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Experimental and Numerical Investigation of Tool Life of Single Point Cutting Tool during Turning Process

S. Sowjanya*, D. Sreeramulu and C. J. Rao

Department of Mechanical Engineering, AITAM Engineering College, Tekkali - 532201, Andhra Pradesh, India; sowjanyas357@gmail.com, dowlurusreeram@gmail.com, raoj_chintu@yahoo.com

Abstract

The heat generated at the tool-chip interface dissipates the heat into the tool, which causes the rise in temperature at the tool tip during the metal cutting process. The temperature rise in cutting tool tends to soften it and causes loss of tool material in the cutting edge leading to its failure. **Objective:** To determine the temperature distribution along the tool tip for different cutting parameters like feed rate, cutting speed and depth of cuts. **Method:** In this study, tool chip interface temperature was determined in cutting of mild steel workpiece with HSS as the cutting tool. The effects of different parameters like cutting speed, feed rate and depth of cut are taken into account so as to predict their effects on tool life are studied both in experimental and numerical analysis. **Finding:** In present work the tool life of HSS tool is evaluated at different cutting parameters during turning process. It has been found that the tool life is decreases with feed rate and cutting speed. The optimal process parameters found in turning process are high cutting speed, low depth of cut and lower feed rate. **Conclusion:** The results have shown that change in cutting speed and feed rate has the maximum effect on cutting temperature than depth of cut.

Keywords: Cutting Speed, Cutting Temperature Distribution, Depth of Cut, Feed Rate, Tool Life

1. Introduction

Machining is the processes in which a piece of raw material is cut into a desired final shape and size by a controlled material removal process. Turning is the one of the machining process the workpiece is rotated against the cutting tool. Lathes are principle machine tools used in turning. In turning, the cutting tool with single cutting edge is used to remove material from a rotating workpiece to generate a desired shape. The primary motion is provided by rotating the workpiece and feed motion is achieved by moving the cutting tool slowly in a direction parallel to axis of rotation of the workpiece. The various process parameters during turning process are shown in Figure 1.

The major quantity of heat generated during the metal turning is dissipated to the chip and the small amount of heat is dissipated to the tool which causes a high temperature at the cutting edge of the tool. It is difficult to measure the temperature at the cutting zone of the tool because the workpiece is rotating with the spindle speed .the various methods used to measure the temperature at the cutting zone are metallographic methods like thermocouple method, infrared photographic technique, thermal radiation, thermo sensitive methods and thermocouple insert techniques etc.

**Author for correspondence*

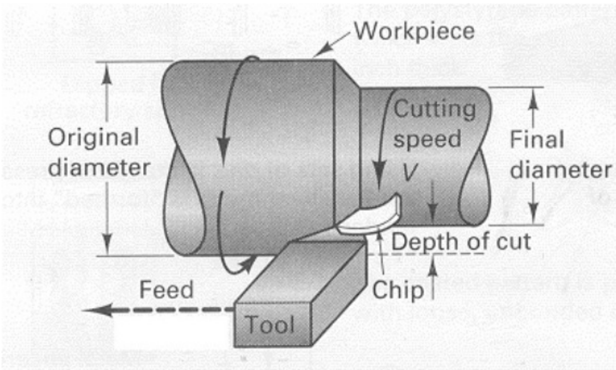


Figure 1. Turning process parameters.

The various parameters involved in metal turning process are feed rate, depth of cut, cutting speed, rake angle, tool and workpiece materials and tool nose radius. The major parameters affecting the temperature distribution in turning of HSS tool are the depth of cut, feed rate and cutting speed. Tool work thermocouples are generally used for measuring the temperatures during the machining processes for varying parameters like feed rate and depth of cut. Thermocouples are inexpensive and can operate over a wide range of temperature measurements.

During metal cutting process, the heat generated is significant enough to cause local ductility of the work piece material as well as the cutting edge. The heat generated as the negative significance on the tool life. So, the temperatures generated at the cutting edge of the tool must be controlled to improve the tool life and performance of tool. It is very important to pay attention to increase the tool life. As increase in tool life the variable cost decreases. The tool life mainly depends upon the parameters like Feed rate, Depth of cut and cutting speed. To increase the tool life the above parameters must be optimized.

