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Prediction of Effect of Cutting Parameter on Fatigue Life of AISI 52100 Steel

Vijay Vanjari[a]*, Aniket Salve[b], Satish chinchanikar[c]

[a,b,c]Dpartment of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune,India, 411048

Abstract

The most important mechanical failure parameter is fatigue failure which caused due to application of fluctuated loads or stresses acting on component whereas fatigue life is mainly depends on the surface roughness, cutting parameter (cutting speed, feed rate and depth of cut), residual stresses and microstructure. The effects of these parameters are commonly accounted to modify the endurance limit of the material. The component fails due fatigue is below the ultimate strength or some time even below the yield strength of the material. This paper gives brief details about experimental evolution of fatigue life of machined AISI 52100 on bending rotating fatigue testing machine. Fatigue testing specimen manufacture on CNC turning using different cutting parameter however selection of parameter was done by Taguchi's orthogonal array and result was analysed by ANOVA which found that cutting speed and feed rate has more influence on fatigue life than depth of cut.

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Keywords: AISI 52100 Steel , ANOVA, Bending Rotaing Fatigue Testing Machine, Surface roghness , Taguchi Method.

1. Introduction

The fatigue life of a member or of a structural detail subjected to repeated cyclic loadings is defined as the number of stress cycles it can stand before failure. It depends upon the member or structural detail geometry, its fabrication or the material used, four main parameters can influence the fatigue strength are stress difference, or as most often called stress range, structural detail geometry, material characteristics, environment. 90% of all failures

* Corresponding author. Tel.: +919028492002.
E-mail address: vijayvanjari19@gmail.com

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of metallic structures caused due to the fatigue failure which found mainly in bridges, aircraft, machine components, etc. Fatigue failure is like brittle failure – even in normally ductile materials which is sudden and catastrophic. In the literature numerous study found on effect of surface integrity on fatigue life material. Stephen Smith., et al.,[1] studied influence of surface integrity on fatigue performance of hard turned AISI 52100 steel with grinding as a benchmark. They examined the relation of fatigue life and surface integrity for five different surface i.e. hard turned with continuous white layer, hard turned with no white layer, ground and super finished hard turned and ground specimen. Surface integrity of specimen studied by surface topography measurement, metallography, residual stress measurement, transmission electron microscope (TEM) and nano- indentation test whereas fatigue test conducted on cycle tension-tension fatigue test. They concluded that fatigue life is more depends on residual stress than white layer and found fatigue life is directly proportional to surface compressive residual stress and the maximum compressive residual stress. Kirana S. S. Lopes., et al., [2] investigated influence of machining parameter on fatigue endurance limit of AISI 4140 steel experimentally. They machined specimen at several cutting speed, depth of cut and feed rate, eliminating the effect of residual stress by hardening. They have measured surface roughness and performed fatigue testing on rotating bending fatigue testing machine of the constant bending moment type and concluded that fatigue limit decrease with increasing roughness parameter. They found that the influence of cutting parameter on fatigue limit is lower than that on surface roughness. Sudhansu Ranjan Das., et al., [3] studied cutting force and surface roughness in machining of hardened AISI 52100 steel using CBN tool by Taguchi's L9 orthogonal array and analysis of variance (ANOVA). They found that cutting speed and feed rate strongly influence the surface roughness whereas the depth of cut affect the cutting force followed by feed rate. Finally they examined the wear surface of the tool and machined surface of the work piece under the optimal cutting condition using optical microscope and scanning electron microscope respectively. Satish Chinachnikar., et al., [4] found effect of feed and cutting speed on surface roughness of hardened AISI 52100 steel under dry and with water and vegetable oil based cutting condition. Youngsik Choi. [5] studied the influence of feed rate on surface integrity and fatigue performance of machine surface of hardened AISI 1053 steel. He found that high feed rate increases crack initiation life and crack propagation life. Feed rate influenced fatigue life significantly and that the effect increases if loading is reserved. Sujit Pawar., et al., [6] found effect of cutting speed and feed rate on residual stresses produced during machining of Hardened AISI 52100. S.K. As et al.[7] showed prediction on the empirical relation between geometric surface parameter and endurance lives which fails to describe, so they presented new approach as finite element analysis to predict effect of surface topography on fatigue. D. Novonic., et al., [8] showed effect of amplitude height parameter, amplitude distribution and shape parameter as well as spatial and hybrid on fatigue life on variety of work piece materials. They reported that lower roughness have longer fatigue life but for some range of amplitude height parameter it depends on residual stresses of work piece and in the absence of residual stress, machined surface roughness excess 0.1 um amplitude height parameter has strong influence on fatigue life. M. Sararatchi., et al., [9] modelled the influence of machined surface roughness on the fatigue life of aluminium alloy with four-point bending specimen in order to explain the high dependence of SN curve. They measured surface topography of specimen using finite element analysis approach by calculating local stress concentration. Sigmund Kyrre As., et al., [10] worked on prediction of surface roughness on fatigue life using finite element analysis and established method for determining residual stresses and microstructure. They were developed two algorithm to identify critical location one on geometry and surface stress solution. Eberhard Kerscher., et al., [11] worked on the increasing the boundaries for fatigue limit of the bearing steel SAE 52100 by thermo mechanical treatments in the maximal dynamic strain ageing and found that in case of non-metallic inclusions are the starting point of fatigue crack then TMT increase the fatigue limit of high strength material. I. Marines., et al., [12] done ultrasonic fatigue tests on bearing steel AISI- SAE 52100 at Frequency of 20 and 30 kHz. They studied the behaviour of material between 10^5 and 10^{11} cycles. Due to expensive and time taking fatigue test, the long-time fatigue tests were carried out on a piezoelectric system to save time and money. They were carried conventional fatigue test on the servo-hydraulic machine at 35 kHz with symmetric cycle stress R= -1 of three different geometry type specimen and smooth specimen at 20 kHz manufacturers. W. Niu., et al., [13] investigated the effect of cutting speed and heat treatment on the fatigue life of Grade 5 and Grade 23 Ti-6Al-4V alloys in the beta annealed and mill annealed heat treated conditions. Sunday J. Ojolo., et al., [14] worked on the influence of cutting speed, feed rate and tool geometry on fatigue life of end-milled 2024-aluminium using design approach alloy because machining involves the thermal, elastic and plastic deformations of the surface layer which result in strain hardening, structural changes and development of residual stresses which cause surface irregularities which may increase the risk of fatigue failure of material during usage. They constructed experimental design such that the specimens were subjected to different machining conditions and Data analysis was carried out with Relia Soft Office TM 7 DOE++ software and Analysis of Variance (ANOVA). They showed that by decreasing the feed rate and increasing the cutting speed significantly resulted in a higher fatigue life. Whereas, the rake angle had the least significant effect on the fatigue life and discovered that the feed rate was found to be the most influential factor. From the above literature we got that surface roughness which is affected by cutting speed, feed rate and depth of cut effect on fatigue life of component and needs to study its effect experimentally.

