Optimisation of Machining Parameters to Maximize Tool Life

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ABSTRACT *The determination of the relationship between roughness & the parameters affecting its value remains an open field of research for scientists & engineers. In the present study an experiment is conducted on a mild steel work piece using different tool specimens. Their surface finish, strength, feed rate & cutting speed are calculated. The results are evaluated, analysed & finally optimising machining parameters are calculated to maximise the tool life.*

Keywords: *Optimisation, Surface roughness, Machining parameters, Materials, Tool life.*

1.Introduction:

The challenge of modern machining industries is mainly focussed on achieving high quality, in term of part/component accuracy, surface finish, high production rate & increase the product life with lesser environmental impact. It is necessary to change & improve existing technology & develop product with reasonable price. So it is necessary to control the process parameter in any manufacturing process. The typical controllable machining parameters for the CNC lathe machines are speed, feed, depth of cut, tool geometry, cutting environment, tool material, work material, etc. which affect desired output like material removal rate, surface roughness, power consumption, tool wear, vibration etc. It is very difficult to take all the parameters that control the surface roughness & material removal rate for a particular process. Therefore, it is important for the researchers to model & quantify the relationship between roughness & the parameters affecting its value. The determination of this relationship remains an open field of research, mainly because of the advances in machining & materials technology & the available modelling techniques. Present study seeks to find out the effect of above parameters & cutting geometry such as tool nose radius on the surface roughness value. Sundram et al. [1] developed the mathematical models for predicting the surface roughness of AISI 4140 steel during the fine turning operation using both TiC coated and uncoated tungsten carbide throw away tools. Mital et al. [2] developed the surface finish models for aluminium alloy 390, ductile cast iron, medium carbon leaded steel, medium carbon alloy steel 4130, and inconel 718 for a wide range of machining conditions defined by cutting speed, feed and tool nose radius. They concluded that cutting speed, feed and tool nose radius have a significant effect on the surface roughness. Choudhury and El-Baradie [3] revealed that cutting speed was the main influencing factor on the tool wear, followed by the feed rate and the depth of cut. Thiele et al. [4] used a three-factor complete factorial design to determine the effects of work piece hardness and cutting tool edge geometry on surface roughness and machining forces. Paulo Davim [5]found the cutting speed has greater influence on the roughness followed by the feed and depth of cut has no significant influence on surface roughness by using the Taguchi method. Suresh et al. [6] developed a surface roughness prediction model for turning mild steel using a response surface methodology to produce the factor effects of the individual process parameters. Surface roughness prediction model has been optimised by using genetic algorithms (GAs).Noordin et al. [7] studied the application of response surface methodology in describing the performance of coated carbide tools when turning AISI 1045 steel. They concluded that feed was the most significant factor that influences the surface roughness, however $(SECA)^2$ and (feed x SECA) also provide contribution for the surface roughness. Petropoulos et al. [8] used multi regression analysis and ANOVA for statistical study of surface roughness in turning of PEEK composite. The result for all three PEEK'S examined increase in feed causes significant increase in all the surface roughness, increase of cutting speed was favourable, as decreases roughness but only slightly. Galanis et al. [9] used 23 full factorial design for AISI 316L steel with three variables named feed, speed and depth of cut for application of femoral head. The established equation showed that the depth of cut was the main influencing factor on the surface roughness. It increased with increasing the depth of cut and feed rate respectively, but it decreased with increasing the cutting speed. Abdulkareemet. al. [10] have investigated of the influence of the three most important machining parameters of depth of cut, feed rate and spindle speed on surface roughness during turning of AISI 1045. Box Behnken experimental design method as well as analysis of variance (ANOVA) is used to analyse the influence of machining parameters on surface roughness height Ra. From the experiments they concluded that the feed rate is found to be the most important parameter effecting Ra, followed by cutting speed while spindle speed has the least effect. They also found that machining with high cutting speed and spindle speed has positive effect on Ra as against feed rate Verma et. al. [11] have taken ASTM A242 type-1 ALLOY steel of 250 mm long with 50 mm diameter of material for experimentation using a CNC lathe machine. L9 array taken and for analysed the data Taguchi and ANOVA approach used. They concluded that speed (57.47% contribution) is the most significant factor affecting surface roughness and followed by feed (23.46% contribution). Cutting speed is the least significant factor affecting surface roughness. Makadia et al.[12] investigated the main turning parameters such as feed rate, tool nose radius,cutting speed & depyh of cut on the surface roughness by using Response Surface Method (RSM). The surface roughness was found to increase with the increase in the feed & it decreased with increase in the tool nose radius. Singh et al. [13] showed that Optimization of Machining Parameters to Minimize Surface Roughness using Integrated ANN-GA approach that provides the ANN-GA method for determining the optimum machining parameters leading to minimum surface roughness. Alagarsamy et al.[14] applied Taguchi experimental method for optimization of process parameters in turning of Aluminium alloy 7075 using tungsten coated carbide tool. From experiment it was found that the most significant factor influencing metal removal rate (MRR) followed by feed rate & depth of cut was the least significant factor. Ghan et al (15) Provided literature review on machining parameters such as cutting speed, feed & depth of cut of different materials.

