

Wear Dependent Tool Reliability Analysis during Cutting Titanium Metal Matrix Composites (Ti-MMCs)

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ABSTRACT

Metal matrix composites (MMCs) exhibit superior characteristics such as low weight, high stiffness, and high mechanical and physical properties. Inheriting such an outstanding combination of specifications, they are nowadays considered as the promising materials in the aerospace and biomedical industries. However, the presence of high abrasive reinforcing particles in MMCs leads to severe manufacturing issues. Due to the tool-particle interactions which occur during the machining of MMCs, high tool wear and poor surface finish are induced and those elements are considered as the main drawbacks of cutting MMCs. In this study, dry turning experiments were conducted for two different inserts and coated carbide on a bar of titanium metal matrix composite (Ti-MMC). Semi-finishing machining is operated with cutting parameters based on the tool supplier's recommendations which were not fully optimized. The maximum flank wear length (VB_{max}) was selected as the tool wear criteria. Furthermore, analyses were performed on the tool flank face using a Scanning Electron Microscope (SEM). The reliability analysis was performed based on the test results in order to assess the useful life of the cutting tools. The reliability function and mean time to failure were selected for the tools' reliability assessment. The reliability of both tools, due to the wear of the inserts, was analyzed and compared. The reliability assessment of the cutting tool can be very useful for tool manufacturers and manufacturing companies for production planning and tool management.

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INTRODUCTION

Tool life and tool wear tests are regarded as one of the most commonly used criteria for evaluating machinability, which will not only reveal the performance of the tool but also the evaluation of the work-piece material that can be achieved through analysis [1, 2]. During the machining of MMCs, hard reinforcing particles are responsible for severe abrasive wear on the inserts [3, 4].

Different parameters, such as cutting conditions, tool geometry, tool and work-piece material, type, size and volume fraction of reinforcing particles affect the tool wear mechanism during machining of MMCs [5, 6, 7]. The main wear mode during the machining of MMCs has been said to

be the flank wear. Furthermore, reinforcing particles will cause two-body and three-body abrasive wear. The particles debonded from the matrix could abrade the tool while rolling between the tool and the matrix and result in a three-body wear mechanism; while they may abrade the tool and make two-body abrasive wear when they are still attached to the matrix material [6, 7, 8]. During a three-body abrasion wear, vertical scratches will be generated on the tool flank face, whereas a two-body abrasion wear will result in holes and cavities on the tool face. Induced vertical scratches and holes on carbide tool flank face can be seen in [Figure 1](#).

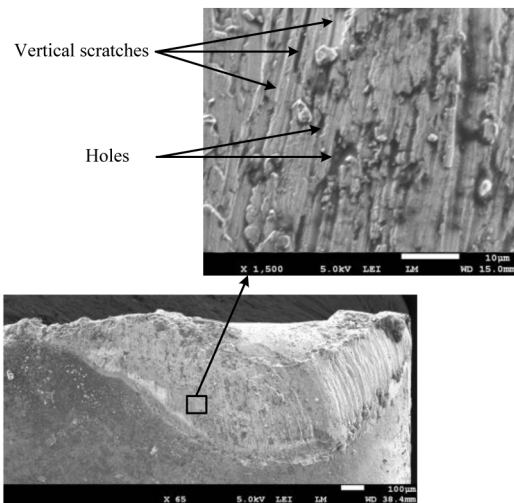


Figure 1. Two-body and three-body abrasion wear on the carbide insert

Different tool materials are suggested for cutting MMCs such as Polycrystalline Diamond (PCD), Cubic Boron Nitride (CBN), coated and uncoated carbide inserts. CBN inserts, which belong to the super-abrasive family of tool materials have proven to be able to improve the process productivity when machining difficult-to-machine materials [9]. This can be attributed to their high hardness and stability at high temperatures, high melting point and low coefficient of friction [10, 11, 12]. Owing to their ability to remain sharp during long machining operations, they can be used under high machining loads, while preserving the desired surface integrity [9].

The physical vapor deposition (PVD) coated carbide inserts also inherit superior characteristics during the machining of hard materials, due to their hot hardness and wear resistance in addition to their considerably lower price compared to PCD and CBN inserts [13].

CBN and PVD coated carbide inserts are employed in this study for the machining of Ti-MMCs. To evaluate the cutting tool life while machining the Ti-MMCs material, the reliability theory is proposed to model the random nature of the wear phenomena. Consequently, a quantitative estimate of the cutting tool reliability function and Mean Time To Failure (MTTF) might be obtained. Many researches have been conducted in cutting tool reliability. Hitomi et al. [14] and Wager and Barash [15] have observed that cutting tool life can be represented by a normal distribution. To quantify the reliability of carbide tools, Negishi and Aoki [16] have studied the influence of feed on cutting tool life during intermittent cutting. Moreover, DeVor et al. [17] have studied the probabilistic nature of cutting tool life. From these studies, a general understanding of the random nature of tool life became accepted.

The various wear mechanisms and corresponding tool degradations, which essentially depend on the cutting speed and on the tool and part materials, can generate different

statistical distributions as the normal, the log-normal or the Weibull distributions. To evaluate the reliability and useful life of cutting tools, a mathematical model based on the theory of probability is necessary. This stochastic model is related to the random variable associated with the operating time to failure of the cutting tool.

This approach was developed by Klim et al. [18] in a cutting tool reliability analysis for variable feed milling. The analysis was based on statistical distributions obtained from experimental results and took simultaneously into account the crater and flank face wear as tool failure criteria.

EXPERIMENT SETUP

For this study, a cylindrical bar of 4.5 inch diameter made of Ti-6Al-4V alloy matrix reinforced with a 10 to 12% of volume fraction of TiC particles was used. Two different inserts were employed for these dry machining tests. The inserts are the low content CBN 170 inserts and also the TH1000 coated carbide inserts (Figure 2).

