ATLANTIS PRESS
Atlantis Highlights in Engineering (AHE), volume 1
International Conference on Science and Technology (ICST 2018)

Optimizing Process Parameter Machining From Combined Energy Consumption and Material Removal Rate On ST 41-3

Teguh Prasetyo[1], Mukhib Bussafi[2], Nachnul Anshori, Mahrus K. Umami[3], Mirza Pramudia[4]
Department of Industrial & Mechanical Engineering
University of Trunojoyo Madura
Bangkalan, Indonesia
[1]teguh.prasetyo@trunojoyo.ac.id, [2]mukhibbussafi@gmail.com, [3]mahrus_umami@yahoo.co.id, [4]mpramudia@gmail.com

***Abstract*— Machining processes are spent a lot of energy in the manufacturing industry. On the other hand, we understand that energy should be minimum. The purpose of this study is to find the optimal machining parameters that allow the most energy-efficient processes. The study focused on optimization of parametric process machining on combination energy consumption and material removal rate in machining on Steel ST 41-3. The data were evaluated using the Taguchi method and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Finally, the research has successfully to get the best parameter of machining are cutting speed of 22.8 (mm / min), feeds (0.01 mm/tooth) and the depth of cuts (1.5 mm). At the parameter machining setting have the lowest energy used level. Experiments in this study will be carried out in a laboratory scale, and the results of these experiments can be used as a reference in its application in the industrial world.**

Keywords—Parameter Machining; Energy Consumption; Material Removal Rate; Taguchi; TOPSIS.

I. INTRODUCTION

In the last few years, efficiencies energy is a big issue in manufacturing processes. Because the most cost in manufacturing processes comes from energy consumption. Material Removal Rate (MRR) is an important aspect of the machining process to be optimized [1]. MRR has an important influence on productivity of a manufacturing industry, especially in the metal cutting process (the metal cutting process becomes vital) in the rouging stage (rough cultivation stage before finishing) [2]. [3] Optimizing energy consumption and MRR can improve the efficiency of machining processes in the manufacturing industry.

Optimization of energy consumption and MRR responses will be carried out by determining the optimal value of machining parameters that affect both responses. Machining parameters (factors) used include cutting speed, feed, and depth of cut [4]. In this study, a combination of Taguchi method and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is used to determining the optimal value of machining parameters. Experiments in this study will be carried out in a laboratory scale, then the results of these experiments can be used as a reference in its application in the industrial world. Taguchi method [5] is a method of optimizing single response process parameters. [6] The Taguchi method can provide optimal results with a number of more efficient trials. The use of TOPSIS method in this study is used to complete the determination of a combination of factor levels that can provide the most optimal results for the response (energy consumption and MRR).

II. LITERATURE REVIEW

A. Material Removal Rate (MRR)

Material Removal Rate is one indicator that can be used to measure the performance of the machining process [8]. MRR which is defined as the amount of material volume wasted per unit of time [9] is influenced by several parameters. These parameters are cutting speed (v), feed (z), and depth of cut (d) [5] [6].

$$v = \frac{\pi . d . n}{1000} \tag{1}$$

$$v_f = f_z . n . z \tag{2}$$

$$MRR = \frac{d . w . v_f}{1000} \tag{3}$$

Where,

z = *tooth*	v = cutting speed (*m/min*)
D = diameter (*mm*)	v_f = feed (*mm/min*)
n = RPM	f_z = feed (*mm/tooth*)
w = width (*mm*)	d = depth of cut (*mm*)

III. METHODS

A. Taguchi Method

Taguchi method is an orthogonal matrix design that is used to analyze parameters with little experiment. The optimal level process value is the level that has the highest relationship.

Furthermore, through ANOVA analysis can find out which process parameters are important

optimal and efficient results with relatively easy applications [8].

B. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one method of Multiple Criteria Decision Making (MCDM). The principle of the TOPSIS method is that the chosen alternative must have the shortest distance from the positive solution or the negative solution from a geometric point of view [3].

