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Analysis of Milling Tool Life – A Review

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ABSTRACT: Milling is the most common form of the machining in which the cutter removes metal as the work is fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. In the commercial manufacturing processes tool life of milling cutter is considered as an important factor. Analyzing and examining of milling processes are usually based on some main parameters such as speed, feed, depth of cut etc.

Here we have a review of such papers which are investigating the prediction of milling cutter tool life by using carbide (coated/uncoated) tool materials and by using various methodologies. It also gives the characteristics of the coated and uncoated carbide material.

KEYWORDS: milling, coated/uncoated carbide tool, process parameters, tool life prediction.

I. INTRODUCTION

Milling is the machining process of using rotating cutters to remove unwanted material from the workpiece by feeding in a direction at an angle with the axis of the tool. It covers a wide variety of different operations. The various milling process done by different milling cutter may be grouped under separate headings

1. Peripheral milling
2. Face milling

The world is continually searching for the cost reduction solution in less lead time in order to maintain their profit. It has long been recognized that condition during cutting, such as feed rate, cutting speed, and depth of cut should be selected to optimize economic of machining operation as assessed by productivity, the total manufacturing cost per component or some other suitable criteria. Regarding the economic aspects tool life estimation is a more important factor which is affected by various conditions like speed, feed and depth also it depends on the tool geometry, tool material, cutting fluid, workpiece material.

In every machining system, one simply can't ignore the significant role that cutting tool play. Most of the time quality of finished product would rely on the quality of cutting tools. The quality and the performance of the cutting tool will directly affect the machining systems and overall productivity. In this paper, we have a review of the carbide tool material and its tool life prediction. Coated and uncoated carbide tools are widely used in the metal-working industry and provide the best alternative for most milling operations.

II. WHAT IS THE CARBIDE TOOL?

As the requirement for versatile cutting tool increases, cutting tool suppliers also continuously developed the products that can pass through the manufacturer's demand. Lots of materials have experimented upon some have passed the standards while others were simply dropped. Nowadays there are mostly two types of the materials are used as the cutting tool material that is as follows-

1. High-speed steel.
2. Carbide cutting tool.

According to the chemistry, carbides are nothing but the group of the compound made up of the carbon and one other element that can be metal, boron, silicon, tungsten, titanium and cobalt, nickel, molybdenum as a binder . The carbide tool is made up of the powder metallurgy technique. When machining using carbide tools also known as the carbide

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tipped cutting tool. Carbide cutting tools edges are carbide tips which are brazed onto steel bodies used for under conventional cutting conditions. There is actually many compounds entered in this group, some of them are more popular are as follows_

1. Calcium carbide
- 2 Aluminium carbide
- 3.Silicon carbide
- 4.Tungsten carbide
- 5.Iron carbide. etc

ADVANTAGES OF CARBIDE CUTTING TOOL

1. Torsion strength is twice as that of the HSS.
2. Carbide tools have a longer working life because they have higher resistance to wear.
3. They are cost effective as compared to the high-speed tools.
4. It does not lose their hardness up to 1000 c.

III. COATED AND UNCOATED CARBIDE TOOL

To increase the life of the carbide material to boost the productivity; that carbide material is coated with some other coatings that are TiN (titanium nitride), TiC (titanium carbide), Ti(c)N (titanium carbide-nitride), and newer coating is known as the DLC (diamond like carbide) Chromium nitride (CrN). The coating enhances the tool properties it generally increases the tool hardness ultimately tool life, reduces the cycle time, promotes the better surface finish. It allows the cutting edges efficiently pass through the material without having material stick to it. It has the ability to run at 2 to 3 times the speed of uncoated tooling. It also helps to lessen the temperature related with the cutting process and increases the tool life. It usually deposited via thermal CVD (Chemical Vapour Deposition) and, for certain applications, with the mechanical PVD (Physical Vapour Deposition) method.

