

Application of Taguchi and Grey Relational Analysis for Parametric Optimization of End Milling Process of ASSAB-XW 42

Nuraini Lusi^{1,*} Dian Ridlo Pamuji² Anggra Fiveriati³ Akmad Afandi⁴

Galang Sandy Prayogo⁵

^{1,2,3,4,5}Department of Mechanical Engineering, Politeknik Negeri Banyuwangi, Indonesia

*Corresponding author. Email: nurainilusi@poliwangi.ac.id

ABSTRACT

The quality characteristics of surface roughness and MRR of the end mill process have been considered to be optimized simultaneously. The input parameters that are considered are cutting fluid, cutting speed, feeding speed, and depth of cut. Optimization is carried out using the experimental design of the Taguchi method, the signal-to-noise (S/N) ratio obtained from the Taguchi method is then used in GRA for multi-response optimization. Grey Relational Grade (GRG) results include the prediction of the optimum level of input parameters and their relative significance to several quality characteristics. Based on the results of the analysis of the variance of GRG, it was found that the percentage of contribution was obtained. The results of the process parameters that gave the greatest influence were the feeding speed of 39.8%, followed by a cutting depth of 30.52%, cutting fluid, 11.67%, and cutting speed of 5.13%.

Keywords: ASSAB-XW 42, end mill, grey relational analysis, Taguchi.

1. INTRODUCTION

ASSAB XW-42 steel is one type of tool steel with high hardness. The hardness of the steel is 30-60 HRC. Excellent corrosion resistance is the characteristic of this ASSAB XW-42 steel. This steel is also commonly used in the manufacturing sector, such as in the bending and blanking industries. It is commonly used in the manufacture of chisel workpieces or in cutting equipment and it's used to produce punches and dies.

The End milling is one of the most commonly used machines for removing workpiece material, profiles and contours, slots, radius and grooves. Essentially, the end milling process differs from other milling methods because of the kinds of equipment used to grind those materials. In comparison to cutters and drill bits, the end mill chisels have teeth piercing on the sides and ends of the mill. The end milling is most also used for the assembly of workpieces with other components. During assembly, surface roughness becomes a very critical indicator of the consistency of the surface being processed. To get the engine components from the end milling process according to specifications, the selection of cutting parameters must be considered. Feeding, spindle rotation and depth of cut are the main

parameters in the milling process that can be set directly on the end mill machine. Other parameters such as tool type and coolant is a parameter that cannot be set directly on the machining process.

The surface finish is an essential measure since it can improve friction resistance, fatigue strength or creep resistance [1]. The results of the ASSAB XW-42 steel machining process are required to have low surface roughness and high precision. Apart from the accuracy of the size, the final quality of the machining process is determined by the value of surface roughness [2]. Surface roughness in the end milling machining process is influenced by the parameters of the end milling process such as feeding motion and cutting speed [3].

The high quality of surface finish could reduce or eliminate the need for advanced finishing processes. Surface roughness also affects several functional attributes such as heat transmission, ability to withstand lubricants, surface friction, wear, etc. Therefore, to achieve a good surface finish quality requires proper selection and control of process parameters. The productivity of the machining process is indicated by the rate of material processing/material removal rate (MRR). The higher the MRR, the higher the

productivity. Every production process will always be required to produce high quality with high productivity.

The Taguchi method is a method that allows making smart choices in the experimental field of the experimental parameter subset. which makes it possible to study the entire experimental space with a minimum number of experimental determinations[4]. Taguchi proposes a systematic and effective method for conducting experiments, a method that leads to the right solution in terms of performance and cost [5]. In this study, the Taguchi method will be used to analyze the process parameters that produce the optimal response, namely minimum surface roughness and maximum MRR.

Determination of the optimal parameters for performances can be determined by the simultaneous optimization method, by combining the Taguchi method with GRA. GRA is an optimization method based on the grey system theory that is used to solve complex interrelationships between multiple responses. Rajeswari et al. [6] adopt RSM-based grey relational analysis to conducts the machinability characteristics of the end milling process. Spindle speed, feed and depth of cut were selected as input parameters to yield the minimum surface roughness, cutting force, tool wears with the maximum material removal rate simultaneously. Kuram et al. [7] investigated the process of micro-milling of Al 7075 material. The response variable was tool wear, force and surface roughness. The parameter processes were spindle speed, feed per tooth and depth of cut. Fu Huang et al.[8] observed the effects of the electrochemical discharge machining (EDM) parameters using the Taguchi method coupled with grey relational analysis (GRA) and principal component analysis, this method efficiently obtaining the optimized combination of machining parameters and also a useful approach to improve the machining performance characteristics. This study used the ASSAB XW-42 as workpiece material. Taguchi method coupled with GRA applied to obtain the optimum conditions for material removal rate (MRR) and surface roughness in the end milling process. An orthogonal array L18 is created using the Taguchi design to conduct the experiments. Finally, a description of the analysis concludes the report.

