions and electrical power consumption.

The roughness of the machined surface, rendered by R_a (µm), underwent a 3µm linear variation along 120 minutes, starting from minute 120 until minute 240, after the preset wear criterion was reached in the 120th minute. (Fig. 2)

This slow linear variation can also be observed in the photos taken with the surface camera – Fig. 3.

The acoustic pressure also displays a similar trend as to the one followed by roughness – Fig. 4.

The power consumption registered shows no change at all once with the onset of the wear, thus being constant (1.2 kW/1.2 kW/1.0 kW). The cause of this phenomenon may be, on the one hand, the big size of the 5-axis milling machine involved in the experiment, and, on the other hand, the finishing-specific cutting conditions, with force values much smaller than in roughing. Therefore, it would be necessary to assess the power consumption of this type of tool on smaller scale machines and / or using more sensitive measuring devices.

Aspects regarding the tool wear recorded during these experiments are thoroughly discussed in the paper [2] and they are in accordance with those presented by [3, 4, and 5].

Taking into account the aspects laid above, we can conclude by stating that if we were to set wear criteria depending on the type of cutting operation, we could say that this tool was used until the end of its tool life, in what regards the finishing process. Once out of this area and keeping its cutting ability, it instantly enters (can be engaged in) certain semi-finishing operations. Thus, it is reasonable to claim that the limits specific to the finishing process were reached and there was a sliding in the second area, that of the limits featuring in semi-finishing. Moreover, those mentioned by [1] being considered, with regard to the increase of this tool type's life, the ball nose end mill can be further successfully employed in finishing operations. From this point of view, we can say that we are dealing with a limitation based on technological conditions, or limits on the profiling multi point cutting tool types (a wear criterion was registered for the technologic context using the tool vertically positioned; the same criterion can be attained once again by tilting the tool at certain angles and thus engaging another new/less used section on the cut length).

Industrial practice considers that a tool reaches the end of its life the moment it fails to provide the dimensional accuracy and the reference-required surface quality [6, 7]. A tool is meant for processing several types of materials with different cutting regimes. There may as well appear situations in which the worn-out tool cannot provide the dimensional precision and quality for a certain type of material, but in the case of processing another type of material, it is able to grant the accuracy and quality of the target surface (Fig. 1).

There is the situation in which after the setup of the processing technology for a piece by means of a CAM soft, a certain tool (either new, or worn-out), used in the cutting conditions recommended by the tool producer, may be noticed to fail in accomplishing that operation from the tool life perspective (the machining time is too long compared to the cutting tool durability). In this case, a different cutting regime from the one recommended by the manufacturer must be established, in order to ensure the tool resistance throughout the machining period and to provide the necessary accuracy for the machining of that surface. Any changes in the cutting regime trigger changes in the surface quality. For this reason, we recommend as a wear criterion, the RELATIVE change in the surface quality, i.e. the surface quality modification compared to the one obtained with the same cutting regime when the tool was new, without relating it to a constant reference, obtained after processing under standard cutting conditions. As for ball-nose end mills, similar to those involved in this experiment, I recommend the practical testing of the cutting capacity held by these tools, in a tilting position to the machined surface.

4. CONCLUSIONS

The approach of tool life concept requires completion through the definition given in ISO 3685, detailing the aspects comprised in the phrase "specified phenomenon".

It is highly recommended to advance and develop a general map for the tool life criterion, filled with specific limiting criteria on tool types, types of processes, types of operations, and compatibility between tool material and machined material, aspects which could bring an essential contribution to the approach of the cutting tribosystem, in a general frame, but also in the particular cases.

The energetic experiments require direct connection to the tool wear at a high level of sensitivity.

This type of procedure may develop in an inner source of cutting capacity, tool materials, energetic balance for industrial companies.

REFERENCES

[1] DICIUC, V. (2009). *Optimization of the tilting sequence for ball-nose end mills when 5-axis milling of sculptured surfaces*, Proceedings of the 3rd International Conference for Young Researchers and PhD. Students – ERIN, ISBN 978-80-248-1982-2.

[2] LOBONȚIU, M., DICIUC, V. and COSMA, M. (2009). *Aspects regarding the wear of ball-nose end mills.* Proceedings of the 9th International Conference AMO.

[3] KUMAR, A.S., DURAI, R.A., SORNAKUMAR, T. (2006). *The effect of tool wear on tool life of alumina-based ceramic cutting tools while machining hardened martensitic stainless steel*, Journal of Materials Processing Technology, Vol.173, p.151-156.

[4] LACALLE, L.N., LAMIKIZ, A., SANCHEZ, J.A., ARANA, J.L. (2002). *Improving the surface finish in high speed milling of stamping dies,* Journal of Materials Processing Technology, Vol.123, p.292-302.

[5] STANFORD, M. și LISTER, P.M. (2005). *Investigation into the relationship between tool-wear and cutting environments when milling an austenitic stainless steel and En32 low carbon steel.* Industrial Lubrication and Tribology, Vol.57/2, p.73-79.

[6] *** *Tool life testing with single point turning tools.* ISO 3685/1993.

[7] *** *Tool life testing in milling.* ISO 8688/1989.

ACKNOWLEDGEMENTS: The current paper is part of a research project financed by **CNCSIS** (The National University Research Council) Romania. **Project title**: *Contributions to the metal cutting tribosystem.* **Project code**: RU-PNII-TD36/2008, **Project manager**: Eng. Vlad DICIUC

Authors:

PhD, Eng, Mircea LOBONȚIU, Professor, , North University of Baia Mare, Romania,
Email: mircea.lobontiu@ubm.ro
MSc, Eng, Vlad DICIUC, North University of Baia Mare, Romania,
Email: vlad.diciuc@ubm.ro
PhD, Eng, Vasile Nasui, Professor, North University of Baia Mare, Romania,
Email: vasile.nasui@ubm.ro