C. Tools and Material

1. HSS Endmill

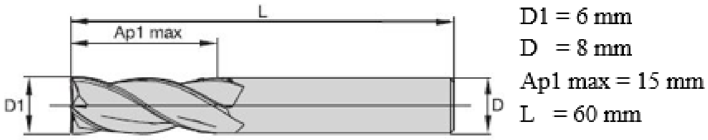

Fig. 1. Figure 1. HSS Endmill [12]

2. CNC ProMill 8000

Fig. 2. Figure 2. CNC ProMill 8000 [10]

3. ST 41-3
   ST 41-3 is one type of material that is often used in the industrial world. The use of ST 41-3 is mainly used in making bars, plates, structural shapes, axles, connecting rods, shafting etc [11].

4. *Power Meter* Hioki 3286-20

Fig 3. Power Meter Hioki 3286-20 [12]

IV. Results and Discussion

TABLE I. LEVEL COMBINATION OF MACHINING PARAMETER PROCESS

No	Machining Parameter Process	Level 1 (1)	Level 2 (2)	Level 3 (3)
1	Cutting speed (*v*), m/*min*	22,8	33,9	45,0
2	feed (*fz*), mm/*tooth*	0,0100	0,0125	0,0150
3	Dept of cut (d), mm	0,150	0,825	1,500

TABLE II. EXPERIMENT DATA

No	Treatment Factor code			Repetition 1	
	v	*fz*	*d*	*Wcutting (Wh)*	*MRR (Vol/min)*
1	1	1	1	5,88	43,3929
2	1	2	2	6,0919	293,7363
3	1	3	3	5,0875	656,7568
4	2	1	2	4,8958	356,4
5	2	2	3	4,3333	810
6	2	3	1	2,5764	87,2
7	3	1	3	5,2603	852,6316
8	3	2	1	2,625	108
9	3	3	2	3,2406	703,4211

A. ANOVA Consumption Energy

Steps taken to identify factors that significantly influence the response variable. This is done on the average of the response variables (energy consumption and MRR) in the milling process that arises due to treatment factors. In this ANOVA test the error value (α) is 5%. Here are the hypotheses used.

a. Effect of cutting speed (v)

H0 = There is no significant effect of cutting speed factor (v) on energy consumption

H1 = There is a significant effect of cutting speed factor (v) on energy consumption

b. Influence effect (fz)

H0 = There is no significant effect of feed factor (fz) on energy consumption

H1 = There is a significant influence of the feed factor (fz) on energy consumption

c. Effect of cutting depth (d)

H0 = There is no significant influence from the cutting depth factor (d) on energy consumption

H1 = There is a significant influence from the cutting depth factor (d) on energy consumption

If Fcount > FTabel: Reject H0 or Fcount ≤ FTabel: Accept H0

TABLE III. ANOVA MEAN ENERGY CONSUMPTION

Source	DF	SS	MS	F-VALUE	PC
v	2	5,45	2,7	89,59	40,31%
fz	2	4,02	2	66.055	29,60%
d	2	3,84	1,9	63.139	28,27%
Error	2	0,06	0		1,82%
Total	8				100%

Based on the percentage contribution (PC) in table III it can be seen that the cutting speed factor (40.308%) has the greatest influence.

TABLE IV. TUKEY TEST FACTOR VS ENERGY CONSUMPTION

	Cutting Speed			Feed			Depth of cut		
Level	1	2	3	1	2	3	1	2	3
N	3	3	3	3	3	3	3	3	3
Mean	5,56	4,08	3,778	5,4	4,31	3,8	5	5	3,57
Grouping	A	B	B	A	B	B	B	A	A

B. ANOVA Material Removal Rate

This ANOVA test aims to find the treatment factors (cutting speed, in feed and cutting depth) which significantly affect the material removal rate. In this ANOVA test the error value (α) is 5%. Here are the hypotheses used.

a. Effect of cutting speed (v)

H0 = There is no significant effect of the cutting speed factor (v) on the material removal rate

H1 = There is a significant effect of the cutting speed factor (v) on the material removal rate

b. Influence effect (fz)

H0 = There is no significant effect of feed factor (fz) on the material removal rate

H1 = There is a significant effect of feed factor (fz) on material removal rate

c. Effect of cutting depth (d)

