OPTIMIZATION OF TURNING PARAMETERS FOR SURFACE ROUGHNESS IN CNC TURNING

By

P.K. SOOD * RAKESH SEHGAL ** D.K. DWIVEDI ***

*-** Department of Mechanical Engineering, National Institute of Technology, Hamirpur (H P), India.
*** Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, India.

ABSTRACT

In this study, the effect and optimization of cutting parameters on surface roughness in a CNC turning operation was investigated by using the Taguchi method. The experimental studies were conducted under varying cutting speeds, feed rate, depth of cut and approach angle. An orthogonal array, the signal-to noise (S/N) ratio, and analysis of variance (ANOVA) were employed to study the performance characteristics in turning of hypereutectic Al-Si-Mg alloys produced by conventional and stir casting techniques. The alloys under investigation were prepared by controlling melt using induction heating and melting furnace. The cutting operations were carried out under dry conditions on a CNC turning centre using coated carbide inserts. The conclusions revealed that the feed rate and cutting speed were the most influential factors on the surface roughness. The optimal conditions obtained for surface roughness for the Al-20Si-0.05 Mg-1.2Fe developed by stir cast technique is more significant than those developed by conventional technique.

Keywords: Cutting Parameters, Surface Roughness, Taguchi Method, Analysis of Variance, Workpiece Material, Tool Material.

INTRODUCTION

The cost of manufacturing is obviously the main consideration in the selection of process. For successfully marketing a product, its manufacturing cost must be competitive. For higher production rates machines with higher degree of automation are to be used. The most significant are NC / CNC machine tools, which have been provided with higher power, greater spindle speed, spindle accuracy, better control systems and wide range of speeds and feeds [1, 2]. The aluminum alloys are used in variety of engineering applications like structural, automobile components, food processing, oil and gas industries etc, because of light weight and greater tensile strength. The quality of the surface plays an important role in the performance of turning as a good quality turned surfaces improves fatigue strength and corrosion resistance. Surface roughness also affects the several functional attributes of parts, such as, contact causing surface friction, wearing, and heat transmission [3,4]. As turning is the primary operation in most of the production processes in the industry, surface finish of the turned components has greater influence on the quality of the product. Surface finish has been found to be influenced in varying amounts by factors such as cutting speed, feed rate, depth of cut, work material characteristics, work hardness, tool geometry types of chips produced, alloying elements present, stability of machine tool and work piece set up and cutting conditions [5]. Pure aluminum adheres to the tool and forms built-up edge apart from producing long chips that are too ductile to break. Chip form and chip breakability are generally influenced by the alloy composition and material properties. Iron is restricted to maximum of 0.8 or 1% in permanent mould cast alloys. Intermetallic constituents such as $CuAl_2$ or $FeAl_3$ similarly act as chip breakers without reducing the life of the cutting tool and improve the surface finish [6].The stir casting is a tool for enhancement of localized surface properties. It increases the ductility and strength and also improves the surface properties during machining operation [7]. The surface parameter used to evaluate the surface roughness in this study is the roughness average (Ra). The roughness average is the area between the roughness profile and its centre line or the integral of the absolute value of the roughness profile height over the evaluation length [8]. The

Taguchi process helps to select or to determine the optimum cutting conditions for turning process. The various researchers developed many mathematical models to optimize the cutting parameters to get lowest value of surface roughness. The Taguchi design of experiments was used to optimize the cutting parameters and results are analyzed using analysis of variance (ANOVA) method [9].

1. Experimental Procedure

1.1 Material

Experimental alloys were prepared by careful melting of master alloys Al-30% Si, Al-10% Mg, and Al-10% Fe in appropriate quantities with aluminum of 99.99% purity in an Induction melting furnace. After proper mixing, the molten alloys were cast in a metallic mold (40 mm X 37 mm X 150 mm) by a conventional cast and stir casting technique. Stir casting was carried out at 400 RPM after careful selection of stirring speed for obtaining defect free aluminum alloys for machining investigation. The nominal compositions of experimental alloys are as shown in Table 1.

