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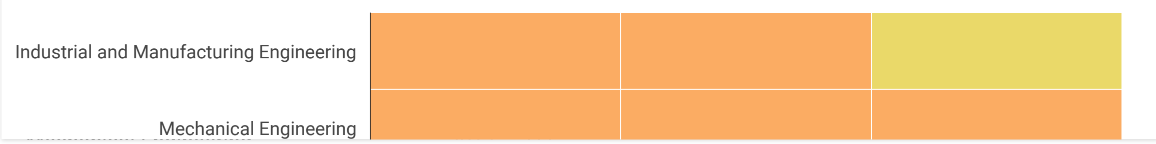

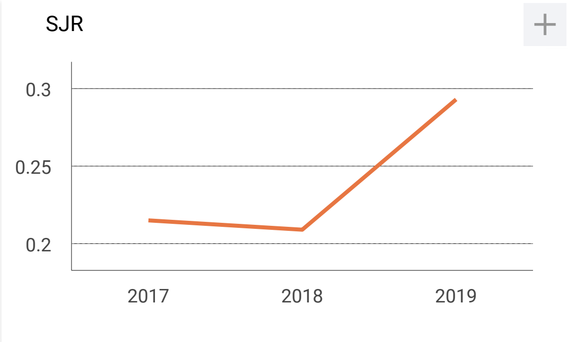

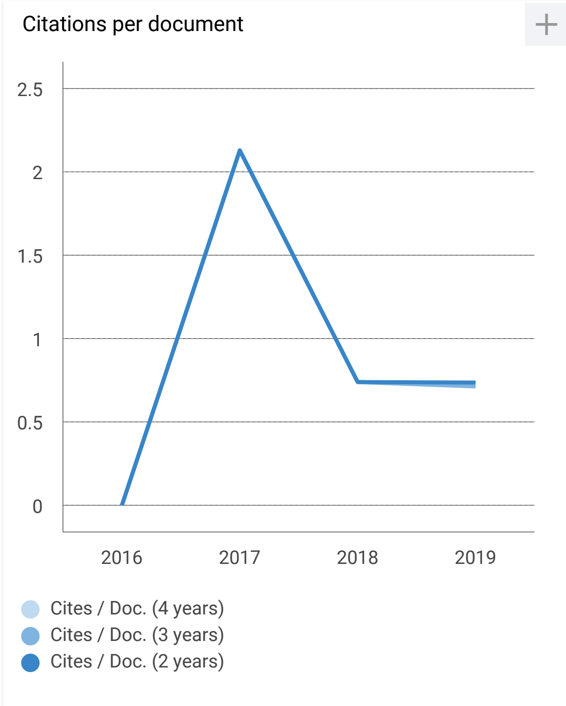

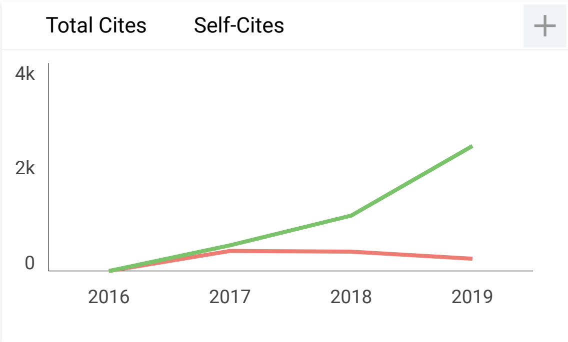

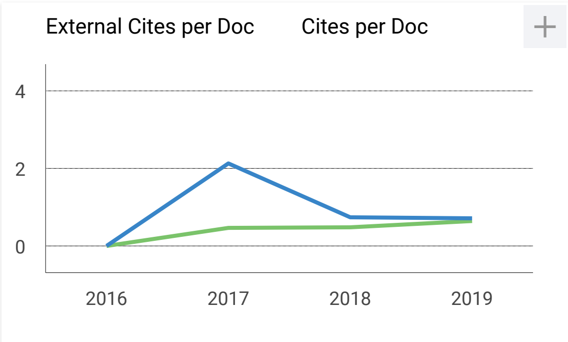

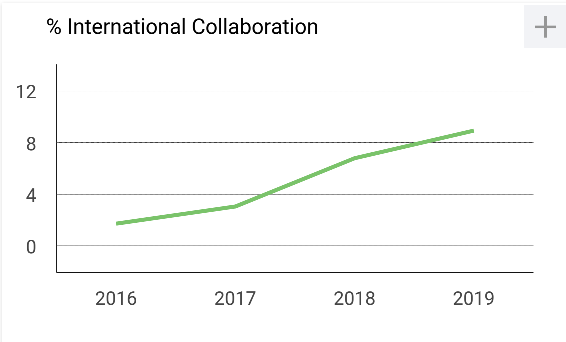

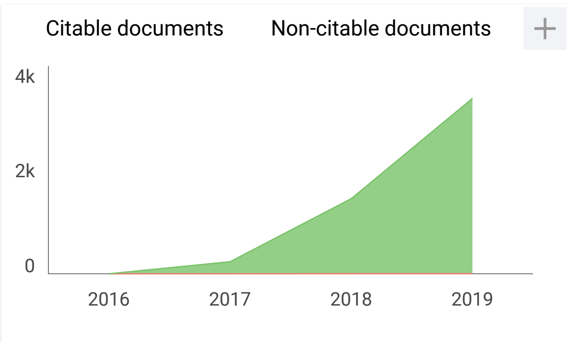

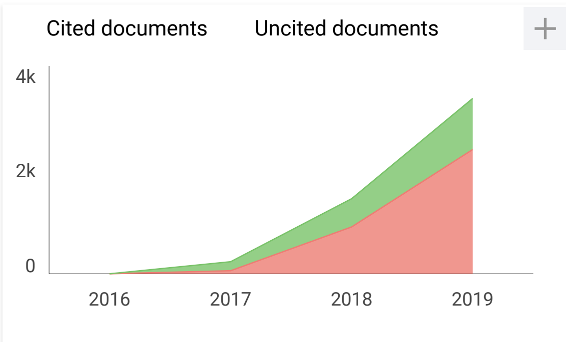

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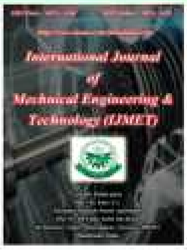

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OPTIMIZATION OF CNC MILLING PARAMETERS THROUGH THE TAGUCHI AND RSM METHODS FOR SURFACE ROUGHNESS OF UHMWPE ACETABULAR CUP

W. D. Lestari, R. Ismail, J. Jamari, A. P. Bayuseno
Diponegoro University, Faculty of Engineering,
Department of Mechanical Engineering, Semarang, Indonesia
Jl. Prof. Soedarto, Tembalang, Semarang 50275, Indonesia

P. W. Anggoro
University of Atma Jaya Yogyakarta, Faculty of Industrial Technology,
Department of Industrial Engineering, Yogyakarta, Indonesia
Jl. Babarsari 44, 55281, Yogyakarta, Indonesia

ABSTRACT

CNC milling is a flexible technology for machining UHMWPE with low machinability. This study was undertaken for modeling of the experimental data with CNC milling parameters (spindle speed, feed rate, and step over) against the response of surface roughness of UHMWPE acetabular cup. Here the significant machining parameters on the surface roughness were first analysed by ANOVA, while the optimized parameters for yielding the minimum surface roughness were determined with the Taguchi method and the Response Surface Methodology (RSM). In the milling of UHMWPE acetabular cup, the method was confirmed valid for optimizing the cutting parameters with the minimal surface roughness. Accordingly, the minimum surface roughness determined by the Taguchi method could correspond to the optimum levels of spindle speed of 6500 rpm, the feed rate of 1500 mm/rev and step over about 0.1 mm. The Taguchi and RSM based models yielded the consistent results, hereby justifying their suitability. In conclusion, the examination by statistical indicators confirmed the acceptability of these examples.

Key words: UHMWPE acetabular cup; Surface roughness; Taguchi method; RSM; Cutting parameters.

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1. INTRODUCTION

Ultra-high molecular weight polyethylene (UHMWPE) is an engineering thermoplastic polymer, which is commonly applied to an acetabular cup in the hip arthroplasty due to it has remarkable mechanical and physical properties including excellent abrasion resistance, self-lubrication property, fatigue resistance, shock resistance, high chemical stability, resistance to low temperature, and biocompatibility [1-2]. Moreover, the acetabular cup frequently experiences in the wear debris mediated osteolysis, when employed in the total hip arthroplasty [3]. Many factors such as adhesive, abrasive or fatigue mechanisms may reduce its lifespan and eventually need in revision surgery [4]. In this respect, the lifespan of the acetabular cup could be influenced by the wear resistance of the material and the specific conditions of each patient [2]. Specifically, the surface quality of the UHMWPE acetabular cup mainly controls the wear behavior of the hip-joint components.