1.1 Tool Life

Tool life is defined as the time elapsed between the two successive grindings of the tool. During this time the tool cuts the material effectively and efficiently. The tool life of a cutting tool must be higher. Conditions giving a shorter tool life will be uneconomical because tool grinding and tool replacement must be takes place thereby increasing the variable cost of the machining. The life of the cutting tool can be calculated by using Taylor's equation. The taylor's tool life is given by the equation

$$V\,T^n = C$$

Where V is cutting velocity in m/min, T is tool life in min and n, C are the constants which can be obtained during experiment or can be taken from machinery hand book.

1.2 Cutting Tool Materials

Cutting tool material plays an important role in turning process. The cutting tool material should possess the following characteristics to produce good quality and economical parts.

- Hardness and strength of the tool must be maintained at elevated temperatures.
- Toughness of the tools is necessary for the tool tip not to undergone fracture.
- Wear resistance of the tool must be high in order to get high tool life.
- High temperature stability.

Generally, HSS tools are widely used in these days because these can withstand increased cutting speeds and temperatures. By adding alloying elements to the plain carbon steels like manganese, chromium, vanadium, tungsten, molybdenum and cobalt can increase the following characteristics like hardening capability, high toughness, resistance to fracture, abrasive wear resistance and strength to high speed steels. These are highly suitable for interrupted cuts. It has hot hardness value of 600°c.

In this present work, the machining operation is carried out on mild steel workpiece with HSS single point cutting tool.

1.3 Theoretical Fundamentals

In this experiment, 3-dimensional steady state heat conduction equation is used to predict the temperature distribution in tool. The equation can be written as (Molinari et al, 2005):

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q(x,y,z,t)}{k} = \frac{1}{\alpha}\partial T/\partial t$$

Where K=thermal conductivity, T = temperature, α = thermal diffusivity coefficient

1.4 Assumptions in Analytical Model

For calculating temperature distribution at tool work interface and tool life the following assumptions are made.

- The contact between tool and chip interface is thermally perfect.
- The heat generated during turning process mostly affects the tip of the cutting tool so the analysis is carried out only at the tip of the tool.
- The boundaries are kept at the room temperature (T_α = 20°C).
- The heat lost by radiation is small and negligible.

2. Literature Review

Several experiments have been conducted by considering the different machining parameters like cutting speed, depth of cut, feed rate and rake angles. The researchers have been investigated the effects of these machining parameters on the cutting forces, temperature and tool life.

N. Trajcevski et al.[1] proposed that the cutting temperature is a function of feed rate, depth of cut and cutting speed. They are performed the turning operation on lathe by using ceramic cutting tool inserts which are made from mixed ceramics. Average temperature is determined by using of natural thermocouple method and computer aided research equipment. They found that the cutting temperature mostly depends upon the cutting speed and feed rate and less on depth of cut.

N. A. Abukhshim et al.[2], they done the determination of temperature distribution and maximum temperature developed at the rake face of the cutting tool. New temperature measurement results are obtained from an imaging camera in high speed cutting of high strength alloy. Finally, they reviewed the estimation of heat generation, heat partition and temperature distribution in metal machining. For temperature measurement of the high speed cutting process the most promising candidates are the fibre-optic pyrometers and infrared thermography techniques. Compared to other methods these techniques could measure temperature, as well as, the cooling rate easily, accurately and with fast time response.

L. B. Abhang and M. Hameedullah[3] they determined the maximum temperature at the tool chip interface by using thermocouple. They worked on the alloy steel workpiece with carbide tool so as to investigate the temperature distribution at the tool chip interface. Here they are using k-type tool work thermocouple which is connected between the cold and hot junction to measure voltage so as to find out the temperature at the tool chip interface.

Maheshwari N. Patil[1] and Sheppard[4] presents a methodology to determine tool forces, distribution of temperatures to estimate distribution of stresses and deformation on the single point cutting tool in the process of metal cutting. Experimental set up is made for force measurement during cutting using dynamometer and analyze the effect on the tool. Use ANSYS, NASTRAN software for analysis of single point cutting tool. Analyze the residual stresses developed in the tool and optimizing the tool life.

S. R. Carvalho et al.[5] proposed the estimation of temperature and heat flux at the tool chip interface by using the inverse heat conduction problem. The thermal modelling can be obtained by a numerical solution of the transient three-dimensional heat diffusion equation that considers both the tool and the tool holder assembly. The temperature field in any region of the tool set (insert, shim and tool-holder) is calculated from the heat flux estimation at the cutting interface.