1.2 Experimental Set Up

The experiment was carried out in the institute central workshop on a CNC turning centre. Coated carbide insert (CCMTT090304) CVD multilayer coated and a cobalt–enriched substrate was used for machining. The cutting operations were carried out dry, that is, without the use of coolants for the experimental work. The surface roughness values of machined surface were measured by surface roughness tester (SJ 301), Mititota make after each set of experiment. The cutting conditions chosen are shown in Table 2.

2. Experimental results

In this study, the cutting parameter design by the Taguchi method is adopted to obtain optimal surface roughness component in turning. The experiments were carried out with four factors at four levels each, as shown in Table 2. The use of an orthogonal array to reduce the number of experiments for determining the optimal cutting parameters for surface roughness was done. Results of the cutting experiments are analyzed using the S/N and ANOVA for surface roughness. Based on the results of S/N and ANOVA, optimal cutting parameters with performance characteristic, with the smallest S/N ratio have been obtained.

Alloy	Processing method	Si	Mg	Fe	Al
Alloy-1	Conventional cast	20	0.5	1.2	balance
Alloy-2	Stirring	20	0.5	1.2	balance

Table 1. Nominal composition of Al-Si alloys (Element Wt %)

Symbol	Cutting Parameter	Unit	Level-I	Level-II	Level-III	Level-IV
A	Cutting speed	m / min	100	125	150	175
B	Feed rate	mm / rev.	0.1	0.2	0.3	0.4
C	Depth of cut	mm	1.0	1.5	2.0	2.5
D	Approach. Angle	degree	45	60	75	90

Table 2. Cutting parameters used to study Surface Roughness

2.1 Optimization of machining parameters for surface roughness

Analysis of effect of each factor (cutting speed, fed rate. depth of cut and approaching angle) on surface roughness have been performed. The result for surface roughness of alloy developed by conventional method and stirring are shown in appendix (Table 3). The response table for hypereutectic alloy developed by conventional cast and stirring technique are shown in Table 4 and 5. The results of analysis of variance to judge which process machining parameter affects the performance characteristic are shown in Table 6 and 7. The experimental results indicates that for Alloy 1, based on Taguchi predication the feed rate and cutting speed are the two factors that have the highest different values of 3.77 and 3.74 respectively and are significant. The feed rate and

Sr. No.	Cutting Speed m/min.	Feed mm/rev.	Depth of Cut mm	App -angle	Surface roughness Values for alloy -1	Surface roughness Values for alloy -2
1	100	0.1	1.0	45	5.58	4.15
2	100	0.2	1.5	60	4.07	4.07
3	100	0.3	2.0	75	4.66	4.26
4	100	0.4	2.5	90	7.46	6.67
5	125	0.1	1.5	75	5.96	3.65
6	125	0.2	1.0	90	3.24	3.21
7	125	0.3	2.5	45	4.17	3.9
8	125	0.4	2.0	60	4.12	3.90
9	150	0.1	2.0	90	4.01	2.33
10	150	0.2	2.5	75	2.14	2.00
11	150	0.3	1.0	60	5.40	3.08
12	150	0.4	1.5	45	3.05	2.66
13	175	0.1	2.5	60	5.12	3.34
14	175	0.2	2.0	45	4.26	3.59
15	175	0.3	1.5	90	2.40	2.14
16	175	0.4	1.0	75	3.87	3.59

Table 3. Results for surface roughness for alloy developed

Level	Speed	Feed	Depth of cut	A. Angle
1	-14.49	-14.17	-12.89	-12.40
2	-12.60	-10.40	-11.25	-13.33
3	-10.75	-12.01	-12.58	-11.81
4	-11.53	-12.80	-12.66	-11.83
Delta	3.74	3.77	1.64	1.52
Rank	2	1	3	4

Table 4. Response table for S /N ratio for Ra for Alloy-1

Level	Speed	Feed	Depth of cut	A. Angle
1	-13.40	-7.35	-11.89	-10.94
2	-12.30	-10.91	-8.63	-11.06
3	-9.90	-10.19	-10.71	-10.23
4	-9.92	-11.97	-11.20	-11.19
Delta	3.58	4.62	3.26	0.95
Rank	2	1	3	4

