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Parameter Optimization of ASSAB XW 42 Tool Steel on End Milling Process with MQCL Using Taguchi-WPCA

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***Abstract*—Determination of a combination of process variables that are not appropriate in the end milling process will result in high surface roughness and can reduce the metal removal rate. Therefore, it is necessary to adjust the end milling process variables with the appropriate minimum quantity cooling lubrication. This study aims to obtain a combination of end milling process variables on ASSAB XW-42 material using the Taguchi-WPCA method to minimize arithmetic roughness (Ra), quadratic roughness average (Rq), and average roughness from peak to valley (Rz), and maximize metal removal rate (MRR) simultaneously. The cooling fluid method used is the minimum quantity of cooling lubrication (MQCL). The end milling process variable that is varied is the cutting fluid (soluble oil and vegetable oil), spindle speed (178 rpm, 310 rpm, and 570 rpm), feed rate (33.5 mm / minute, 59.4 mm / minute and 111.9 mm / minute) and the cutting depth (0.125 mm, 0.25 mm and 0.5 mm). The cutting tool used in this study is solid carbide end mill having four cutting edges with a diameter of 10 mm. The experimental design of the L_{18} orthogonal array was used in this study. The results showed that the optimal roughness of the workpiece surface and metal removal rate (MRR) was given by vegetable oil cutting fluid, 570 rpm of spindle speed, 33.5 mm / minute of feed rate, and 0.25 mm of the cutting depth. The Cutting fluid, spindle speed, and feed rate have a significant effect on the response variables observed simultaneously.**

***Keywords*— end mill; MRR; MQCL; optimization; surface roughness; ASSAB XW 42; Taguchi-WPCA.**

I. INTRODUCTION

Cutting tools in the milling process that are widely used in the industry of manufacturing, such as the automotive industry, aircraft, and plastic molds are end mill. The cutting edge of the end mill cutting tool is on the tip of the face and the spiral side. The selection of variable end milling processes such as feed rate, spindle speed, cutting depth and tool type and the coolant must be precise to obtain a low workpiece surface roughness value and high metal removal rate. The function of the coolant in the machining process is to bring down the friction coefficient, bring down the heat of the cutting tool and clean the chip from the material surface. Also, the use of coolant can increase the quality of the workpiece surface [1]. Besides being useful during the metal cutting process, coolant causes health problems for operators and the environment [2]. The coolant in the machining process consists of a mixture of water and oil, containing irritant and allergic ingredients such as surfactants, alkanol amines and preservatives [3]. Exposure to excessive metal cutting fluid can cause skin irritation [3]–[5]. The method of providing cutting fluid using an environmentally friendly coolant is the focus of current research [6], [7]. One method of providing environmentally friendly coolant is to use Minimum Quantity Cooling Lubrication [8]–[10].

Surface roughness is used to check the end quality of the work surface resulting from the process of machining [11]. At the same time, the metal removal rate (MRR) is used to check the productivity. The greater the MRR, the higher the productivity. However, the characteristics of quality and productivity in the process of machining are different. The roughness of the surface has the characteristics that the smaller is better and the MRR the higher the best. Therefore, determining the combination of variable milling processes such as cutting speed, feeding and proper cutting depth to get optimal results is very important to do besides the use of environmentally friendly coolant. This step is done so that when carrying out the machining process does not use the trial and error process in determining the process variables. Taguchi is an optimization method for a single response that effectively controls the quality of the product. Whereas for multiple responses optimization, it is used a combination of the Taguchi method with weighted principal components analysis (WPCA), fuzzy logic, grey relational analysis (GRA), and genetic algorithm (GA). Das et al. carried out the optimization of the Al 7075 / SiCp MMC material in the turning process by using the Taguchi method combined with WPCA [12]. Panda et al. optimized the turning process variables to optimize the response of surface roughness using the Taguchi method combined with the WPCA method [13]. While Nayak et al. did the optimization parameters of the abrasive jet machining process using a combination of the Taguchi method with WPCA [14].

