ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.9, No.01 pp 134-141, 2016

Effect of lead variation on surface roughness and optimization of cutting parameters in turning operation for Brass alloys

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Abstract: Surface roughness of Brass alloys is investigated practically by varying the machining parameters such as spindle speed, feed rate and depth of cut. The tool used is a carbide insert which is widely used in industry and easily available. The investigation was done under dry cutting conditions. This study involves the optimization of a combination of spindle speed, feed rate and depth of cut to have a best surface finish which will lead to reduced cost, less manufacturing time and better quality. The design of experiments was done using Taguchi method and L9 array was used. The Analysis of Variance (ANOVA) and Signal-to-Noise ratio were used to study the performance characteristics in turning operation. The analysis shows that the increase in amount of lead in the alloy leads to decrease in the surface roughness after turning. The analysis also shows that spindle speed has the minimum contribution towards Ra (surface roughness) for all three alloys under study and depth of cut has highest contribution towards Ra for all the alloys. There are two purposes of this research, first was to find out a particular combination of cutting parameters in turning operation to have the best surface roughness and second was to identify the effect of amount of lead in brass alloy on the characteristics of surface roughness.
Keywords: Surface roughness, ANOVA, Turning, Cutting parameters, Taguchi method.

1. Introduction

Surface roughness is the measure of the texture of surface quantified by the vertical deviation of a real surface from its ideal form, is a good judge of the performance of a mechanical component. The goal of a manufacturer is to decrease surface roughness without hampering the cost of machining and product to a large level. Decreasing the surface roughness of machined products depends upon the control of cutting parameters such as cutting speed, feed rate and depth of cut. If the cutting parameters are optimized in a way that they give the best surface finish, will reduce the effort and worry of a manufacturer to a great extent.

Brass alloys are used for making bushings which act as bearing between shaft and housing. These are used in tractors, pumps, electricity generators, earth moving machinery. The presence of lead in these alloys is done to reduce the cost. Brass alloys are formed using casting process by mixing the molten form of metals by weight. For example Gun metal also known as red brass has 10% to 12% of copper, 5% zinc, 3% to 5% iron and remaining copper is formed by taking the weight percentage of material and then casting them in a desired shape.

The turning operation of brass alloys was traditionally done using a simple lathe machine however the current trend suggest the use of CNC turning center machine to a large. Since the brass alloys has vital application in bushings so the machining operations involved are turning and boring. Tungsten coated carbide inserts are used for turning of brass alloys and turning is done under dry conditions.

Taguchi method is method used by researchers to have such a combination of experiments with varying parameters to have an optimum result for the same. A large number of experiments were to be done but employing Taguchi will reduce this to a small set of experiments with almost same results and less operation time. The aim of present study is to study the surface roughness of brass alloys after turning operation on CNC turning with carbide coated insert under various combinations of cutting parameters. In addition an analysis on the effect of percentage of lead In alloy on surface roughness after turning operation is also discussed. Analysis of variance (ANOVA) is employed to find out the effective cutting parameters for best surface finish among the alloys under study.

Optimization of cutting parameters has been a very interesting topic for researchers because a large number of materials are machined and turning is one of the prime methods to provide desired shape to products. Output of machining is determined by surface finish, productivity and tool life for maximum quality and reduced production cost. R.A. Mahdaviejid et al[1] had done the experimental analysis on steel and determined that quality of machined surface decreased with increased feed rates and depth of cut while the cutting speed had the least effect on surface finish after machining. However the experiments carried by N. Sateesh Kumar et al.[2] on carbon steels revealed that surface roughness increased with increased feed rate and depth of cut and surface quality decreased with decrease in spindle speed. A similar study done by C. Natarajan et al. [3] on a brass specimen C26000 gave the conclusion that feed rate is the most influential parameter for the quality of surface roughness followed by spindle speed and depth of cut. The same study carried C. Natarajan et al.[3] on aluminum samples revealed that feed rate is the most influential factor in determining the quality of surface. A study done by Ilhan Asitu et al.[4] on AISI 304 austenitic steel showed that feed rate is the most significant factor for surface roughness with 85.5 % contribution towards bringing down the average roughness values.