2. Experimental Detail

The main purpose to do this study is to calculate fatigue life through experimentation for effect of such cutting parameter on component which will avoid the sudden failure of the component during its service life.

2.1. Work-piece Selection

Work-piece material used for manufacturing the specimen for fatigue testing was AISI 52100 steel having hardness (15-20) HRC of diameter 13 mm. This material has a high carbon percentage and chromium containing low alloy steel that is used in manufacturing of bearing in rotating machinery part in the industries. The chemical composition of the AISI 52100 is given in Table 1.

Table 1. Chemical composition of AISI 52100 steel [1].

Element	Vol. %
C	0.98-1.1
Cr	1.40
Fe	97.05
Mn	0.35
Si	0.25
P	0.25
S	0.25

2.2. Selection of Cutting Parameter

Specimen manufactured by using different combination of cutting parameter such as feed rate, depth of cut and cutting speed. The range selected for cutting parameter is cutting speed (1200-2000) rpm, feed rate (0.05-0.15) rev/mm and depth of cut (0.2-0.4) mm [3]. Table 2. Show the different values of cutting speed, feed rate and depth of cut of turning of steel. Taguchi's orthogonal L9 array used for the number of experiment performed on CNC turning for manufacturing specimen for fatigue test. Fallowing table 3 shown the obtain value by Taguchi's orthogonal array on Minitab 17 software.

Table 2. Cutting parameter for machining.

Cutting Speed(rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1200	0.05	0.2
1600	0.1	0.3
2000	0.15	0.4

Table 3. Taguchi's orthogonal array

Sr. No.	Cutting Speed	Feed Rate	Depth of Cut
1	1200	0.05	0.2
2	1200	0.1	0.3
3	1200	0.15	0.4
4	1600	0.05	0.3
5	1600	0.1	0.2
6	1600	0.15	0.4
7	2000	0.05	0.4
8	2000	0.1	0.2
9	2000	0.15	0.3

2.3. Specimen Manufacturing

Design of experiment made the 27 run for the three factor and three variables. As the number of experiment reduced to nine bye Taguchi's Orthogonal L9 array. Specimen used for fatigue testing is manufacturing on CNC turning machine using CNC program and the grade of the inserts is TH1000 which is very hard super fine grained substrate with PVD coated TiSiN- TiAIN Nano laminated. Figure 1 shows the specimen for fatigue test manufactured on CNC turning actually this is the failed specimen after the effect of fatigue load application.

