Optimization of machining parameters for minimum surface roughness indicators during the turning of AISI 316 L stainless steel

Shailendra Singh Rathore[1] , Mahesh Jangid[2], Sharad Srivastava[2]
[1]M.Tech, RIET Jaipur
[2]Assistant Professor in RIET, Jaipur

Abstract-

Product quality is very important for the company. This is because, bad quality products will affect the consumer's confidence, image and sales of the company. It may even affect the survival of the company. So, it is very important for every company to make better quality products. Product quality is also very important for consumers. In the manufacturing industry, it is commonly stated that "Quality drives productivity." Improved productivity is a source of greater revenues,employment opportunities and technological advances. In manufacturing industries, manufacturers focus on both the quality and productivity. To increase the productivity, computer numerically control (CNC) machine tools have been implemented during the past decades. Surface roughness is one of the most important parameters to determine the quality of product. The mechanism behind the formation of surface roughness is very dynamic, complicated, and process dependent. Several factors influence the surface roughness obtained in a CNC turning operation. These can be categorized as controllable factors (spindle speed, feed rate and depth of cut) and uncontrollable factors (tool geometry and material properties of both tool and work piece. The aim of present study is to develop surface roughness prediction models using response surface methodology (RSM) based on centre composite rotatable design (CCRD). An attempt has also been to analyse the effect of machining conditions on surface roughness during turning of AISI 316 L stainless steel with carbide insert.

Keywords: production, eminence, turning, surface roughness, turning parameters, response surface methodology (RSM)

1.INTRODUCTION

Turning in a lathe is defined as to remove excess material from work piece to produce a cone-shaped or cylindrical surface in the form of chips from the outer diameter. Turning is used for the machining of a peripheral surface:

i) By the work piece revolving.

ii) By a single point cutting tool,

iii) By the cutting tool feeding analogous to the axis of the specimen and at a space that will remove the peripheral surface of the specimen

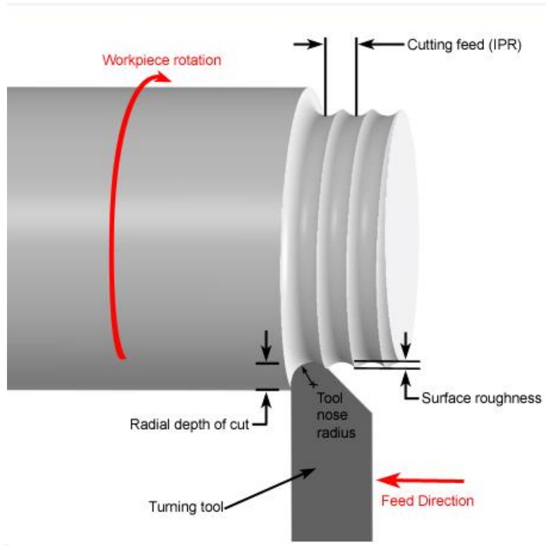


Fig -1: Adjustable parameters in turning operation

1.A Cutting Aspects in Turning

Speed, deepness of cut and feed are three principal facets which distresses turning operation. There are also some additional features such as category of substantial and sort of tool has an enormous impact, on the other hand these three features are key that an operative can amend at the time of machining.

Cutting Speed Cutting speed is the speed that the material moves past the cutting edge of the tool. Cut speed can be defined as revolutions per minute (RPM) or as surface feet per minute (SFM). Revolutions Per Minute (RPM) relates directly to the speed, or velocity, of the spindle. It annotates the number of turns completed in one minute around a fixed axis. RPM maintains the same revolutions per minute throughout the entire operation. RPM mode is useful for:

• Center cutting operations (drilling) • When the diameter at the beginning and end of a cut only differs slightly

• During threading to allow the perfect synchronization between spindle revolution and Zaxis motion to allow precise threads Surface Feet Per Minute (SFM) is a combination of the cut diameter and RPM. The faster the spindle turns, and/or the larger the part diameter, the higher the SFM.