H0 = There is no significant effect of the cutting depth factor (d) on the material removal rate

H1 = There is a significant influence from the cutting depth factor (d) on the material removal rate

If Fcoun t> FTabel: Reject H0 or Fcount ≤ FTabel: A

TABLE V. ANOVA MEAN MATERIAL REMOVAL RATE

Source	DF	SS	MS	F-VALUE	PC
v	2	75032	37516	2,21	
fz	2	11818	5909	0,348	
d	2	707935	4E+05	20.851	81,33%
Error	2	33951	16976		18,67%
Total	8	828737			100%

The conclusion of these results is that there is a significant effect of the cutting depth factor on the average MRR value.

TABLE VI. TUKEY TEST VS MRR

Depth of cut	N	Mean	Grouping	
3	3	769,048	A	
2	3	450,506	A	B
1	3	82,647		B

The difference between the third and the first level shows the use of the second level will result in a significant difference in MRR values.

C. Calculation of S/N *Matrics* Ratio*, Norm dan Weight Matrics*

TABLE VII. S/N MATRICS RATIO, NORM AND WEIGHT MATRICS

No	Data S/N Ratio		Norm Matrix		Weight Matrix	
	E cutting	***MRR***	***E cutting***	***MRR***	***E cuting***	***MRR***
n1	-14,8893	32,7742	0,3841	0,2182	0,5624	0,3218
n2	-15,2149	493.909	0,3925	0,3288	0,5747	0,4849
n3	-14,6302	56,3089	0,3775	0,3749	0,5526	0,5528
n4	-14,2179	50,9617	0,3393	0,3393	0,537	0,5003
n5	-13,1495	58,1213	0,387	0,387	0,4967	0,5706
n6	-8,1812	39,7533	0,2647	0,2647	0,309	0,393
n7	-14,6672	58,5643	0,3899	0,3899	0,554	0,575
n8	-8,3516	40,6039	0,2703	0,2703	0,3155	0,3986
n9	-10,4012	56,9443	0,3791	0,3791	0,3929	0,5591
max					0,5747	0,575
min					0,309	0,3218

In this ANOVA test the error value (α) is 5%. Here are the hypotheses used.

a. Effect of cutting speed (v)

H0 = There is no significant effect of cutting speed factor (v) on energy consumption

H1 = There is a significant effect of cutting speed factor (v) on energy consumption

b. Influence effect (fz)

H0 = There is no significant effect of feed factor (fz) on energy consumption

H1 = There is a significant influence of the feed factor (fz) on energy consumption

c. Effect of cutting depth (d)

H0 = There is no significant influence from the cutting depth factor (d) on energy consumption

H1 = There is a significant influence from the cutting depth factor (d) on energy consumption

If Fcount> FTabel: Reject H0 or Fcount ≤ FTabel: Accept H0

TABLE VIII. ANOVA S/N MATRICS RATIO CONSUMPTION ENERGY

Source	DF	SS	MS	F-VALUE	PC
v	2	24,103	12,051	89,428	36,23%
fz	2	19,294	9,647	71,586	28,92%
d	2	22,126	11,063	82,092	33,22%
Error	2	0,27	0,1348		1,64%
Total	8	65,792			100%

Based on this, it can be concluded that there is a significant effect of all treatment factors on the average response value of energy consumption.

TABLE IX. TUKEY TEST FACTOR VS S/N MATRICS RATIO CONSUMPTION ENERGY

	Level	N	Mean	Grouping
Cutting Speed	1	3	-14,9	B
	2	3	-11,9	A
	3	3	-11,1	A
Feed	1	3	-14,6	B
	2	3	-12,2	A
	3	3	-11,1	A
Depth of cut	1	3	-10,5	B
	2	3	-13,3	A
	3	3	-14,1	A