A study done by C. Vilarinho et al.[5] suggested that the composition of alloys affect the cutting forces acting on the brass work piece during machining. Study revealed that Cu-Sn-Zn system alloys had the lowest values of cutting and feed forces. However the presence of aluminum did not show any correlation and similar results were obtained for the copper content in alloy. However the presence of Zn in Al-Cu-Zn system revealed the increase in cutting forces. The study on lead free silicon brass alloys done by Mohamed A. Taha et al.[6] showed that the specimens with 1% silicon by weight exhibits maximum strength, maximum cutting force and continuous chip while tool wear and surface roughness had minimum values. Increase in silicon content to 4% increased the tool wear by 140 % and surface roughness by 25%.

Hamdi Aouici et al.[7] had an observation during study of the effect of work piece hardness, cutting speed, feed rate and depth of cut on surface roughness and cutting force components on AISI H11 steel with CBN insert that cutting force components are highly influenced by depth of cut and work piece hardness while for surface roughness both feed rate and work piece hardness has statistical significance.

C.J Rao et al. [8] studied the significance of speed, feed rate and depth of cut on surface roughness and cutting force components during turning of AISI 1050 steel which shows that the feed rate has significant influence on cutting force whereas no significant effect on surface roughness. This study also shows that all three parameter interactions have significant influence on cutting forces but no parameter interaction has significant influence on surface roughness. V Sivaraman et al. [9] did the study the effect of cutting parameters on cutting forces during the turning of micro alloyed steel. R. Deepak Joel Jhonson et al. [10] studied the effect of cutting parameters and quantity of lubrication on OHNS(Oil Hardened Non shrinkable steel). Girish Kant et al.[11] provided a multi-objective predictive model for the minimization of power consumption and surface roughness during machining. Carmita Camposeco-Negrete[12] did study on the contributions of feed rate, depth of cut and speed to optimize cutting power, energy consumed and surface roughness during turning of AISI 6061 T6. Shreemoy Kumar Nayak[13] investigated the effect of cutting speed, feed rate and depth of cut on material removal rate, cutting forces and surface roughness during turning of AISI 304 austenitic stainless steel. M. Nalbant et al. [14] studied the performance characteristics in turning operations of AISI 1030 steel bars using Tin coated inserts. J.A Ghani et al.[15] optimized the end milling parameters while machining hardened steel AISI H13 with Tin coated P10 carbide inserts. D.I Lalwani et al.[16] investigated the effect of cutting parameters(cutting speed, feed rate, depth of cut) on cutting forces and surface roughness in finish hard turning of MDN 250 steel using coated ceramic tool. W. Grzesik [17] has done the characterization of surface roughness generated during hard turning performed with mixed ceramic(aluminum oxide plus TiC or TiCN) and PCBN tools at variable feed rate and changes in surface profiles were also investigated under different amount of tool wear. Khaider Bouacha et al. [18] studied the hard turning of AISI 52100 hardened at 64 HRC to determine the relation between cutting parameters(cutting speed, feed rate, depth of cut) with output variables(Surface roughness, cutting forces). Gaurav Bartarya et al.[19] made an attempt to develop a force prediction model during finishing of AISI52100 steel hardened to 60 HRC with uncoated CBN tool and to determine the best combination of machining parameters for better performance in terms of surface roughness within selected range of cutting parameters. Mohammadjafar Hadad et al.[20] did the MQL(minimum quantity lubrication) turning of AISI 4140 steel to study the influence of nozzle position and cutting parameters(cutting speed, feed rate and depth of cut) on machining forces, surface roughness and temperature. The above stated research did not study the effect of amount of lead on the surface roughness of brass alloy at the optimum machining parameters.

2. Materials and methods

The machine used for turning tests was a Lokesh TL 160 an industrial type of CNC (computer numerically controlled) turning center installed in industry two years ago which is equipped with variable spindle speed motor from 50 to 3500 rpm and a 10 kW motor was used to drive the spindle motor.

The material under study is brass alloy whose three different compositions are identified. The unleaded alloy of brass is Gun metal also termed as Red brass contains 88% copper, 10% Tin and 2% zinc is also termed as pure in local language. The second composition under study is LTB-4 containing 14 to 16% lead and last is leaded bronze containing highest percentage of lead which 22- 26%.

Table 1: Composition of brass alloys under study

S.No	Alloy	Composition
1.	Gun metal	Copper (88%), Tin (10%) and Zinc (2%)
2.	LTB-4	14%-16% Lead, 4%-6% Tin, 2% Nickel, 1% impurities and remaining %age of copper
3.	Leaded Bronze	22-26% Lead, 4% Tin, 1% impurities and remaining %age of copper.

The work pieces are in the form of hollow cylinders with 51 mm diameter. The work pieces are trued, cleaned by removing a 0.3 mm depth of cut from the outer surface prior to the final machining on CNC lathe machine for final tests.

