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Research Article

OPTIMIZATION OF BALL END MILLING PARAMETERS OF AISI 4340 STEEL USING ANOVA METHODLOGY

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ABSTRACT

This paper focussed on the optimal machining parameters of Ball end milling process on AISI 4340 steel plates. Surface roughness will play an important role in quality aspect of manufacturing environment. Influencing of machining parameters such as spindle speed, Angle and depth of cut of ball end milling process is investigated. Mainly surface roughness of AISI 4340 steel plates during end milling process which investigated by employing Taguchi design of experiment and Analysis of variance (ANOVA). The significant parameters are identified by Signal to Noise ratio. The results of experiments represent Angle of machining is an influencing parameter in Ball end milling process.

INTRODUCTION

Milling process is one of the common metals cutting operations and especially used for making complex shapes and finishing of machined parts. The quality of the surface plays a very important role in the performance of the milling as a good quality milled surface significantly improves fatigue strength, corrosion resistance or creep life. Particularly, in the manufacture of dies, surface roughness of which is c Hazim El-Mounayri, ZakirDugla and Haiyan Deng (2009) developed a surface roughness model in End Milling by using Swarm Intelligence. From the studies, data collected from CNC cutting experiments using Design of Experiments approach. Then the data obtained were used for calibration and validation. The inputs to the model consist of Feed, Speed and Depth of cut while the output from the model is surface roughness. The model is validated through a comparison of the experimental values with their predicted counterparts. A good agreement is found from this research. The proved technique opens the door for a new, simple and efficient approach that could he applied to the calibration of other empirical models of machining. Wang *et al*. (2005) studied on the surface roughness of brass machined by micro-end-milling miniaturized machine tool.

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The cutting parameters considered were spindle speed, feed rate, depth of cut and tool diameter. They applied statistical methods, such as ANOVA and RSM to analyze the experiment data. From their experiment, they found that the value of surface roughness increase linearly with the increasing of the tool diameter and spindle speed. Feed rate played an important role when the parameters are constant. Babur Ozcelik and Mahmut Bayramoglu (2005) developed a statistical model by response surface methodology for predicting surface roughness in high-speed flat end milling process under wet cutting conditions by using machining variables such as spindle speed, feed rate, depth of cut and step over. They observed that, the order of significance of the main variables is as total machining time, of cut, step over, spindle speed and feed rate, respectively. Hun-Keun Chang *et al*. (2006) established a method to predict surface roughness in-process. In their research, roughness of machined surface was assumed to be generated by the relative motion between tool and work piece and the geometric factors of a tool. The relative motion caused by the machining process could be measured in process using a cylindrical capacitive displacement sensor (CCDS). The CCDS was installed at the quill of a spindle and the sensing was not disturbed by the cutting. A simple linear regression model was developed to predict surface roughness. Using the measured signals of relative motion. Surface roughness was predicted from the displacement signal of spindle motion.

The linear regression model was proposed and its effectiveness was verified from cutting tests. Prediction model had prediction accuracy of about 95%. Results showed that the developed surface roughness model could accurately predict the roughness of milled surface. Julie Z.Zhang *et al*. (2006) determined optimum cutting parameters for face milling through the Taguchi parameter design method. From the experiment results showed that the effects of spindle speed and feed rate on surface roughness were larger than depth of cut for milling operations. In addition, one of the noise factors, tool wear was found to be statistically significant.Oğuzçolak *et al*. (2005) predicted the milling surface roughness by using gene expression programming (GEP) method. They considered the cutting speed, feed and depth of cute of end-milling operations. They concluded that by using GEP algorithm, surface roughness prediction has been done using a few experiment data. GEP is coming from its ability to generate mathematical equations that can be easily programmed even into programming for use in monitoring of surface quality. Based on the literature review, the most parameters that widely considered when investigating the optimal surface roughness are feed rate, spindle speed and depth of cut. Most of the researches didn't consider the uncontrolled parameters, such as tool geometry, tool wear, chip loads, and chip formations, or the material properties of both tool and work piece.

AISI 4340

Alloy steels are designated by AISI four-digit numbers. They comprise different kinds of steels having composition exceeding the limitations of B, C, Mn, Mo, Ni, Si, Cr, and Va set for carbon steels. AISI 4340 alloy steel is a heat treatable and low alloy steel containing chromium, nickel and molybdenum. It has high toughness and strength in the heat treated condition.