To increase the lifespan of the artificial bearings can be made by the surface property modification through ranging from carbon-fiber reinforcement, high-pressure crystallization, and elevated doses of cross-linking, as well as the addition of vitamin E [1]. Additionally, the surface properties of UHMWPE acetabular cup in term of surface roughness can be modified through a machining process of a UHMWPE round rod product. However, machining of this product subjects to damage due to its low machinability and mechanical properties including toughness, rigidity, abrasion resistance, and heat resistance [5].

Further to the machining process of UHMWPE acetabular cup requires a proper selection of cutting parameters, which can be provided with values based on their mechanical and physical properties. A comparative study on the machining of different polymers including PA6 (magnesium), PA6 (Na), polyoxymethylene (POM C) and the HD1000 (UHMWPE) has been performed by Keresztes et al. [6]. Apparently, the machining of PA6 (Mg) generated higher cutting force [7], but the machining of HD1000 produced the lower one. Further to machining HDPE 80 and HDPE 100 polymer, the feed rate significantly influenced the yield of surface roughness. Additionally, the step over contributes a substantial increase in the temperature level during the machining polymer. In particular, the highest temperature level could be found in the cutting zone of HDPE 80 rather than that of HDPE 100. Significantly, the ease for machining of typical thermoplastic and thermosetting polymers relates to their viscous properties, which eventually control the surface integrity, chip formation, and cutting forces [8].

Further, the product quality in the machining process is mainly focussed on better surface roughness and dimensional accuracy. The importance of surface roughness is also realized on the contact region of the component, because it may influence on the tribological properties, corrosion resistance, fatigue strength, and aesthetic appearance of the product [9-11]. Furthermore, the surface roughness is also considered important on the machined parts, which can control wear, friction, and heat transmission [12]. However many factors such as work-piece material, cutting tool material, and machining parameters, may influence the surface roughness of any machined components. Here the machining parameters are easy to be adjusted for attaining a closer expected value of surface roughness.