The equipment used for surface roughness testing was a stylus instrument. MitutoyoSurf Test SJ-201P was used to measure the surface roughness of the machined specimen. The stylus is placed on the work piece, since the surface always has curved profile the stylus will move up and down, due to which an Emf will produce which is converted to digital signal and gives the value in terms of Ra which is the mean value of deviation from the reference.

The Taguchi method which is powerful tool in the design of experiment is used to optimize the turning parameters for the effective machining of brass alloys to have best surface finish. This method requires the use of S/N ratio to measure the quality characteristics deviating from the desired value. To obtain the better testing parameters, the minimum is better quality characteristic for machining of brass alloys was taken to measure the surface roughness. The S/N ratio of each level was computed and with the help of that best combination for surface roughness was determined.

The machining parameters were spindle speed, feed rate and depth of cut. Three levels for each were specified and Taguchi design was used to form a L9 array.

Table 2: L9 Taguchi design for machining parameters

S. No	Spindle Speed(rpm)	Depth of cut(mm)	Feed Rate(mm/rev)
1	800	1	0.2
2	800	0.5	0.25
3	800	1.5	0.1
4	1200	1	0.25
5	1200	0.5	0.1
6	1200	1.5	0.2
7	1600	1	0.1
8	1600	0.5	0.2
9	1600	1.5	0.25

3 Results and Discussion:

Determination of optimum cutting parameters

3.1 Material under study LTB 4:

The effect parameters spindle speed; feed rate and depth of cut were analyzed using ANOVA for LTB-4, gun metal and brass. A confidence level of 95% is used. Three repetitions for each trial was completed so as to measure signal to noise ratio.

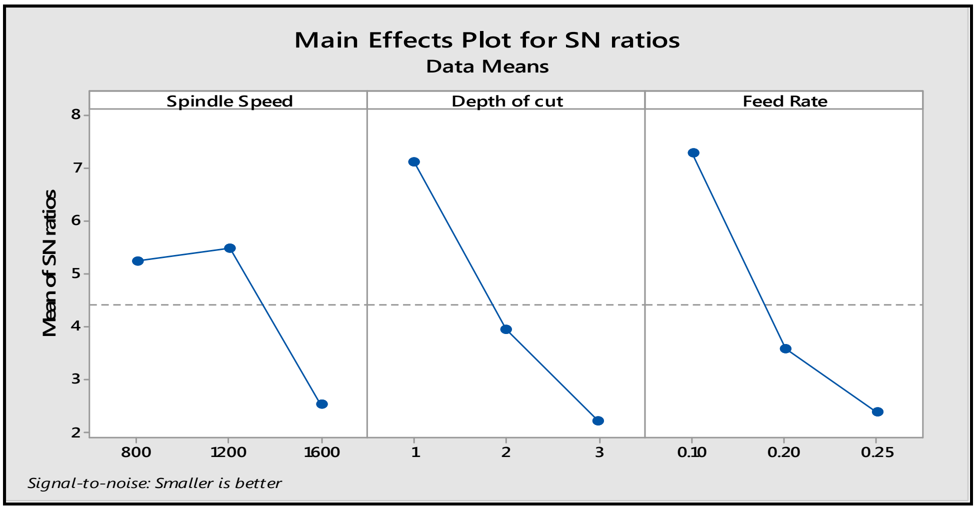

Figure1:Plot of SN ratios for LTB-4 with all three parameters

Table 3 : Results for Ra after CNC machining of LTB 4 at various input parameters

Sr No.	Spindle speed(RPM)	Depth of cut (mm)	Feed Rate (mm/rev)	Ra (Mean) µm
1.	800	3	0.1	0.47
2.	800	1	0.25	0.51
3.	800	2	0.2	0.68
4.	1200	1	0.1	0.30
5.	1200	3	0.2	0.76
6.	1200	2	0.25	0.66
7.	1600	3	0.25	1.31
8.	1600	2	0.1	0.57
9.	1600	1	0.2	0.56

Analysis of Variance for SN ratios:

Table 4: ANOVA for S/N ratio of Ra for material LTB-4

Source	DF	Seq SS	Adj SS	Adj MS	F
Spindle Speed	2	16.250	16.250	8.125	6.93
Depth of Cut	2	37.247	37.247	18.624	15.89
Feed Rate	2	39.538	39.538	19.769	16.87
Residual Error	2	2.344	2.344	1.172	
Total	8	95.378			

The results were analyzed using ANOVA for identifying the significant factors with the help of S/N ratios for the mean Ra at 95% confidence interval in Table 4. The table shows that the optimum parameters for surface finish for the given material are spindle speed at 1200 rpm, feed rate 0.1mm and depth of cut 1mm. ANOVA suggests that the most important factor for Ra is Feed Rate (F 16.87value) before Depth of Cut (F 15.89value) and last spindle speed (F 6.93value).

