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PREDICTION OF TOOL LIFE OF UNCOATED CARBIDE INSERT

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ABSTRACT

Over the last few years an extensive study has been carried out on the machining of metals to predict cutting force, cutting temperature and tool wear. Tool life is one of the most important parameter in the machining research area and it forms basis to evaluate the performance of the tool material and to assess machinability of the work material In general, carbide inserts looses its life by gradual wear. In the present study, experiments are conducted to study the wear behavior of Carbide tool insert during turning of Carbon steel (AISI 1055). The influence of independent variables or the primary machining parameters such as cutting speed, feed and depth of cut on the tool life is studied. The cutting parameters are varied and wear behavior of carbide insert is studied under dry cutting conditions. A generalized mathematical model is formulated to predict tool life with a power form equation using cutting parameters. The wear of the cutting insert is evaluated by Tool Makers Microscope. The experimental studies indicate that the cutting speed has more effect on the tool life than feed rate and depth of cut. The results shows that the experimental values of Tool life and the Tool life values predicted from Mathematical model are in good agreement with each other.

Keywords: *Tool life, Machining, Flank Wear.*

1. Introduction

Over the last few decades an extensive study has been carried out on the machining of metals to reduce machining cost and to develop a pragmatic approach to the manufacture of parts of acceptable dimensional accuracy and surface quality. During metal cutting, tool is subjected to continuous wear and hence loses its ability to cut efficiently. The tool life forms basis to evaluate the performance of the tool material and to assess machinability of the work material. Tool wear/Tool life is an important aspect in evaluating the performance of a metal cutting process. It is indispensable to predict tool life under varying cutting conditions and it becomes main issue towards this study. A general literature survey is done on investigation and analysis of tool life, tool wear and failure, and optimization. In general, investigations were focused on orthogonal models.

The following paragraphs discuss the work of various researchers relevant to present field of investigation.

Lajis M A et al., [1] and Burhanuddin Y et al., [2] have developed tool life models to predict tool life. The cutting parameters such as cutting speed, feed and depth of cut were used to predict tool life with a power form equation. Lajis M A et al., used Response surface methodology to develop first and second order models and predicted the average error of tool prediction less than 10% by Analysis of Variance (ANOVA). Burhanuddin Y et al., showed the significance of cutting depth to tool life in the cutting speed range of 180-280m/min and no contribution of CBN content on tool life. Hari Singh et al.,[3] have developed the mathematical models of tool life and surface roughness for turning with titanium carbide coated tungsten carbide inserts and applied Response surface methodology to develop the models in the form of multiple regression equations. The importance of mathematical models for correlating the interactive and higher order influences of various machining parameters on material removal rate and surface roughness through RSM has been studied by Ravikumar R et a.,[4]. ANOVA has been carried out to validate the mathematical models. Vipin B B Arora et al., [5] have studied the tool life models for turning of cast steel material with uncoated cemented carbide tool during heavy machining operations under dry conditions with varying depth of cut. The tool life models have been developed in terms of cutting speed, feed and depth of cut using regression analysis and factorial design method.

A study of Tool wear and constants of tool life equation (C, n) [6] has been carried out during orthogonal cutting of AISI 1025 under dry and wet

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conditions. The results of dry and wet cutting conditions were compared and showed a percentage increase of 18% in the constant ‘C’ and a decrease of 7% in the constant ‘n’ at 0.9 wear criterion which leads to a percentage increase in the tool life. Matsumura T et al., [7] have simulated the tool wear with cutting force and cutting temperature by employing principle of minimum cutting energy in the force model to predict the cutting force. The abrasive wear model has been applied to the flank wear prediction and has been used to predict the flank wear progress, which gave the wear rate with the stress and the temperature on the flank wear land. Sundaram S et al., [8] have evaluated the flank wear during turning of C45 steel of 250 BHN hardness with Polycrystalline diamond (PCD) insert and obtained correlation between the tool wear and AE parameters by using the experimental study. Lin H M et al.,[9] have studied tool wear mechanisms in turning of high hardness alloy steel by CBN tools and noticed that the abrasion dominates tool wear at low cutting speed and at high cutting speeds, a protective layer would be formed on the chip-tool interface to act as a diffusion barrier. Hence, tool wear rate was reduced and the usable life of the CBN tool was prolonged. When the cutting speed was further increased, cutting temperature becomes the dominant factor instead of the cutting force. Hari Singh [10] has investigated optimal values of turning parameters cutting speed, feed and depth of cut, which may result in optimizing tool life of TiC coated carbide inserts. The Taguchi’s design of experiments approach has been used to study the effects of the selected process parameters on the tool life.