More recently, the machining parameters in the CNC milling process of the different materials on the results of the surface roughness have been investigated by many researchers. Significant impacts of cutting parameters (depth of cut, feed rate, and cutting speed) on the surface roughness are known for a given cutting tool and work-piece setup [13-15]. Taguchi-Grey relational optimization method had been applied for examining influence of parameters such as tool path strategic, feed rate and spindle speed on the surface roughness and machining time [16]. Similarly, the surface roughness of the AISI 304 austenitic stainless work-piece was examined through adjustment of cutting speed, feed rate, and depth of cut

[17]. It was reported previously that the better surface roughness could be attained by setting the lowest level of feed rate, and the highest level of cutting speed. The specific cutting energy and the average surface roughness of the hardened AISI 4140 steel were examined and optimised by end milling with the Minimum Quality Lubrication (MQL) [18]. In this study, the optimum parameters corresponded to cutting speed of 32 m/min, the feed rate of 46 mm/min, and the coolant flow rate of 150 ml/h. Also, the use of grey fuzzy logic for examining the cutting force, the surface roughness of Ra and Rz has been proposed by optimizing machining parameters (cutting speed, feed rate, depth of cut)[19]. The feed of 40 mm/min, cutting speed of 600 rpm, and a depth of cut of 0.30 mm was considered as the best combination of machining parameters. Moreover, the ANOVA statistics supported the finding that the cutting speed has contributed significantly to the surface roughness.

Further to the Taguchi method and regression analysis was applied for evaluating the influence of machining parameters (cutting tool, cutting speed, and feed rate) on the surface roughness and flank wear of steel. Obviously, the surface roughness is mainly controlled by the feed rate, while the cutting speed significantly corresponds to flank wear [20]. Similarly, controls of machining parameters to provide the minimum surface roughness of hybrid composites, cutting force, tool wear, and the maximum material removal rate during end milling operation were discussed using RSM based grey relational analysis [21]. In particular, the machinability of hybrid composites is mainly dependent on the selected level of spindle speed and the weight percentage of SiC.

Likewise, the machining parameters (cutting feed, tool diameter, axial and radial depth of cut) could be controlled to provide the low surface roughness and low cutting force [22]. In this study, the excellent surface quality with the moderate cutting power consumption using cutting tool of 8 mm diameters, could be achieved at the lower values of feed per tooth, radial depth of cut and axial depth of cut. A multi-objective optimization method based on the weighted grey relational analysis and response surface methodology (RSM) has been used to optimize the cutting parameters (i.e. spindle speed, feed rate, depth of cut, the width of cut) in the milling process of metal [23]. In the evaluation of the cutting energy for milling process, the low cutting speed may provide more energy efficient than cutting speed at the initial speed.

Since UHMWPE has low ductility, it may be damaged by an excessive heat generated during CNC milling, and therefore the machining parameters should be carefully determined. However, the selection of those parameters may be an exhaustive task and requires high cost of experimentation. Here, a design of experiment methodology through the optimization of machining parameters is required for yielding the minimal surface roughness.

More recently in the machining of polymers and metals, the significant work has been made for modelling and optimizing cutting parameters using Taguchi and Response Surface Method (RSM). The use of RSM, the artificial neural network (ANN), and the desirability function (DF) methods had been tested for optimizing cutting parameters during turning of the polyoxymethylene (POM C) polymer providing that cutting speed was the significant factor contributing to surface roughness, cutting force, cutting power, and productivity [24]. Additionally, the minimum surface roughness of polymer could be obtained for the surface finish turning operation. Moreover, Taguchi and ANOVA analysis were employed for evaluating the turning of AISI 6061 T6 under rough conditions confirming that feed rate was the most significant factor for minimizing energy consumption and surface roughness [25].

Likewise, the mathematical model and optimized parameters were obtained by Taguchi-RSM (TM-RSM) methodology for Duplex turning of alloy steel (AISI 1040) with the single point cutting tools made of high-speed steel (HSS) [26]. The optimal cutting parameters corresponding to the feed rate of 0.50 mm/rev, cutting speed of 25 m/min, primary depth of cut about 0.20 mm and secondary depth of cut about 0.10 mm was found by the TM-RSM based hybrid approach and provided the significant improvement of surface roughness. Due to the wide applicability of the hybrid approach in the machining process, this approach is potential applied for milling experiments of UHMWPE through optimizing cutting parameters. Additionally, modelling and optimization of cutting parameters in the milling of UHMWPE can be used for minimizing the overall cost of the tool, production, and maintenance. Even though there are much research works carried out to study the impact of CNC milling parameters on the different productivity and quality aspects for polymer and composites, no current research has been reported in the literature for the CNC machining of UHMWPE acetabular cup.

The present study was undertaken to optimise cutting parameters in the CNC milling of UHMWPE acetabular cup for minimizing the surface roughness as required for the bearing material of the hip joint. The cutting parameters (tool-path strategy, spindle speed, feed-rate and step over) were investigated to relate the yield of surface roughness. Taguchi methodology was chosen to model cutting parameters to produce the minimal value of surface roughness in the milling operations. The optimum parameters obtained from the Taguchi methodology were subsequently employed as a design of the experimental method in RSM.