If two round pieces of different sizes are turning at the same revolutions per minute, the larger piece has a greater surface speed because it has a larger circumference and has more surface area. As the tool plunges closer to the center of a workpiece, the same spindle speed will yield a decreasing surface speed. This is because each revolution represents a smaller circumferential distance, but takes the same amount of time. Most CNC lathes have CSS (constant surface speed) to counteract the natural decrease in surface speed, which speeds up the spindle as the tool moves closer to the turning axis. CSS adjusts the revolutions per minute to maintain a constant surface speed at every distance from the center. Eq. 1.1

$V=\pi DN$ m/min

1000

Where,

v=cutting speed in metres/min.

D= Diameter of the specimen in mm, and

N= Speed of spindle in rpm.

Feed Rate Feed rate is the velocity at which the cutter is advanced along the workpiece. Feed rate is expressed as units of distance (inch) per minute or per single revolution. Feed rate can be defined as inch per minute (IPM) or inch per revolution (IPR). IPR is more commonly used. Values for IPR and IPM are easily converted with the following formulas: IPM = IPR x RPM IPR = IPM / RPM So, for a spindle speed of 306 RPM and a feed rate of .01 IPR, the IPM can be calculated as follows: IPM = .01 x 306 = 3 IPM.

Depth of Cut

It is the advancement of tool in the job in a direction perpendicular to the surface being finished. Depth of cut depends upon cutting speed, rigidity of machine tool and tool material etc.

Eq. 1.3 mm d D dcut 2

Here,

D= initial diameter in mm of the specimen and d = final diameter in mm of the specimen.

Tool material: Tool material used for the experiment purpose is

Tool material-Carbide tip tool

STS (5/8" x 6") 15.88 x 152.80 mm

1.B Single Point Cutting Tool Geometry, Angles, Nomenclature and Signature-

As its name indicates, a tool that has a single point for cutting purpose is called single point cutting tool. It is generally used in the lathe machine ,shaper machine etc. It is used to remove the materials from the workpiece.

1. Shank: It is that part of single point cutting tool which goes into the tool holder. Or in simple language shank is used to hold the tool.

2. Flank: It is the surface below and adjacent of the cutting edges. There are two flank surfaces, first one is major flank and second one is minor flank. The major flank lies below and adjacent to the side cutting edge and the minor flank surface lies below and adjacent to the end cutting edge.

3. Base: The portion of the shank that lies opposite to the top face of the shank is called base.

4. Face: It is the top portion of the tool along which chips slides. It is designed in such a way that the chips slides on it in upward direction.

5. Cutting edge: The edge on the tool which removes materials from the work piece is called cutting edges. It lies on the face of the tool. The single point cutting tool has two edges and these are

(i) Side cutting edge: The top edge of the major flank is called side cutting edge.

(ii) End cutting edge: The top edge of the minor flank is called end cutting edge.

6. Nose or cutting point: The intersection point of major cutting edge and minor cutting edge is called nose.

7. Nose radius: It is the radius of the nose. Nose radius increases the life of the tool and provides better surface finish.

8. Heel: It is a curved portion and intersection of the base and flank of the tool.

Angles

The various angles of the single point cutting tool have great importance. Each angle has its own function and speciality.

1. End Cutting Edge Angle: The angle formed in between the end cutting edge and a line perpendicular to the shank is called end cutting edge angle.

2. Side Cutting Edge Angle: The angle formed in between the side cutting edge and a line parallel to the shank.

3. Back Rack Angle: The angle formed between the tool face and line parallel to the base is called back rake angle.

4. End Relief Angle: The angle formed between the minor flank and a line normal to the base of the tool is called end relief angle. It is also known as front clearance angle. It avoid the rubbing of the workpiece against tool.

5. Lip Angle/ Wedge Angle: It is defined as the angle between face and minor flank of the single point cutting tool.

6. Side Rake Angle: the angle formed between the tool face and a line perpendicular to the shank is called side rake angle.

7. Side Relief Angle: the angle formed between the major flank surface and plane normal to the base of the tool is called side relief angle. This angle avoids the rubbing between workpiece and flank when the tool is fed longitudinally.