II. Materials and Method

A. Materials

ASSAB XW-42 tool steel was used in this experiment as a workpiece with a dimension of (80x30x30) mm, as shown in Fig. 1. The tool used was four cutting edge end mills with a diameter of 10 mm. The traditional Milling machines with a maximum spindle rotation of 2000 rpm was used in this experiment. Mitutoyo surf test and stopwatch were respectively used to measure surface roughness and cutting time. Then, the cutting time is put in equation 1 to get the MRR. MRR is the volume of material removed per unit of time or minute [15].

$$MRR = \frac{V}{t} \ \ (mm^3/min) \qquad (1)$$

Where:
V = Volume of material removed (mm^3),
t = Machining time (minute)

Fig. 1 Experiment workpiece

B. Experimental Design

Process variables used in this study are shown in Table 1. The response variables used in this experiment are average arithmetic roughness (Ra), quadratic roughness average (Rq), and average roughness from peak to valley (Rz) and metal removal rate (MRR). The method of applying coolant used is the minimum quantity of cooling lubrication (MQCL). Based on Table I, the total degrees of freedom of the response variable is 7. The degrees of freedom from the orthogonal matrix used must be larger than or equal to the total degrees of freedom of the predetermined factors and levels [16].

TABLE I
PROCESS VARIABLE AND IT'S LEVEL

No.	Process Variable	Level		
		1	2	3
1	Coolant (CF)	Soluble oil	Vegetable oil	-
2	Spindle speed (N)/rpm	178	310	570
3	Feed rate (V_f)/mm/min	33.5	59.4	111.9
4	Cutting depth (A)/mm	0.125	0.25	0.5

According to the choices available, orthogonal L18 matrices meet the requirements to be used as experimental designs, as shown in Table 2.

TABLE II
MATRIX ORTHOGONAL L_{18}

No.	CF	N (rpm)	V_f (mm/min)	A (mm)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

C. Optimization Taguchi-WPCA

The Taguchi Method seeks to achieve this goal by making products and processes insensitive to various noise factors, such as materials, manufacturing equipment, human labor, and operational conditions. However, the Taguchi technique is only used to make one response [17]. Taguchi techniques can be combined with WPCA to do multiple-responses optimization simultaneously.

The WPCA is used to remove the correlation among the responses and to change the correlated responses to an uncorrelated responses index named the major components (Principal Components) [18]. The main components that each have different variance values are independent of each other; therefore, to produce the total variance value, each variance of the main component is considered or used as a weight. The main components are accumulated first to count the Multi Responses Performance Index (MPI). Next, the value of combined quality loss (CQL) is calculated, which is defined as the deviation from the MPI value from the desired ideal value. CQL aims to reduce the MPI deviation from the ideal value [14]. The Taguchi-WPCA optimization stage can be seen in Fig. 2.

III. Results and Discussion

The value of arithmetic roughness (Ra), quadratic roughness average (Rq), and average roughness from peak to valley (Rz) and metal removal rate (MRR) results from this study are shown in Table 3. Surface roughness Ra, Rq and Rz are measured by using surftest Mitutoyo SJ-210 while the metal removal rate is calculated by using equation 1. Based on Table III, the lowest surface roughness of Ra is 0.494 μm in combination experiment of number 18. While the lowest surface roughness of Rq and Rz is 0.693 and 2.534 μm, respectively in combination experiment of number 17. Whereas the most significant metal removal rate (MRR) is in combination experiment of no. 8 at 332,760 mm^3/minute. Therefore, an optimization process is needed to get the setting of the end milling process variables that produce a low surface roughness value with a high metal removal rate (MRR).