Chemical composition

Table 1. Chemical composition of AISI 4340

ELEMENT	COMPOSITION
Iron, Fe	95.195 - 96.33
Nickel, Ni	1.65 - 2.00
Chromium, Cr	0.700 - 0.900
Manganese, Mn	0.600 - 0.800
Carbon, C	0.370 - 0.430
Molybdenum, Mo	0.200 - 0.300
Silicon, Si	0.150 - 0.300
Sulfur, S	0.0400
Phosphorous, P	0.0350

Mechanical properties

The mechanical properties of annealed AISI 4340 alloy steel are displayed in the following table

Table 2. Mechanical properties of AISI4340

Tensile strength	745 MPa
Yield strength	470 MPa
Bulk modulus	140 GPa
Shear modulus	80 GPa
Elastic modulus	190-210 GPa
Poisson's ratio	0.27-0.30
Elongation at break	22%
Reduction of area	50%
Hardness, Brinell	217

Experimental set up

Fig 1. Vertical milling machine (PAC mills)

Ball end milling tool

Ball nose cutters or ball end mills similar to slot drills, but the end of the cutters are hemispherical. They are ideal for machining 3-dimensional contoured shapes in machining centers for example in moulds and dies. They are sometimes called *ball mills* in shop-floor slang, despite the fact that that term also has another meaning. They are also used to add a radius between perpendicular faces to reduce concentrations. There is also a term *bull nose* cutter, which refers to a cutter having a corner radius that is fairly large, although less than the spherical radius of a ball mill; for example, a 20-mm diameter cutter with a 2-mm radius corner.

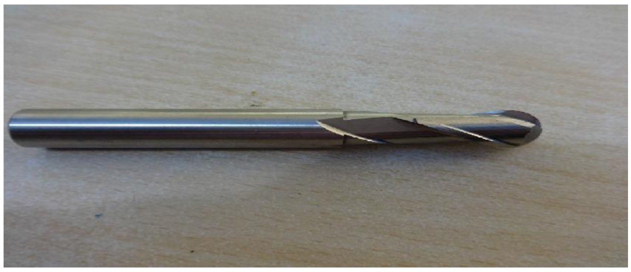


Fig 2. Ball end milling cutter

Work piece (AISI 4340) images

Level	Spindle speed	Angle	Depth of cut
1	-6.595	-5.055	-6.067
2	-5.712	-6.173	-6.157
3	-6.153	-7.232	-6.235
Delta	0.883	2.177	0.168
Rank	2	1	3

Fig. 3. AISI4340 steel specimens

Specimen size (AISI 4340)

Length 40
Breadth 30
Height 40
No of Experiments: 9
Methodology: Taguchi (DOE)

Milling parameters
Spindle speed
Angle of machining
Depth of cut

Analysis of variance

In statistics, analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error. For this reason, ANOVAs are useful in comparing two, three, or more means.

Ball end milling parameters

Table 3. Ball End milling parameters

S.No	Spindle speed	Angle	Depth of cut	Surface roughness	S/N ratio
1	1	1	1	1.8984	-5.56775
2	1	2	2	2.1212	-6.53163
3	1	3	3	2.4222	-7.68420
4	2	1	2	1.6878	-4.54642
5	2	2	3	1.9886	-5.97095
6	2	3	1	2.1422	-6.61720
7	3	1	3	1.7886	-5.05026
8	3	2	1	1.9988	-6.01539
9	3	3	2	2.3424	-7.39322

The Figure 3 shows the relationship between spindle speed and cycle of ball end milling process of AISI 4340 steel with various machining parameters conducted in vertical milling machine and represent spindle speed is an influencing parameter.