2. OPTIMIZATION METHODOLOGY

2.1. Taguchi Method

Taguchi Methods is a statistical method developed by Genichi Taguchi to improve the quality of production and engineering. Taguchi Methods involves reducing the variation of the process through the robust design of the experiment. The main objective of this method is to produce a high-quality product at a very low cost. Taguchi developed a method for designing experiments to investigate how much influence different parameters

have on the mean (average) and variance of process performance characteristics that determine how well the process functions. The experimental design introduced by Taguchi involves orthogonal arrays to organize parameters that have an effect on the process and the levels that need to be varied. The Taguchi Method does not test all possible combinations but rather tests only a few. This test will produce a collection of important data that can determine which factors have the most effect on product quality with minimum experimentation to save time and money. Taguchi method is also very common as an offline quality concept design [9].

2.2. Grey Relational Analysis (GRA) Method

2.2.1. Calculate The Signal to Noise (S/N) Ratio

The applications in which the concept of S/N ratio is useful are the improvement of variability reduction and the improvement of measurement. In this study, the MRR is to be maximized and SR to be minimized. Hence smaller the better characteristics have been applied for SR and larger the better characteristics have been applied for the MRR. The S/N ratios for each type of characteristic can be calculated as follows [10]:

Larger is better (maximize):

$$S/N = -10 \log \left[\sum_{i=1}^n \frac{(1/y_i^2)}{n} \right], \quad (1)$$

and

Smaller is better (minimize):

$$S/N = -10 \log \left[\sum_{i=1}^n \frac{y_i^2}{n} \right]. \quad (2)$$

A linear normalization of the S/N ratio of experimental result for the experiment for the responses is performed in the range between 0 and 1. The S/N ratio obtained from Table 3 was normalized by using the following equation [10]:

$$X_i^* = \frac{X_i(k) - \min_k X_i(k)}{\max_k X_i(k) - \min_k X_i(k)} \quad (3)$$

Here, $i = 1, 2 \dots m$;

$k = 1, 2 \dots n$;

2.2.2. Grey Relational Coefficient and Grey Relational Grade (GRG)

All $X_i^*(k)$ then converted into $\xi_i(k)$ or grey relational coefficient (GRC) by using the following equation [10]:

$$\xi_i(k) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{0,i}(k) + \zeta \Delta_{max}}, \quad (4)$$

where $\Delta_{0i} = \|x_0(k) - x_i(k)\|$ is the difference of the absolute value between $x_0(k)$ and $x_i(k)$; ζ the distinguishing coefficient; $\Delta_{min} = \forall j^{min} \in$

$i\forall k^{min} \|x_0(k) - x_j(k)\|$ is the smallest value of Δ_{0i} ; and $\Delta_{max} = \forall j^{max} \in i\forall k^{max} \|x_0(k) - x_j(k)\|$ is the largest value of Δ_{0i} . The GRC of each performance characteristic converted into one multi multi-response output which is called grey relational grade (GRG).

3. EXPERIMENTAL DESIGN AND RESULT

The workpiece used in this study is ASSAB XW-42 tool steel material with dimensions (30 x 30 x 80) mm and 45 HRC hardness. The tool used is a solid carbide end mill with four cutting edges, a diameter of 10 mm and an overall length of 75 mm. The process parameters used are shown in Table 1. Each process variable has 3 (three) levels. As shown in the table. in this study, there are 4 (four) process variables. 3 (three) process variables consisting of 3 (three) levels and 1 (one) process variable consisting of 2 (two) levels.

Table 1. Process Parameter of End Milling

Process Parameter	Level 1	Level 2	Level 3
Cutting speed (Cs)	5.6 m/min	9.7 m/min	17.9 m/min
Feeding speed (f)	33.5 m/min	59.4 m/min	111.9 m/min
Depth of cut (Ar)	0.25 mm	0.5 mm	0.125 mm
Cutting fluid	Soluble oil	Vegetable oil	-

The experiment in this study was carried out with 2 (two) replications and carried out randomly (random) based on a combination of process variables in the L₁₈ orthogonal array. The result of this study shown in Table 2.

Table 2. Experimental Layout using Orthogonal array L₁₈

No.	Cutting Fluid	Cs (m/minute)	F (mm/rev)	Ar (mm)
1	Soluble oil	5.6	33.5	0.25
2	Soluble oil	5.6	59.4	0.5
3	Soluble oil	5.6	111.9	0.125
4	Soluble oil	9.7	33.5	0.25
5	Soluble oil	9.7	59.4	0.5
6	Soluble oil	9.7	111.9	0.125
7	Soluble oil	17.9	33.5	0.5
8	Soluble oil	17.9	59.4	0.125
9	Soluble oil	17.9	111.9	0.25
10	Vegetable oil	5.6	33.5	0.125
11	Vegetable oil	5.6	59.4	0.25
12	Vegetable oil	5.6	111.9	0.5
13	Vegetable oil	9.7	33.5	0.5
14	Vegetable oil	9.7	59.4	0.125
15	Vegetable oil	9.7	111.9	0.25
16	Vegetable oil	17.9	33.5	0.125
17	Vegetable oil	17.9	59.4	0.25
18	Vegetable oil	17.9	111.9	0.5

The experiment result and S/N ratio of this study shown in Table 3 and Table 4 present the normalization and the deviation sequence.