Nomenclature

There is three coordinate systems which are most popular in tool nomenclature. And these are

1. Machine Reference System (MRS)

2. Orthogonal Tool Reference System (ORS) or Orthogonal Rake System

3. Normal Reference System (NRS).

Signature

The shape of a tool is specified in a special sequence and this special sequence is called tool signature. The tool signature is given below

(i) Back rake angle

(ii) Side rake angle

(iii) Clearance or End Relief angle

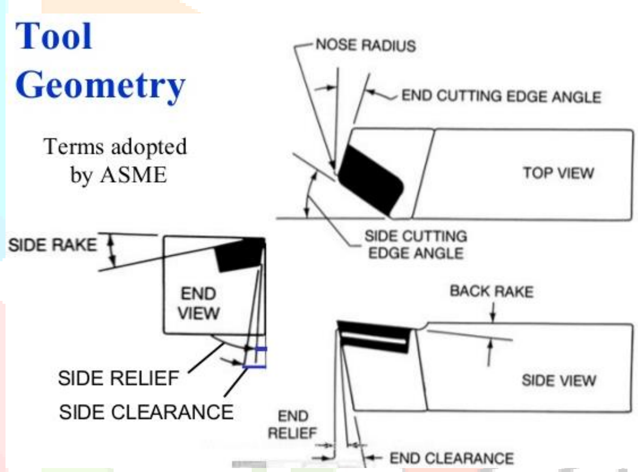
(iv) Side Relief angle

(v) End cutting edge angle

(vi) Side cutting edge angle

(vii) Nose radius

A typical tool signature of single point cutting tool is 0-7-6-8-15-16-0.8. Here this tool signature indicates that the tool has 0, 7, 6, 8, 15, 16 degree back rake, side rake, end relief, side relief, end cutting edge, side cutting edge angle and 0.8 mm nose radius.



1.C Turning Machines

There are various types of lathe machines used for turning operation. Such as:

(A) A metal lathe or metalworking lathe -is a large class of lathes designed for precisely machining relatively hard materials. They were originally designed to machine metals; however, with the advent of plastics and other materials, and with their inherent versatility, they are used in a wide range of applications, and a broad range of materials. In machining jargon, where the larger context is already understood, they are usually simply called lathes, or else referred to by more-specific subtype names (toolroom lathe, turret lathe, etc.). These rigid machine tools remove material from a rotating workpiece via the (typically linear) movements of various cutting tools, such as tool bits and drill bits.

(B) An automatic lathe is a lathe (usually a metalworking lathe) whose actions are controlled automatically. Although all electronically controlled (CNC) lathes are automatic, they are usually not called by that name, as explained under "General nomenclature". The first kinds of automatic lathes were mechanically automated ones, from the 1870s until the advent of NC and CNC in the 1950s and 1960s. CNC has not yet entirely displaced mechanically automated machines. The latter type of machine tool is no longer being newly built, but many existing examples remain in service.

The objective of this research is:

1. Development of surface roughness prediction models using RSM based on CCRD.

2. To analyze the effect of turning parameters (cutting speed, feed rate, and depth of cut) on surface roughness parameters during turning of AISI 316 L stainless steel.

3. To optimize the surface roughness parameters for minimum surface roughness indicators.

2. LITERATURE REVIEW

Grzesik (1996) made an attempt to predict surface roughness in turning with a single point tool. It was calculated by using brammertz formula. At the end it is found that the proposed methodology results in a better evaluation of the natural surface roughness produced by turning.
Choudhury and Baradie, (1997) developed surface roughness prediction models for turning EN 24T steel with uncoated carbide inserts utilizing response surface methodology. A factorial design technique has been used to study the effects of the main cutting parameters such as cutting speed, feed, and depth of cut, on surface roughness. The results revealed that response surface methodology combined with factorial design of experiments is a better alternative to the traditional one variable at a time approach for studying the effect of cutting variables on responses such as surface roughness and tool life. This significantly reduces the total number of experiments required.

Nian et al., (1999) used Taguchi method to optimize multiple performance characteristics including tool life, cutting force and surface finish in turning of S45C steel bars by using tungsten carbide tool. The orthogonal array, multi-response signal-to-noise ratio and analysis of variance have been employed to study the performance characteristics in turning operations. Three cutting parameters namely, cutting speed, feed rate and depth of cut were optimized for maximum tool life, minimum cutting force and maximum surface finish. It has been found that the Taguchi method provides a simple, systematic and efficient methodology for the optimization of the cutting parameters.

3.RESEARCH GAPS AND OBJECTIVES-

objectives and the steps of the present study are-
1. Development of surface roughness prediction models using RSM based on CCRD.
2. To analyze the effect of turning parameters (cutting speed, feed rate, and depth of cut) on surface roughness parameters during turning of AISI 316 L stainless steel.
3. Optimization of cutting parameters for minimum surface roughness parameters i.e Ra, Rq, Rt in turning of AISI 316 L stainless steel.