Sana J. Yaseen[6] studied the effects of rake angle, cutting speed, feed rate, and tool and workpiece materials on the temperature and heat flux. He concluded that the temperature increases with increase in cutting speed and feed rate where as the cutting temperature decreases with increase in rake angle.

Sushil D. Ghodam[8] proposed that by applying coating on the tool the life of the tool was increased. The tool work thermocouple was used for the experimental analysis of the tool life because it was inexpensive. The comparisons were made between the temperature distribution for coated and uncoated tool. These showed that with coatings the temperatures generated within the tool were decreases so the tool life was increased.

J. Nithyanandam et al.[9] studied the influence of input parameters like feed rate, speed and depth of cut to reduce tool wear rate and to improve the surface finish of the machined part in titanium alloy(Ti-6Al-4V) using coated carbide inserts. They concluded that the feed rate is the dominant parameters for surface finish and depth of cut has the minimum effect on surface roughness. The optimum parameters for titanium alloy were obtained as cutting speed = 175 m/min, feed rate = 0.05mm/rev and depth of cut = 0.5mm.

3. Proposed Work

In this work the temperature distribution is analysed by varying the different parameters like feed rate, depth of cut and cutting speed during turning process. The

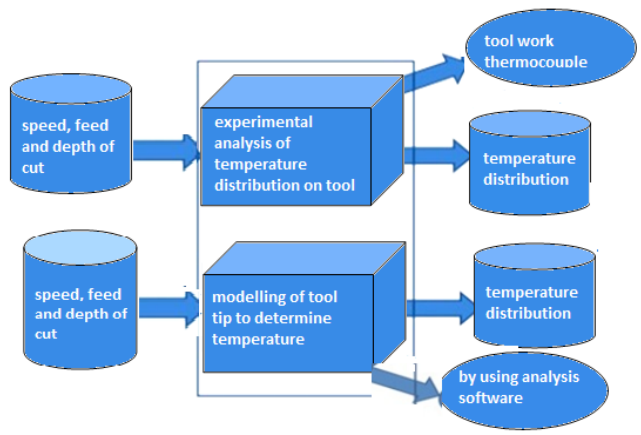


Figure 2. Block diagram for proposed work.

temperatures at the tool tip are calculated by using tool-work thermocouple. By using the temperatures the cutting forces and the life of the tool is calculated.
The tool tip is modelled by using analysis software and temperature distribution is obtained the fatigue (life) is calculated .The comparisons are made between experimental data and numerical analysis. The block diagram for the present work is shown in Figure 2.

3.1 Objectives of the Work

- Determination of the temperature distribution along the cutting edge of the tool by varying the feed rate, depth of cut and cutting speed.
- To evaluate the cutting forces, power produced and tool life during the turning process.
- Evaluation of the fatigue tool life by using ansys software.
- Comparison of the results obtained from experimental data and ansys software.
- Determination of optimum parameters at which the temperature effect is less for the tool life.

3.2 Evaluation of Tool Life by Experiments

The experiment is conducted on the HSS tool operating on mild steel workpiece in turning. These machining tests were carried out in a conventional lathe. The workpiece material used in the experiment was mild steel in the form of cylindrical bar having a diameter of 30mm. the temperatures were measured by using tool work thermocouple. The thermocouple wire is brazed to the tool at a distance of 2mm from the tool tip. The tests were carried out to observe the influence of machining parameters like depth of cut, feed rate and cutting speed.

The temperature variation at the tool tip during turning process at different feed rates by keeping speed and depth of cut constant are shown in Table 1. The variation of the temperatures at the tool tip during machining process by varying depth of cuts and feed rates and cutting speeds are kept constant and those are tabulated in Table 2. the temperature variation at the tool tip at different cutting speeds by keeping depth of cut and feed rate are shown in Table 3.