2. METHODOLOGY

2.1. Milling Eksperiments

Table 1 The Physical and mechanical properties of UHMWPE

Properties	Values
Density	0.930 – 0.945 g/ml
Elastic modulus	0.8 – 1.5 GPa
Tensile yield strength	19.3 – 23 MPa
Elongation at fracture	200 -350 %
Ultimate stress	30.4 – 48.6 MPa

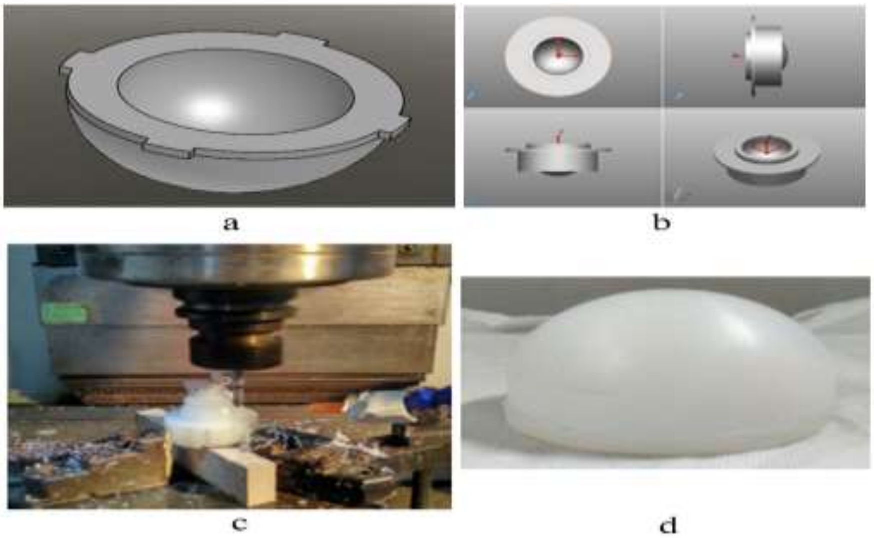

Figure 1 The process of machining UHMWPE as acetabular liner. (a) 3D model acetabular cup. (b) 3D isometric assy jig for the acetabular cup on CNC machine. (c) 3D product UHMWPE assy with jig on CNC YCM. (d) 3D product acetabular cup with UHMWPE material

UHMWPE used for this milling test has the physical and mechanical properties and are presented in Table 1. The workpiece has a round bar with 100 mm in diameter. The milling tests were conducted in the dry cutting condition on three-axis CNC milling machine (YCM 1020 EV 20), which is equipped with the cutting tool (SECO-93060F) of end mill cutting tool (6 mm in diameter) and ball nose cutter (JS533060D1B0Z3-NXT). The procedure of the machining of the acetabular liner is shown in Figure 1. After finishing the experiment, the average surface roughness (Ra) was measured at three points around the circumference of the inner sphere of the workpiece using surface roughness tester (Mark Surf PS1). The cut-off distance was determined as 2.5 mm.

2. 2. Experimental Design

The machining experiments were performed at varying cutting parameters (spindle speed, feed rate, and step over). These parameters are presented in the range of values provided with manufacturer recommendations, of which the orthogonal matrix presents the number of control variables and the state of each variable. The orthogonal matrix depends on the degree of freedom, which has been computed from the predetermined elements and layers. Table 2 presents the types of the factors and their level factors of cutting parameters examined in this study.

Table 2 Factor and their levels of the selected variables

Factor	Level factor		
	1	2	3
Spindle speed (rpm)	6500	7000	7500
Feed rate (mm/rev)	1000	1500	2000
Step over (mm)	0.01	0.05	0.1

Further to the design of experiments requires the total degree of freedom (DoE), which is calculated from the orthogonal array (OA) [27]. In this work, three levels for each control factor was defined. Moreover, L_{27} of Taguchi orthogonal array was employed for running experiments (33). Here 27 runs of machining were selected and the level for each machining parameter is presented in Table 3. To optimize cutting parameters required the average values of surface roughness for the analysis of the experimental data.