4. DESIGN OF EXPERIMENT

Number of experiments required, mainly depends on the approach adopted for design of experiment. In this study, the design suggested by CCRD has been implemented for the experiments. The machining parameters and their levels are shown in table 3.3. Complete design layout for experiments is summarized in table 3.4 and experimental results are summarized in table 3.6. This demonstrates a total of 20 runs required for complete experimentation. Twenty experiments constitute 23factorial point, six centre point and six axial points.

Table 3.3 Factors and levels of independent variables according to response surface methodology.

Symbol	Cutting parameters	Unit	Levels				
			-α	-1	0	+1	+α
A	Cutting speed	m/min	100	140.54	200	259.46	300
B	Feed rate	mm/rev	0.10	0.20	0.35	0.50	0.60
C	Depth of cut	mm	0.10	0.20	0.35	0.50	0.60

Table 3.4 Complete design layout

Run	Factor 1A: Cutting Speed	Factor 2 B: Feed rate	Factor3 C: Depth of cut
1	140.54	0.20	0.20
2	259.46	0.20	0.20
3	140.54	0.50	0.20
4	259.46	0.50	0.20
5	140.54	0.20	0.50
6	259.46	0.20	0.50
7	140.54	0.50	0.50
8	259.46	0.50	0.50
9	100	0.35	0.35
10	300	0.35	0.35
11	200	0.1	0.35
12	200	0.6	0.35
13	200	0.35	0.1
14	200	0.35	0.6
15	200	0.35	0.35
16	200	0.35	0.35
17	200	0.35	0.35

18	200	0.35	0.35
19	200	0.35	0.35
20	200	0.35	0.35

5. MEASUREMENT OF SURFACE ROUGHNESS

Surface roughness is defined as the finer irregularities of the surface texture that usually result from the inherent action of the machining process or material condition. It is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. The most accepted parameter is centre line average (CLA) surface roughness values denoted by (Ra). It is quantified by the vertical deviation of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. It is typically considered to be the high frequency, short wavelength component of a measured surface. In addition to this, now a days, other surface roughness parameters like root-mean-square roughness (Rq) and maximum peak-to-valley roughness (Rt) become also more popular.

In this research, a portable surface roughness tester (Model No TR 210 manufactured by Beijing TIME High Technology Ltd. Beijing City, China) has been used to measure surface roughness indicators of finished work pieces. The constants for surface roughness tester for all the measurements of work pieces were standard ISO 97R, 0.8 mm cut-off, least count of 0.001μm. The measurements were repeated at three different locations of the finish work piece in the direction of the tool movement. Finally, the mean of surface roughness values were considered for the particular trial. Technical specifications of the surface roughness tester are summarized in table 3.5 and the results obtain after measurements of surface roughness indicators of machined work pieces

6 ANOVA ANALYSIS

6.1 DIAGNOSIS OF ASSUMPTIONS OF ANOVA FOR AVERAGE SURFACE ROUGHNESS MODEL

The analysis of variance (ANOVA) is based on two assumptions.

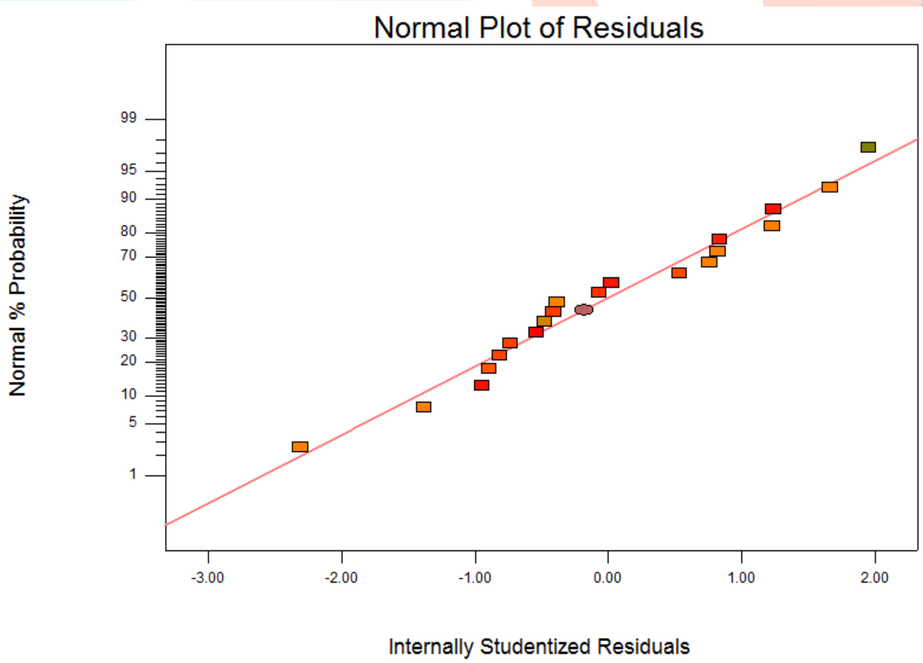
(1) The variables are normally distributed