3.2 Material under study Gun Metal:

The Ra value for Gun metal which is an alloy of Copper having 10-12% Aluminium, 5% Zinc, 3-5% Iron and less than 2% impurities was analyzed for three levels of spindle speed, feed rate and depth of cut.

Table 5:Results for Ra after CNC machining of Gun metal at various input parameters

S.No	Spindle Speed(rpm)	Depth of cut(mm)	Feed Rate(mm/rev)	Ra
1	900	0.5	0.25	1.21
2	900	1.5	0.20	1.07
3	900	2.5	0.10	0.46
4	1300	0.5	0.10	0.39
5	1300	1.5	0.25	1.45
6	1300	2.5	0.20	0.85
7	1700	0.5	0.20	0.88
8	1700	1.5	0.10	0.44
9	1700	2.5	0.25	1.39

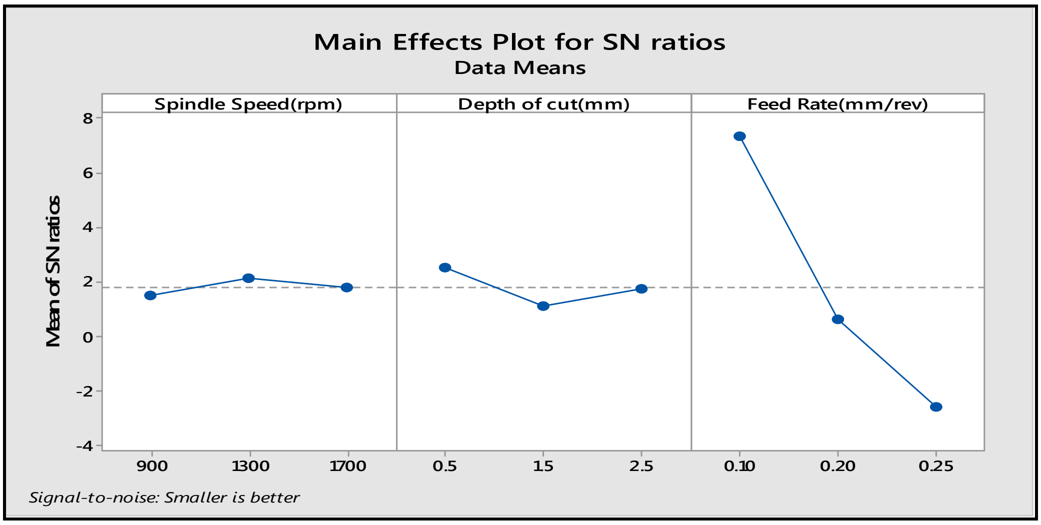

Figure 2: Plot of S/N ratios for Gun metal for all three parameters for Ra

Analysis of Variance for SN ratios:

Table 6: Analysis of variance for S/N ratio for gun metal for the input parameters for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F
Spindle Speed	2	0.0042	0.0042	0.000211	0.02
Depth of Cut	2	0.03849	0.03849	0.019244	1.65
Feed Rate	2	1.27336	1.27336	0.636678	54.52
Residual Error	2	0.02336	0.02336	0.011678	
Total	8	1.33562			

The results were analyzed using ANOVA for identifying the significant factors with the help of S/N ratios for the mean Ra at 95% confidence interval in Table 6. The Table shows that the optimum parameters for Ra of the given material are spindle speed at 1300 rpm, feed rate 0.1mm and depth of cut 0.5mm. ANOVA suggests that the most important factor for Ra is Feed Rate (F 54.52value) before Depth of cut (F 1.65 value) and last spindle speed (F 0.02value).

***3.3* Material under study Leaded Bronze:**

The results for Ra for leaded bronze for the given parameters are discussed and graphical analysis is done.