IV. COATING CHARACTERISTICS

1. **HARDNESS-** In general the harder material or surface, the longer the tool will last. Titanium Carbo-Nitrate (TiCN) has higher surface hardness versus that of the Titanium-Nitride (TiN). The supplementary carbon to the TiCN 33% elevated hardness. With the surface hardness near to the 9,000 Vickers, CVD diamond that has been developed on to the tools illustrate 10 to 20 times improved tool life compared to the PVD coating.
2. **WEAR RESISTANCE-** This is the capacity of the coating to defend against the graze or abrasion. The coated tool material having high wear resistance.
3. **SURFACE LUBRICITY-** A higher coefficient of friction causes augmented heat, leading to shorter coating existence or coating failure. However, a lower coefficient of friction enhances the tool life. The amount of heat can be abridged by a surface that lacks coarseness or irregularities. This slicks surface lets the chips slides off the face of the tool, generating less heat. A higher surface lubricity also can allow for increases speed when compared to the non-coated version.
4. **OXIDATION TEMPERATURE-** This is the point at which the handling starts to break down. Although the Titanium Aluminium Nitride (TiAlN) coating may not be as hard as TiCN at room temperature, it proves to be much further successful in an application where heat is generated. This coating holds its hardness at elevated temperature due to the coating of aluminum oxide which is form between work material and tool. End mills are commonly coated with this type with the help of PVD coating.
5. **ANTI-SEIZURE-** Built up age is very common in nonferrous material like aluminum or brass.BUE can lead to chipped of the tool or over sizing of the part. This may be an aid with the poor coolant properties which directly affect the tool life.

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V. LITERATURE-BASED ON EVALUATION OF PREDICTION OF TOOL LIFE

Some research papers related to prediction of milling tool life are followings_

1 .K. Kadirgama, K. A. Abou-El-Hossein, B. Mohammad, M. M. Noor and S. M. Sapuan accepted 9 May 2008- The aim of this study is to build up the tool life prophecy model for P20 tool steel is nothing but a chromium-molybdenum alloyed steel with help of statistical method, using coated carbide cutting tool. The end mill can be equipped with two square inserts whose all four edges can be used for cutting. The tool inserts were prepared by Kennametal and had an ISO catalog number of SPCB120308 (KC735M). In this study, only one inserts per one experiment were mounted on the cutter. The insert had a square shape, back rake angle of 0°, the clearance angle of 11°, and a nose radius of 0.794 mm and had chip breaker. KC735M inserts are coated with a single layer of TiN. The coating is accomplished using PVD techniques to an utmost of 0.004 mm thickness. This prediction model was then compared with the results obtained experimentally. By using Response Surface Method (RSM) of the experiment, first and second order models were developed with 95% confidence level. The tool life was developed in terms of cutting speed, feed rate, axial depth and radial depth, using RSM and design of the experiment. In general, the results gained from the mathematical model are in superior accord with that obtained from the experiment data.

MODELS FOR TOOL LIFE AND EXPERIMENTAL SETUP

They give the model of relationship between the machining responses and machining independent variables-

$$Y = m \text{ Cutting speed} + n \text{ Feed rate} + p \text{ Axial depth} + q \text{ Radial depth} + C.$$

(Y is the response; C, m, n, p, and q are the constants.)

In machining investigate, the Box-Behnken design has found a wide relevance compared to other experiment designs used for RSM. The Box-Behnken design is based on the combination of the Factorial with partial block designs. It does not involve a large number of tests as it considers only three levels (-1, 0, 1) of each self-governing parameter (Box and Behnken, 1966). The Box-Behnken design is normally used for non-sequential experimentation when a test is allowed only once. It allows a proficient estimate of the parameters in the first and second order models. Using statistical software the cutting conditions of 29 experiments are generated and the experiments are conducted randomly on Okuma CNC machining centre MX-45 VA and using a standard coolant to lessen errors. In order to calculate the experimental error, the 29 experiments consider five times repeating of the central point of the cutting circumstances. After a series of the first-round trial, tests had been conducted and based on the recommendations specified by the tool and workpiece manufacturers, the cutting conditions of the main experiments were established.

CONCLUSION

It was concluded that the feed rate, cutting speed, axial depth and radial depth played a most important role in shaping the tool life. On the other hand, the tool life increases with a reduction in cutting speed and feed rate. According to the paper, the flank wears irresponsible for a reduction in carbide tool life.



Measurement of flank wear.

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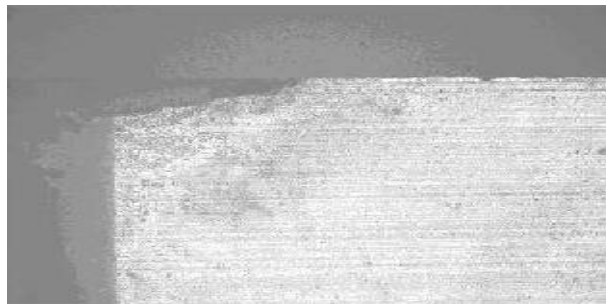
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For end-milling of P20 tool steel, the optimum conditions are required to make best use of the coated carbide tool life are as follow:

- Cutting speed-140 m/s,
- Federate-0.1 mm/rev,
- Axial depth-1.5 mm,
- Radial depth-2mm.

