Tool life estimation using acoustic emission signal

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Abstract. A study was carried out on predicting the working life of a metal-cutting tool using an acoustic emission signal in comparison with predicting the working life of a metal-cutting tool based on the standard chemical and mechanical properties of the material being processed. A group of samples of six steels with a known chemical composition and mechanical properties was used as materials. Lifetime testing was carried out during milling with a single-blade cutter and the initial ranking of the steels according to their workability based on the relative intensity of wear rate of the tool was obtained. Acoustic emission signal reading was performed under similar processing conditions with determination of the integral energy characteristic of the RMS signal. During comparison of the relative hardness, the relative sulfur content and the relative RMS, it was found out that only for RMS there is correct compliance with the results of lifetime testing. The result obtained shows the effectiveness of the use of the acoustic emission signal for predicting the tool working life.

1. Introduction
Diagnostics based on acoustic emission of processes is becoming more widespread in various fields from medicine to geology. In engineering, the study of acoustic emission processes is carried out in the areas of quality control of materials [1] and process control [2]. The use of acoustic emission during cutting of metals, in particular for assess of workability, takes place in the areas of analysis [3, 4] and process control in real-time [5]. Control of the cutting process in real time on the equipment with the appropriate CNC ensures the replacement of worn tools with the maximum expiration of service life. However, a significant part of metalworking operations is performed on equipment that does not technically allow managing the process in real time. Therefore, the issues of analytical laboratory evaluation of tool working life when replacing the material being processed remain important and relevant.

When switching to a new material to be processed tool life more accurate is determined under the current production conditions, but such tests are associated with the risk of tool overspending, increasing labor intensity and scrap, therefore, the task of forecasting tool life is relevant. The method of determining the tool life based on the results of laboratory lifetime testing with high reliability of the results is not effective, because it is associated with significant time and material costs.

Predicting tool life based on the standard chemical and mechanical properties of the material being processed, as a rule, does not give results when there are minor differences in the chemical composition and hardness of the materials being compared - it has low resolving power.
One of the ways to solve the indicated issue is to predict workability according to special non-
standard material properties, which are physically closer to the cutting process than hardness and
chemical composition and at the same time do not require significant costs for their production.

The source for obtaining special non-standard properties of the material which correspond to the
research of cutting processes, is the flow of acoustic information (acoustic waves of deformation and
fracture processes) accompanying the cutting — acoustic emission.

The aim of the study is to investigate the possibility of predicting the tool working life by acoustic
emission of the cutting process of low-alloyed, low- and medium-carbon structural steels used for the
production of transmission parts and chassis of cars.

2. Materials, tools and methods of experimental research
Samples of steel 18H1G1FR, 20H1G1F, 20H1G1R, 30HGSA, 40HGNM, 20H1G1FR in the form of
rolled steel Ø50 were used for experimental researches. The nomenclature of the samples was
composed in the way to include steels which a priori different in workability: such as 30HGSA and
40HGNM and a group of four test samples of low carbon low alloyed nickel-free steels as a typical
representative of samples with uncertain variability. The chemical composition and hardness of the
tested samples HB 5/750/20 are given in table 1.

| Grade       | Hardness | C    | Si    | S     | P     | Cr | Ni | Fe |
|-------------|----------|------|-------|-------|-------|----|----|----|
| 18H1G1FR    | 173      | 0,18 | 0,30  | 0,018 | 0,012 | 1,25 | 0,13 | basic |
| 20H1G1F     | 178      | 0,19 | 0,33  | 0,022 | 0,013 | 1,27 | 0,14 | basic |
| 20H1G1R     | 160      | 0,21 | 0,34  | 0,028 | 0,014 | 1,20 | 0,14 | basic |
| 30HGSA      | 233      | 0,33 | 1,11  | 0,004 | 0,022 | 0,91 | 0,14 | basic |
| 40HGNM      | 194      | 0,40 | 0,32  | 0,026 | 0,013 | 0,70 | 0,77 | basic |
| 20H1G1FR    | 168      | 0,19 | 0,27  | 0,029 | 0,019 | 1,19 | 0,09 | basic |

In order to obtain reference workability values, the lifetime tests were carried out during milling
with a single-blade cutter with a blade made of a high-speed steel R6M5F3 with a control of the wear
value using a microscope MBS-10. Processing conditions are the following: face milling with a single-
blade cutter Ø100mm of sample Ø50mm, cutting depth t = 1mm, feed per minute Sm = 16mm / min,
feed per rotation So = 0.08mm/r, feed per tooth Sz = 0.08 mm/tooth, rotation speed n = 200 rpm,
cutting speed V = 63 m/min, the axis of the tool and work-piece - no offset.

