A SUGGESTION OF NEW CLAIMS IN TOOL QUALITY STANDARDS

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Abstract. The necessity of some modifications in the tool quality standards, regarding the claims about tool reliability, is motivated in the present paper. In this sense, the author demonstrates that the most suitable model for reliability indicators estimation of the cutting tools is the two-parameter Weibull model. On the basis of some cutting tests, the author indicates the mode in which the change of cutting conditions during the tests does influence the reliability model parameters.
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1. Introduction

The notion *tool reliability* stands in the attention of the researchers from the cutting tools domain for some decades ago, but this propriety was not till now the concern of tool producers as a quality criterion of their products.

This fact has at least the following explanations:

- till now the quality standards for cutting tools make no reference to the tool reliability, not even to some specific claims about it;
- the literature on cutting tools shows a great diversity of opinion regarding the reliability indicators estimation manners, for different tool types;
- by default of some standard procedures of reliability level estimation, the necessary tests to obtain some realistic results are expensive and would take too long time.

If the reliability characteristics of the tool would be noticed by the producers, this should be a good opportunity for the users to establish an adequate strategy of tool replacement before these gives great errors or even fall. For the tool producers, the optimum combination between the reliability level of the manufactured tools and their cost represents a real condition for market penetration and keeping up.

For these reasons, the cutting tools reliability must become a quality parameter which has to be checked and certified at the delivery, as other parameters are, like dimensions, roughness and so on.

At the present, the valid standards on the general technical conditions for cutting tools ask the checking of tool in precise working conditions. Such a checking does not offer a quantitative information about the time the tool keeps its cutting qualities, and therefore does not provide an objective indicator for the comparison of different manufacturers tools.

The inclusion of reliability demands in tool quality standards would eliminate such a drawback, because tool performances will be guaranteed for a precisely nominated time.

2. Reliability indicators estimation for cutting tools

In order to estimate the reliability of cutting tools one can use the same indicators as generally are used for any other industrial products [1], namely:

- the reliability function *R(t)* defined as the probability of the working time *T* of a tool till it reaches the failure criterion be greater than a prescribed time *t*,

$$R(t) = \text{Prob}\{T > t\}, \tag{1}$$

- the distribution density of the working time without failure,

$$f(t) = -\frac{d\,R(t)}{dt}, \tag{2}$$

- the failure rate, defined as the probability that the tool reaches the failure criterion in the time interval (*t*, *t*+*dt*),

$$z(t) = \frac{f(t)}{R(t)}, \tag{3}$$

- the mean time between failures,

$$MTBF = \int_0^\infty t \cdot f(t)\,dt\,. \tag{4}$$

The values of these indicators may be estimated on the basis of testing data obtained by

cutting tests made on tool batches, till the tool admissible wear is reached.

A very suggestive indicator for the tool reliability may be also their durability, defined as cutting time in prescribed conditions, till the admissible tool wear is reached with an imposed probability.

At the present time, the tool durability is defined as the cutting time till the admissible wear is reached, while its estimation is made on the basis of cutting tests on tool batches. Statistical processing of these data is made accepting for the tested tools a normal distribution of the durability [2].

But, many researchers established on the basis of their experimental data that the graph of the durability versus time is not a symmetrical one, as would be the case in a normal repartition. Therefore, an asymmetrical graph of the durability (with an asymmetrical left branch) would be more adequate as a theoretical model.

Extending the claims of STAS 10307-75 (Industrial processes reliability. Reliability indicators) [3] over to cutting tools also, the estimation of the above enumerated indicators can be made on the basis of test data, using the expressions:

$$\hat{f}(t,t+\Delta t)=\frac{N(t)-N(t+\Delta t)}{\Delta t\cdot N(0)}, \tag{5}$$

$$\hat{R}(t)=\frac{N(t)}{N(0)}, \tag{6}$$

$$\hat{z}(t,t+\Delta t)=\frac{N(t)-N(t+\Delta t)}{\Delta t\cdot N(t)}, \tag{7}$$

$$MTBF=\frac{1}{N(0)}\sum_{i=1}^{N}t_i, \tag{8}$$

where $N(0)$ is the number of tools from the tested batch; $N(t)$ is the number of tools in working conditions at the moment t; t_i is the moment of the admissible wear at the tool 'i'; Δt is the suitable time interval.