Using these parameters, a tool life of 39.46 min was obtained



Microscope picture of cutting tool



2 .Turned L. Ginta, A.K.M. Nurul Amin, A.N.M Karim,Anayet U. Patwari M.A. Lajis have analyzed optimization of tool life for end milling titanium alloy ti-6al-4v using uncoated WC-Co inserts. Response surface methodology attached with small central composite design (CCD) was occupied in developing the tool life.

MODELS FOR TOOL LIFE AND EXPERIMENTAL SETUP

Models for the machining responses for end milling in terms of the cutting parameters can be expressed as:

$$R = CV^k f^l d^m$$

End milling tests were performed on Vertical Machining Centre (VMC ZPS, Model: MLR 542) with full fascination cutting and under dry conditions. Machining was performed with a 20 mm diameter end mill tool holder fixed with one uncoated WC-Co insert.

Design-expert version 6.0.8 software was applied to establish the first-order and the second-order models and develop the contours. The adequacy of the predictive model was verified using analysis of variance (ANOVA) at 95% confidence level.

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CONCLUSION

Response surface methodology has been proved as a superior method in designing the experiments, modeling the models, and optimizing the cutting parameters in end milling of titanium alloy using uncoated WC-Co inserts under dry conditions.

It is initiated that cutting speed has the most important effects on tool life, followed by feed and axial depth of cut.

The optimum

Cutting speed-39 m/min

Feed-0.78 mm

Axial depth-0.061 mm/tooth

DOC for end milling of titanium alloy Ti-6Al-4V.

3. Vijay Arora, Gurpreet Iqbal Singh were analyzed prediction of tool life with condition monitoring system on end milling of EN31 using P30 Tungsten uncoated carbide tool. The experiment was performed with the help of Taguchi method design. The effects of cutting speed, feed rate and depth of cut on tool life of P30 were discussed. They put forward a novel technique for the tool wear measurement based on machine vision. Tool images are captured with cutting operations using a machine vision system for the analysis. The proposed scheme is shown to be effective for the tool wear prediction and that tool wear is ultimately affected by the tool life.

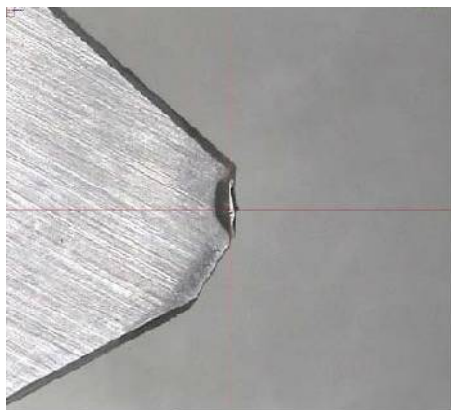
CONCLUSION

To get maximum tool life, optimum cutting parameters are required. Some formulae are given below to calculate optimum cutting parameters-

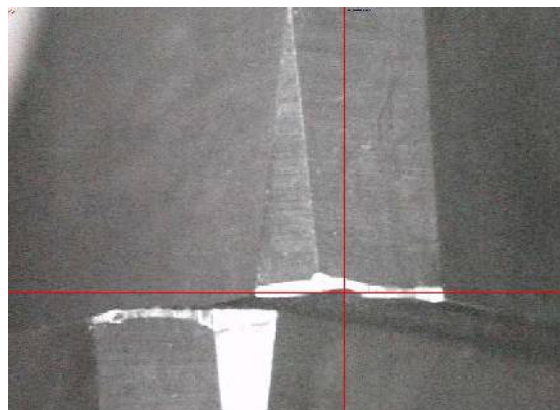
$$\text{Cutting speed} = \frac{\pi D N}{1000} \text{ m/min}$$

$$\text{Feed per tooth} = \frac{\text{feed}}{N \times T}$$

$$\text{Feed per revolution} = \text{feed per tooth} \times T$$



Nose wear after 10 passes



Compared Image of Wear and Unwear Sample

4. Jaharah A. Ghani Firdaus Mohamad Hamzah Mohd. Nizam Ab. Rahman Baba Md. Deros have performed the experiment on the reliability of tool life prediction model in end milling AISI H13 tool steel using P10 TiN coated carbide tool. The development of the data model was established by using Taguchi method. For the prediction of tool life, the speed within the range of 224m/min to 355m/min, the feed rate of 0.1 mm/tooth to 0.25mm/tooth & depth of cut of 0.3mm to 0.8mm are presented.