Table 5. Response table for S /N ratio for Ra for Alloy-2

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contr. (%)
Speed	3	29.76	29.76	9.92	0.64	0.636	24.78
Feed	3	31.41	31.41	10.47	0.68	0.620	26.16
DOC	3	6.62	6.62	2.21	0.14	0.927	5.53
A. Angle	3	6.10	6.10	2.03	0.13	0.935	5.08
Error	3	46.16	46.16	15.39			38.45
Total	15	120.05					100

Table 6. Results of analysis of variance for Ra for Alloy-1

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contr. (%)
Speed	3	10.80	10.80	3.60	0.56	0.679	9.53
Feed	3	73.47	73.47	24.47	3.79	0.152	64.65
DOC	3	7.76	7.76	2.58	0.40	0.764	6.83
A. Angle	3	2.18	2.18	0.72	0.11	0.947	1.92
Error	3	19.39	19.39	6.465			17.07
Total	15	113.58					100

Table 7. Results of analysis of variance for Ra for Alloy-2

cutting speed have more influence on surface roughness values. Significant factor (P) values for both are 0.620 and 0.636 in percentage, respectively. The contribution of the feed rate and cutting speed are 26.16% and 24.78% respectively. From the graphical representation it is evident that the optimal; machining conditions occurs at the cutting speed of 150 m/min, feed rate of 0.2 mm/rev, depth of cut 1.5 mm and approaching angle of 75^0. Feed rate is the significant factor that effect on the surface roughness followed by cutting speed with highest delta value of 4.62 and 3.58 for Alloy 2. Results of analysis of variance indicate that significant value for feed rate and cutting speed occurs at 0.152 and 0.679 respectively. The contribution of feed rate and cutting speed are 64.65 and 9.53 respectively. It is evident from the S/N ratio graph that the best parameters for surface roughness are found at cutting speed 150 m/min (level 3), feed rate 0.3 mm /rev. (level 3), depth of cut 1.5mm (level 2) and approaching angle 75^0 (level 3), these are significant and will yield minimum values for surface roughness (Figure 1 a and b).

3. Discussions

Results indicates that for hypereutectic aluminum-silicon-magnesium alloy developed by both technique the feed rate has strongest effect on surface roughness followed by cutting speed according to the rank value of each control factor. From the results it can be observed that the optimal parametric conditions occurs for minimum surface roughness for Al-20Si-0.5Mg-1.2Fe processed by stirring technique than the conventional method. Primary α-Al dendrite becomes more equalized and Al-Si eutectic is much finer. The morphological changes of primary and eutectic Si are observed as can be seen from Figure 2 (a, b). The primary Si morphology changes from needle type to plate type (rectangular type) and uniform distribution of fine silicon particles have been observed when alloy is