(2) Homogeneity of variance. Significant violation of either assumption can increase the chances of error.

To check the assumption of normal distribution, the normal probability plot of the residuals for surface roughness is shown in figure.4.1. The normal probability plot indicates whether the residuals of average surface roughness follow a normal distribution or not, if the residuals follow a normal distribution majority of points will follow a straight line except some moderate scatter even with normal data. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.

Fig.4.2 represents residuals versus the predicted average surface roughness plot. It tests the assumption of constant variance. The plot should be a random scatter. The figure shows that there is no obvious pattern and it shows unusual structure. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

A graph of the predicted average surface roughness values versus the actual average surface roughness values is shown in Fig.4.3. It helps detect a value, or group of values, that are not easily predicted by the model. The data points should split evenly by the 45 degree line. The figure reveals that all the data points split evenly by the 45 degree line.



6.2 ANOVA TABLE FOR AVERAGE SURFACE ROUGHNESS

The ANOVA is commonly used to perform test for significance of the regression model, test for significance on individual model coefficients and test for lack-of-fit of model. This analysis was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. Table 4.1 represents the ANOVA table for the quadratic model for average surface roughness parameter (Ra).

Table 4.1 ANOVA table for quadratic model for Ra

Table 4.1 ANOVA table for quadratic model for R_a

Source	Sum of Squares	Degree of freedom	Mean Square	F Value	p-value Prob > F
Model	33.709	9	3.745	49.595	< 0.0001 S
A-cutting speed	4.002	1	4.002	52.996	< 0.0001 S
B-feed	27.980	1	27.980	370.486	< 0.0001 S
C-depth of cut	0.010	1	0.010	0.130	0.7258 NS
AB	0.789	1	0.789	10.454	0.0090 S
AC	0.012	1	0.012	0.154	0.7029 NS
BC	0.042	1	0.042	0.559	0.4721 NS
A^2	0.047	1	0.047	0.624	0.4480 NS
B^2	0.539	1	0.539	7.132	0.0235 S
C^2	0.202	1	0.202	2.680	0.1326 NS
Residual	0.755	10	0.076		
Lack of Fit	0.528	5	0.106	2.325	0.1880 S
Pure Error	0.227	5	0.045		
Cor Total	34.465	19			
Std. Dev.	0.275		R-Squared		0.978
Mean	3.116		Adj R-Squared		0.958
C.V. %	8.821		Pred R-Squared		0.874
PRESS	4.343		Adeq Precision		24.776

It shows that the value of "Prob. > F" for model is 0.0001 which is less than 0.05, that indicates the model is significant, which is desirable as it indicates that the terms in the model have a significant effect on the response. In the same manner, The value of "Prob. > F" for main effect of speed and feed, and two-level interaction of speed and feed, and second-order effect of feed are less than 0.05 so these terms are significant model terms. Other model terms said to be insignificant model terms. The insignificant model terms should be removed to improve the prediction ability of the model using elimination methods.

The value of "Prob. > F" for lack-of-fit is 0.1880, which is greater than 0.05 that indicate that lack of fit is insignificant. If the model does not fit the data well, this will be significant. The non-significant lack of fit is desirable.