2. Tool life, Work piece & Tool materials

2.1 Tool life

The total life accumulated before tool failure occurs is termed as tool life. There is no exact or simple definition of tool life. However, in general, the tool life can be defined as tool's useful life which has been expended when it can no longer produce satisfactory parts. The most commonly used criteria for measuring the tool life are (i) total destruction of tool when it ceases to cut. (ii) a fixed size of wear land on tool flank. The greatest variation of tool life is with the cutting speed & tool temperature which is closely related to cutting speed. Tool temperature is seldom measured & much study has been done on the effect of cutting speed on tool life. In 1907, Taylor gave the following relationship between cutting speed & tool life,

$$VT^n = C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

Where V is the cutting speed(m/min), T is the time in minutes for the flank wear to reach a certain dimension i.e. tool life. C is the constant & n is an exponent which depends upon cutting conditions. The values for n may be taken

n =0.1 to 0.15 for HSS tools
= 0.2 to 0.4 for Carbide tools
= 0.4 to 0.6 for Ceramic tools.

The tool life also depends to a great extent on the depth of cut "d" & a feed rate per revolution "f". Assuming a logarithmic variation of C with d, the equation can be written as

$$VT^n d^m = C \ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

It has been seen that decrease of life with increased speed is twice as great (exponentially) as the decrease of life with increased feed. Hence considering the feed rate the equation can be redesigned as

$$VT^n d^m f^x = C \ldots\ldots\ldots\ldots\ldots\ldots\ldots [3]$$

2.2.Work piece:

In this present experiment, Mild steel rod of 20 mm diameter having a length of 250 mm is taken as work piece. It can be machined & shaped easily due to its inherent flexibility. It can be hardened with carburizing, making it the ideal material for producing a range of consumer products. The high amount of carbon also makes it vulnerable to rust. Compared to other types of steel, this type is ideal for welding purposes as it conducts electric current effectively without tarnishing the metal surface in any way.Unlike other grades of carbon steel which tend to be brittle, mild steel is hard, yet malleable, making it ideal choice for the construction of pipelines

2.3. Tool materials:

In this experiment, three types of tool materials are used i.e tungsten carbide coated tool, non-coated carbide tool & HSS tool. During machining, coated carbide tools ensure higher wear resistance, lower heat generation & lower cutting forces, thus enabling them to perform better at higher cutting conditions than their uncoated counterparts.HSS tool can withstand higher temperatures without losing its temper (hardness). This property allows HSS tool to cut faster than high carbon steel, hence the name high speed steel. Carbides are most important because of their high hardness over a wide range of temperature, high elastic modulus, high thermal conductivity & low thermal expansion.

3. Working Principle

Raw material in the form of mild steel (14 mm diameter) is used for making the specimens to be tested for fatigue strength in fatigue testing machine. The specimens will be according to the specifications shown in figure 1. The specification is machined in CNC machine as the given specification can not be achieved by conventional machining. Tapping of 15mm is done on one side of the specimen to help it hold in the fatigue testing machine. 3 specimens are obtained using three different tools namely HSS, tungsten coated carbide & non-coated carbide. During machining process, the parameters like cutting speed, depth of cut & feed rate are maintained at 1000rpm, 0.2mm & 0.2mm respectively. Surface finish of each specimen is checked using digital surface profile gauge. The specimens are then employed to the fatigue testing machine shown in figure 2. The indicator indicating the number of revolution is set to zero. Constant load is maintained & the number of revolution is obtained till neck formation takes place & finally the specimen fractures. Observations are noted down & tabulated. The combination of tool material & work piece material for which the maximum fatigue strength is obtained. Further machining is done to obtain the cutting forces in in the three coordinates. To obtain the forces, the lathe machine with lathe tool dynamometer is equipped shown in figure 3. The first set of observations for forces along the three coordinates are obtained by keeping the cutting speed & depth of cut constant & varying the feed rate. The observations so obtained are tabulated. The next set of observations for forces along the three coordinates are obtained by keeping the feed rate & depth of cut constant & varying the cutting speed. The observations so obtained are tabulated. For each set of observations graphs are plotted & conclusions are drawn for the same.