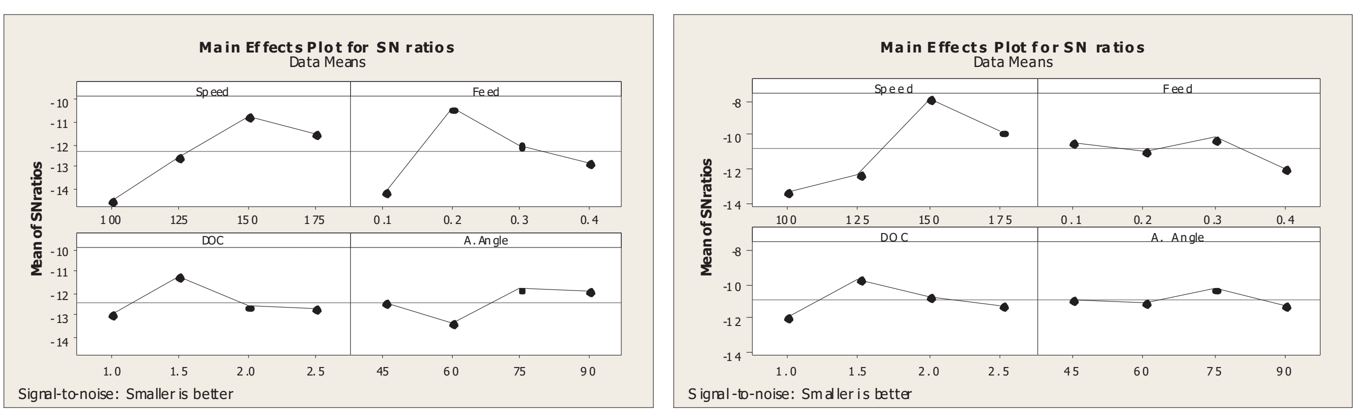

Figure 1. (a) S/N ratio for surface roughness for Al-20Si-0.5 Mg -1.2 Fe (Conventional cast), (b) Al-20Si-0.5Mg-1.2Fe (Stir-cast)

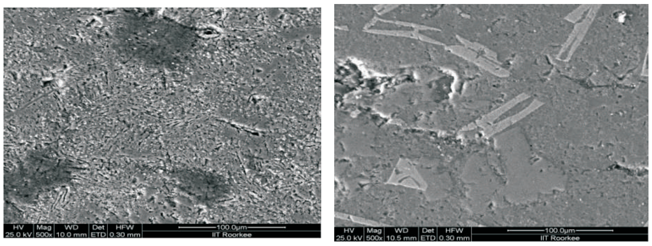

Figure 2. SEM image of elements present (a) Al-20Si-0.5Mg-1.2Fe (conventional), (b) Al-20Si-0.5Mg-1.2Fe (stir cast)

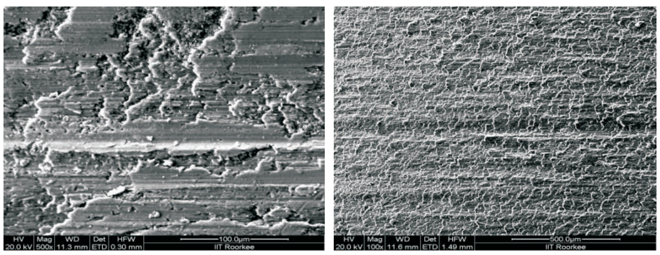

Figure 3. SEM image of machined surface a) Al-20Si-0.5Mg-1.2Fe (conventional)) at cutting speed (150 m/min), feed rate (0.2/rev), depth of cut (2.5 mm) and A. angle (75^0), b) Al-20Si-0.5Mg-1.2Fe (stir cast) speed of (150/min), feed rate (0.2m/rev), depth of cut (2.5mm) and A. angle (75^0)

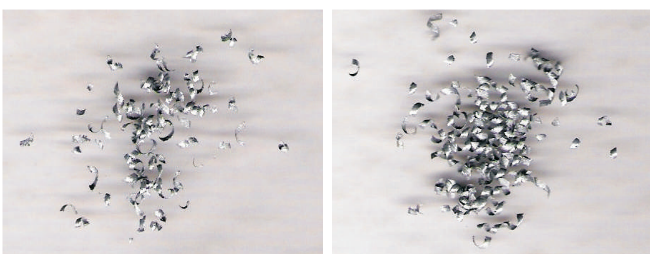

Figure 4. Shape of the chips produced a) Al-20Si-0.5Mg-1.2Fe (conventional)) at cutting speed (150 m/min), feed rate (0.2/rev), depth of cut (2.5 mm) and A. angle (75^0), b) Al-20Si-0.5Mg-1.2Fe (stir cast) speed of (150/min), feed rate (0.2m/rev), depth of cut (2.5mm) and A. angle (75^0)

produced by stir cast technique. This may be due to the reason that stirring has altered the micro structure of alloy. Results of Taguchi design of experiment indicates that for alloys developed by conventional cast and stirring technique minimum surface roughness values occurs at speed peed of 150 m/min, feed rate 0.2m/rev, depth of cut 2.5 mm and approaching angle of angle 75^0. Figure 3 (a, b), shows the quality of surface produced. The surface produced by stir cast technique has low value of Ra as evident from Table 3 and surface produced is smoother. This may be attributed due to chemical homogeneity caused by stirring and reduced porosity contents. Figure 4 (a, b) shows that shape of chips produced is broken helical which is desired from of the chips for Al-20 Si -0.5 Mg -1.2 Fe produces by stirring method in compression to alloy processed by conventional technique. This is due to the reason that stirring of alloy has increased the ductility of alloy to some extent .