Table 3. S/N ratio of Responses

No.	Ra (µm)	S/N MRR	S/N Ra
1	0.714	15.210	2.929
2	0.806	20.571	1.879
3	0.855	24.407	1.361
4	0.654	15.227	3.685
5	0.726	24.494	2.781
6	0.807	24.478	1.863
7	0.606	15.114	4.351
8	0.687	25.221	3.267
9	0.749	22.338	2.510
10	0.658	21.184	3.639
11	0.723	17.587	2.823
12	0.794	23.384	2.001
13	0.577	19.412	4.776
14	0.690	23.701	3.229
15	0.720	19.425	2.859
16	0.650	21.585	3.745
17	0.532	17.681	5.478
18	0.494	23.398	6.125

Table 4. Normalization and dev. sequence

Exp	Normalization S/N		dev. Sequence	
	MRR	Ra	MRR	Ra
1	0,009	0,6709	0,9905	0,3291
2	0,540	0,8913	0,4601	0,1087
3	0,919	1,0000	0,0805	0,0000
4	0,011	0,5122	0,9888	0,4878
5	0,928	0,7019	0,0719	0,2981
6	0,926	0,8946	0,0735	0,1054
7	0,000	0,3724	1,0000	0,6276
8	1,000	0,5999	0,0000	0,4001
9	0,715	0,7588	0,2852	0,2412
10	0,601	0,5218	0,3994	0,4782
11	0,245	0,6931	0,7553	0,3069
12	0,818	0,8657	0,1818	0,1343
13	0,425	0,2832	0,5748	0,7168
14	0,850	0,6079	0,1504	0,3921
15	0,427	0,6856	0,5735	0,3144
16	0,640	0,4996	0,3598	0,5004
17	0,254	0,1358	0,7460	0,8642
18	0,820	0,0000	0,1804	1,0000

4. CONCLUSION

Based on the research that has been carried out with the Taguchi method and GRA. it can be concluded that the optimal response variable simultaneously can be obtained by setting a type of coolant with soluble oil. a cutting speed at level 1. feeding at level 3. and depth of cut at level 3.

REFERENCES

- [1] K. Patel, A. Batish, and A. Bhattacharya, "Optimization of surface roughness in an end-milling operation using nested experimental design," pp. 361–373, 2009.
- [2] S. H. Tomadi, J. A. Ghani, C. H. C. Haron, H. M. Ayu, and R. Daud, "Effect of cutting parameters on surface roughness in end milling of AlSi/AlN metal matrix composite," *Procedia Eng.*, vol. 184, pp. 58–69, 2017.
- [3] N. Qehaja, K. Jakupi, A. Bunjaku, M. Bruçi, and H. Osmani, "Effect of machining parameters and machining time on surface roughness in dry turning process," *Procedia Eng.*, vol. 100, no. 1, pp. 135–140, 2015.
- [4] M. Titu, "Contribution on Taguchi 's Method Application on the Surface Roughness Analysis in End Milling Process on 7136 Aluminium Alloy Contribution on Taguchi 's Method Application on the Surface Roughness Analysis in End Milling Process on 7136 Aluminium Alloy," 2016.
- [5] B. Pop and A. Bianca, "Application of Taguchi's Method for Study of Machining Parameters on Surface Roughness of 7136 Aluminum Alloy in End Milling," in *Applied Mechanics and Materials*, 2015, vol. 809, pp. 123–128.
- [6] B. Rajeswari and K. S. Amirthagadeswaran, "Experimental investigation of machinability characteristics and multi- response optimization of end milling in aluminium composites using RSM based grey relational analysis," *Measurement*, vol. 105, pp. 78–86, 2017.
- [7] E. Kuram and B. Ozcelik, "Measurement Multi-objective optimization using Taguchi based grey relational analysis for micro-milling of Al 7075 material with ball nose end mill," *Measurement*, vol. 46, no. 6, pp. 1849–1864, 2013.
- [8] S. Huang, Y. Liu, and J. Li, "Multi-Objective Optimization of Electrochemical Discharge Machining Using Taguchi Based Grey Relational Analysis Coupled With Principal Component Analysis," vol. 19, no. 3, pp. 145–152, 2016.
- [9] N. Ahmad, S. Kamal, Z. A. Raza, T. Hussain, and F. Anwar, "Multi-response optimization in the development of oleo-hydrophobic cotton fabric using Taguchi based grey relational analysis," *Appl. Surf. Sci.*, vol. 367, pp. 370–381, 2016.
- [10] H. S. Lu, C. K. Chang, N. C. Hwang, and C. T. Chung, "Grey relational analysis coupled with principal component analysis for optimization design of the cutting parameters in high-speed end milling," vol. 9, pp. 3808–3817, 2008.