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An overview on the cutting tool factors in machinability assessment

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ABSTRACT

Purpose: This paper is devoted to present and discuss the current trends of cutting tool technological challenges.
Design/methodology/approach: The main focus was on tool wear mechanisms, tool life relations and tool life response model. A details search on the literature was conducted and some concluding remarks were made.
Findings: The response surface methodologies combined with the factorial design of experiment were found to be very useful techniques for tool life testing.
Practical implications: This paper shows that the response surface methodology (RSM) can be used in the design of experiment to develop tool life models for several materials and the same approach can be used for modeling other machinability performance measures (Response) such as surface roughness etc.
Originality/value: This paper is designed to be beneficial for researchers working in the machinability area in order to provide an up to date review on the cutting tool technological development.
Keywords: Machining; Cutting tool; Machinability; Tool wear; Tool life

1. Introduction

Many types of tool materials, ranging from high carbon steel to ceramics and diamonds, are used as cutting tools in today's metal working industry. It is important to be aware that differences do exist among tool materials, what these differences are, and the correct application for each type of material. The various tool manufacturers assign many names and numbers to their products. While many of these names and numbers may appear to be similar, the applications of these tool materials may be entirely different. In most cases the tool manufacturers will provide tools made of the proper material for each given application. In some particular applications, a premium or higher priced material will be justified. This does not mean that the most expensive tool is always the best tool. Cutting tool users cannot afford to ignore the constant changes and advancements that are being made in the field of tool material technology. When a tool change is needed or anticipated, a performance comparison (Up to date review) should be made before selecting the tool for the job. The optimum tool is not necessarily the least expensive or the most expensive, and it is not always the same tool that was used for the job last time. The best tool is the one that has been carefully chosen to get the job done quickly, efficiently and economically [1-3].

2. Tool material reqirements

The ideal requirements of a satisfactory cutting tool can easily be defined, but it is more difficult to specify a tool material that meets all these requirements over a wide range of cutting conditions. The physical and metallurgical requirements of a good cutting tool material include (a) High yield strength at cutting temperature; (b) High fracture toughness; (c) High wear resistance; (d) High fatigue resistance; (e) High thermal capacity and thermal conductivity; (f) Low solubility in the workplace material; (g) High thermal shock resistance; and (h)Good oxidation resistance.

3. Cutting tool classification

According to ISO standards, cutting tool materials are classified into four major groups, based roughly on their chemical compositions. These are hard metals, ceramics, boron nitride, and diamond, and they are designated by letter symbols, H, C, B, and D, respectively Initial recommendation for selection of these tools can be obtained from standards and also from well known manufactures [3-4].

4. Effect of material tool geometry

A positive rake angle is generally desirable because it reduces cutting forces, temperature, and power consumption. HSS cutting tools are almost always ground with positive rake angles, typically ranging from +5 ° to +20 ° With the development of the very hard tool materials (e.g. cemented carbides, and ceramics), changes in tool geometry were required. As a group these materials have higher hardness and lower toughness than HSS. Also their shear and tensile strength are low relative to their compressive strengths, and their properties can not be manipulated through heat treatment like those of HSS. Finally, cost per unit weight of these very hard materials is higher than the cost of HSS. These factors have affected cutting tool design for the very hard tool materials in several ways. First, the very hard material must be designed with either negative rake or small positive angles. This change tends to load the tool more in compression and less in shear, thus favoring the high compressive strength of these very hard materials. Cemented carbides, for example, are used with rake angles typically in the range from -5 ° to +10 °. Ceramics have rake angles between -5 ° and -15 °. Relief angles are made as small as possible (5 ° is typical) to provide a much support for the cutting edge as possible [2]. Another deference is the way in which the cutting edge of the tool is held in position. The geometry of the HSS tool is ground from a solid shank. The higher cost and differences in properties and processing of the hard tool materials have given rise to the use of inserts that are either brazed or mechanically clamped to a tool holder. The shank is made of tool steel for strength and toughness. Mechanical clamping is used for cemented carbides, ceramics, and other hard materials. The significant advantage of the mechanically clamped insert is that each insert contains multiple cutting edges. When an edge wears out, the insert is unclamped, indexed (rotated in the tool holder) to the next edge.

5. Cutting tool (insert) selection

In general, the insert shape should be selected relative to the cutting edge (or lead) angle and the accessibility or versatility required for the application. For strength economy, the largest point (included) angle is selected. Figure (1) shows the range of standard insert shapes in varying point angles. Scale 1 shows "S" for strength (for cutting edge) and "A" for accessibility at each end, while Scale 2 shows "V" for vibration tendency and "P" for power requirement as two extreme factors for the selection of an insert shape [6].