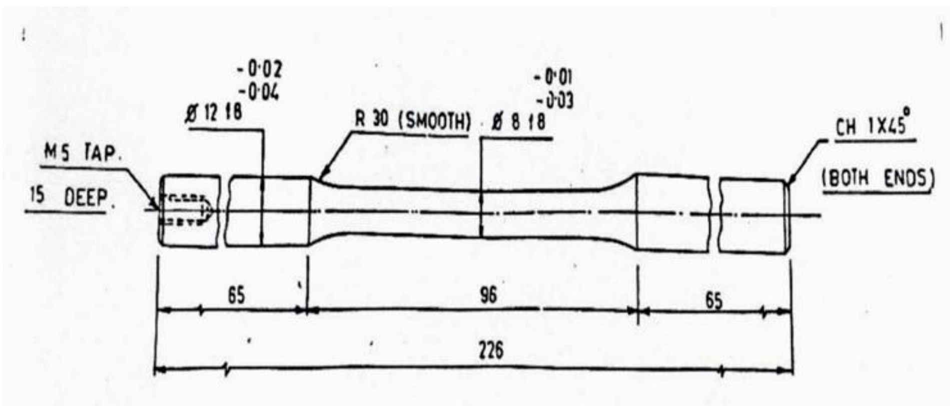

Figure 1 Standard Fatigue Specimen

Figure 2 Fatigue Testing Machine

Figure 3 Lathe Machine with lathe tool Dynamometer

4. Results & discussions:

The machinability in this work was evaluated by the surface finish of the machined surface of the workpiece. The results obtained through the experiments were presented in table-1. From the results it was found that for machining mild steel with tungsten coated carbide, the work piece would have the best surface finish implying that it would also have the maximum tensile strength.

Table-1 for Surface finish

Sl. No.	Non-coated carbide			Coated carbide			High Speed Steel		
	R_a	R_q	R_z	R_a	R_q	R_z	R_a	R_q	R_z
1	4.602	5.598	29.150	3.326	5.058	30.862	3.539	4.368	22.239
2	4.704	5.833	31.345	3.189	4.364	26.493	4.239	5.404	35.764
3	4.801	5.923	32.355	3.637	4.505	21.429	5.543	6.686	30.808

Figure-4, figure-5 & figure-6 showed the feed force vs cutting speed, thrust force vs cutting speed & cutting force vs cutting speed at constant feed rate i.e. 0.04mm. In figure 4 the feed force increases with increase of cutting force, reaches maximum at 224 rpm & then decreases with increase of cutting speed. This is because of with increase in cutting speed, the nature of friction changes from static to dynamic & the coefficient of friction decreases. The minimum feed force is obtained when cutting speed is 90 rpm. In figure -5 the thrust force first increases with increase of cutting speed, reaches maximum at 97 kgf & decreases gradually with increase of cutting speed. It is minimum at a cutting speed of 500 rpm. In figure-5 the cutting force decreases with increase of cutting speed & it is minimum at a cutting speed of 500 rpm. Analysing all these three figures, it is concluded that feed force, thrust force & cutting force corresponding to the cutting speed of 500 rpm are considered for the calculations to optimize power & tool life. The cutting speed with respect to various forces are given in table-2.