The cutting forces, power and tool life are obtained by varying the different parameters like depth of cut, feed rate and cutting speed are shown in Table 4, Table 5,

Table 1. Thermal analysis at different feed rates (speed=340rpm, depth of cut=1 m)

SI. No.	Feed rate (mm/rev)	Sampling lengths of work piece (mm)							
		30	60	90	120	150	180	210	240
1	0.35	172.8	187.2	192.4	196.3	197.5	201.6	0204.7	213.1
2	0.70	193.6	223.8	234.5	240.4	247.9	252.1	255.6	263.4
3	1.4	201.5	237.6	256.5	268.5	274.4	281.1	283.7	286.1

Table 2. Thermal analysis at different depth of cuts (feed rate=1.4mm/rev, speed=340rpm)

SI. No.	Depth of cut (mm)	Sampling lengths of work piece (mm)							
		30	60	90	120	150	180	210	240
1	0.5	123.3	137.8	142.5	148.2	149.1	150.6	152.6	153.8
2	1.0	188.7	234.5	253.8	262.5	274.1	279.6	281.4	284.4
3	1.5	211.9	261.0	285.6	295.6	298.7	304.7	320	328.8

Table 3. Thermal analysis at different speeds (feed rate=1.4mm/rev, depth of cut=1mm)

SI. No.	Speed rate (rpm)	Sampling lengths of work piece (mm)							
		30	60	90	120	150	180	210	240
1	230	172.1	200.5	211.5	214.7	217.0	217.5	218.2	224.2
2	340	175.2	198.1	216.8	224.2	234.6	239.1	240.3	243.5
3	514	179.4	209.4	224.5	231.5	241.6	250.6	253.0	260.6

Table 4. Results obtained against varying depth of cut

SI. No.	Depth of cut (mm)	Force (N)	Power (KW)	Tool life (min)
1	0.5	392	205.86	472.55
2	1	784	397.75	128.09
3	1.5	1176	565.06	72.96

Table 5. Results obtained against varying feed

SI. No.	feed rate (mm/rev)	Force (N)	Power (KW)	Tool life (min)
1	0.35	196	85.45	1433.83
2	0.7	392	164	1828.81
3	1.4	784	314	2363

Table 6. The distribution of the temperatures at varying the depth of cuts at regular intervals of time is plotted in Figure 3. The distribution of the temperatures at varying feed rates at regular intervals of time is plotted in Figure 4. The temperature distribution at varying cutting speeds at regular intervals of time is plotted in Figure 5. The variations of temperature with cutting speeds at the distance from cutting edge are shown in Figure 6.

The formulae involved in the present work are (C.J. Rao et al.[7])

Cutting velocity $V = \Pi DN/1000$

Power Required: $P = (K \times D \times V \times F)/(60*1000)$

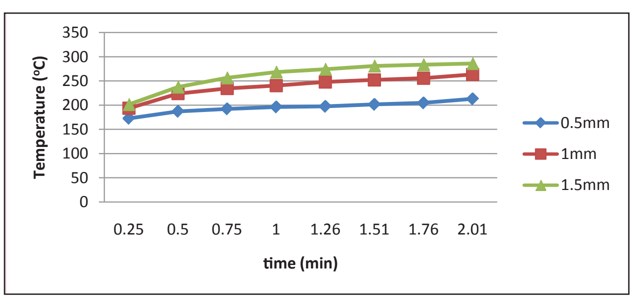


Figure 3. Temperature vs. time at different Depth of Cuts.

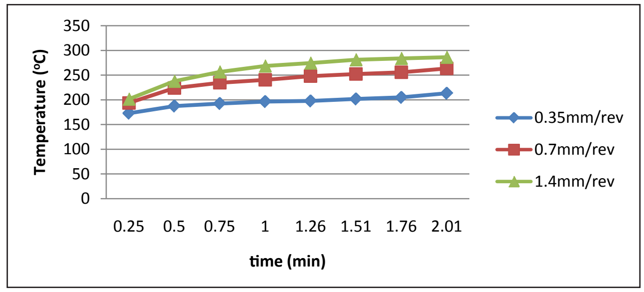


Figure 4. Temperature vs. time at different feed rates.

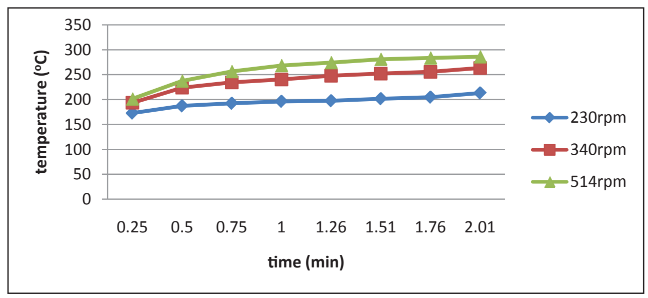


Figure 5. Temperature vs. time at different cutting speeds.