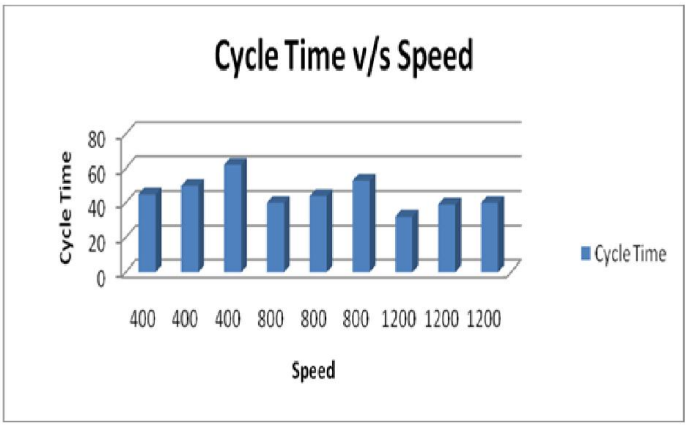


Fig. 4. Relation of spindle speed and cycle time

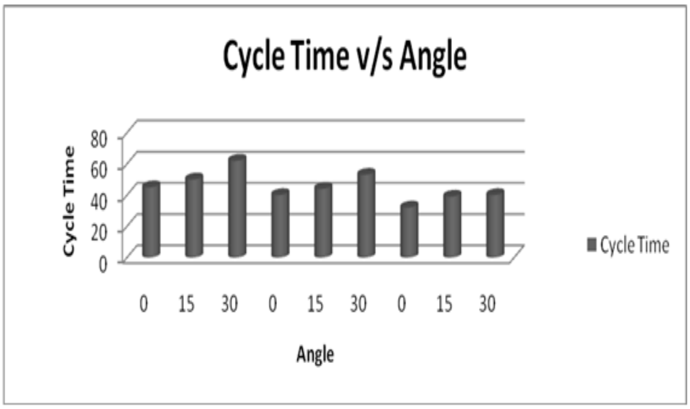


Fig. 5. Relation of Cycle speed and Angle

The Figure 4 shows the relationship between spindle speed and angle of ball end milling process of AISI 4340 steel with various machining parameters conducted in vertical milling machine.

Response Table for Signal to Noise Ratios of surface roughness values (Smaller is better)

Table 4 S/N ratio of surface roughness

Table 3 denotes Angle of machining is a dominating parameter in Ball end milling process of AISI 4340 steel and play an important role for producing lower surface roughness.

Table 5 ANOVA values for Ball end milling process of AISI4340

The Figure 6 shows Interaction plot of Ball end milling process and indicate spindle speed and angle are the dependable parameters of milling process and depth of cut is an independent parameter while achieving lower surface roughness of AISI4340steel plates.

The Figure 7 represent surface plot for achieving lower surface roughness with different ball end milling parameters of AISI4340 steel specimen.