The low content CBN 170 insert used for this study, contains 65% per volume of CBN with a grain size of 2 μm . The ceramic bonders are composed of TiCN and SiC whisker fibers.

The TH1000 insert is based on a super fine WC-grained, 5% of weight of binder phase content substrate which has a TiSiN - TiAlN nanolaminated PVD coating with a 2.5 μm total coating thickness and a nose radius of 0.8 mm.

In addition to a different tool material, the geometries of those two inserts are not identical. A positive chip breaker is present on the cutting face of the TH1000 insert contrary to the flat cutting face of the CBN 170 insert.

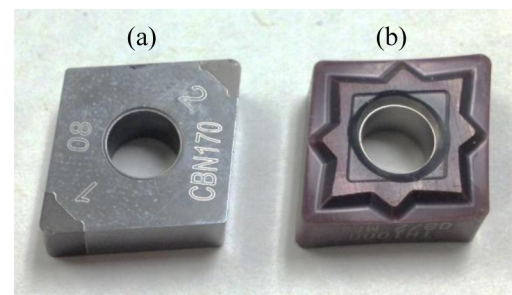


Figure 2. CBN 170(a) and TH1000 (b) inserts

These turning tests were performed on a Mazak Quick Turn Nexus 200, CNC turning machine. The setup of the experiment is shown on Figure 3.

The tool wear was measured with an Olympus SZ-X12 microscope.

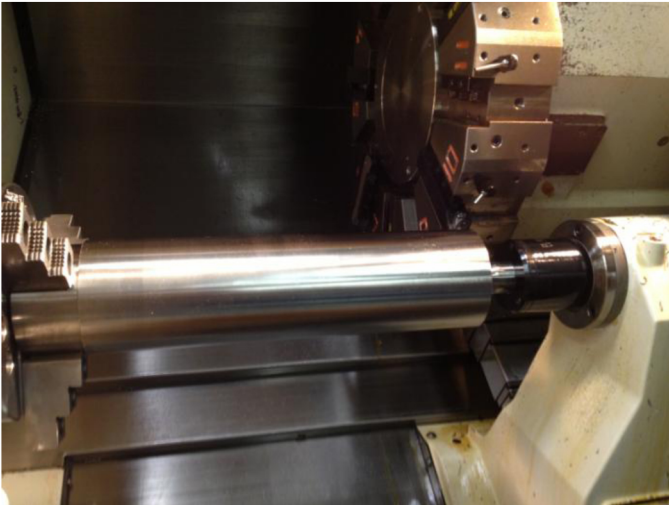


Figure 3. Experimental Setup

METHODOLOGY

In this study, the geometrical criterion (maximum tool flank wear length - VB_{Bmax}) was selected as the failure criteria. The maximum value of the tool flank wear, corresponding to the tool failure, was defined as 0.2 mm.

The cutting conditions for this type of material are not yet fully optimized; therefore the chosen cutting conditions are based on the supplier's recommendations and the parameters are listed in Table 1. For each tool, the experiments were performed under the mentioned cutting conditions. Each experiment was performed under constant cutting time, for the same type of tool, equal to 60 seconds and 6 seconds for the TH1000 and CBN 170 inserts respectively. The tool wear was measured after each run and the experiments were continued until the tool wear criterion was reached. The same procedure was repeated five times for each kind of insert. The results are used for the reliability analysis.

Table 1. Standard cutting parameters for the used inserts

Parameters \ Insert type	TH1000	CBN 170
Cutting Speed (m/min)	60	200
Feed Rate (mm/rev)	0.15	0.15
Depth of Cut (mm)	0.20	0.20

For the reliability analysis, a cutting tool has two possible states: an operating state and a failed state. In the former, a tool possesses sufficient characteristics to properly fill its intended function for machining. The latter corresponds to the state where the tool is unable to cut correctly and in terms of probability it is considered as an event opposed to the operating state.

The transition of a tool from a working state to a failure state is defined as a failure. In reality, the failure of the cutting tool is observed as an excessive wear or as a cutting edge breakage. Often, the breakage of a cutting edge is due to an incompatible choice of the cutting parameters or tool inner defect. For the purpose of this study, the failure by breakage has been disregarded and only the wear has been considered as a failure criteria. During the tests, no breakage failure was observed and therefore this hypothesis is considered to be valid.

For a cutting tool, the acceptable wear is generally based on geometrical, technological, physical or economic criteria. The geometrical criteria take into account the geometric changes of the cutting edge, the technological criteria consider the change of the machined surface's roughness and its dimensions, the physical criteria take into account the cutting forces or the temperature variations and the economic criteria are based on the manufacturing costs.

In this study, the cumulative wear on the tool flank was chosen as the observed modes of damage. The tool failure was defined by maximum tool flank wear length - VB_{Bmax} and the random variables of the time to failures were derived from the test results. The reliability function and Mean Time To Failure (MTTF) are chosen to assess the cutting tool reliability and operating life.

The reliability function is expressed as follows:

$$R(t) = \int_t^{\infty} f(t) dt \quad (1)$$

where $f(t)$ is the failure probability density function and the mean time to failure is obtained by:

$$MTTF = \int_0^{\infty} R(t) dt \quad (2)$$

From the experimental results measured on cutting tools in the same cutting conditions, the statistical laws associated with the random variable were estimated and mean tool life was computed.

RESULTS AND DISCUSSION

The critical value of flank wear VB_{Bmax} of 0.2 mm was adopted for the purpose of this analysis. The tool operating times to failure were obtained for each case from the set of wear curves for the adopted limit VB_{Bmax} . The tests' results for CBN 170 and TH1000 are presented in Figures 4 and 5 respectively.