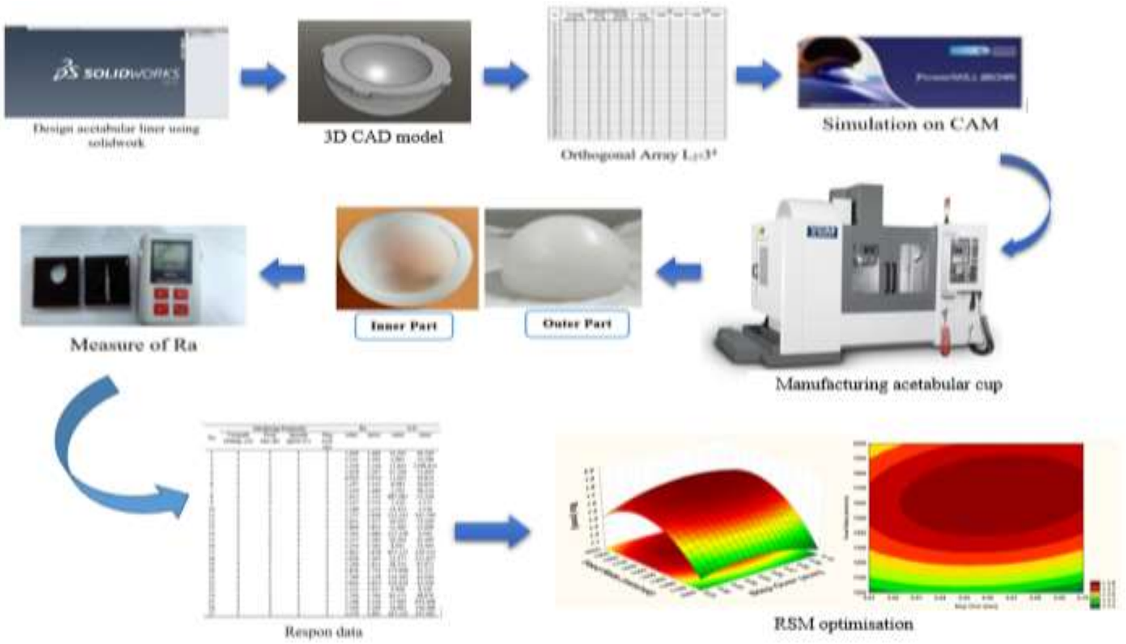

Figure 2 Flowcart of experimental procedure for the milling of UHMWPE acetabular cup

The experimental data were recorded randomly with the combination of parameters corresponding to the experimental design in accordance with the orthogonal matrix in Table 3. This randomization was done with the help of MINITAB software 2017. On any combination of parameters, the experiment was performed with twice repetition to represent the data reliability. The experimental steps of this research are presented in Figure 2.

Table 3 The $L_{27}3^4$ orthogonal array, surface roughness results and S/N ratios

No	Machining Parameter			Ra	S/N
	Spindle speed (A)	Feed rate (B)	Step over (C)		
1	1	1	1	1.1607	19.283
2	1	1	1	0.8890	11.312
3	1	1	1	0.7293	7.614
4	1	2	2	1.4450	29.887
5	1	2	2	1.1540	19.062
6	1	2	2	0.8853	11.219
7	1	3	3	1.3400	25.702
8	1	3	3	0.9920	14.086
9	1	3	3	1.1493	18.908
10	2	1	2	0.9943	14.152
11	2	1	2	1.3597	26.462
12	2	1	2	1.3517	26.151
13	2	2	3	0.9933	14.123
14	2	2	3	0.9730	13.551
15	2	2	3	0.5770	4.765
16	2	3	1	1.7107	41.887
17	2	3	1	1.3040	24.339
18	2	3	1	0.9673	13.394
19	3	1	3	1.6713	39.983
20	3	1	3	1.3710	26.905
21	3	1	3	1.1220	18.019
22	3	2	1	1.5257	33.317
23	3	2	1	1.3860	27.496
24	3	2	1	1.5413	34.005
25	3	3	2	1.7580	44.237
26	3	3	2	1.4673	30.818
27	3	3	2	1.2793	23.427

2.3. Analysis of Variance (ANOVA)

In this work, ANOVA was used to help the design parameters determining the significant factors on the output response. The percentage contribution was determined by ANOVA for each factor in terms of the sum of square parameters, F-value, P-value. A mean level of 5% (i.e., a confidence interval of 95 %) was set-up for all the responses. Here a ratio of the regression means square to the mean square error is given by F-value for the significance of each factor, while the F0.05 value represents the contribution of each term to be significant. Furthermore, R-sq is the ratio of the explained variation of the total variation indicating the accuracy of the model.

Further to CNC milling of UHMWPE analyzed with ANOVA provided the response surface quadratic models of the specific surface roughness. The quality of the models was checked to resolve the minor and major technological factors in the present analysis along with their interaction factors versus the responses. In particular, ANOVA was used to determine the significant effects of spindle speed, feed rate, and step over on the surface roughness.

2.4. Response Surface Methodology (RSM)

RSM was selected here for modeling and optimizing the independent variables based on data from simulation experiments, physical experiments, and experimental findings [28], in which the relationship between the independent variables and the response surfaces could be determined. The RSM-based mathematical model relating the response (y) and the set of independent variables (input parameters) could be expressed as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 + \cdots + \beta_k + \epsilon \quad (1)$$

where y is surface roughness (Ra) and Xi (A, B, and C) are the independent variables. The second order of the RSM model was selected in the study because of capable of representing the system under the given experimental domain. The RSM-based second order mathematical model of surface roughness is then expressed as:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum\sum_{i<j}^{\sim} \beta_{ij} x_i x_i + \epsilon \quad (2)$$

Here y is the predicted surface roughness (Ra); β_0 is a constant; β_i , β_{ii} , and β_{ij} are respectively the first, the second degree coded input parameters and parameter interactions.

2.5. Taguchi Methodology

The Taguchi method has been extensively applied for engineering analysis [29] and was selected here as a design methodology for determining the significant factors on output responses. This method was chosen because it markedly reduces the number of experiments by means of orthogonal arrays and can minimize the effects of the factors out of command. Also, the method can decrease the experimental time, reduce the cost and find out significant factors in a shorter time period [30]. The average and the disagreement of the output response (experimental result) at each context of parameters could be shown in an orthogonal array (OA). This response is then analyzed in a single performance standard using the signal-to-noise (S/N) ratio. The various S/N ratios can be presented as “smaller-the-better”, “larger-the-better”, and “nominal-the-better” in which the categories of the excellence typical responses are considered.