D. ANOVA Material Removal Rate

In the ANOVA test, the current error value (α) is 5%. The following is the original statement.
A. Key cutting speed (v)
H0 = There is no significant factor of cutting speed factor (v) on the level of material removal
H1 = there is a significant effect of cutting speed factor (v) on the rate of material removal
b. Influence effect (fz)
H0 = There is no significant factor of feed factor (fz) on material removal rate
H1 = significant influence of infeed factor (fz) on the level of material removal
c. Cutting depth measurement (d)
H0 = There is no significant factor from the cutting depth factor (d) to the rate of material removal
H1 = there is a significant influence from the cutting depth factor (d) on the rate of material removal

If Fcount> FTabel: Reject H0 or Fcount ≤ FTabel: Accept H0

TABLE X. ANOVA S/N RATIO MATERIAL RWMOVAL RATE

Source	DF	SS	MS	F-VALUE	PC
v	2	52,382	26,191	10251,75	7,34%
fz	2	19,152	9,576	3.748,220	2,68%
d	2	642,39	321,144	125.702,700	89,98%
Error	2	0,005	0,003		0,003%
Total	8	713,83			100%

In table X, it can be seen that the cutting depth factor has the greatest effect on changes in MRR variance values.

E. Tukey Test Factor Vs S/N Ratio MRR.

TABLE XI. ANOVA S/N RATIO MATERIAL REMOVAL RATE

	Level	N	Mean	Grouping
Cutting Speed	1	3	46,16	C
	2	3	49,61	B
	3	3	52,04	A
Feed	1	3	47,43	C
	2	3	49.372	B
	3	3	51	A
Depth of cut	1	3	37,71	C
	2	3	52,43	A
	3	3	57,67	A

F. Different in positive – negatif Ideal Solution and Overall Performance Indicators

TABLE XII. ANOVA S/N RATIO MATERIAL REMOVAL RATE

No	Combination			Si+	Si-	OPI
	v	fz	d			
1	1	1	1	0,2535	0,2534	0,4999
2	1	2	2	0,0901	0,3118	0,7759
3	1	3	3	0,0313	0,3357	0,7759
4	2	1	2	0,0836	0,2896	0,776
5	2	2	3	0,0781	0,3117	0,7996
6	2	3	1	0,3236	0,0685	0,1748
7	3	1	3	0,0207	0,3523	0,9445
8	3	2	1	0,3135	0,0771	0,1975
9	3	3	2	0,1825	0,2517	0,5796

G. Anova Test Combining The Response Of Energy Consumption And MRR

In this ANOVA test the error value (α) is 5%. Here are the hypotheses used.
a. Effect of cutting speed (v)
H0 = There is no significant effect of cutting speed factor (v) on energy consumption and MRR
H1 = There is a significant effect of cutting speed factor (v) on energy consumption and MRR
b. Influence effect (fz)
H0 = There is no significant effect of feed factor (fz) on energy consumption and MRR
H1 = There is a significant effect of infeed factors (fz) on energy consumption and MRR

c. Effect of cutting depth (d)
H0 = There is no significant influence from the cutting depth factor (d) on energy consumption and MRR
H1 = There is a significant influence from the cutting depth factor (d) on energy consumption and MRR

If Fcount> FTabel: Reject H0 or Fcount ≤ FTabel: Accept H0

TABLE XIII. ANOVA COMBINE RESPONSE OF ENERGY CONSUMPTION AND MRR

Source	DF	SS	MS	F-VALUE	PC
v	2	0,046	0,023	1061,28	6,91%
fz	2	0,057	0,029	1.318,330	8,59%
d	2	0,562	0,281	12.948,630	84,46%
Error	2	0	0		0,03%
Total	8	0,665			100%

Based on the results of calculations in table XIII, it can be seen that the cutting depth factor has the greatest influence on the combination of energy consumption response and MRR. The magnitude of the effect of the depth of cut is indicated by the percentage contribution (PC) of 84.463%.