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MODELS FOR TOOL LIFE AND EXPERIMENTAL SETUP

A lot of data has been collected to establish a relation between tool life and cutting parameters (cutting speed, feed rate & depth of cut). The regression model accuracy could be checked by using average percentage deviation (ϕ) as given by-

$$\Phi = \frac{\sum_{i=1}^m \Phi_i}{m} \text{ Where, } \Phi = \text{average percentage deviation of all samples}$$

m = the sample size data

Φ_i = percentage deviation of single sample data

$$= \frac{T_i - T_o}{T_i} \times 100$$

T_i = actual tool life measured

T_o = predicted tool life from multiple regression equations.

The average percentage deviation (ϕ) is calculated from the multiple regression models plays an important role in judging model adequacy. The average percentage deviation (ϕ) calculated is equal to 77% from the data set of 18 trials. This shows that the predicted model could only predict the tool life (T) with about 23% accuracy. Therefore the coefficient of multiple determination (R^2) alone is not sufficient to check the accuracy of the regression model. Tool life Model-this model gives the relationship between independent variables of milling parameters like cutting speed, feed rate, depth of cut & tool life. Mathematically it is represented as –

$$T = C(v^l f^m d^n)^{\epsilon}$$

Where, v , f , d are cutting speed, feed rate, depth of cut respectively. C , l , m , n are constant.

The above tool life equation can be written as,

$$\ln T_p = -2.359 - 1.279 \ln f - 2.30 \ln d$$

This model describes the data adequately at 95% confidence interval with the confidence of multiple determination of 0.845.

CONCLUSION

For checking the accuracy of the regression model, the coefficient of multiple determination is insufficient so average percentage deviation is calculated. In this experiment average percentage deviation is 77% which indicates predicted model could only 23% accuracy.

The predictive model is adequate at 95% confidence limit with confidence of multiple determination of 0.845 by regression analysis using SPSS.

5. Jaydeep M. Karandikar, Ali E. Abbas, Tony L. Schmitz were applied Bayesian inference to estimate constants in tool life equation (i.e. exponent n & constant C) using discrete grid method. For this experiment, they used an uncoated carbide tool & 1018 steel as workpiece material. The results are used to update initial beliefs about constants & they are used to predict tool life using a probability density function.

After that, they implement extended form of the Taylor tool life equation which includes dependence on both cutting speed & feed for turning operation. The dependence on cutting speed is indicated by an exponent p & dependence on feed is indicated by an exponent q and model also includes constant c . To find these constants Bayesian inference is applied using the Metropolis-Hastings algorithm of the Markov Chain Carlo (MCMC) approach.

MODELS FOR TOOL LIFE AND EXPERIMENTAL SETUP

Taylor's relationship between tool life & cutting speed is given by-

$$VT^n = C \quad \dots(1)$$

Where, V = cutting speed in m/min

T = tool life in min

n & C = constants depends on the tool-workpiece combination.

In this experiment, Bayesian inference method used which forms a normative & rational method for belief updating. Using Bayes rule, information collected through experiment was combined with the prediction about the event to obtain a posterior distribution-

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$$P(A|B, \&) = \frac{P(A\&)P(B|A,\&)}{P(B\&)} \quad \dots (2)$$

By applying Bays inference to Taylor's tool life equation,

$$P(n, C|T, \&) \propto P(n, C\&) P(T|n, C, \&)$$

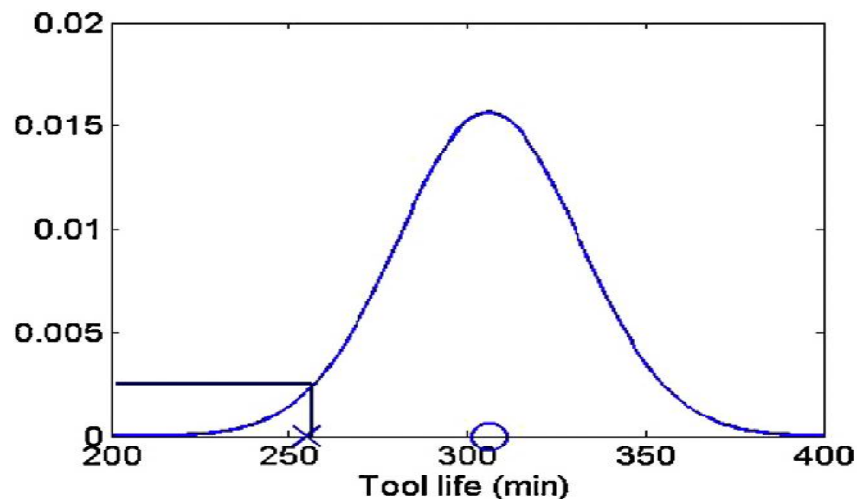
Where, $P(n, C\&)$ = prior joint distribution of n & c

$P(T|n, C, \&)$ = likelihood of observing experimental result for tool life T , given n & C .