Mehrban M et al., [11] have carried out design of experiments method to investigate tool life in turning process. The effects of cutting parameters have been studied by applying a full factorial design. Analysis of variance for the main factors of design and their interactions were studied for their significance. Finally, a model using multiple regression analysis between cutting speed, feed rate and depth of cut with the tool life had been established. Bouchelaghem H et al.,[12] have used least square method to establish a mathematical model for tool life as a function of cutting speed. The effect of cutting speed on wear, effect of wear on tool life, roughness, cutting forces and productivity were studied. Luo X et al., [13] have conducted theoretical and experimental studies to determine the intrinsic relationship between tool flank wear and operational conditions in metal cutting processes using carbide cutting inserts. They developed a new flank wear rate model to evaluate tool flank wear land width. Yong Huang et al., [14] have proposed an analytical model to the CBN tool flank wear rate as a function of tool/workpiece material properties, cutting parameters and process arrangement in three-dimensional finish hard turning. The main wear mechanisms in CBN turning of hardened steels were considered to be a combination of abrasion, adhesion, and diffusion and the contribution of each wear mechanism has been related to cutting conditions, tool geometry, and material properties of the tool and the workpiece. Habeeb H H et al., [15] have discussed the behavior of cutting tools in term of tool wear, tool life and surface roughness integrity during machining of nickel based alloys 242. Flank wear was found to be the predominant tool wear.

The evaluation of tool wear was done by Thamizhmnaii et al., [16] during hard turning of martensitic stainless steel. The evaluation was done using CBN cutting tool on SS 440C stainless steel with hardness between 45 to 55 HRC. Maity K P et al., [17] have conducted experiments for hot-machining operation of high manganese steel using a carbide cutting tool. The regression analysis has been performed to develop a tool life equation as a function of cutting speed, feed, depth of cut and temperature. The adequacy of the model was tested and effects of cutting conditions on tool life were also investigated. Dave H et al., [18] have optimized the process parameters of milling machine using combination of Taguchi method and Grey relational analysis method by taking speed, feed and depth of cut as input parameters and cutting force, torque and power as target values. They used L16 orthogonal array of Taguchi method and obtained feed as the maximum influencing factor on target characteristics. The different tool wear mechanisms has been studied by Rajesh Y Patil [19] to predict useful tool life. Different Tool life models and Tool wear rate models have been reported. Yahya Isik [20] assessed the effect of different coating materials on machinability in the turning of AISI 1050 steel. The cutting forces and flank wear values were measured throughout the tool life. The machining performance of different coating materials was evaluated and cost analysis was performed for the comparison of the economic viability between different coating materials.Ramji et al., [21] have evaluated the flank wear and surface roughness in turning of gray cast iron using cryogenically treated carbide inserts. They used Taguchi’s Orthogonal Array technique and ANOVA to identify the effect of parameters on the response variables.

2. Experimental Procedure

The experiments have been conducted on ACE, two axis CNC turners at R R Techno Products, Peenya Industrial Area, Bangalore. It is a two axis CNC turner, with maximum allowable cutting speed of 250m/min, turret with 12 stations and can accommodate work pieces of diameter 6mm to 300mm and length up to a maximum of 320mm. The flank wear has been measured by Tool Maker's microscope. Several times the experiments have been interrupted in order to measure the flank wear. The adverse surface defects on the work materials that can affect results are eliminated by removing top surface with small depth of cut. The flank wear values have been measured after 10, 20, 30, 40, 50 and 60 minutes.

Fig. 1 ACE Two Axes CNC Turner

2.1 Specifications of work piece, tool and tool holder

Work Piece: CARBON STEEL (AISI 1055)
Composition: C- 0.6%, Mg-0.8%, Si-0.35%, S-0.06%, P-0.06 % (max), hardness- 255BHN
Tool insert-WIDIA makes uncoated Carbide insert was used with designation CCMT090304FR24, Rhombic, nose angle 80˚and relief angle 7˚.