Fig. 1 Failed specimen tested on fatigue testing machine

2.4. Surface roughness.

The most important factor which is affected due to the variation of cutting parameter is surface integrity / surface roughness and is important to measured which so the effect of these cutting speed, depth of cut and feed rate on surface of the specimen. Surface roughness measured by SURTRONIC Taylor Holmen experimentally over the length which comes under fatigue load with using average roughness Ra, root mean square Ry and Rl having 0.5 um reading error of instrument.

2.5. Fatigue Testing

Fatigue test was performed on the rotating bending fatigue testing machine with constant value bending moment i.e. 200kgcm. Ultimate tensile strength and yield strength of AISI 52100 steel is 714.14 MPa and 664.59 MPa respectively. Fatigue testing machine having maximum running speed is 2400 rpm, testing diameter or fatigue load carrying diameter of specimen is 8mm which is manufactured according to the ASTM E-466-96. Figure 2 shown fatigue failure of specimen on rotating bending fatigue testing machine which is having specification maximum bending moment was 200 kg.cm, gripping diameter of test specimen was 12mm, Testing diameter 8mm, length of the specimen was 226 mm, Accuracy of applied bending moment ± 1 %. Calculation of bending moment value for fatigue test specimen. The specimen loading arrangement results in a constant bending moment PL/2 over the length of specimen. Where, P = Load applied over the specimen Kg., L = 10 cm. Now, Bending moment, $M_b = \frac{PL}{2} = \frac{P+10}{2}$ $= \frac{10L}{2}$ = 5P kgcm

Bending stress, $f_b = \frac{M_b}{Z} kgcm^2$

Where, Z = Section modulus = $\frac{\pi d^3}{32}$ for circular cross section.

Fig 1. Bending Rotating Fatigue testing machine

3. Result And Discussion

The experimental collected data were analyzed using Minitab software for the effect of fatigue life on machined component. The analyzed results showed using signal to noise response and mean of means effect plot for larger is better response. Table 5 gives the ANOVA for the fatigue life. ANOVA technique for the statistical analysis of data obtained. As there is only 9 number of experiments available it is important to know which factor has more influence on the response which is done by the ANOVA technique and calculate the percentage of each parameter on effect of fatigue life[15]. SN response analysis done on the data obtained after experimentation and which shown in the table 4. The mean of means graph shows that fatigue life increases for the cutting speed range 1200 to 1600 rpm and decreases from 1600 to 2000 rpm and for feed rate it found that as it is increases from 0.05 to 0.15 fatigue life of the machined AISI 52100 steel decreases.

Table 4 Experimental data obtained.

No. of experiment	Cutting Speed	Feed Rate	Depth of Cut	Fatigue life	Time taken in min
1	1200	0.05	0.2	397722	94.696
2	1200	0.1	0.3	376489	89.64
3	1200	0.15	0.4	365215	86.93
4	1600	0.05	0.3	968523	230.6
5	1600	0.1	0.2	869859	206.89
6	1600	0.15	0.4	789207	187.91
7	2000	0.05	0.4	640923	152.6
8	2000	0.1	0.2	592204	141.00
9	2000	0.15	0.3	148571	37.37

Table 4. ANOVA table

Source	Dof (f)	Sum of square (S)	Variance (V)	F-Ratio (F)	Percentage Contribution (P)
Cutting Speed	2	4.25×10^{11}	2.125×10^{11}	1.016	72.27
Feed rate	2	9.049×10^{10}	4.52×10^{10}	2.03	15.39
Depth of cut	2	3.069×10^{10}	1.023×10^{10}	0.489	5.34
Pooled Errror	2	4.182×10^{10}	2.091×10^{10}		
Total	8	5.461×10^{11}			93