$P(n, C|T, \&)$ = posterior joint distribution of n & C even an experimental result of tool life T .

CONCLUSION

To determine the likelihood function & posterior joint distribution, the discrete grid method is used. The value of tool life T for the first experiment was 255.3 min at $N=1500$ rpm ($V=89.8$ m/min). The range of values of n & C was divided into 500×500 grid points. The values of tool life were calculated at each point (i.e. the selected $\{n, C\}$ pair) using equation(1).



E.g. consider $n=0.3$ and $C=500$ m/min, the tool life at selected $\{n,C\}$ pair at 1500 rpm using equation(1) is 305.9min. The distribution of tool life T was assumed to be normal at each grid point with uncertainty equal to 10% of experimental value.

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PAPER NAME/DATE	AUTHOR NAME	TYPE OF MILLING	EXPERIMENTAL METHOD	WORK PIECE MATERIAL	TOOL MATERIAL	CONCLUSION
1.Prediction of tool life by `statistic method in end-milling Operation. (9 may2008)	K. Kadirgama. K. A. Abou-El-Hossein. B.Mohammad. M. M.Noor. S. M.Sapuan.	End milling.	Response surface method, ANOVA.	P20 tool steel	Coated carbide	-optimum conditions are 1.cutting speed-140 m/s 2.feedrate-0.1mm/rev 3.axial depth-1.5mm. -tool life was developed in terms of cutting speed, feed rate, axial depth, radial depth. -tool life increases with reduction in cutting speed and feed rate. -tool life-39.46min.
2. Modeling and Optimization of Tool Life for End Milling. (27Nov 2008)	Turnad L. Ginta. A.K.M. Nurul Amin. A.N.MKari m. Anayet U.Patwari. M.A. Lajis.	End milling under dry condition	Response surface method with CCD. ANOVA.	Ti-6Al-4v.	Uncoated carbide WC-Co.	-flank wear has been considered as the criteria for tool failure. -optimum conditions are 1.cutting speed-39m/min 2.feedrate-0.78mm 3.axial depth-0.061mm/tooth
3. Prediction of Tool Life with Condition Monitoring System on End Milling of EN31. (March-2014)	Vijay Arora. Gurpreet Iqbal Singh.	CNC type vertical milling.	Taguchi method.	EN31 tool steel.	P30 tungsten uncoated carbide tool.	-get maximum tool life, optimum cutting parameters are required.
4. The Reliability Of Tool Life Prediction Model In End Milling (June 2006)	Jaharah A.Ghani. Firdaus Mohamad Hamzah. Mohd. Nizam Ab. Rahman Baba Md.Deros	End Milling	Taguchi method.	AISI H13 tool steel	P10 Ti N coated carbide	-optimum conditions are 1.Cutting speed-224 m/min to 355 m/min, 2.feed rate of 0.1 mm/tooth to 0.25 mm/tooth 3. depth of cut-0.3 mm to 0.8 mm.

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5. Tool life prediction using Bayesian updating. Part 1: Milling tool life (27 June2013)	Jaydeep M. Karandikar. Ali E. Abbas. Tony L. Schmitz	milling	Taylor tool life equation, discrete grid method.	1018steel	Uncoated carbide tool.	-According to the Taylor tool life equation, tool life reduces with increasing cutting speed.
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VI. CONCLUSION

Here we have review of 5 papers of coated/ uncoated carbide tool material life for the milling operation and from those papers, we conclude that

1. There are various factors affects on the tool life of the coated/ uncoated carbide tool material they are as follows-
Workpiece material
Cutting parameters (cutting speed, feed rate, and depth of cut)
Cutting fluid
The temperature at the cutting edge.
2. There are various methods used to the prediction of tool life which are more useful for the better tool life eg Taguchi, ANOVA, response surface method, Tylor tool life equation, discrete grid method.
3. Coated carbide tool has a better life than uncoated carbide tool.
4. Tool geometry also affects the life of the tool.

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