In this work, the S/N ratio for “smaller-the-better” criterion was considered that the output response of surface roughness should be minimum. This category of the S/N ratio can be expressed as [31]:

$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum x^2\right) \quad (3)$$

where x is the dependent variables (i.e. surface roughness); n is the number of experimental studies. The quality characteristic, a great rate of S/N ratio relates to non-negative with a target value of zero. Consequently, the optimum level of the procedure parameters is to minimize level with an S/N ratio [20].

3. RESULTS AND DISCUSSION

The 3D design of acetabular liner made by a solid work software resulted in the dimensional data of the acetabular liner was subsequently employed for CNC milling. Moreover, the cutting parameters were optimized by Taguchi method. The selected four cutting parameters on the surface roughness were then examined by a mathematical model of the experimental data (Table-3). The surface roughness of acetabular cup was set-up for a value of fewer than 2.00 µm, whereas the optimum parameters were then calculated by Taguchi method-RSM approach with the help of MINITAB software 2017 and Statistics V6, respectively. Here, each treatment (row) was performed three times for the measurement of Ra (µm) data response (column). Two types of the measured surface roughness of acetabular cup (the outer and inner side) were determined.

3.1. Optimization using Taguchi Methodology

The significance of each control variable (A, B, and C) on the surface roughness were first analyzed by Taguchi method which was computed using Eq. 3 and presented as the signal-to-noise (S/N) ratio of each experimental run. The results of S/N ratios are presented in Table 3. The levels of each factor resulted from the optimization process are presented in Table 4 (presented in bold). Furthermore, the optimum value of the S/N ratio of each factor relates to the optimal level [32]. Apparently, the spindle speed of 1st level, the feed rate of 2nd level, and the stepover of 3rd level correspond to the minimum surface roughness. Additionally, the 'Delta' value was obtained by the difference for the variance between the lowest level and highest level of S/N ratio under a certain factor. According to this delta value, 'Rank' of factors was supported to conclude the qualified importance of factors [33]. At this point, the spindle speed was the most important effect on the specific surface roughness followed by the feed rate and the step over.

Further to the better S/N ratio of the surface roughness was achieved at the lowest level of spindle speed (6500 rpm), the middle level of feed rate (1500 mm/rev) and the highest level of the step over (0.1 mm). Therefore, the combination of these parameters was the ideal setting of achieving the smallest surface roughness during this work.

Table 4 Response table for S/N ratios (smaller is better) for Ra

Factors	**Surface Roughness (Ra)**			**Delta**	**Rank**
	Level 1	**Level 2**	**Level 3**		
A	**-0.7714**	-1.1268	-3.3346	2.5632	1
B	-1.4570	**-1.2285**	-2.5474	1.3189	2
C	-1.8718	-2.3286	**-1.0324**	1.2962	3

Note: Bold number designate optimal factor level S/N

3.2. Prediction Optimal Performance

The significance of the machining factors on the minimum surface roughness (Ra) could be estimated from values in Fig. 3 and Table-5, which can be exploited to approximate the mean surface roughness with optimal operating conditions. The obtained factor was significant in both S/N and ANOVA that is spindle speed providing the minimum roughness rates. An assessment of the averaged value for the greatest substantial factor at A1 level to yield the minimum surface roughness is presented in Table 6.

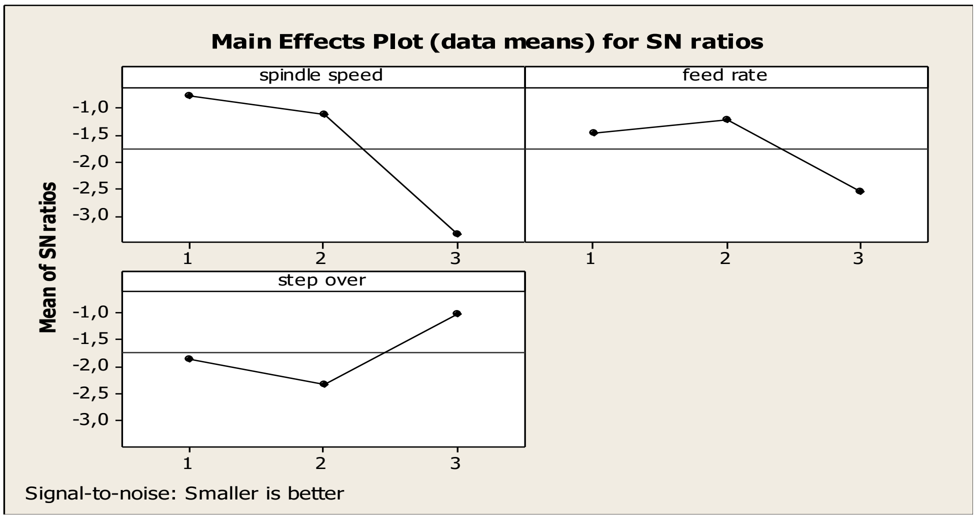

Figure 3 Main effect plot for mean S/N ratio of surface roughness

Table 5 Results of ANOVA) for Ra

Source of Variance	DF	Seq SS	Adj SS	Adj MS	*F*	P
A	2	0.74050	0.74050	0.37025	5.64	0.011
B	2	0.14729	0.14729	0.07365	1.12	0.345
C	2	0.13152	0.13152	0.06576	1.00	0.385
Error	20	1.31275	1.31275	0.06564		
Total	26	2.33206				

Table 6 Means values at each level for Ra

Control Factor	Surface Roughness (Ra)			Delta	Rank
	Level 1	Level 2	Level 3		
A	**1.083**	1.137	1.458	0.375	1
B	1.183	1.164	1.330	0.165	3
C	1.246	1.299	1.132	0.167	2

*Bold value represents the levels of the substantial factors for optimum result and the obtained best design.