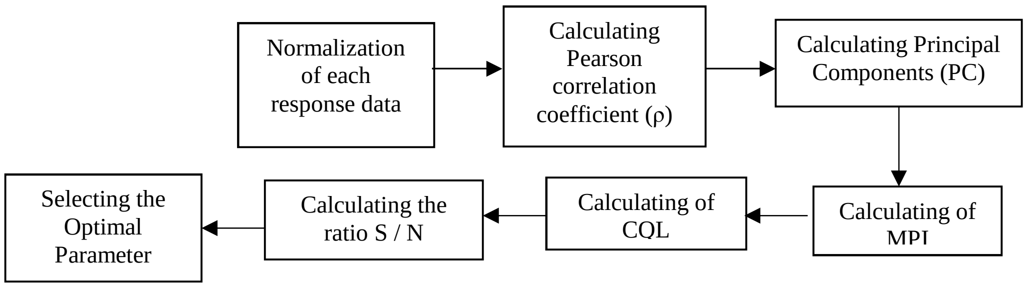

Fig. 2 The stage Taguchi-WPCA

TABLE III
Experiment Result

No.	CF	N (rpm)	V_f (mm/mint)	A (mm)	Experiment Result (μm)			mm^3/min
					Ra	Rq	Rz	MRR
1	Soluble Oil	178	33.5	0.125	0.714	1.014	4.324	33.187
2	Soluble Oil	178	59.4	0.25	0.806	0.984	4.274	114.049
3	Soluble Oil	178	111.9	0.5	0.855	0.880	3.888	275.845
4	Soluble Oil	310	33.5	0.125	0.654	0.874	3.917	33.323
5	Soluble Oil	310	59.4	0.25	0.726	0.843	3.588	281.472
6	Soluble Oil	310	111.9	0.5	0.807	0.897	3.938	280.441
7	Soluble Oil	570	33.5	0.125	0.606	0.739	3.485	32.463
8	Soluble Oil	570	59.4	0.5	0.687	0.955	4.035	332.760
9	Soluble Oil	570	111.9	0.125	0.749	0.849	3.682	171.318
10	Vegetable Oil	178	33.5	0.5	0.658	0.869	3.641	131.332
11	Vegetable Oil	178	59.4	0.125	0.723	0.862	3.718	57.370
12	Vegetable Oil	178	111.9	0.25	0.794	1.019	4.532	217.949
13	Vegetable Oil	310	33.5	0.25	0.577	0.747	3.012	87.335
14	Vegetable Oil	310	59.4	0.5	0.690	0.912	4.025	234.483
15	Vegetable Oil	310	111.9	0.125	0.720	0.897	3.858	87.606
16	Vegetable Oil	570	33.5	0.5	0.650	0.679	2.870	144.053
17	Vegetable Oil	570	59.4	0.125	0.532	0.693	2.534	58.621
18	Vegetable Oil	570	111.9	0.25	0.494	0.760	3.021	218.670

A. *The Normalization of Each Response Data*

Normalization that is the process of transforming the experiment results as shown in Table 3, values ranging from zero to one. The method used for the normalization process influenced by the characteristics of the responses. Smaller the best for surface roughness follows equation 2. Higher the best for metal removal rate follows equation 3. The equation used to normalize the responses is [16]:

a. Smaller the best

$$S_{ij} = \frac{minL_{ij}}{L_{ij}} \quad (2)$$

b. Higher the best

$$S_{ij} = \frac{L_{ij}}{maxL_{ij}} \quad (3)$$

The results of the data normalization are shown in Table 4. The results of the normalization process Lij are between 0 and 1. The maximum value of Lij is 1 and is considered an ideal condition.

B. Calculating the Pearson Correlation Coefficient (ρ)

The next step is estimating the Pearson correlation coefficient (ρ). The correlation coefficient is used to see whether there is a correlation between the observed response variables. The calculation of the Pearson Correlation is done using equation 4.

$$\rho = \frac{Cov(Q_{j,}Q_k)}{Q_j \, x \, Q_k} \quad (4)$$

The correlation coefficient between responses is shown in Table 5. The Pearson correlation coefficient (ρ) does not equal zero, so there is a correlation among responses. The highest Pearson correlation coefficient value of 0.710 is the correlation between the surface roughness of Rq and Rz. While the lowest correlation value of -0.230 is the correlation between Rq surface roughness with Metal Removal Rate (MRR).

The Correlation value can be positive and negative numbers. If it is positive, the relationship is one-way. If it is negative, the relationship is not unidirectional.