The indicators estimated with these relations characterize the tested batch and can not be extended to the time values longer than the total duration of testing. Evidently, the estimated values are influenced by the adopted value of the admissible wear and by the working regime during testing.

In order to estimate the tool reliability over a time interval longer than testing duration, one must use parametrical methods which assume the choice of an adequate repartition for the cutting duration till the admissible wear is reached.

But the researchers opinions are contradictory, regarding the most suitable theoretical repartition to use for describe the reliability of different types of tools [1]. So, J.G. Wager and M.M.Barash as well as Z.Hitomi and N.Nakamura consider as adequate the lognormal distribution for the durability of the cutters with metallic carbide edge. The same repartition is recommended by K.S.Wang, W.S. Ling and F.S. Hsu [4]. Katev [5] recommends the Weibull distribution for threading dies and for small drills, but a normal distribution for HSS drills and tools. There are used also alfa-repartition and Rayleigh repartition (for taps and hobs).

The problem of the choice of suitable theoretical distribution is very important because, in function of it, for the same data set one can estimate reliability indicators presenting differences of 10% - 20%.

In the following, the author attempts to motivate the fact that, even in the case of a given tool type, the adopted theoretical distribution does change its aspect, depending on the cutting conditions in which the time till the admissible wear apparition was obtained.

Taking into account that the experimental data obtained by many authors present asymmetrical graphs of the probability density, we shall use the two-parameter Weibull model, whose $f(t)$ curve has a similar shape.

The probability density expression in the case of this model is

$$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], \tag{9}$$

where β and η parameters can be find graphically or analytically [5, 6].

The expressions of the other reliability indicators of the Weibull model are as follows:

- the reliability function,

$$R(t)=\exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], \tag{10}$$

- the failure intensity,

$$z(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}, \tag{11}$$

- the mean time between failures,

$$MTBF=\eta+\Gamma\left(\frac{1}{\beta}+1\right), \tag{12}$$

where Γ is the integral gamma function [3].

In order to increase the precision of determination, we better use an analytical method. In terms of the Weibull model, we can use for the reliability indicators β and γ one of the following methods: the maximum likelihood method, the smallest squares method or the moments method [7].

The maximum likelihood method consists in taking as parameter estimations those values which maximize the likelihood function defined as

$$L(t_i,\beta,\eta)=\prod_{i=1}^{n} f(t_i,\beta,\eta). \tag{13}$$

As the maximum value of L appears when the ln$L$ function takes its maximum, the values of β and γ parameters are determined as solutions of the equations system

$$\frac{\partial \ln L(t_i,\beta,\eta)}{\partial\beta}=0,\qquad \frac{\partial \ln L(t_i,\beta,\eta)}{\partial\eta}=0. \tag{14}$$

The smallest squares method used for the parameters β and γ determination shall be expressed by the condition

$$S=\sum_{i=1}^{n}\frac{[y_i-f(t_i,\beta,\eta)]^2}{s_i^2}=\min, \tag{15}$$

where y_i are the observed values of f and their dispersion is s_i^2.

In the terms of the moments method, we have to equalize the theoretical moments of first and second order with those calculated on the basis of experimental data; so we get an equations system which provides the searched parameters as its solutions.

In this purpose, the first order moment (relation (8)) and the second order moment respectively, will be equalized with the mean value and with standard deviation, both calculated on the basis of testing data with relations:

$$\bar{t}=\frac{1}{n}\sum_{i=1}^{n}t_i, \tag{16}$$

$$s=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(t_i-\bar{t})^2}\,. \tag{17}$$

3. Experimental results

In order to emphasize the working conditions influence on the most suitable mathematical model to describe the reliability of some HSS cutters, we made cutting tests on a batch of 12 cylindrical cutters. The machined test-pieces were made from OLC 45 steel having a hardness of 190 HB. The machining conditions were: cutting speeds of 30 m/min, 40 m/min and 50 m/min with feeds s_d of 0.05 mm/teeth, 0.1 mm/teeth and 0.15 mm/teeth respectively. The cutting process was stopped when the flank wear reached the maximum admissible value h_α = 0.5 mm.