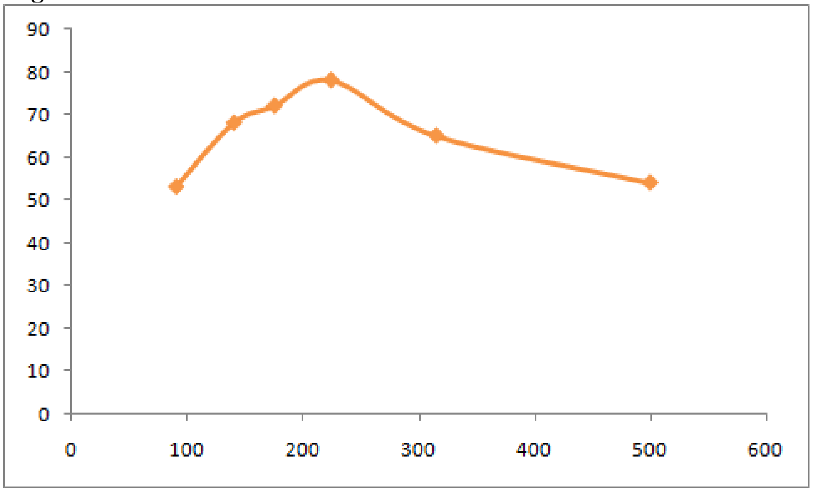

Figure 4. Feed force vs cutting speed
X axis: Cutting speed in rpm
Y axis: Feed force in kgf

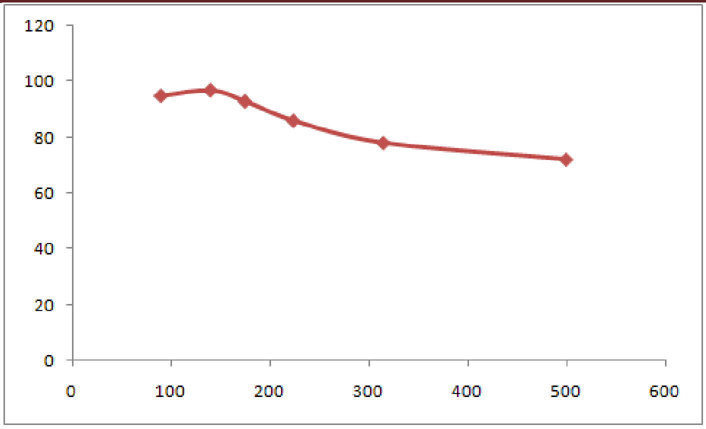

Figure 5. Thrust force vs cutting speed
X axis: Cutting speed in rpm
Y axis: Thrust force in kgf

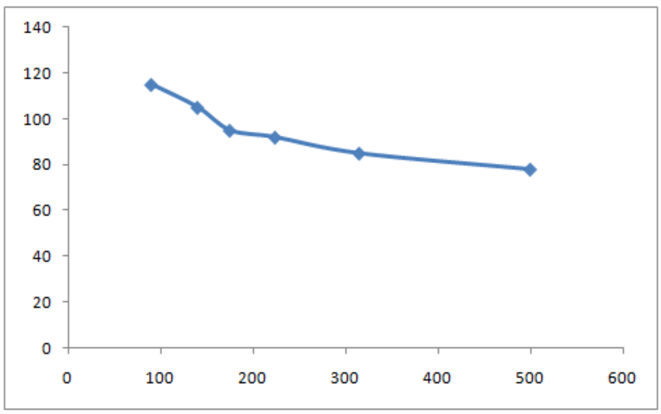

Figure 6. cutting force vs cutting speed
X axis: Cutting speed in rpm
Y axis: cutting force in kgf

Table 2. Cutting speed with forces at constant feed rate

Serial No.	Cutting speed N(rpm)	Feed force P_x (kgf)	Thrust force P_y (kgf)	Cutting force P_z (kgf)
1	90	53	95	115
2	140	68	97	105
3	175	72	93	95
4	224	78	86	92
5	315	65	78	85
6	500	54	72	78

The feed force vs feed rate, thrust force vs feed rate & cutting force vs feed rate at constant cutting speed are shown in fig. 7. 8 & 9 respectively. From figure 7, 8 &9 it is found that the feed force, thrust force &cutting force are increased with increase of feed rate & these are minimum at 0.1 mm/rev. So the values of feed force, thrust force & cutting force corresponding to the feed rate at 0.1mm/rev are considered for the calculation to optimize power & tool life. The feed rate with respect to various forces are given in table-3.