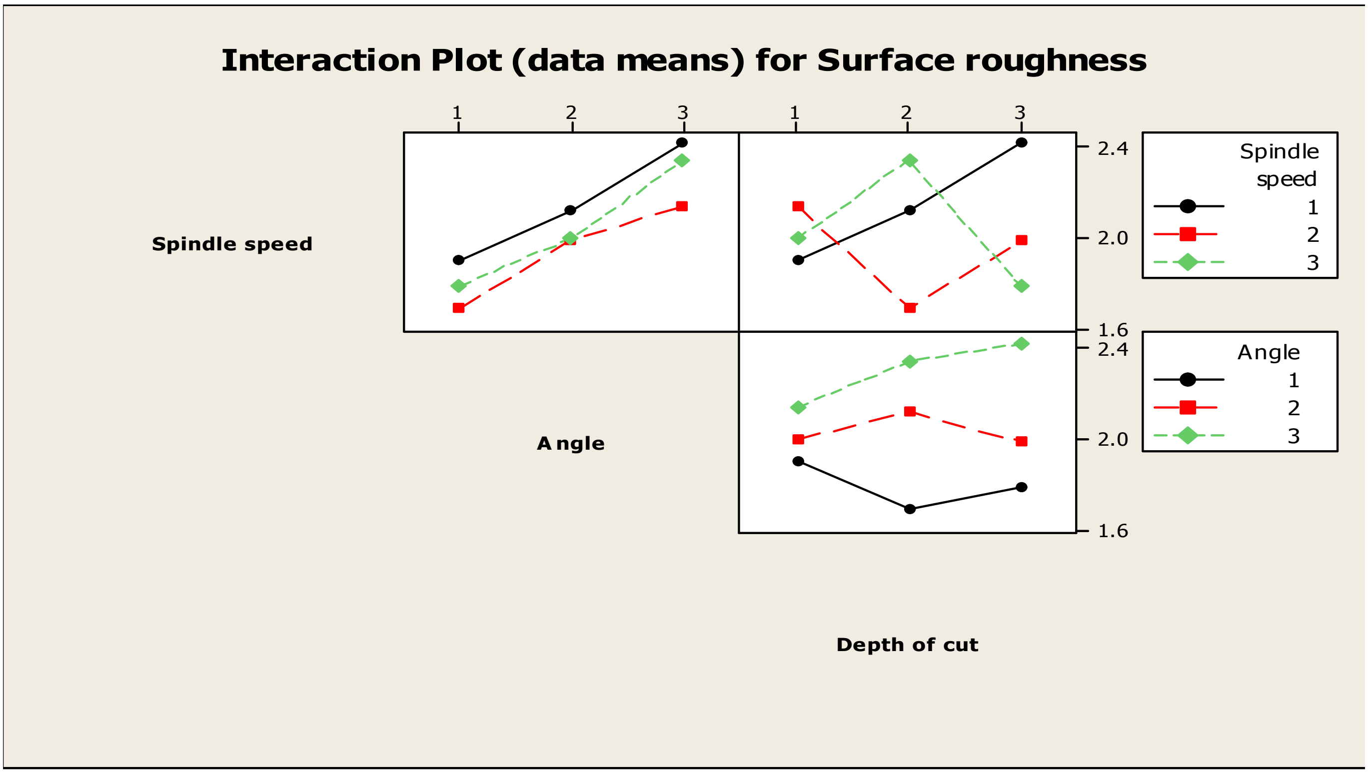


Fig. 6. Main effect of Ball End milling parameters of AISI4340

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Angle	2	0.391401	0.391401	0.195701	71.54	0.014
Spindle speed	2	0.064730	0.064730	0.032365	11.83	0.078
Depth of cut	2	0.004494	0.004494	0.002247	0.82	0.549
Error	2	0.005471	0.005471	0.002736		
Total	8	0.466096				