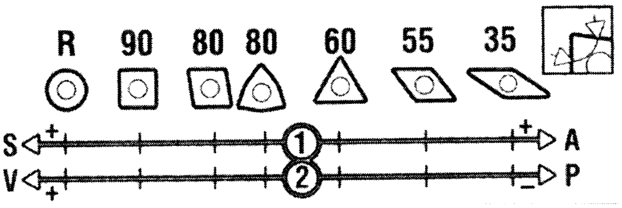

Fig. 1. The range of standard tool shapes in varying point angles [6]

Also, among the most significant factors considered in the selection of the insert type are the cutting tool geometry and the type of clamping of the tool insert. The geometry of the insert plays a critical role in achieving the desired surface finish producible on the machined surface and in controlling the chips (i.e. breaking the chips into small and acceptable shapes and forms). The insert nose radius affects the surface finish achievable according to the well-established (and idealized) model of surface finish generations by feed marks and the corresponding relationship. Higher feed rates and lower tool nose radius values produce rougher surfaces. However, in the finish machining range (i.e.. at low feeds and depths of cut), the practically achievable surface roughness values are always larger than the theoretically estimated values [4]. The complex work-tool material interactions that take place at the cutting edge in finish machining have been shown to attribute to this.

6. Tool failure types and failure criteria

Gradual wear occurs at two principal locations on a cutting tool: The top rake face and the flank. Accordingly two main types of tool wear can be distinguished: The crater wear and flank wear, illustrated in Figures (2)and Figure(3).

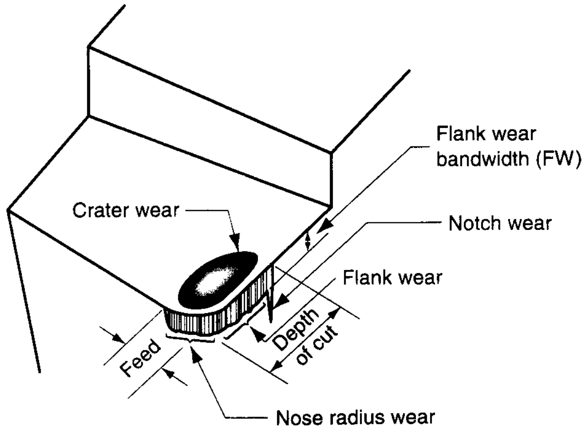

Fig. 2. Diagram of worn cutting tool, showing the principal locations and types of wear that occur [2]

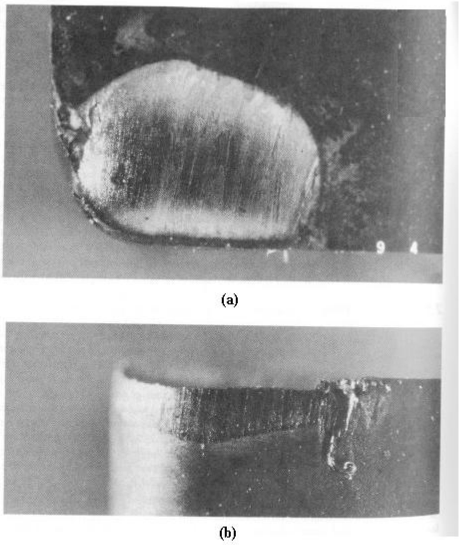

Fig. 3. a) crater wear and b) flank wear[2]

The modes of tool wear vary depending on factors and parameters such as cutting speed, feed rate, tool geometry, compatibility of tool and workpiece, etc. Basically, there are three major types of tool wear namely: major cutting edge wear (flank wear), and minor edge wear (end clearance wear), crater wear and notch wear. The most common criteria for tool failure include: (a) Complete failure, (b) Preliminary failure (e.g., appearance on the surface finish), (c) Flank failure (d) Size (dimension) failure and finish failure, (e) Cutting force (power), or thrust force, or feed - force failure.

7. Specification of tool-life

The most significant aspect of tool-life assessment is the measure of tool-life. Various methods exist to specify tool-life. The most common among these methods are: Machine time elapsed time of operation of machine tool, volume of metal removed, number of pieces machined, equivalent of cutting speed (Taylor speed) and relative cutting speed.

8. Tool-life empirical modeling

Tool-wear, tool-life investigations in machining have been among the most significant research topics during the last several decades. A large domain of specific knowledge has been acquired and many tool-wear/tool-life models have been developed through analytical modeling and experimental observations [4]. Work by Colding set the pace for renewed interest in machining optimization for productivity and cost [5]. In his work, he expressed his initial tool-life relationship, which was established as a function of equivalent chip thickness (ECT) and cutting speed, in terms of measurable cutting temperature, by developing a new temperature-tool-life relationship. A computer-based mathematical model was developed by Lindstrom [6] for tool-life estimation in an adaptive control system includes the capability for extrapolation of the cutting data field. This work was later extended to include a statistical evaluation aimed at economic optimization [4].