In order to record the acoustic emission signal, a stand based on personal computer including a
wideband sensor with a 60dB preamplifier and a bandwidth of 50 ... 1000 KHz and an Advantech PCI-
1714UL board was used. The acoustic emission sensor is placed on the work-piece with a constant
milling width of B = 15mm. The recording mode - sampling frequency is 5 MHz, the interval length of
the recording is 1s, the pause between intervals is 0, the number of intervals is 50.

Each material of the group was tested three times during lifetime tests. The number of passes and
the average rate of tool wear were recorded for all three repetitions h. The specific wear of the tool per
pass was calculated $h_S$. The relative wear during processing the i material the $h_{RI}$ is calculated based
on the value of the maximum specific wear $h_{S_{max}}$ according to the formula:

$$h_{RI} = \frac{h_{SI}}{h_{S_{max}}}$$  \hspace{1cm} (1)
Regarding the content of alloying elements, the relative hardness and relative RMS are calculated similarly with respect to the corresponding maximum values of the characteristics.

The integral energy characteristic of the acoustic emission signals RMS is calculated by the formula:

\[
RMS = \frac{1}{n} \sum_{j=1}^{n} \frac{1}{F_s \cdot t} \sum_{i=1}^{F_s} (x_i - \bar{x})^2 ,
\]

where \( n \) – number of signals; \( F_s \) – sampling frequency, Hz; \( x \) – instant signal crest value, B; \( t \) – signal length, с.

In order to assess the correspondence of the results between the relative wear \( y \) and the three basic relative characteristics \( x \) of the studied materials (RMS, hardness, sulfur content), the correlation coefficient \( r_{xy} \) calculated by the formula:

\[
 r_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}
\]

### 3. Results and discussion

The results of lifetime testing during milling are shown in table 2 with ranking by relative specific wear and these results indicate that the greatest specific wear (minimum tool life) exists when processing steel 30HGSA.

Table 2. Results of lifetime testing

| № item | Steel grade | Quantity of passes | Average wear (mm) | Specific wear (mm/pass) | Relative specific wear |
|--------|-------------|--------------------|-------------------|-------------------------|-----------------------|
| 1      | 20H1G1FR    | 5                  | 0.13              | 0.026                   | 0.11                  |
| 2      | 20H1G1F     | 5                  | 0.16              | 0.032                   | 0.13                  |
| 3      | 20H1G1R     | 5                  | 0.18              | 0.036                   | 0.15                  |
| 4      | 18H1G1FR    | 5                  | 0.20              | 0.04                    | 0.17                  |
| 5      | 40HGNM      | 5                  | 0.38              | 0.076                   | 0.32                  |
| 6      | 20H1G1FR    | 1                  | 0.24              | 0.24                    | 1                     |

The relative values of sulfur content, hardness, and RMS for the group of studied materials are shown in table 3.

Table 3. Relative characteristics of compared materials

| №  | Steel grade | Relative sulfur content | Relative hardness | Relative RMS |
|----|-------------|-------------------------|-------------------|--------------|
| 1  | 20H1G1FR    | 1.00                    | 0.72              | 0.10         |
| 2  | 20H1G1F     | 0.76                    | 0.76              | 0.14         |
| 3  | 20H1G1R     | 0.97                    | 0.69              | 0.24         |
The correlation of relative characteristics studied materials with the results of lifetime testing are shown in table 4.

| Description                        | Relative sulfur content | Relative hardness | Relative RMS |
|-------------------------------------|-------------------------|-------------------|--------------|
| Similar workability steels          | -0.68                   | -0.02             | 0.92         |
| (№ 1-4 in table 3)                 |                         |                   |              |
| All studied steels                  | -0.88                   | 0.96              | 0.99         |

The presented results show that the absolute value of the correlation coefficient exceeds 0.5 in all studied cases. As far as the tool life is the reciprocal value of wear, the tool life is directly affected by the sulfur content and back is affected by hardness and RMS.

When considering steels with similar workability values (numbers 1–4), the sulfur content and hardness correlate much worse with the results of lifetime testing. The correlation of the RMS acoustic emission signal remains quite high.

In general, the experiment demonstrated that the use of acoustic emission to predict the durability of metal-cutting tools is relatively more effective.

4. Conclusions
1. When predicting the working life of the metal-cutting tool depending on the material being processed, the sulfur content, hardness and RMS of the acoustic emission signal allow us to estimate the relative change in tool life when comparing materials from different groups with a significant difference in workability.

2. Prediction of the working life of metal-cutting tools depending on the material being processed on materials of one group (easily machined automotive steel) is reliable using the RMS acoustic emission signal (correlation 0.92) and unreliable using sulfur content (correlation -0.68) and hardness (correlation -0.02).

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