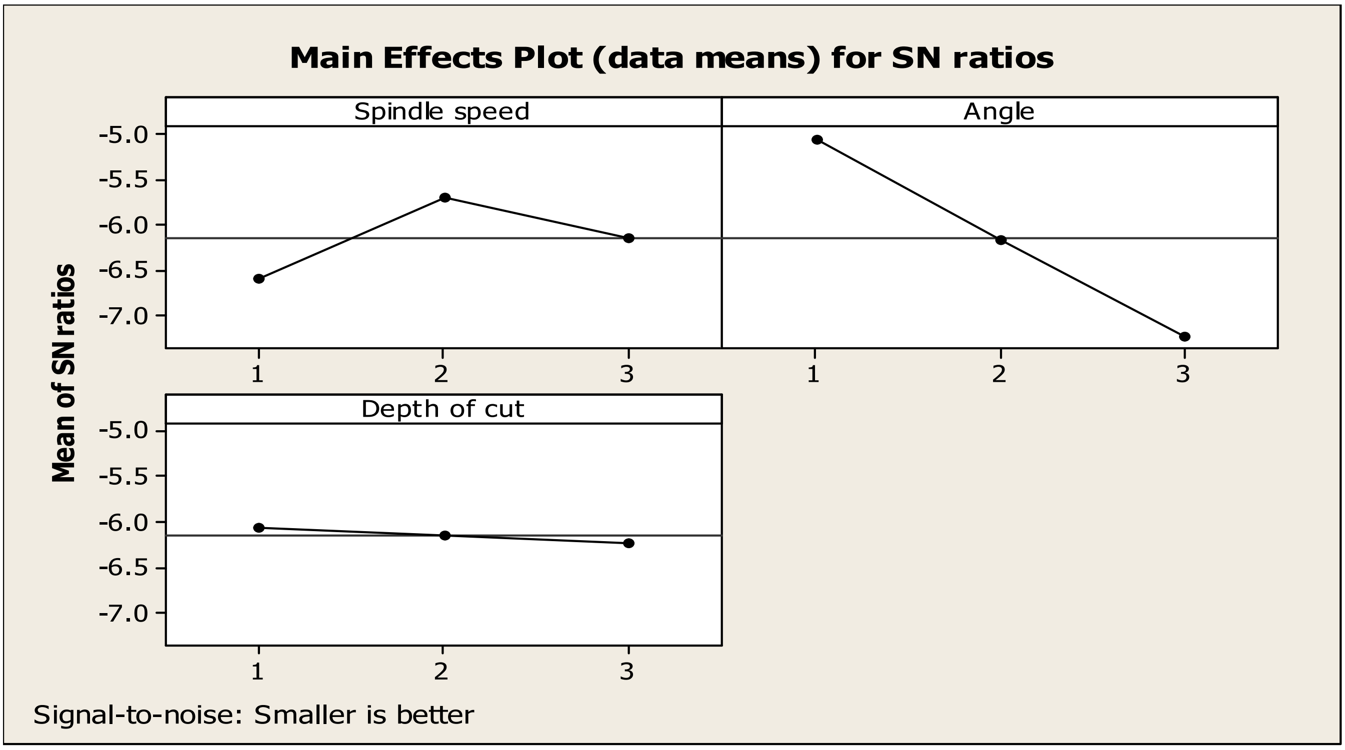
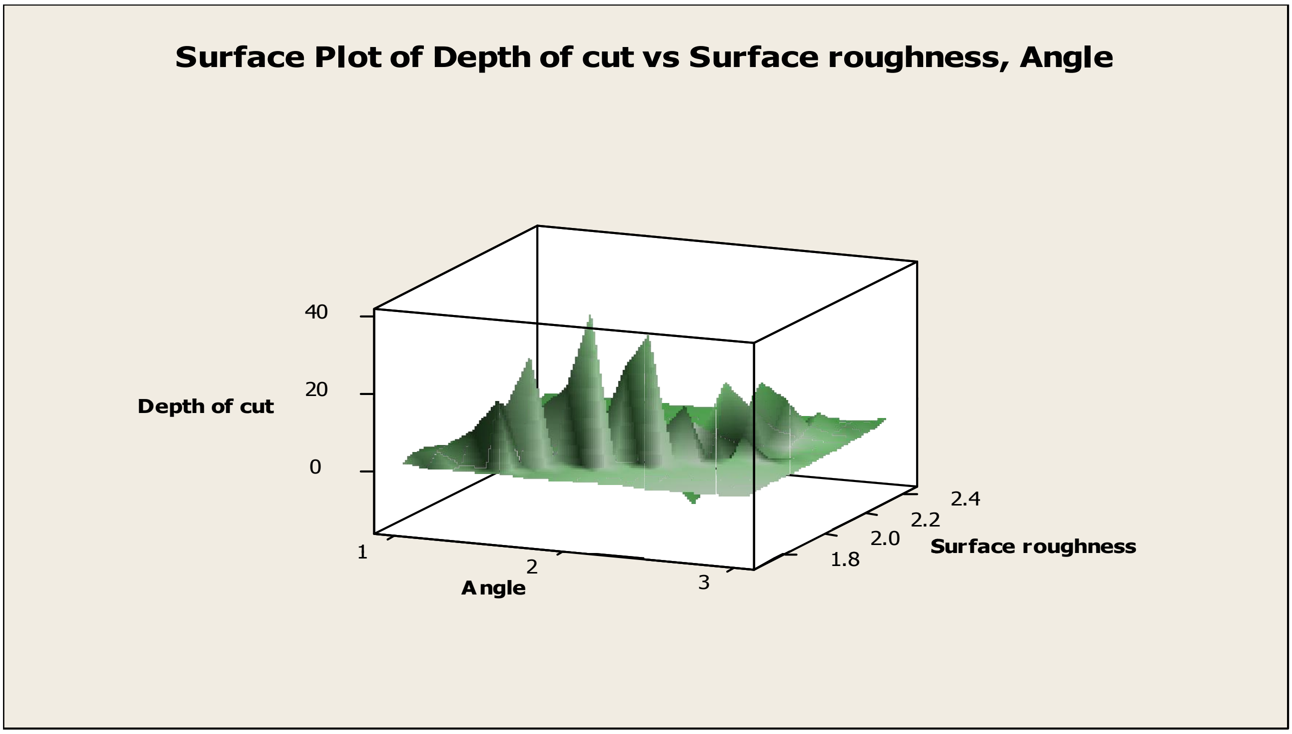


Fig. 7. Interaction plot for End milling parameters of AISI4340



Conclusion

It concludes that the ball end milling process on AISI 4340 steel plates which represents the following

- Optimal parameters of end milling process of AISI 4340 are 800 rpm of spindle speed, Zero degree of angle of machining and 0.1mm depth of cut for producing lower surface roughness.
- The higher value of T test in ANOVA denotes angle of machining play an important role for producing lower surface roughness in Ball end milling process.
- AISI 4340 steel have good machinability property during ball end milling process.

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