Table 3. Feed rate with forces at constant cutting speed

Serial No.	Feed rate (mm/rev)	Feed force P_x (kgf)	Thrust force P_y (kgf)	Cutting force P_z (kgf)
1	0.1	28	31	37.5
2	0.2	36	41	48.8
3	0.4	70	75	82

4	0.5	90	94.8	109
5	0.6	100	103.2	113

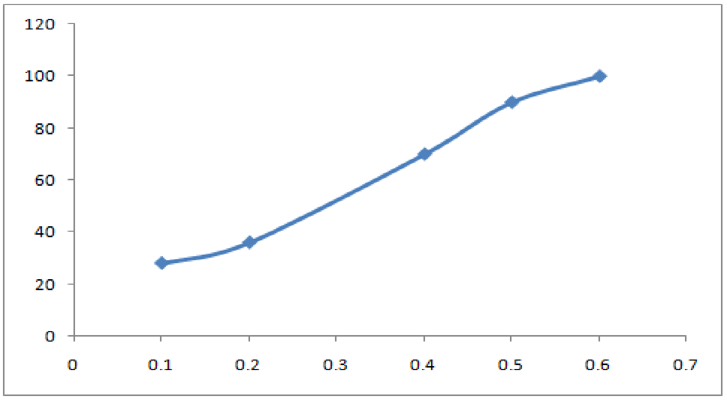

Figure 7. Feed force vs feed rate
X axis: Feed rate in mm/rev
Y axis: feed force in kgf

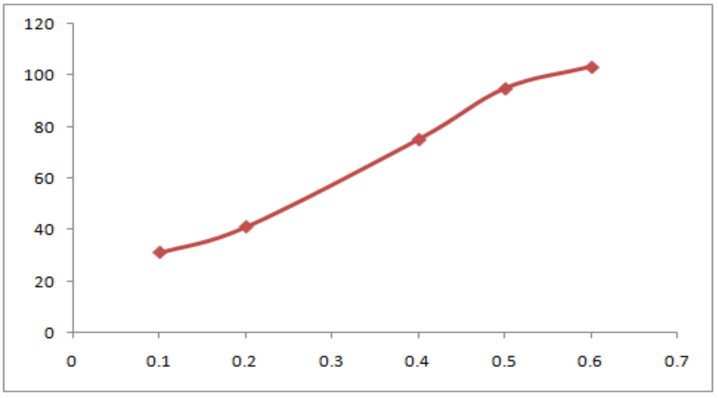

Figure 8. Thrust force vs feed rate
X axis: Feed rate in mm/rev
Y axis: thrust force in kgf

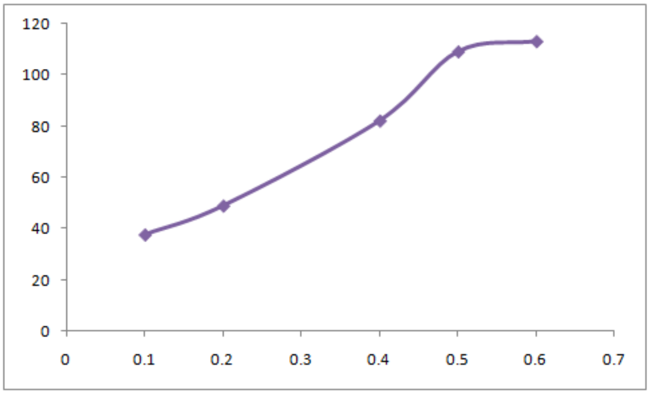

Figure 9. Feedforce vs feed rate
X axis: Feed rate in mm/rev
Y axis: feed force in kgf

5. Conclusion:

The raw material in the form of mild steel is machined using three different tools namely HSS, tungsten coated & carbide tool. The specimens so obtained are undergone surface finish & fatigue strength test. From the results it is found that for tungsten coated tool the surface finish is the best & the work piece has maximum fatigue strength. After analysing the figures, the optimised values of the parameters are as follows

Feed rate (f) = 0.1 mm/rev
Cutting speed (N) = 500 rpm
Depth of cut (d) = 0.4 mm
Considering the above values of machining parameters, tool life can be maximised by using the following expression

$$VT^n d^m f^x = C$$

Here N = 500 rpm
n = 0.2 for carbide tool, x = 0.2, m = 0.2 & Optimised data's are
f = 0.1mm/rev, d = 0.4 mm, V = 18.84 m/min then
Tool life = T = 530.56 minutes

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Dr. Ramesh Chandra Mohapatra was born in Orissa, India in 1969. He graduated from Department of Mechanical Engineering of UCE, Burla, now VSSUT, Burla, Orissa, India. He received the degree of M.Tech in Thermal Engineering from Department of Mechanical Engineering of Indian Institute of Technology (IIT), Kharagpur, West Bengal, India and PhD in Mechanical Engineering from Utkal university,Vanivihar, Bhubaneswar, Orissa, India. He is presently working as Associate Professor & HOD of Mechanical Engineering Department in Government College of Engineering, Keonjhar, Orissa, India.

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