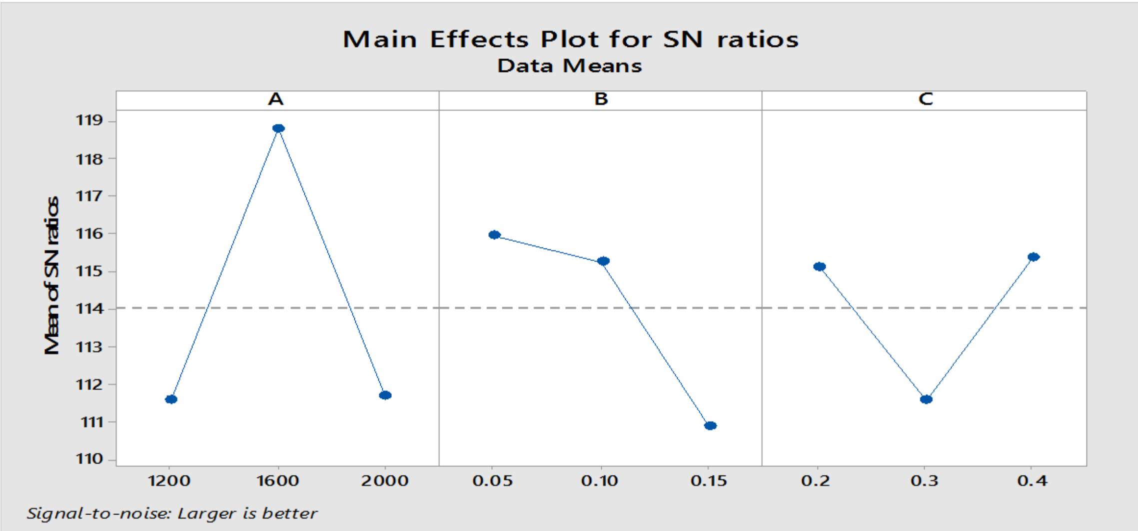

Fig 3. (A) SN response for cutting speed, (B) SN response for feed rate, (C) SN response for depth of cut

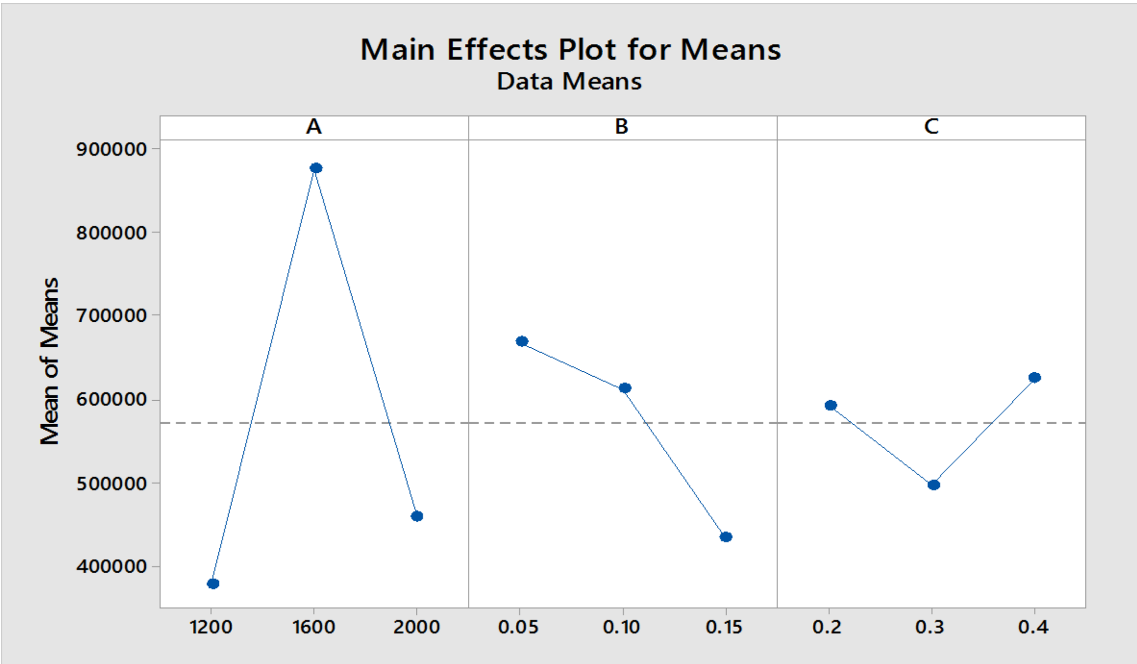

Fig. 4 (A) Mean of Means for cutting speed, (B) Mean of Means for feed rate, (C) Mean of Means for depth of cut.

4. Conclusion

From the result analysis in analysis of variance the Rotating bending fatigue testing machine gives the number of cycle to fails a component at constant bending moment as there is only nine experiment performed. It is difficult to known the effect of fatigue strength and cutting parameter at same time so experiment was done at constant bending moment i.e. 200 kg-cm as the nature of all specimen is same and we found the effect of cutting parameter of fatigue life than the fatigue strength. The main motive is to know the effect of cutting parameter on fatigue life so for only nine specimen it is difficult to draw the S-N curve. From the result obtained it is found that fatigue life is more for better surface finish or for lower surface roughness value and it is increases with decrease in surface roughness. Fatigue life is mostly depends the cutting speed and feed rate than the depth of cut. From ANOVA it is found that 75.27 % fatigue life affected by cutting speed, 15.39 % by feed rate and 5.34 % by depth of cut.

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