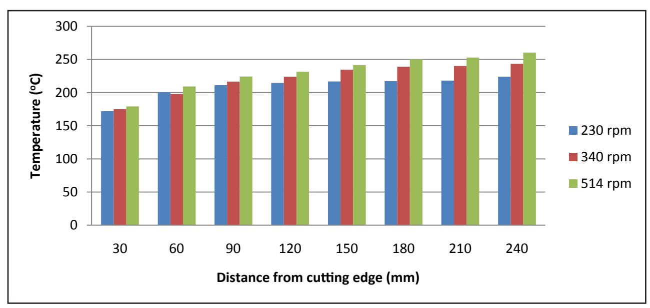


Figure 6. Temperature vs. cutting speed at same distance from cutting edge.

Table 6. Results obtained against varying speed

SI. No.	Speed (rpm)	Force (N)	Power (KW)	Tool life (min)
1	230	784	36.15	210704.32
2	340	784	57.56	14658
3	514	784	76.47	2755.76

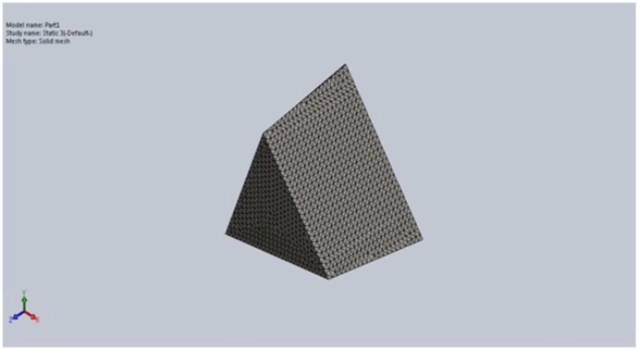


Figure 7. Generation of mesh for the model.

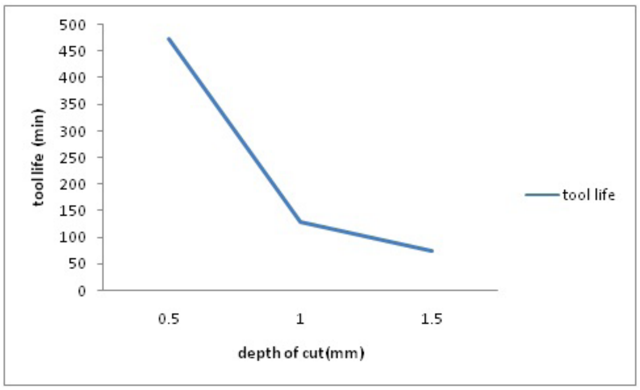


Figure 8. Max von misses stress in the cutting tool.

Cutting Force: F = (K x D x F)

The tool life variation with speed and depth of cut are shown in Figure 8 and Figure 9. The tool life decreases with increase in speed and depth of cut.

4. Numerical Analysis using ANSYS Software

In this paper, 3-dimensional steady state heat conduction simulation method is used. In this the alloy steel material is used for cutting tool .the tool is modelled as elastic isotropic type. The maximum von misses stress distribution is determined for the cutting tool. The high mesh quality is generated for the model by using solid works standard mesh. The bottom face of the cutting tool is fixed and force of 500N is applied on the tip of the tool. The cutting tool material properties are shown in Table 7. The standard mesh generated in numerical analysis is shown in Figure 7. The resultant forces acting on the tool is shown in Table 8. The loads acting on the tool are shown in Table 9. The von misses stress distribution and equivalent strain distribution within the tool in analysis is shown in Table 10 and Table 11.

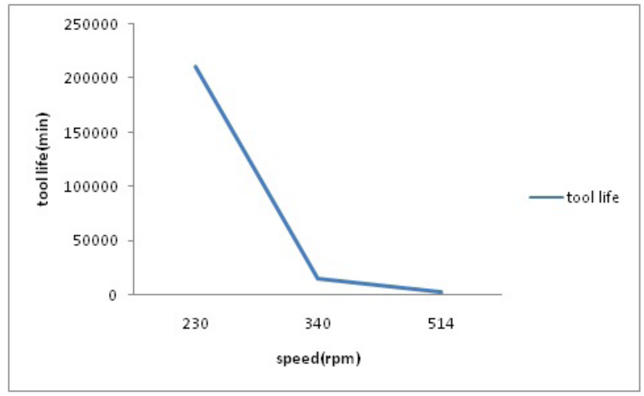


Figure 9. Equivalent strain distribution in cutting tool.