The mean of the surface roughness can be estimated as [34]:

$$\overline{\mu_{A_1}} = \overline{A_1} - \overline{T_{Ra}} \quad (4)$$

$= 1.083 - 1.226$

$= 0.143$ µm

Where. $\overline{T_{Ra}} = 1.226$ was calculated from Table 3.

The confidence interval (CI) can verify the model of Ra from the confirmation experiment. The confidence interval for the expected better values was estimated according to [19]:

$$CI = \sqrt{F_{\alpha.1.dof\,V_{error}}\,V_{error}\,x\left(\frac{1}{n_{eff}}\right)} \quad (5)$$

$$n_{eff} = \frac{Number\ of\ experiments}{1 + total\ dof\ in\ items\ in\ used\ in\ \overline{\mu}\ \ estimate} \quad (6)$$

The results of the confirmation test for the output response could be achieved in the confidence interval with a 95 % confidence level. Therefore, the optimization for surface roughness could be validated using the Taguchi method at a significant level of 0.05. The confirmation experiment of the acetabular cup is:

$F_{0.05;1.26} = 4.23\ (tabulated)$

$F_{0.05;1.26} = 4.23\ (tabulated)$

$V_{error} = 0.06564\ (from\ Table\ 5)$

$$n_{eff} = \frac{27}{1+2+2} = 5.4$$

Thus. $CI_{Ra} = \pm\ 0.00640515$

The predictive mean of Ra is : $Ra_{pred} = 0.143\mu m$

$|\overline{\mu_{A_1}} - CI| < \overline{\mu_{A_1}} < |\overline{\mu_{A_1}}| + CI$

0.143 – 0.00640515 < 0.143 < 0.143 + 0.00640515

0.1366 µm < $\overline{\mu_{A_1}}$ < 0.1494 µm

3.3. Analysis of using Response Surface Method

The RSM approach was adopted here for evaluating the model and optimum cutting parameters applied for CNC milling of the UHMWPE acetabular cup. The experimental results were employed to develop the RSM model with the help of statistics software (Statistica V6). The software was also practiced for the evaluation of the collected data from milling experiments. The RSM model and analysis of machining parameters were based on the dry milling process, while the yield of surface roughness (Ra) could be obviously examined from the three-dimensional (3D) and 2D plots three-dimensional (3D) and 2D plots.

Further to these plots for assessing the machining factors versus the yield of surface roughness were generated using the polynomial of the second-order model (Eq. 2). Because three variables are present in each plot, the center level for each plot is considered as constant for every assessment. Here 3D response surface plots are shown in Figures 4a-c. It can be perceived how the independent variables influencing the surface roughness.

Furthermore, the experimental data obtained from the optimization process was then used to develop the second order mathematical model. Correspondingly, this model can be extracted as a function of the cutting parameters (feed rate, step over, and spindle speed) for the surface roughness. Figure 4 shows the significance of cutting parameters on the response of surface roughness of the inner part of the acetabular cup. The optimum Ra value of the inner acetabular cup about 1.72 µm corresponds the spindle speed of 7219 rpm, the step over of 0.069 mm, and the feed rate of 1636 mm/rev.

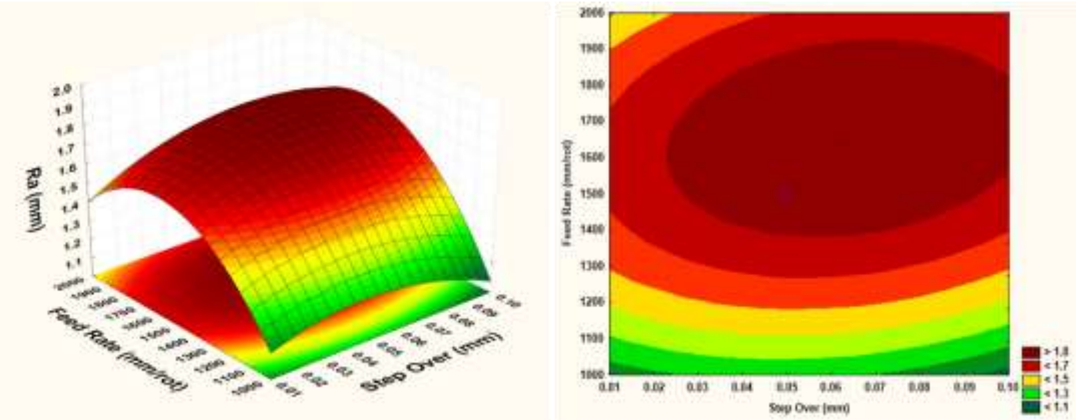

Figure 4(a) Surface plots of surface roughness of the inner acetabular cup: effects of feed rate and step over.

