Optimization of Cutting Parameters for Effective Product Life

G. Diwakar, K.Sai Ram Sastry, T. Srinivas, A. Ameer Sohel, K.V. Sai Ram

Abstract: ***Machine components in the industry are manufactured with variety of machining operations. Each machining operation performs with respect to the applications of the component. For example, power transmitting shafts undergo the turning operation during the manufacturing process. While the shaft in the working condition will undergo the fluctuating load stresses on its surface. To withstand that fluctuating loads and to attain a long life of the shaft, the surface roughness is the major factor that plays the main character. The surface roughness of the shaft depends on the cutting parameters while in the machining process. In this present work, the specimens of the medium carbon steel are machined in CNC by varying different cutting parameters. The machined specimen surface roughness was calibrated with surface roughness tester. The fatigue analysis of the different roughness specimens was performed on the BISS Nano 25KN UTM. Finally, the work was concluded by analyzing which cutting parameter conditions are better to sustain the fluctuating loads and to attain better fatigue life by the component.***

Index Terms: Machining, Cutting Parameters, Surface Roughness, Fatigue Analysis, Fatigue Life

I. INTRODUCTION

In the fatigue failure various factors considered are a component material, notch size, surface finish, environmental conditions etc. The parameters which vary with respect to machining conditions are surface roughness, residual stresses, and microstructures.

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The fatigue failure depends on factors like component material, notch size, surface finish, environmental conditions etc. The parameters which vary with respect to machining conditions are surface roughness, residual stresses, and microstructures.

The surface finish of the machine parts is considered important process influencing the fatigue crack initiation life, that crack initiation life determines the final fatigue life. Regarding the roughness of the surface, the reversal stress and surface structure were the main characteristics depending on the process of surface quality. The effects of the factors on the strength of fatigue have not resulted in the present day; the design, the engineering to introduce the surface finishing factor or the roughness factor to modify the fatigue limit in practical design through the modification method is not a reasonable and accurate evaluation of the effects of the surface on the fatigue strength.

The machined component's fatigue life depends on the surface roughness quality. The fatigue cracks usually initiate from free surfaces, the surface highest load was exposed to environmental conditions. Due to the concentration of stress, the factors effect with the surface is the initiation of the crack. In major cases, the initiation and propagation of the crack depends on the integrity of the surface produced by machining.

The surface of the machine member has important aspects that must be defined and control. They are the surface and metallurgical conditions, surface irregularities and a surface pattern. The surface integrity of the surface relationship between surface geometry and physical properties like residual stresses, hardness and the microscopic structures of the surface pattern. The integrity of the surface influences the quality of the machined surface, both becoming extremely important and producing structural components that can withstand the very high static and dynamic stresses. The functionality of the machine component is influenced by surface integrity at the point towards characteristics such as micro structure, hardness, and surface roughness.

II. EXPERIMENTAL PROCEDURE

A. Material and its properties:

The material in the research work is medium carbon steel specimen. The chemical properties and its mechanical properties were identified by microstructure and tensile test. The material chemical and mechanical properties are mentioned in the table1 and table2.

Table 1:

Chemical Properties	
Carbon(C)	0.14% -0.20%
Iron (Fe)	98.81 – 99.26 %
Manganese (Mn)	0.60% - 0.90%
Phosphorous (P)	0.040%
Sulphur (S)	0.050%

Table2:

Properties	
Brinell’s Hardness	228(BHN)
Hardness Knoop	190
Vickers Hardness	116
Ultimate Tensile Strength	796 MPa
Yield Tensile Strength	495.6 MPa
Elongation at Break	15%
Reduction of Area	36%
Modulus of the elasticity	205 GPa
Bulk Modulus	140 GPa

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Poisson Ratio	0.27
Machinability	65%
Shear Modulus	80 GPa

B. Machining of the Specimens:

The medium carbon steel specimens were machined with respect to the ASTM E606 standards for the fatigue analysis. The machined specimen after machining was shown in Fig 1.