Conclusions

- The study shows that Taguchi method is an efficient method for determining the optimum machining parameters to achieve lower values of surface roughness.
- It can be concluded that feed rate was the most dominate cutting parameter for the Surface roughness followed by the cutting speed, then depth of cut and Approaching angle. The optimal conditions obtained for surface roughness for the Al-20Si-0.05Mg-1.2Fe developed by stir cast technique is more significant then those developed by Conventional Cast.
- The optimal machining conditions for surface roughness for Al-20Si-0.05Mg-1.2Fe alloy developed by stir cast technique resulted at Cutting speed of 150 m / min, feed rate (0.3 mm /rev depth of cut 1,5 mm and approach. angle 75^0 where as for Al-20Si -0.05 Mg-1.2Fe alloy developed by conventional cast technique resulted at Cutting speed 150m / min, feed rate 0.2 mm /rev, depth of cut 1.5 mm and Approaching Angle 75^0.

References

[1]. Sood., P.K., Sehgal Rakesh, & Dwivedi D.K. (2009, July 10-11). Study on Chip Formation in Machining ((Al-Si- 1. 2Fe) Hypereutectic Aluminum Alloy. *Proceeding of the National Conference on Desigin & Manufacturing Issues in Automobile and Allied Industry.* pp 16-22. IIT M, Chennai.

[2]. Trent., E. M, (2000). *Metal Cutting*, pp 57-97. Butterworth Heinemann.

[3]. Reddy., B. Sidda, Padmanabhan G. & Reddy . Vijay Kumar. (2008). "Surface Roughness Prediction Techniques for CNC Turning". *Asian Journal of Scientific Research.* I (3). pp 256-264.,

[4]. Mahapatra., S. S., Patnaik., Amar & Patnaik., Parbina. Ku. (2006, July 27-29). Parametric Analysis and Optimization of cutting Parameters for Turning Operations based on Taguchi Method. *Proceeding of the International Conference on global Manufacturing and Innovation*, pp1-8.

[5]. **Bajic., D ., Lela., B. & Zivkovic, (2008).** "Modeling of Machines Surface Roughness & optimization of Cutting Parameter in Face Milling". *Metalurgua*.pp 331-334.

[6]. **Thamizhmanil., S., Saparudin. S., & Hassan. S. (2007).** Analyses of surface roughness by turning process using Taguchi method". *Journal of Materials and Manufacturing Engineering*. pp 503-506.

[7]. **Sharma, Vishal S., Dhiman,. Suresh, Sheghal,. Rakesh & Kumar,. Surinder, (2008).** "Assessment and optimization of cutting parameters while turning AISI 52100 Steel". *International Journal of Precision Engineering and Manufacturing*, Vol. 9,2008, pp 54-62.

[8]. **Haci, Unsacar Faruk & Subyman. Yaldiz, (2006).** "Investigation of the effect of rake angle and approaching angle on main cutting force and tool tip temperature". *International Journal of Machine Tools and Manufacture,* Vol 46, pp 132-141.

[9]. **Nalbant, M, Gokkaya. H & Sur. G,. (2007).** "Application of Taguchi method in the optimization of cutting parameters for surface roughness in truing". *Journal of Materials and Design.* pp 1379-1385.

ABOUT THE AUTHORS

P. K. Sood is working as a Workshop Superintendent, Central Workshop, Department of Mechanical Engineering at National Institute of Technology (HP). He received his B.E. degree in Mechanical Engineering from A.P. S. University, Rewa (MP). He received his M.E. degree in Mechanical Engineering with specialization in Production and Industrial System Engineering from IIT Roorkee and pursuing Ph.D. from NIT, Hamirpur (HP). He teaches undergraduate and M.Tech. courses for CAD/CAM students. His area of interest includes Manufacturing Process and Welding Engineering.

*** Department of Mechanical Engineering, National Institute of Technology, Hamirpur (H P), India.*

**** Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, India.*