C. Calculating Principal Components (PC)

Based on Table 5, all responses are correlated. The calculation of the principal component score (PC) is carried out to eliminate the correlation between responses. The principal component consists of eigenvalue, AP (accountability proportion), eigenvector, and CAP (cumulative accountability proportion). They all can be seen in Table 6. The eigenvector values of Y_1, Y_2, Y_3 and Y_4 in Table 6 are used to calculate the principal component scores of PC_1, PC_2, PC_3 and PC_4 by using equation 5.

$$Y_i(k) = \sum_{j=1}^{n} S_{ij}(j)\beta_{kl} \quad (5)$$

Where Y_i is the value of the principal component score (PC), S_{ij} is the normalized data, and β is the eigenvector value. The result of the Individual principal component (PC) values is shown in Table 7. The principal components (PC) shown in Table 7 represent each response. Principal component 1 (PC_1) represents the surface roughness response Ra, principal component 2 (PC_2) represents the surface roughness response Rq, principal component 3 (PC_3) represents the surface roughness response Rz and principal component 4 (PC_4) represents the response to the metal removal rate (MRR).

TABLE IV
DATA NORMALIZATION

No.	CF	N (rpm)	V_f (mm/min)	A (mm)	Data Normalization			
					Ra	Rq	Rz	MRR
Ideal					1	1	1	1
1	Soluble Oil	178	33.5	0.125	0.692	0.670	0.586	0.100
2	Soluble Oil	178	59.4	0.25	0.613	0.690	0.593	0.343
3	Soluble Oil	178	111.9	0.5	0.578	0.772	0.652	0.829
4	Soluble Oil	310	33.5	0.125	0.755	0.777	0.647	0.100
5	Soluble Oil	310	59.4	0.25	0.680	0.805	0.706	0.846
6	Soluble Oil	310	111.9	0.5	0.612	0.757	0.643	0.843
7	Soluble Oil	570	33.5	0.125	0.815	0.919	0.727	0.098
8	Soluble Oil	570	59.4	0.5	0.720	0.711	0.628	1.000
9	Soluble Oil	570	111.9	0.125	0.660	0.800	0.688	0.515
10	Vegetable Oil	178	33.5	0.5	0.751	0.781	0.696	0.395
11	Vegetable Oil	178	59.4	0.125	0.684	0.788	0.682	0.172
12	Vegetable Oil	178	111.9	0.25	0.622	0.667	0.559	0.655
13	Vegetable Oil	310	33.5	0.25	0.856	0.909	0.841	0.262
14	Vegetable Oil	310	59.4	0.5	0.716	0.745	0.630	0.705
15	Vegetable Oil	310	111.9	0.125	0.687	0.757	0.657	0.263
16	Vegetable Oil	570	33.5	0.5	0.760	1.000	0.883	0.433
17	Vegetable Oil	570	59.4	0.125	0.928	0.981	1.000	0.176
18	Vegetable Oil	570	111.9	0.25	1.000	0.893	0.839	0.657

TABLE V
PEARSON CORRELATION COEFFICIENT

No.	Response	P	Information
1	Ra & Rq	0.710	Correlation
2	Ra & Rz	0.781	Correlation
3	Ra & MRR	-0.308	Correlation
4	Rq & Rz	0.937	Correlation
5	Rq & MRR	-0.265	Correlation
6	Rz & MRR	-0.230	Correlation

TABLE VI
EIGENVALUE, EIGENVECTOR, AP AND CAP

	Y_1	Y_2	Y_3	Y_4
Eigen value	2.7449	0.8863	0.3152	0.0536
Eigen vector	0.533	0.045	0.831	0.153
	0.565	0.172	-0.49	0.641
	0.576	0.216	-0.243	-0.75
	-0.256	0.96	0.104	0.047
AP	0.686	0.222	0.079	0.013
CAP	0.686	0.908	0.987	1

TABLE VII
INDIVIDUAL PRINCIPAL COMPONENT (PC)