Fig1: The Specimens after machined by varying cutting parameters.

C. Effect of cutting parameters on surface roughness:

The specimens are machined in the CNC lathe machine by varying the cutting parameters depth of cut and feed rate at constant speed of 1200RPM. The surface roughness of the specimens machined with different cutting parameters were calibrated with the surface roughness tester "Mitutoyo SURFTEST SJ210" as shown in the figure3. The surface roughness variation with respect to the cutting parameters were plotted in the figure4 and figure5.

Fig 3: Surface Roughness Calibration of machined specimens

Table 3:

S.no	DEPTH OF CUT (mm)	FEED (mm/Rev)	Ra (µm)
1	0.6	0.08	1.092
2	0.6	0.15	4.062
3	0.6	0.25	4.726
5	0.5	0.2	1.976
6	0.6	0.2	2.591
7	0.7	0.2	3.529
8	0.8	0.2	6.550

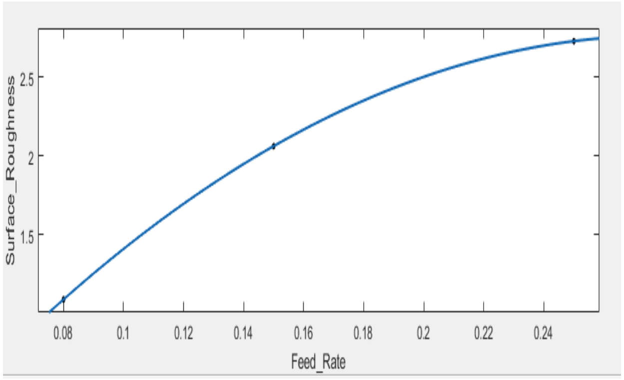

Fig 4: Varying of the Surface Roughness with respect to feed rate.

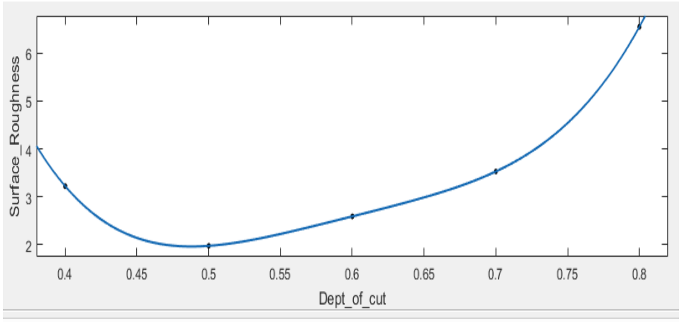

Fig 5: Varying of the Surface Roughness with respect to the Depth of cut

III. FATIGUE ANALYSIS

The machined specimens were undergone the fatigue analysis in the machine "BISS NANO 25KN UTM". The fatigue life N_f was conducted by the crack initiationN_i and the crack propagation N_p by the following equation $N_f = N_i + N_p$. The analytical formula of crack initiation and crack propagation published by Tanaka accumulated by the model. The crack initiation life estimated related to the different surface roughness.

$$N_i = \frac{9\Delta k_{th}^2 G}{E(s_a - s_e)^2 \pi (1-\nu) a_0} \qquad \text{(i)}$$

Where the Δk_{th} is the threshold stress intensity factor, G is the shear modulus of the material, E is the young's modulus, ν is the poisons ratio the material and the a_0 is the micro-defect size at the initial crack length estimated by solving and finding material constants by solving the Paris law of the crack propagation.

$$a_0 = 2.42\, R_a \qquad \text{(ii)}$$

Where the $R_a$is the surface roughness value.

The failure of the material from initial micro defect crack length to the failure from the Paris law mentioned below:

$$\frac{da}{dN} = C(\Delta k)^n \qquad \text{(iii)}$$

Where the Δk is the stress intensity factor, C and n are the material constants and $\frac{da}{dN}$is the number of cycles to propagate crack length to failure.