Fig. 2 Tool Maker's Microscope

3. Results and Discussion

Tool Life: The tool life values for different cutting speeds are obtained at Tool life criteria of V_B =0.35mm with respect to ISO 3685 1977 (E). Then these experimental tool life values and the corresponding cutting speeds are plotted on log- log sheet to obtain relation between the tool life and the cutting speed by performing regression analysis. The equation of the form $TL = \frac{C_1}{V_c^{\,a}}$ i.e., tool life equation as a function of cutting speed is developed. The same procedure is repeated for different cutting conditions and the values of 'C_1' and 'a' are averaged to obtain the final equation of tool life. The same procedure is repeated to obtain the tool life equation as a function of feed rate and depth of cut. The tool life equation in terms of cutting speed, feed and depth of cut is analytically derived and is of the form $TL = \frac{K}{V_c^a f^b doc^c}$.

The cutting conditions, type of tool insert used for cutting process and type of work material to be machined influence the wear pattern of the tool insert. In general, adhesion, abrasion and diffusion are considered as main tool wear mechanisms. The effect of each mechanism in turn depends on the combination of tool and work material, cutting conditions etc. It is observed that the carbide tool experiences gradual wear in the selected range of process parameters and hence fails gradually. The flank wear is due to friction between the flank face of the tool and the machined surface. The abrasive wear is the most dominant flank wear that appears by grooving on the flank face of the tool. This is mainly due to pull out of tool particles by the interaction of tool and work material. At the contact area between tool flank and work material, the tool particles adhere to work piece surface and are periodically sheared off. At higher range of cutting conditions, adhesion of tool and work material will be more.

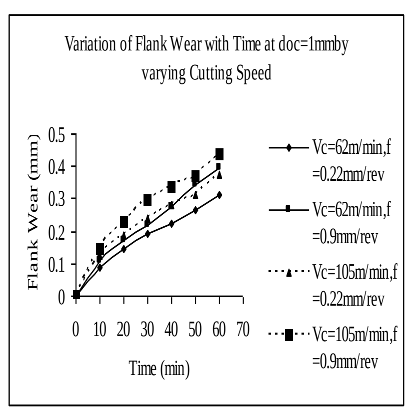

Fig. 3 Plot of Flank Wear with Time at Different Cutting Speeds

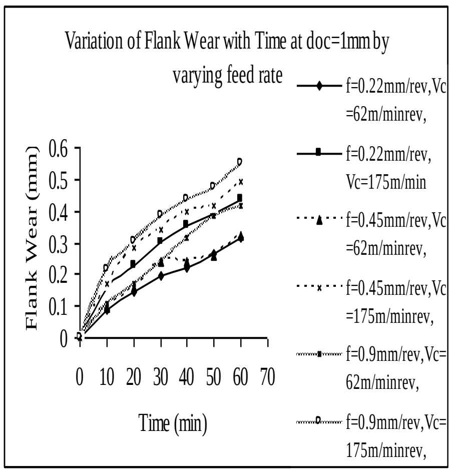

Fig. 4 Variation of Flank Wear with Time at Different Feed Rates

From Figures 3,4 and 5, it has been observed that the flank wear behavior is greatly influenced by cutting speed amongst the process parameters. The growth of flank wear is more with change in cutting speed when compared to change in feed rate and depth of cut. The feed rate is the second dominating parameter to influence the flank wear. The flank wear values are in acceptable range with lower depth of cut and feed for a given cutting speed. At higher values of cutting speed, feed and depth of cut, the tool wears out quickly and results in reduced tool life.