No.	CF	N (rpm)	V_f (mm/min)	A_a (mm)	PC_1	PC_2	PC_3	PC_4
Ideal					1.418	1.794	0.183	-0.275
1	Soluble Oil	178	33.5	0.125	1.059	1.169	0.302	-0.169
2	Soluble Oil	178	59.4	0.25	0.970	1.139	0.207	-0.170
3	Soluble Oil	178	111.9	0.5	0.907	1.197	0.039	-0.187
4	Soluble Oil	310	33.5	0.125	1.189	1.309	0.336	-0.189
5	Soluble Oil	310	59.4	0.25	1.008	1.308	0.063	-0.203
6	Soluble Oil	310	111.9	0.5	0.909	1.199	0.026	-0.187
7	Soluble Oil	570	33.5	0.125	1.348	1.481	0.383	-0.214
8	Soluble Oil	570	59.4	0.5	0.891	1.212	-0.059	-0.187
9	Soluble Oil	570	111.9	0.125	1.068	1.291	0.194	-0.196
10	Vegetable Oil	178	33.5	0.5	1.142	1.336	0.246	-0.198
11	Vegetable Oil	178	59.4	0.125	1.158	1.302	0.336	-0.192
12	Vegetable Oil	178	111.9	0.25	0.862	1.096	0.048	-0.166
13	Vegetable Oil	310	33.5	0.25	1.387	1.574	0.397	-0.232
14	Vegetable Oil	310	59.4	0.5	0.985	1.240	0.067	-0.187
15	Vegetable Oil	310	111.9	0.125	1.105	1.264	0.280	-0.187
16	Vegetable Oil	570	33.5	0.5	1.368	1.604	0.356	-0.243
17	Vegetable Oil	570	59.4	0.125	1.580	1.771	0.545	-0.263
18	Vegetable Oil	570	111.9	0.25	1.352	1.625	0.215	-0.241

D. Calculating of MPI

After the principal component (PC) is calculated, the next step is to calculate the Multi Response Performance Index (MPI) following equation 6. the AP value as in Table 6 is used as a weight to calculate MPI.

$$MPI = (PC_1 x 0.686) + (PC_2 x 0.222) + (PC_3 x 0.079) + (PC_4 x 0.013) \quad (6)$$

The results of multi-response performance index (MPI) calculations can be seen in Table 8. The MPI values represent the entire principal component score.

TABLE VIII
MULTI RESPONSE PERFORMANCE INDEX (MPI)

No.	CF	N (rpm)	V_f (mm/min)	A (mm)	MPI
Ideal					1.382
1	Soluble Oil	178	33.5	0.125	1.008
2	Soluble Oil	178	59.4	0.25	0.933
3	Soluble Oil	178	111.9	0.5	0.889
4	Soluble Oil	310	33.5	0.125	1.130
5	Soluble Oil	310	59.4	0.25	0.984
6	Soluble Oil	310	111.9	0.5	0.889
7	Soluble Oil	570	33.5	0.125	1.281
8	Soluble Oil	570	59.4	0.5	0.873
9	Soluble Oil	570	111.9	0.125	1.032
10	Vegetable Oil	178	33.5	0.5	1.097
11	Vegetable Oil	178	59.4	0.125	1.108
12	Vegetable Oil	178	111.9	0.25	0.836
13	Vegetable Oil	310	33.5	0.25	1.329
14	Vegetable Oil	310	59.4	0.5	0.954
15	Vegetable Oil	310	111.9	0.125	1.058
16	Vegetable Oil	570	33.5	0.5	1.319
17	Vegetable Oil	570	59.4	0.125	1.516
18	Vegetable Oil	570	111.9	0.25	1.302

E. Calculate CQL (Combined Quality Los)

After calculating the MPI value, the next step is to perform a CQL calculation. CQL value calculation is done by calculating the absolute difference between MPI values in ideal conditions with MPI values from response data. The results of calculating the combined Quality Loss (CQL) are shown in Table 9.