Table 7: Observation table for calculation of Ra at given machining parameters

S.No	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)	Ra (micro meter)
1	800	0.25	0.5	0.90
2	800	0.2	1	0.88
3	800	0.1	1.5	0.66
4	1200	0.1	0.5	0.64
5	1200	0.25	1	0.81
6	1200	0.2	1.5	0.77
7	1600	0.2	0.5	1.21
8	1600	0.1	1	0.81
9	1600	0.25	1.5	0.89

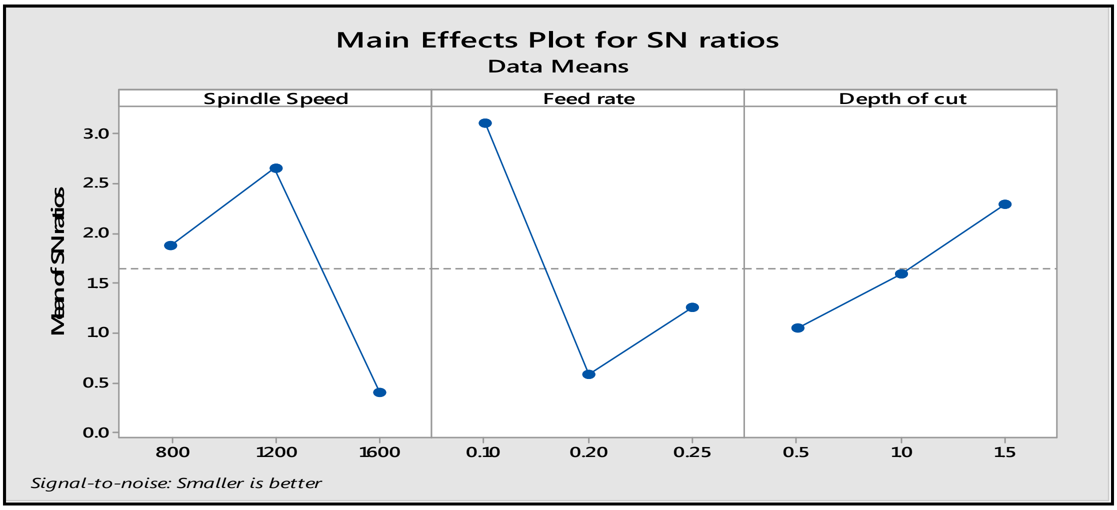

Figure 3: Plot of S/N ratios for leaded bronze for all three parameters for Ra

Analysis of Variance for SN ratios:

Table 8: Analysis of Variance for means for leaded bronze for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F
Spindle Speed	2	0.08282	0.08282	0.041411	6.33
Depth of Cut	2	0.09669	0.09669	0.048344	7.39
Feed Rate	2	0.03109	0.03109	0.015544	2.38
Residual Error	2	0.01309	0.01309	0.006544	
Total	8	0.22369			

The results were analyzed using ANOVA for identifying the significant factors with the help of S/N ratios for the mean Ra at 95% confidence interval in Table 8. The Table shows that the optimum parameters for Ra of the given material are spindle speed at 1200 rpm, feed rate 0.20mm and depth of cut 0.5mm. ANOVA suggests that the most important factor for Ra is Depth of cut (F 7.39value) before Feed Rate (F 6.33 value) and last feed rate (F 0.74value).

Conclusions:

In this work, three brass alloys which were LTB-4, Gun Metal and Aluminum Bronze were machined with CNC turning center for three levels of spindle speed, depth of cut and feed rate for determining optimum combination of the parameters to give best surface finish Ra and maximum material removal rate. The experimental outcomes were analyzed with the help of MINTAB; the following conclusions were found from the results:

1. The optimum parameters for Ra (surface finish) for LTB-4 are spindle speed 1200rpm, feed rate 0.1mm and depth of cut 0.5mm.
2. The optimum parameters for Ra (surface finish) for Gun metal are spindle speed 1300 rpm, feed rate 0.5mm and depth of cut 1mm.
3. The optimum parameters for Ra (surface finish) for leaded bronze are spindle speed 1200 rpm, feed rate 0.1 mm and depth of cut 0.5 mm.
4. The optimum parameters for surface finish for all three alloys is same but the difference lies in the fact that LTB-4 an alloy containing 16% Lead , 8 % Tin, 0.8 % Zinc behaved best for the given machining parameters resulting in minimum value of Ra which is 0.30 µm.
5. The surface finish of the Leaded Bronze was observed to maximum for the optimum parameters which gives us the conclusion that the presence of high amount of lead which is 22-26% is affecting the response of the product for a better surface finish. This means that for a better surface finished product one should avoid lead in the alloy.

Acknowledgements:

The authors are grateful to Department of Chemistry and Mechanical Engineering, LFTS, Lovely Professional University for providing support for doing this research work.

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