The R2 value (the measure of proportion of total variability explained in the model) is equal to 0.978 or close to 1, which is desirable. The adjusted R2 value is equal to 0.96; it is particularly useful when comparing models with different number of terms. The result shows that the adjusted R2 value is very close to the ordinary R2 value. Adequate precision value is equal to 27.776; A ratio greater than 4 is desirable which indicates adequate model discrimination. Adequate precision value compares the range of the predicted values at the design points to the average prediction error.

Table 4.2 represents the ANOVA table for the reduced quadratic model for surface roughness parameter Ra by selecting the backward elimination procedure to automatically reduce the terms that are not significant.

Table 4.2 Reduce ANOVA table for quadratic model for Ra

Source	Sum of Squares	Degree of freedom	Mean Square	F Value	p-value Prob > F
Model	33.413	4	8.353	119.189	< 0.0001
A-cutting speed	4.002	1	4.002	57.106	< 0.0001
B-feed	27.979	1	27.979	399.223	< 0.0001
AB	0.789	1	0.789	11.264	0.0043
B^2	0.642	1	0.642	9.163	0.0085
Residual	1.051	15	0.070		
Lack of Fit	0.824	10	0.082	1.814	0.2652
Pure Error	0.227	5	0.045		
Cor Total	34.464	19			
Std. Dev.	0.265		R-Squared		0.969
Mean	3.116		Adj R-Squared		0.961
C.V. %	8.497		Pred R-Squared		0.920
PRESS	2.742		Adeq Precision		36.372

It shows that the value of “Prob. > F” for model is 0.0001 which is less than 0.05, that indicates the model is still significant after elimination, which is desirable as it indicates that the terms in the model have a significant effect on the response.

7. SUMMARY

This chapter presents the mathematical models, ANOVA table and optimization of machining parameters. Various plots, contour plots and 3D graphs have been studied for obtaining optimal values. The next chapter will describe the conclusions drawn from the study and future scope for further research.

8.CONCLUSION AND FUTURE SCOPE

A five level three numeric factors response surface methodology based on the central composite rotatable design technique has been used for the development of mathematical models to predict surface roughness.
The important conclusions drawn from the present work are summarized as follows:
1. Out of three parameters, feed seems to be the most significant and influential machining parameter that affect the surface roughness parameters (Ra , Rq and Rt) followed by cutting speed.

2. The depth of cut has insignificant influence on the surface roughness parameters.

3. The mathematical models developed clearly show that surface roughness increases with increasing the feed but decreases with increasing the cutting speed.

4. The results of ANOVA and the confirmation runs verify that the developed mathematical models for surface roughness parameters shows excellent fit and provide predicted values of surface roughness that are close to the experimental values, with a 95 per cent confidence level.

8.REFERENCES

1. Abouelatta O.B., Madl J.(2001) , Surface roughness prediction based on cutting parameters and tool vibrations in turning operations Journal of Material Processing Technology , vol. 118 pp.269-277.

2. Aggarwal aman, singh Hari, kumar Pradeep and singh Manmohan (2008). “Optimization of multi quality characteristics for CNC turning under cryogenic cutting environment using desirability function”, Journal of Material Processing Technology, Vol. 205, pp. 42-50.

3. AlagarsamyS.V. and RajakumarN. (2014), “Analysis of influence of turning process parameters on material removal rate and surface roughness of AA7075 using taguchi’s method and response surface methodology”, International Journal of Applied Research and Studies, Vol. 3, ISSN 2278-9480.

4. Aouici Hamdi, Yallese Mohamed Athmane, Chaoui Kamel and Mabrouki Tarek (2012). “Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization”, Journal on Measurement, Vol. 45, pp. 344-353.

5. Asi Osman, Can Ahmet Cetiln, Pineault James and Belassel Mohammed (2009), “The effect of high temperature gas carburization on bending fatigue strength on SAE 8620 steel”, Journals on Material and Design, Vol. 30, pp. 1792-1797.

6. Asi Osman, Can Ahmet Cetin, Pineault James and Belassel Mohammed (2007), “The relationship between case depth an bending fatigue strength of gas carburized SAE 8620 steel”, Journals on Surface and coating technology, Vol. 201, pp. 5979-5987 .

Asilturk Ilhan and Akkus Harun (2011). “Determining the effect of cutting parameters on surface roughness in hard turning using the taguchi method”, Journal on Measurement, Vol. 44, pp. 1697-1704.