H. Tukey Test Significant Factors Combining The Response Of Energy Consumption And MRR

TABLE XIV. ANOVA COMBINE RESPONSE OF ENERGY CONSUMPTION AND MRR

	Level	N	Mean	Grouping
Cutting Speed	1	3	0,7302	A
	2	3	0,5834	B
	3	3	0,5739	B
Feed	1	3	0,7401	A
	2	3	0,5910	B
	3	3	0,5564	A
Depth of cut	1	3	0,291	C
	2	3	0,711	B
	3	3	0,886	A

I. The Best Level Combination

TABLE XV. THE BEST LEVEL COMBINATION FACTORS

Level	**Cutting Speed (mm/min)**	**Feeds (mm/tooth)**	**Depth of cut (mm)**
1	0,7302	0,7401	0,2907
2	0,5834	0,591	0,7105
3	5739	5564	0,8863

The best level of all factors with response rates from various levels. Based on the results of the response rate, the highest level is the first speed (22.8 mm / minute). The best level for feed factor is the first level (0.01 mm / tooth). The best level for depth factor is the third level (1.5 mm).

V. CONCLUSION AND FURTHER RESEARCH

The aim of the research was to develop machining parameters process with the lowest consumption energy. The machining parameters are cutting speed 22.8 mm/min, feed 0.01 mm/tooth and depth of cut 1.5 mm. Through this parameters it is expected that the cost of the production process will decrease. In this study the point of view is only the speed of the machining process for energy efficiency, especially the ST 41-3 steel material. Material differences will produce different parameters, so there are still many studies on other material machining processes.

ACKNOWLEDGMENT

This study was done by supports of the Department of Industrial and Mechanical Engineering, University of Trunojoyo Madura. Authors also thank to all our colleagues who have participated and reviewers of this conference.

REFERENCES

[1] M. Kaladhar, K. V. Subbaiah, C. S. Rao, & K. N. Rao, “Application of Taguchi approach and utility concept in solving the multi-objective problem when turning AISI 202 austenitic stainless steel”, Journal of engineering science and technology review, vol. 4, no. 1, pp. 55-61, 2011.

[2] M. Kaladhar, K. V. Subbaiah, C. S. Rao, & K. N. Rao, “Parametric optimization during machining of AISI 304 Austenitic Stainless Steel using CVD coated DURATOMIC™ cutting insert”, International Journal of Industrial Engineering Computations, vol. 3, pp. 577–586, 2012.

[3] V. S. Gadakh, “Parametric optimization of wire electrical discharge machining using TOPSIS method”, Advances in Production Engineering & Management, vol. 7, no. 3, pp. 157-164, 2012.

[4] T. Peng, and X. Xu, “Energy-efficient machining systems: a critical review”, International Journal Adven Manufacturing Technology, vol. 72, pp. 1389–1406, 2014.

[5] B. Singaravel and T. Selvaraj, “Optimization Of Machining Parameters In Turning Operation Using Combined Topsis And AHP Method”, Tehnicki vjesnik/Technical Gazette, vol. 22, no. 6, pp. 1475-1480, 2015.

[6] L. An, P. Yang, H. Zhang, M. Chen, “Multi-Objective Optimization for Milling Operations using Genetic Algorithms under Various Constraints”, International Journal of Networked and Distributed Computing, Vol. 2, No. 2, pp. 108-114, 2014.

[7] H. B. Wang, H. F. Ting, J. T. Chen, & D. S.Wang, “Optimizing Multiple Quality Characteristics by Taguchi Method and Topsis Algorithm”, International Journal of Organizational Innovation (Online), vol. 4, no. 2, pp. 49-63, 2011.

[8] L. M. Maiyar, R. Ramanujam, K. Venkatesan & J. Jerald, “Optimization of machining parameters for end milling of Inconel 718 super alloy using Taguchi based grey relational analysis”, Procedia Engineering, vol. 64, pp. 1276-1282, 2013.

[9] Y.F. Hsiao., Y.S. Tarng., and K. Y. Kung, “The use of grey-based Taguchi methods to determine Process Parameter of linear motion guide with Multiple Performance Characteristics”, Proceedings of the 9th Joint Conference on Information Sciences (JCIS), pp. 1-8, 2006.

[10] Intelitek, ProMill 8000 CNC Machining Center, Manchester: Intelitek Inc., 2014.

[11] Widia-Hanita, Solid End Mills & Holemaking, Latrobe: Widia Products Group, 2015

[12] Hioki, 3286-20 Clamp on Power Hitester Power Measuring Instruments, . Shanghai : Hioki E E Corporation, 2003