Cutting Tool Reliability Testing and Data Proceeding

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Abstract: - The present paper underlines the necessity of the cutting tools producers warranty about tools reliability and propose also the ways of estimation for such of indicators. In the paper is also proposed to complete the existing standards with requirements about the reliability testing conditions and the methods of testing data proceeding are presented. Also in the paper the Weibull's model adequacy for a large range of machining conditions of HSS cutters is demonstrated. There is also shown that change of these machining conditions affect the values of β and η parameters, as well as the range of TBF.
For these reasons, in order to estimate some realistic reliability indicators, one have to establish proper conditions for reliability tests of cutting tools, especially for HSS cutters.

Keywords: - cutting tools, reliability, testing conditions, mathematical model.

1 Introduction

The present cutting tools quality standards are requiring tests about the tool behavior under prescribed work conditions as well as prescribed cutting trail. After the cutting test, the tools must agree with the technical quality conditions previously required by the standards and they have to preserve their former cutting qualities.
Such a testing does not permit to point out the measure in which the tools maintain their cutting capacities in time and therefore does not offer an objective indicator able to compare tools from different purveyors. The use of the *tools reliability notion* could be a solution, because it represents the property of tools to keep their capabilities in time, under prescribed cutting conditions.

2 Standard reliability requirements for cutting tools

By definition, the cutting tool reliability is the probability than the cutting duration till a prescribed criterion of failure would be reached be greater than a prescribed time, t:

$$R(t) = \Pr ob\{T > t\} \quad (1)$$

Using for cutting tools the same standard about reliability indicators as for industrial products, the tools reliability level my be expressed by following indicators:
- reliability function R(t);
- failure intensity z(t);
- probability density f(t);
- mean time between failures MTBF.

Between these indicators there exist the following relationships:

$$f(t) = -\frac{dR(t)}{dt}, \quad (2)$$

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

$$R(t) = \exp\left[-\int_0^\infty z(t)dt\right], \quad (4)$$

$$MTBF = \int_0^\infty tf(t)dt. \quad (5)$$

and their estimation must be done on basis of cutting time till the failure criterion will be reached.
A very suggestive indicator of the tools reliability may be the *durability*, which is the cutting time under prescribed conditions, till the failure criterion will be reached within a prescribed probability. In order to

raise the degree of certainty of the supplied value of the durability, one can impose a greater value for the probability, approaching the unity, let us say 0.95. So, for an imposed R(t)=0.95, we can determine from relation (4) the value T of durability which is concordant with the condition (1). In other words, the tool will have durability $T_{ef} \geq T$, with a probability of 0.95.
In order to warant the tools reliability, we must add to the present standards requirements about the necessary reliability testing made on batches of tools. With every tool from the tested batches the cutting will be proceeded until the failure criterion will be reached; in such a way will be determined the TBF for every tested sample.

3 Reliability indicators estimation for cutting tools

The testing data obtained for every tool batch can be processed, in order to get reliability indicator estimation, using parametrical and non-parametrical methods.
The local reliability indicators estimation using non-parametrical methods is made on the basis of following relations:

$$\hat{f}(t, t+\Delta t) = \frac{n(t) - n(t+\Delta t)}{\Delta t \cdot n}, \qquad (6)$$

$$\hat{R}(t) = \frac{n(t) - r}{n(t)}, \qquad (7)$$

$$\hat{z}(t, t+\Delta t) = \frac{n(t) - n(t+\Delta t)}{\Delta t \cdot n(t)}, \qquad (8)$$

$$\mathrm{MTBF} = \frac{1}{n} \cdot \sum_{i=1}^{n} t_i. \qquad (9)$$

where: n is the number of samples in the batch; n(t) is the number of tools in good state at the moment t; r is number of observed failures; t_i is the moment of appearance of the "i" failure; Δt is a convenient time interval.
The estimated indicators obtained with relations (6)...(9) are characterizing the tested "population", but cannot be extended over time intervals grater than the testing duration. In order to overcome this trouble, we must use the parametrical methods, which need a presumed repartition of TBF.
In some previous papers [1],[2],[3] we showed that bi-parametrical Weibull repartition is quite suitable to describe the HSS tools reliability. So, the testing data processing may be done presuming for the studied batch a Weibull behavior.
In consequence, the probability density function will be:

$$f(t) = \frac{\beta}{\eta^{\beta}} t^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], \qquad (10)$$

and the reliability function will be:

$$R(t) = \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right]. \qquad (11)$$

where the parameters β and η can be found using analytical methods (maximum likelihood method, least square method or moments method).
Among them, the moment's method is the most rapid. It is supposing to equalize the theoretical moments of "1" and "2' order with the analogous moments deduced from the testing data basis. In this aim [4], we shall determine for the tested batch the mean:

$$\bar{t} = \frac{1}{n} \sum_{i=1}^{n} t_i, \qquad (12)$$

and the standard deviation:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (t_i - \bar{t})^2}. \qquad (13)$$

With these values, we calculate the variation coefficient:

$$c_v = \frac{s}{\bar{t}} \qquad (14)$$

which allows to find the parameter β (see table 2.2 in [4]) and the η parameter will be then:

$$\eta = \frac{\bar{t}}{\Gamma\left(\frac{1}{\beta} + 1\right)}. \qquad (15)$$

Now, having settled these parameters, the reliability for any time may be estimated with relation (1) and mean time between failures will be:

$$\mathrm{MTBF} = \eta \Gamma\left(1 + \frac{1}{\beta}\right). \qquad (16)$$

In order to confirm the method proposed here and to prove that requirements about reliability certification of cutting tools may be introduced in the quality standard of the last one, we present in that follows our results obtained with HSS cylindrical cutters of 63 mm diameter.

A batch of 12 cutters STAS 578-76 was tested, machining test-pieces of OLC45 with 190HB hardness. The machining conditions were: s_d= 0.05 mm/teeth, depth t=6mm, cutting speed v=30 m/min, regular cooling emulsion. The test was stopped when the flank wear reached 0.5 mm.
The obtained data for TBF (in minutes) were: 80, 110, 112, 120, 130,.140,.155,.162, 180, 190, 200, 234. After that, we get from (12)... (14):

c_v= 0.29397,

and from [4]

β=3.8; η=167

In consequence, the probability density has the form:

$$f(t) = 1{,}36 \cdot 10^{-8} \cdot t^{2,8} \exp\left[-\left(\frac{t}{167}\right)^{3,8}\right]. \quad (17)$$

and mean value of TBF was 150 minutes.

4 Influence of cutting conditions on HSS cutters reliability

In order to may use the parametric methods for HSS cutters reliability estimation it must know the theoretical distribution, which describes most adequately the behavior of designed cutter tool.
So far does not exists an unanimous point of view about the most suitable mathematical model to be used in calculus of cutters reliability, and the reliability estimation indicators are more poorly treated in the literature about cutters then other kind of machining tools.
Some authors recommend for the statistical processing of the data acquired from the cutters tests a normal distribution, others recommend Raleigh's distribution, log-normal, alpha or even mixed models [1], [2].
The problem of the most suitable model is a very important one, if we take into account the fact that, for a given set of experimental data, the estimated values of reliability indicators can be different on a range of 10%-20% for different theoretical distribution used.

The problem of most suitable model becomes more important in our days, when every buyer claims a warranted reliability level for the purchased tool.