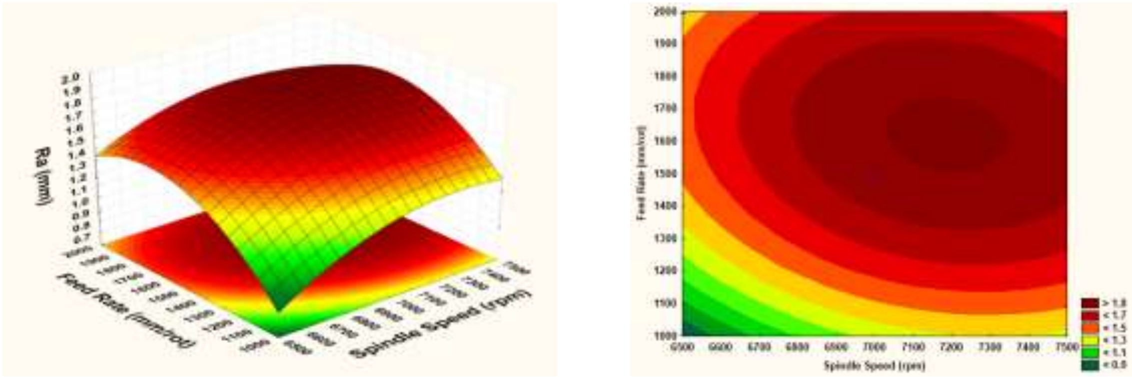

Figure 4(b) Surface plots of surface roughness of the inner acetabular cup: effects of feed rate and spindle speed.

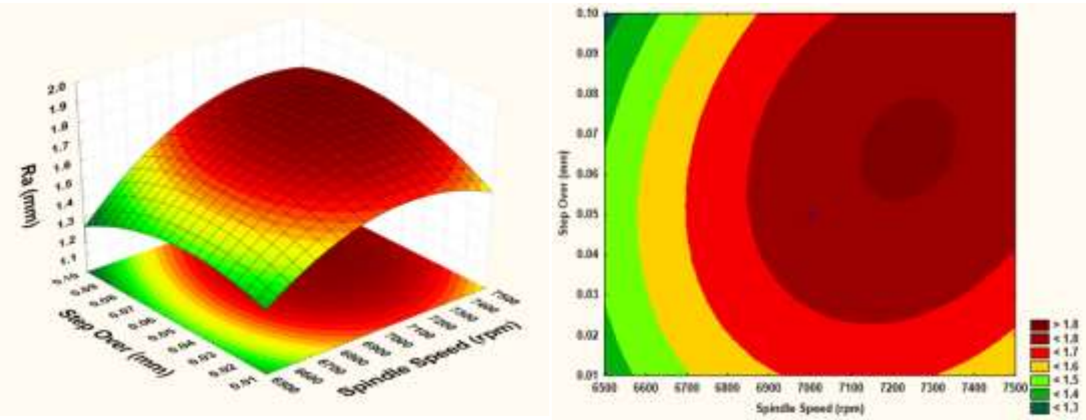

Figure 4(c) Surface plots of surface roughness of the inner acetabular cup: effects of step over and spindle speed.

The feasibility of the response surface quadratic model for the experimental data could be validated by ANOVA as presented in Table 7. Here the first order of step over (C) and its pairwise interactions have substantial effects on the Ra. Conversely, the insignificance of the first order of spindle speed (A), feed rate (B), quadratic of all factors on the roughness parameters is confirmed.

Table 7 ANOVA analysis for the model of Ra

Factor	SS	Df	MS	F	p
A	0.3594	1	0.3594	2.7080	0.1510
A^2	0.3296	1	0.3296	2.4835	0.1661
B	0.5372	1	0.5372	4.0477	0.0909
B^2	1.1051	1	1.1051	8.3265	0.0279
C	0.0107	1	0.0107	0.0803	0.7864
C^2	0.1446	1	0.1446	1.0897	0.3368
AC	0.0419	1	0.0419	0.3155	0.5947
AB	0.0436	1	0.0436	0.3284	0.5874
BC	0.0373	1	0.0373	0.2813	0.6149
Error	0.7963	6	0.1327		
Total SS	2.9421	15			

The quadratic response surface model involves the milling parameters and the surface roughness using the experimental results. Based on the RSM, surface roughness model could be expressed as:

$$Ra\ (\mu m) = -42.9723274 + 0.011142649A - 0.00000075559A^2 - 19.636559383C - 61.20681C^2 + 0.006437484B - 0.00000138B^2 + 0.003207AC - 0.000000295AB + 0.003028384BC \quad (8)$$

With correlation square (R^2 = 98,20%)

The models were examined using a numerical method providing the coefficient of R^2. The SSrsd is the sum of the squares of the residual and SSmodel is the sum of the squares of the model. The response surface models were developed in this study with values of R^2 higher than 80 % (98.20 % for surface roughness). The R^2 values in this case are high and close to 1, which are desirable. Therefore, the coefficients of determination (R^2) imply that mathematical models on Eq. (8) could be used for calculating of the surface roughness.

4. CONCLUSIONS

Based on the machining results, it can be concluded as;

- The better surface roughness of 0.143 µm was found at the different combinations of machining conditions by Taguchi methods. Confirmation tests of Taguchi's optimum results provided the significant reliable results.
- The best variable levels for surface roughness based on the Taguchi method are presented as following: spindle speed at 6500 rpm, feed rate set on 1500 mm/rev and step over was set on 0.1 mm.
- The combination Taguchi and RSM statistical analysis determined that the step over is the most significant factor on the surface roughness (Ra) of the inner acetabular liner with the percent contribution of 98.20 %.
- The Taguchi and RSM could successfully develop and identify of the significant machining factor versus the yield of surface roughness.
- These optimization models of machining parameters can be applied to manufacturing UHMPWE acetabular liner with the required surface roughness and may also reduce the machining cost.

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