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To calculate the number of cycles to propagation of the crack length, relatingequation is given below

$$N_p = \frac{a_0^{\left(1-\frac{n}{2}\right)}}{C S_a^n \beta_1^n \pi^{n/2}\left(\frac{n}{2}-1\right)} \quad \text{(iv)}$$

Where S_a^n was stress amplitude, where $\beta_1 = 0.5\sqrt{\pi}$ geometric correction factor

It can be written by

$$S_a^n N_P = b \quad \text{(v)}$$

Where the

$$C = \frac{a_0\left(1-\frac{n}{2}\right)}{b\beta_1^n \Pi^{n/2}\left(\frac{n}{2}-1\right)} \quad \text{(vi)}$$

By applying the logarithms for the above equation

log N_P = log b- n*logS_a (vii)

Where the C and n are the material constants finding from the above equations and the c is the constant find from the S-N curve of the material.

IV. Fatigue Analysis Procedure

The step by step procedure to perform fatigue analysis as follows

i) The specimen of medium carbon steelis machined as per the ASTM standards E606 to perform the strain-controlled fatigue.

ii) Tensile test on specimen is conducted to find the mechanical properties of the material.

iii) With respect to results of tensile test, maximum and minimum loadsare applied on specimen.

iv) The cyclic loads of the amplitude 390 MPa at 4Hz frequency are applied to the specimens.

v) The results comparing both theoretical and practical are shown below.

Fig 4: The specimen is undergoing the fatigue test

V. RESULTS

By estimation,the failure life of the specimens by varying the surface roughness and applying the stress amplitude of 390 MPa at frequency of 4Hz to find the number of cycles to failure are to be determined by both theoretical and practical. By theoretically estimation of the number of cycles to failure of the components with specific roughness by using the relation as shown below.

$$N_f = \frac{9\Delta k_{th}^2 G}{E(s_a - s_e)^2 \pi(1-\nu)a_0} + \frac{a_0^{\left(1-\frac{n}{2}\right)}}{C S_a^n \beta_1^n \pi^{n/2}\left(\frac{n}{2}-1\right)}$$

The values of the material constant are to be mentioned in the table below:

Table4:

S. no	Ra (Value)	C	n	b
1	1.092	5.26 x $\mathbf{10^{-14}}$	8.14	4.76 x $\mathbf{10^{10}}$
2	1.976	8.56 x $\mathbf{10^{-15}}$	8.31	7.93 x $\mathbf{10^{11}}$
3	2.561	7.32 x $\mathbf{10^{-15}}$	8.11	6.83 x $\mathbf{10^{11}}$
4	3.222	1.92 x $\mathbf{10^{-14}}$	7.21	1.63 x $\mathbf{10^{10}}$
5	3.526	5.92 x $\mathbf{10^{-14}}$	7.92	5.26 x $\mathbf{10^{10}}$
6	4.062	4.98 x $\mathbf{10^{-15}}$	7.80	4.53 x $\mathbf{10^{11}}$
7	4.726	3.28 x $\mathbf{10^{-15}}$	7.88	3.88 x$\mathbf{10^{11}}$
8	6.550	4.82 x $\mathbf{10^{-15}}$	7.22	4.26 x $\mathbf{10^{11}}$

By calculating the fatigue life by using both crack initiation life and the crack propagation life final life of the specimens with different roughness

$$N_f = \frac{9*(7.87)^2*80000}{2.05*10^5(390-298)^2\pi(1-0.3)*2.64*10^{-6}} + \frac{2.64^{\left(1-\frac{8.14}{2}\right)}}{5.26*10^{-14}*420^{8.14}*\left(0.5*\sqrt{\pi}\right)^{8.14}*\pi^{8.14/2}*\left(\frac{8.14}{2}-1\right)} \rightarrow Ra=1.092$$

After performing the experiment fatigue analysis on the specimen, the number of cycles to failure are shown in the below table.