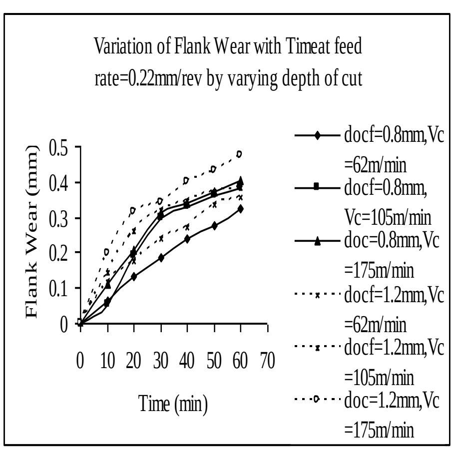

Fig. 5 Variation of Flank Wear with Time at Different Depths of Cut

For a given feed and depth of cut, the growth of flank wear is less at low cutting speed of 62m/min and tool wear is mainly due to abrasive action between tool and work material. The growth of flank wear increases with increase in cutting speed and tends to become maximum at high cutting speed of 175m/min. The tool tip holds the high temperature generated due to high cutting speed for the entire length of machining, there by increases flank wear. At high cutting speed, the temperature involved in machining is the dominant factor to cause tool wear. The carbide insert looses its hot hardness and strength and this causes gradual wear and progressive failure of the tool insert. The flank wear trend will obey the universal wear law for the first two zones i.e., wearing at the beginning, normal wear with the progress of time and the third wear zone i.e., the accelerated wear zone at the end of cutting has not been observed in the present study. This may be due to the selected range of process parameters. There were non uniform flank wears observed at different cutting speeds.

The growth of flank wear was rapid at high cutting speed and a rapid increase of flank wear was observed beyond the cutting speed of 150m/min. As a consequence, the extent of normal wear zone is considerably reduced. The extent of normal wear zone is at 30 to 35 minutes when turning at f=0.22mm/rev, doc=1mm and at Vc=62 and 105m/min as shown. The normal wear zone decreases to 20 to 25 minutes when turning at high cutting speeds of 150 and 175m/min.

The extent of normal wear zone is also affected by feed rate and depth of cut. From the Figure 4, at V_c=175m/min, doc=1mm, and f=0.22mm/rev the extent of normal wear zone is nearly at 40 minutes and this decreases with increase of feed rate i.e., at f=0.45mm/rev and 0.9mm/rev, the normal wear zone extends up to 30 minutes and 28 minutes respectively. Similarly from Figure 5, at V_c=62m/min, f=0.22mm/rev, and doc=0.8mm the extent of normal wear is nearly 32 minutes and this decreases to 28 minutes and 20 minutes with the increase in depth of cut to 1mm and 1.2mm.

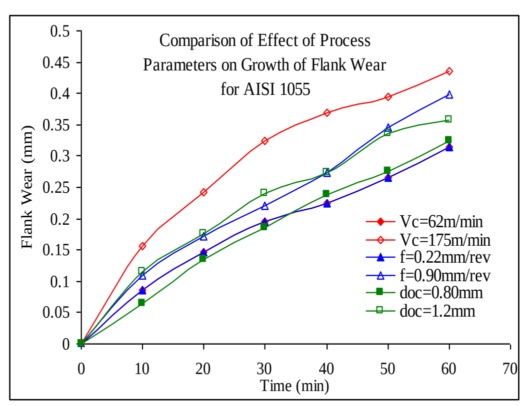

Fig. 6 Comparison of Effect of Process Parameters on Flank Wear

The Figure shows 6 comparison of influence of process parameters on growth of flank wear for AISI 1055 work material. It has been observed that the growth of flank wear with change in feed rate was less than with change in cutting speed. The growth of flank wear with change in depth of cut was found to be less when compared to change in cutting speed and feed rate.

$$TL = \frac{873.1}{V_c^{-0.6105}} \quad (1)$$

$$TL = \frac{34.9326}{f^{-0.3219}} \quad (2)$$

$$TL = \frac{51.948}{doc^{-0.3152}} \quad (3)$$

Therefore, the final equation is of the form

$$TL = \frac{116.0258}{V_c^{0.2033} f^{0.1071} doc^{0.1049}} \quad (4)$$

From equations it has been observed that the exponent of process parameters i.e., a, b and c indicate the extent of effect of process parameters on tool life. These equations are useful for a given combination of tool and work material and the values of speed, feed and depth of cut exponents lie in the numerical region a>b>c. The significance of cutting speed to affect tool life is more than other two parameters and the significance of feed rate on tool life is more than depth of cut. When c is very small, the tool life is virtually independent of depth of cut.