TABLE IX
COMBINED QUALITY LOSS VALUE (CQL)

No.	CF	N (rpm)	V_f (mm/min)	A_a (mm)	CQL
Ideal					0
1	Soluble Oil	178	33.5	0.125	0.374
2	Soluble Oil	178	59.4	0.25	0.449
3	Soluble Oil	178	111.9	0.5	0.493
4	Soluble Oil	310	33.5	0.125	0.252

5	Soluble Oil	310	59.4	0.25	0.398
6	Soluble Oil	310	111.9	0.5	0.493
7	Soluble Oil	570	33.5	0.125	0.101
8	Soluble Oil	570	59.4	0.5	0.509
9	Soluble Oil	570	111.9	0.125	0.350
10	Vegetable Oil	178	33.5	0.5	0.285
11	Vegetable Oil	178	59.4	0.125	0.274
12	Vegetable Oil	178	111.9	0.25	0.546
13	Vegetable Oil	310	33.5	0.25	0.053
14	Vegetable Oil	310	59.4	0.5	0.428
15	Vegetable Oil	310	111.9	0.125	0.324
16	Vegetable Oil	570	33.5	0.5	0.063
17	Vegetable Oil	570	59.4	0.125	0.134
18	Vegetable Oil	570	111.9	0.25	0.080

F. Calculating the value of the signal to noise (S/ N) ratio

The ratio of S/N is calculated based on the characteristics of the CQL value, which is smaller the better, using equation (7). Calculation of the ratio of S/N is done to minimize the value of the estimated loss from the CQL. The results of the calculation of the ratio of S/N are shown in Table 10.

$$S/N = -10 \log \left[\sum_{i=1}^{n} \frac{{y_i}^2}{n}\right] \quad (7)$$

TABLE X
THE S/N VALUE

No.	CF	N (rpm)	V_f (mm/min)	A (mm)	S/N CQL
Ideal					
1	Soluble Oil	178	33.5	0.125	8.540
2	Soluble Oil	178	59.4	0.25	6.950
3	Soluble Oil	178	111.9	0.5	6.136
4	Soluble Oil	310	33.5	0.125	11.975
5	Soluble Oil	310	59.4	0.25	8.004
6	Soluble Oil	310	111.9	0.5	6.147
7	Soluble Oil	570	33.5	0.125	19.907
8	Soluble Oil	570	59.4	0.5	5.870
9	Soluble Oil	570	111.9	0.125	9.122
10	Vegetable Oil	178	33.5	0.5	10.890
11	Vegetable Oil	178	59.4	0.125	11.231
12	Vegetable Oil	178	111.9	0.25	5.264
13	Vegetable Oil	310	33.5	0.25	25.591
14	Vegetable Oil	310	59.4	0.5	7.367
15	Vegetable Oil	310	111.9	0.125	9.791
16	Vegetable Oil	570	33.5	0.5	24.072
17	Vegetable Oil	570	59.4	0.125	17.436
18	Vegetable Oil	570	111.9	0.25	21.974

G. Selecting the Optimal End Milling Process Parameter

The following step is to determine the average of the ratio of S/N for each level and group them as in Table 11. The plot for the average ratio of S/N in Table 11 is shown in Fig. 3. The end milling is processing variable level combinations that produce the optimum response based on Fig. 3 are Cutting Fluid (CF) level 2 namely vegetable oil, level 3 of spindle speed (N) of 570 rpm, level 1 of feed rate (Vf) of 33.5 mm / min and level 2 of the cutting depth (A) of 0.25 mm.

TABLE XI
THE AVERAGE OF S/N CQL

	Level 1	Level 2	Level 3
CF	9.183	14.846	
N	8.168	11.479	16.397
V_f	16.829	9.476	9.739
A	11.349	14.615	10.081
Average		12.015	

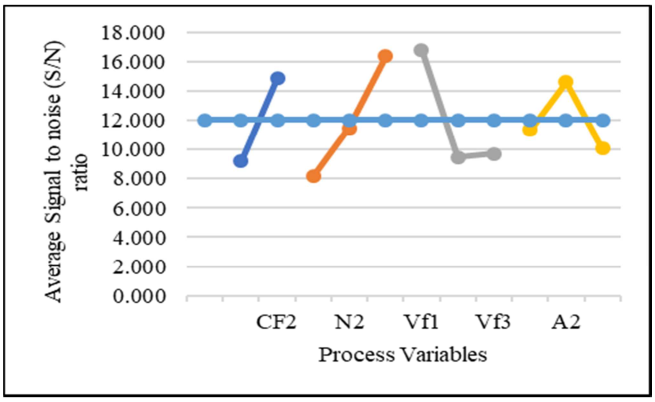

Fig. 3 Plot averages at each level of the process variables

H. Confirmation Experiment

Confirmation experiments are carried out to validate the results that have been obtained [19]. Confirmation experiment is conducted by comparing the results of the combination of optimization with the initial combination. The initial combination and optimum combination can be seen in Table 12, and the result of the confirmation experiment can be seen in Tables 12.