The statistical processing of obtained data and the parameters β and γ estimation using the moments method lead to the following expressions of distribution density:

- for v = 30 m/min and s_d = 0.05 mm/teeth:

$$f(t)=1.36\cdot10^{-8}\cdot t^{2.8}\exp\left[-\left(\frac{t}{167}\right)^{3.8}\right]; \tag{18}$$

- for v = 40 m/min and s_d = 0.05 mm/teeth:

$$f(t)=0.839\cdot10^{-4}\cdot t^{1.3}\exp\left[-\left(\frac{t}{85}\right)^{2.3}\right]; \tag{19}$$

- for v = 50 m/min and s_d = 0.05 mm/teeth:

$$f(t)=0.278\cdot10^{-3}\cdot t^{1.1}\exp\left[-\left(\frac{t}{70.28}\right)^{2.1}\right]; \tag{20}$$

- for v = 50 m/min and s_d = 0.10 mm/teeth:

$$f(t)=0.59\cdot10^{-2}\cdot t^{0.5}\exp\left[-\left(\frac{t}{40}\right)^{1.5}\right]; \tag{21}$$

- for v = 50 m/min and s_d = 0.15 mm/teeth:

$$f(t)=0.031\cdot\exp[-0.031t]. \tag{22}$$

The graphs of these functions are shown in figure 1 and figure 2.

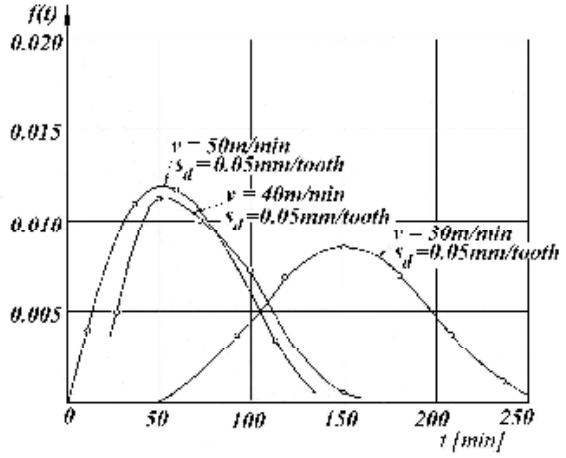

Figure 1. Cutting speed influence on $f(t)$

So, in figure 1 is presented the influence of the cutting speed on the distribution density, while figure 2 shows the influence of the feed on the same distribution density function $f(t)$. One can

observe that the β parameter of Weibull model decreases to greater speeds, so that it is approaching the Rayleigh model (relation (20)), while at greater feeds the distribution function becomes quite an exponential one (relation (22)).

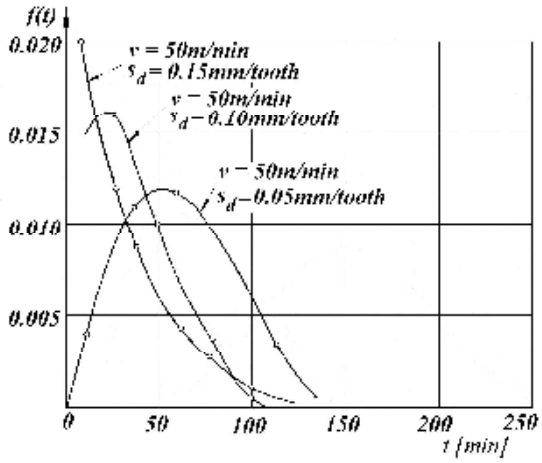

Figure 2. Feed influence on $f(t)$

The Kolmogorov-Smirnov test used to verify the concordance between testing data and the models presented in relations (18) ÷ (22), showed a good adequacy of Weibull's model for reliability description of HSS cutters. Therefore, the author considers that this model could stay as a basis of the estimation of reliability indicators for HSS cutters.

4. Conclusions

The insurance by the tool manufacturer of some values for the reliability indicators might be surely wanted both by the vender as by the user of the products. In this sense, the providing with precise stipulations on tool reliability of the quality standards would ensure an integrated vision and would provide realistic data in order to make a more complex analysis of the quality/cost ratio regarding different tool manufacturing firms.

As pointed above, the estimation basis for the reliability indicators in the case of HSS cutting tools may be the Weibull model (not the normal one, which is at the time being imposed by the standards for cutting tools durability estimation). It would be more important that the standards contain and impose precise checking conditions for reliability, which must correspond to those recommended in the exploitation of each type of tool.

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