Table 5:

While performing the fatigue analysis in the machine

S. No	Surface Roughness (µm)	Number of cycles to failure estimated	Number of cycles to failure Practical	Error (%)
1	1.092	175476	178452	0.2611
2	1.976	144813	154777	5.86
3	2.561	100662	124717	3.892
4	3.222	61453	63404	1.733
5	3.526	58270	59268	0.865
6	4.092	54080	54966	2.47
7	4.726	46772	53671	0.1248
8	6.550	37900	40659	5.767

After sustaining the number of cyclic loads on the specimen the specimen fails in Number of cycles.The specimen after fatigue analysis is shown in below Fig:5

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Fig 5: The specimen failure after the fatigue analysis

The analysis of the specimens with same amplitude and frequency the fracture life of the component is estimated/ The S-N curve of the specimens with different roughness were plotted in the Fig6.

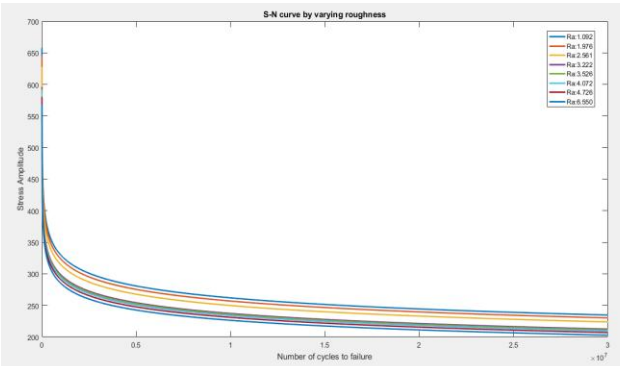

Fig 6: The S-N curve of the specimens with different surface roughness

The relation between the different surface roughness and the number of cycles to failure in fig 7.

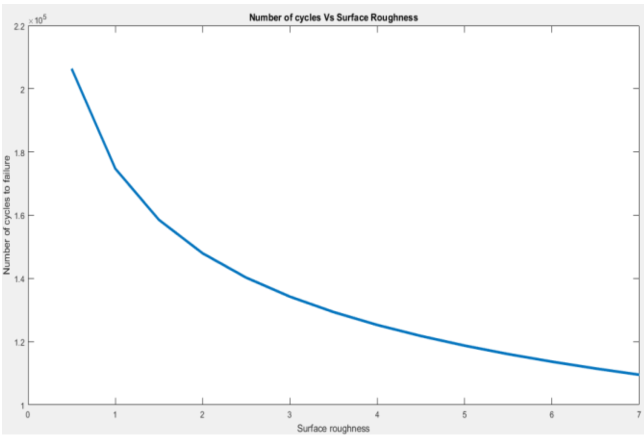

Fig 7: The relation between surface roughness and Fatigue life

Relation between the cutting parameters and Fatigue life as shown in the table 6.

Table 6:

S.no	DEPTH OF CUT (mm)	FEED (mm/Rev)	Ra (µm)	Number of cycles to failure
1	0.6	0.08	1.092	178452
2	0.5	0.2	1.976	154777
3	0.6	0.2	2.561	124717
4	0.4	0.2	3.222	63404
5	0.7	0.2	3.526	59268
6	0.6	0.15	4.092	54966
7	0.6	0.25	4.726	53671
8	0.8	0.2	6.550	40659

VI. Results Discussion

The results of the fatigue analysis show that the failure life of the component changes with varying surface roughness. Theresults alsoshows an impact of cutting parameters in machining process to attain good surface finish by the machine components. This is due the stress concentration at the micro level cracks the fatigue life of component will decrease.

VII. CONCLUSION

The optimization of the medium carbon steel specimencutting parameters with different surface roughness were performed. The results show that the fatigue life of the specimens varied with surface roughness. Also provide that the surface roughness of the component plays one of the leading role to withstand the fluctuating stresses and attain better number of cycles. The cutting parameters with low feed rate, medium depth of cut and high cutting speed gives the good surface finish and provide the good fatigue life by the component to sustain higher loads.

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