5 Weibull model for cutters reliability

If the machining conditions are correctly settled, the HSS cutters failure is appearing only by wear; that means a linear time raising failure intensity z(t). Starting from this fact and taking into account that experimental data often give non-symmetrical graphs of probability density f(t) for the wear affected tools, in the paper [1] was demonstrated that Weibull's model is the most suitable to describe the HSS cutters reliability.
In the present paper we shall treat the measure in which the Weibull's model is affected by the testing conditions of HSS cutters.
In this view, the author made tests with different feeds and speeds on a batch of 12 HSS cylindrical cutters having 63mm diameter. The tests were done by machining pieces of OLC 45 steel, having a hardness of 190 HB and using a regular emulsion cooling.
In that follows, there are presented the different machining conditions and the resulted probability density functions:

- test nr. 1: v = 30 m/min; s_d = 0.05 mm/ teeth

$$f(t) = 1{,}36 \cdot 10^{-8} t^{2,8} \exp\left[-\left(\frac{t}{167}\right)^{3,8}\right], \quad (18)$$

- test nr. 2: v = 50 m/min; s_d = 0.05 mm/teeth

$$f(t) = 0{,}2778 \cdot 10^{-3} t^{1,1} \exp\left[-\left(\frac{t}{70{,}28}\right)^{2,1}\right], \quad (19)$$

- test nr. 3: v = 50 m/min; s_d = 0,15 mm/teeth

$$f(t) = 0{,}031 \exp[-0{,}031t]. \quad (20)$$

The validity of these models was proved using the Kolmogorov-Smirnov's test. The graphs shown in Fig.1 are done on the basis of chosen theoretical models.

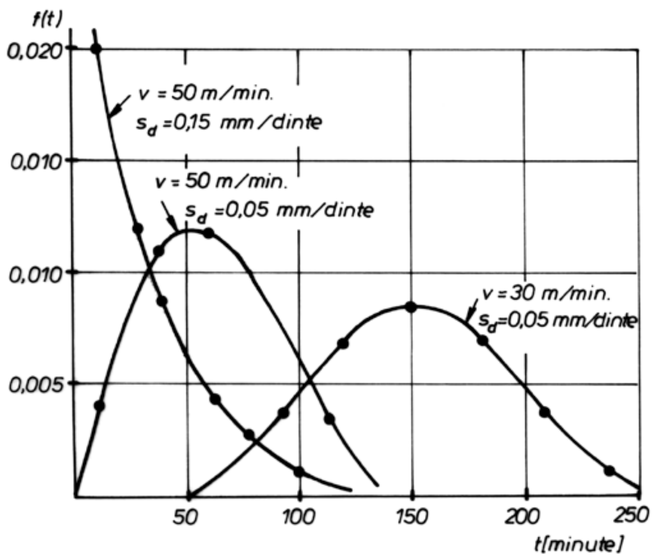

Fig.1 Graphs made on the basis of chosen theoretical models.

From relations (1)... (3), we can observe that machining conditions change does affect the values β and η of Weibull's model parameters. Indeed, the greater are the speed and the feed, the smaller are these parameters.

On the other hand, we can see that, for a 30 m/min speed and a feed of 0.05 mm/teeth, the Weibull's model is very close to normal model but, for a 50 m/min speed and 0.15 mm/teeth feed, Weibull's model is practically superposed on the exponential model (β=1).

In the same figure, we can observe that the harder are the machining conditions, the smaller is the range of TBF values. In the same time, this range is shifted to the left; this evidently means the decreasing values of TBF.

However, the Weibull's model was valid for all three machining condition sets. This fact underlines the Weibull's model utility for cutters reliability estimation. But, taking into account the considerable modification of the β and η parameters with the cutting speed and feed, we have to establish specific machining conditions, if we intend to obtain realistic reliability indicators. For this reason, in the tools standards the reliability requirements must be accompanied by specifications about the proper machining conditions for every kind of tool.

The settlement by standard requirements of these machining testing conditions, besides the Weibull's model acceptance, will lead to the estimation of such reliability indicators so that an objective comparison between the tools supplied by different producer should be possible.

6 Conclusions

The producer guaranty about the reliability indicators of the cutting tools raises the customers' reliance and offers an advantage against the concurrence. Therefore, the setting of a unitary method for reliability indicators estimation is a very actual and timely attempt.

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