All presently known tool-life testing methods specified by major standards are based on the use of flat-faced cutting tool inserts and there are no effective equations for predicting tool-life in machining with grooved tools [4]. Significant progress has been made in developing new chip-groove geometries tool materials, coating techniques, and in the associated development and implementation of tool-life testing methods. However, the dual role of a tool insert for providing longer tool-life and effective chip breaking has not yet been fully investigated despite obvious experimental evidence observed in machining with grooved tools, which fail too frequently because of inappropriate design and/or use of chip-grooves. The tool-life data provided by the tool manufacturers are all basically for the various tool grades with none representing combined effects of tool grades and chip-groove configurations. Moreover, it is also a well-known practice to use a given tool-wear criterion such as flank wear and or crater wear limits, for tool-life estimates. However, it is generally observed that the tool failure is largely a result of a number of different concurrently occurring progressive tool-wear types, such as crater wear, nose wear, flank wear, notch wear, and edge chipping [4].

8.1. New tool-life relationship

A new methodology for measuring the multiple tool-wear parameters in a grooved tool is presented by Jawahir and colleges [7].This recent work on tool-life includes the effects of tool coatings and chip-groove geometry, and the corresponding tool-life equation is expressed as:

$$T = T_R W_g \{ \frac{V_R}{V} \}^{\frac{W_c}{n}} \qquad (1)$$

Where T is the tool-1ife, V is the cutting speed, n is Taylor's tool-life exponent, Wc is the tool coating effect factor, Wg is the chip-groove effect factor, TR is the reference tool-life, and VR is the reference cutting speed.

8.2. Tool-life RSM model

Choudary, El-Baradie, Hashmi and their colleges [8-12] have used response surface methodology (RSM) in the design of experiment scientific approach to develop tool life models for several materials and used the same approach for modeling other machinability performance measures(Responses) such as surface roughness etc. Other researchers have used this methodology for just parametric studies [14-15]. Response surface methodology (RSM) is a combination of experimental and regression analysis and statistical inferences. The concept of a response surface involves a dependent variable " y" called the response variable and several independent variables x1,x2,.xk [13-15]. The RSM was initially developed and described by Box and coworkers [13] in the study of optimization problems in chemical processing engineering. Mead and Pike [14], and Hill and Hunter [15] reviewed the earlier work on RSM. This has been used in tool life modeling, surface roughness modeling, and in other machining processes.

8.3. The RSM mathematical model

The functional relationship between the response (the tool life) of the end milling operation (As an example) and the independent variables investigated can be represented by the following equation:

$$T = C V^{k} f_{z}^{l} a_{a}^{m} \tag{2}$$

Where T is the tool life (min), and V, fz and aa are the cutting speed (m/min), feed per tooth (mm/tooth) and axial depth of cut (mm) respectively. Eq. (2) may be written as:

$$ln\ T = ln\ C + k\ In\ V + l\ In\ f_z + m\ ln\ a_a \tag{3}$$

The constants and parameters C, k, l and m can then be solved by using multiple regression analysis. Computer software packages are available for the multivariable regression indicated above. Microsoft Excel and examples of its use in multivariable linear and exponential regression analysis are given in ref. [17].The interesting issue of this method is that a similar procedure for predictive model development can also be followed for other machinability performance measures (responses). Furthermore, a multi-response optimization can be performed using the available statistical packages such as MINITAB program [18]. The optimization performed with this method is based on experimental results which reduces the approximation errors resulted from mathematical predictive models. Therefore, RSM with the help of the current computer power have facilitated the complicated problem of machinability modeling and optimization.

9. Conclusions

In this article an up to date review on the tool wear and tool life issues have presented. Methods of tool material and tool shape selection have been presented and discussed. The effect of tool material on tool geometry is also mentioned and discussed. In addition, the selection of the shape of cutting tool (insert) has been presented. Tool life model development history is presented with detail discussion of the latest development of tool life including the insert groove in the life estimation. Regarding the modeling it is found that response surface methodology combined with the factorial design of experiment are useful techniques for tool life testing. In this methodology, a relatively small number of designed experiments are required to generate much useful information that is used to develop the predicting equations for tool life. Depending on the tool life data provided by the design of experiment, first-order and second-order predicting equations can be developed. Furthermore, response surface methodology is a powerful tool for performing machinability optimization.

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