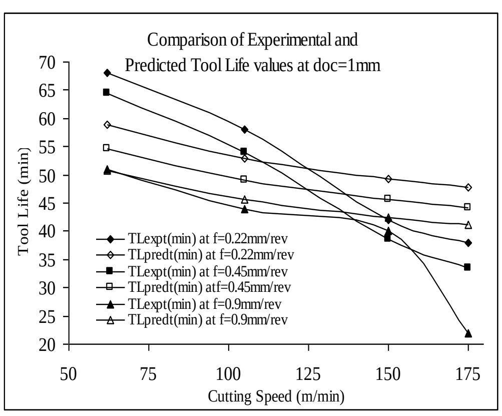

Fig. 7 Comparison of Experimental and Predicted Tool Life Values at Different Cutting Speeds

The lower and medium depth of cut, feed rate and cutting speed yielded better performance of the cutting tool. The longer tool lives have been obtained with medium depth of cut, medium feed rate and lower cutting speed. The selection of primary process parameters cutting speed, feed and depth of cut should be based on consideration of maximum tool life and high production rate.

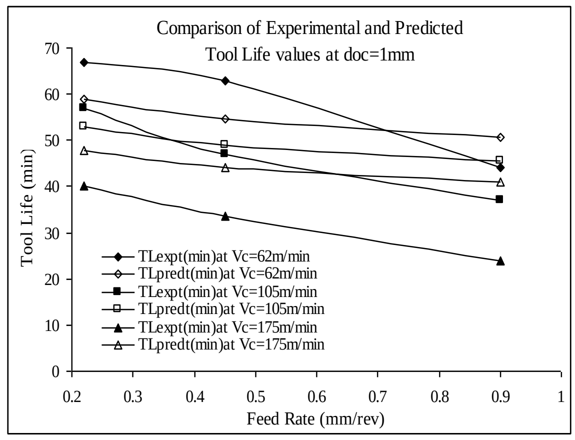

Fig. 8 Comparison of Experimental and Predicted Tool Life Values at Different Feed Rates

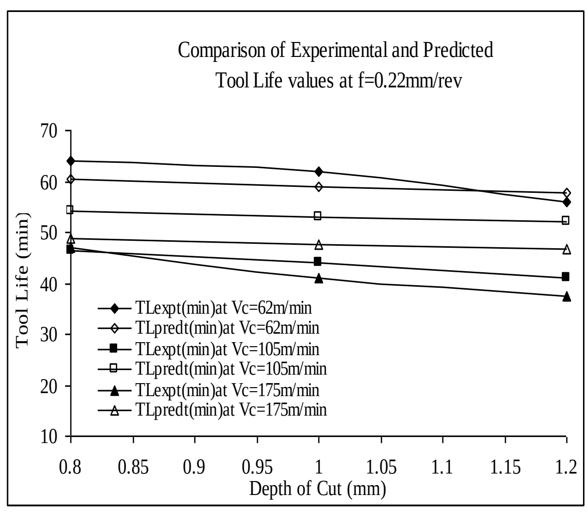

Fig. 9 Comparison of Experimental and Predicted Tool Life Values at Different Depths of Cut

The Figure 7-9 shows variation of experimental and predicted values of tool life with process parameters at different cutting conditions. Comparison of experimental values of tool life and the tool life values predicted from equation during turning of AISI 1055 has been made It has been observed that, for most of the cutting conditions, the experimental and predicted values of tool life are in good agreement with each other. The equation of tool life i.e., equation has predicted tool life values better except for high cutting speed of 175m/min. This may be due to machining constraints during turning at high cutting speeds.

4. Conclusion

There were non uniform flank wear at different cutting speeds. At high speed i.e. at 150m/min the growth of flank wear was rapid and the extent of normal wear zone was considerably reduced. This is justified when turning at 62,105 and 175m/min. The effect of cutting speed is more significant than feed and depth of cut during tool life calculations. This is justified as a>b>c.

The Tool Life model,

$$TL = \frac{116.0258}{V_c^{0.2033} f^{0.1071} doc^{0.1049}}$$

helps to predict the tool life for all cutting conditions without the help of experimental values. The results proved that the experimental and predicted tool life values are in good agreement with each other and for most of the cutting conditions the percentage error is less than 15%.The results discussed here provide more understanding on the machining of carbon steel in order to identify the optimal cutting conditions to provide better tool life and better performance with lower production time.

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Nomenclature

Symbol	Meaning	Unit
Vc	Cutting Speed	m/min
F	Feed	Mm/rev
doc	Depth of Cut	Mm
TL	Tool life	Min
C1, C2, C3	Empirical constants	--

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