TABLE XII
INITIAL COMBINATION AND OPTIMUM COMBINATION

Process Variable	Initial Combination	Optimum Combination
	Level	Level
CF	2	2
N	2	3
V_f	2	1
A_a	2	2
	$CF_2N_2V_{f2}A_2$	$CF_2N_3V_{f1}A_{a2}$

Table 13 shows that the surface roughness value of Ra has decreased by 40.1%, the surface roughness value of Rq has decreased by 20.8%, the Rz surface roughness value has decreased by 5.4%, and the metal removal rate (MRR) has reduced by 43.5%.

TABLE XIII
COMPARISON OF THE INITIAL COMBINATION AND OPTIMUM COMBINATION

	Initial Combination	**Optimum Combination**		
Ra	0.781 µm	0.468 µm	40.1%	Decrease
Rq	0.966 µm	0.765 µm	20.8%	Decrease
Rz	4.141 µm	3.914 µm	5.4%	Decrease
MRR	115.479 mm^3/min	65.251 mm^3/m	43.5%	Decrease

I. Analysis of Variance (ANOVA)

The amount of the contribution and the significant influence of process variables on the response variables studied can be determined by using ANOVA. In this study, ANOVA is carried out on the value of the ratio of signal to noise (S/N) of CQL, which represents all responses simultaneously. The results of ANOVA calculation of the ratio of S/N of CQL are shown in Table XIV.

TABLE XIV
ANALYSIS OF VARIANCE

	DF	**SS**	**MS**	**F**	**F Table**	**% Contribution**
CF	1	144.305	144.305	10.382	3.370	17.080
N	2	205.707	102.853	7.399		23.301
V_f	2	208.818	104.409	7.511		23.709
A	2	65.676	32.838	2.362		4.961
Error	10	139.001	13.900			
Total	17	763.507				

Based on Table XIV, the calculated F value for cutting fluid (CF) and the spindle speed (N) successively are 10,382 and 7,399, and the feed rate (Vf) is 7,511, higher than the F table which is 3,370. This value shows that the cutting fluid (CF), spindle speed (N), and feed rate (Vf) process variables have a significant effect on the response variables observed simultaneously. The variable feed rate gave the most significant contribution in decreasing the total variance by 23,709%, spindle speed by 23,301%, cooling fluid by 17,080%, and cutting depth by 4,961%. The process can be explained that the level of surface quality of the workpiece will increase with increasing cutting speed and will decrease with increasing feed rate [20]. Giving the right coolant on the end milling process can reduce heat during the process and improve the surface quality of the workpiece.

IV. CONCLUSION

This study aims to obtain a combination of end milling process variables on ASSAB XW-42 material using the Taguchi-WPCA method to minimize arithmetic roughness (Ra), quadratic roughness average (Rq), and average roughness from peak to valley (Rz) and maximize metal removal rate (MRR) simultaneously. The cooling fluid method used is the minimum quantity of cooling lubrication (MQCL). Based on the results of the study, the following conclusions can be drawn as follow: The coolant (CF), spindle speed (N) and feed rate (V_f) had a significant effect on the variable arithmetic roughness (Ra), quadratic roughness average (Rq), and average roughness from peak to valley (Rz) and metal removal rate (MRR) which were observed simultaneously. The variable feed rate gave the biggest contribution in decreasing the total variance by 23,709%, spindle speed by 23,301%, cooling fluid by 17,080%, and cutting depth by 4,961%. The end milling process variables are set as follows to get optimal surface roughness response (Ra, Rq and Rz) and metal removal rate (MRR), Vegetable oil coolant type, spindle speed of 570 rpm, a Feed rate of 33.5 mm / minute and radial cutting depth of 0.25 mm.

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