Table 7. Cutting tool material properties

Name	Alloy Steel
Modeltype	Linear Elastic Isotropic
Default failure criterion	Max von Misses Stress
Yield strength	6.20422e+008 N/m2
Tensile strength	7.23826e+008 N/m2
Elastic modulus	2.1e+011 N/m2
Poisson's ratio	0.28
Mass density	7700 kg/m3
Shear modulus	7.9e+010 N/m2
Thermal expansion coefficient	1.3e-005 /Kelvin

Table 8. Resultant forces

Components	X	Y	Z	Resultant
Reaction force (N)	-3.87858	68.3426	-495.292	499.99
Reaction moment (N m)	0	0	0	0

5. Results and Discussion

The optimum parameters obtained to improve the tool life are cutting speed=230rpm, feed rate=1.4mm/rev and depth of cut=0.5mm.

5.1 Effect of Cutting Conditions on Tool-Work piece Interface Temperature

The temperature generated within the region of tool workpiece interface are mainly depends upon the feed rate, depth of cut and cutting speed.

Table 9. Loads on cutting tool

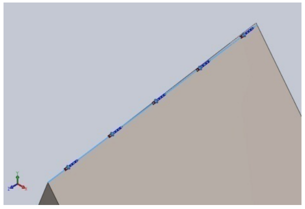
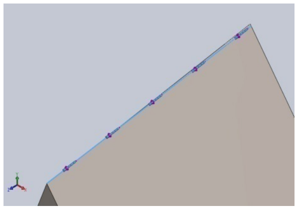
Load Name	Load Image	Load Details
Force-1		Entities: 1 edge(s) Type: Apply force Values: ---, ---, -500 N
Temperature-1		Entities: 1 edge(s) Temperature: 77 Kelvin

Table 10. Von misses stress distribution in the tool

Name	Type	Min	Max
Stress 1	VON: von Misses Stress	5682.14 N/m^2 Node: 52433	6.97033e+008 N/m^2 Node: 2

Table 11. Equivalent strain distribution in the tool

Name	Type	Min	Max
Strain 1	ESTRN: Equivalent Strain	4.73178e-008 Element: 5196	0.000868242 Element: 4455

5.1.1 *Effect of Cutting Speed on Temperature Distribution*

It is indicated from the figure that at speed of 11.92m/min, the maximum temperature is 224.2°C, while at the speed 26.64m/min, the maximum temperature is 260.6°C. High stresses are produced whenever high cutting speeds are used. When the cutting speeds are increased from 11.92m/min to 26.64m/min then the tool life decreases from 14658min to 2755.76 min.

5.1.2 *Effect of Feed Rate on Temperature Distribution*

It is indicated from the figure that at feed rate of 0.35mm/rev, maximum temperature is 213°C, while at the feed rate of 1.4 mm/rev the maximum temperature is 286.1°C. High heat is generated due to friction between the tool and workpiece. Due to this high heat generation the temperatures on the tool tip increases there by decreases the life of the tool.

5.1.3 *Effect of Depth of Cut on Temperature Distribution*

It is indicated from the figure that at depth of cut of 0.5mm the maximum temperature is 153.8°C, while at the depth of cut of 1.5mm the maximum temperature is 328.8°C. The cutting force at the tip of the is also increases there by increases the power consumption. The life of the tool gets reduced from 472.55 min to 72.61 min with an increase in depth of cut from 0.5mm to 1.5mm.

6. Conclusion

The maximum temperature is obtained at the contact region between tool and work during the cutting process.

The optimum process parameters for tool life are given in three different stages as,

- By varying depth of cut and keeping other two process parameters i.e, speed and feed the optimum point is at 0.5mm depth of cut where the cutting force is 392N and the tool life is 472 min.
- By varying the feed rate and keeping other two process parameters constant then the optimum point is obtained at 1.4mm/rev where the cutting force is 784N and the tool life is 2363 min.
- By varying the speed and keeping the other two parameters constant then the optimum point is obtained at

230rpm where the cutting force is 784N and the tool life is 210704 min.

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