Vol. XV & Issue No. 01 January - 2022
INDUSTRIAL ENGINEERING JOURNAL

DEVELOPMENT OF A NOBLE OPTIMIZATION TECHNIQUE FOR MICRO-DRILLING OF AEROSPACE MATERIALS – A CASE STUDY

Dr. Dulu Patnaik

Abstract

The Poly Methyl Meth-Acrylate (PMMA) have resilient corrosion resistance and at below zero temperature, their quality expands, thus making it a valuable low temperature polymer. PMMA has discovered its appropriate utility in aviation application. Mostly micro- drilling operation is used to engineer micro-holes in various materials according to their need. The target of this investigation was to streamline micro-drilling parameters, for example, rotational speed, feed given to tool and point angle on the circularity error, thrust force and machining time in micro-drilling on aerospace material i.e. PMMA. The tests were completed according to Response Surface Methodology based L_{15} orthogonal array. The optimum drilling parameters was determined by using multi-criteria decision making (MCDM) optimization technique. A comparative analysis has been carried out to find out optimal drilling parameters using the two optimization methods.

Keywords: MCDM optimization, Micro Drilling, PMMA, Response Surface Methodology.

1. INTRODUCTION

The PMMA is one of the vital evaluations of transparent thermoplastic having wide designing applications especially in aviation industries and vehicle industries. Micro-drilling is known as the most widely recognized and principal machining process to produce micro holes in different categories. A few execution attributes which are usually utilized for assessing drilling operation, for example, thrust force, torque, hole surface roughness and tool wear, are strongly correlated with the cutting parameters such as cutting speed, feed speed, drill and workpiece material, drill size, drill point angle and coolant conditions. Henceforth, drilling process used for machining PMMA needs precision. The improvement of cutting pace and feed with a specific end goal to acquire great execution qualities is of much significance. It is likewise basic to think about efficiency of material removal rate (MRR), nature of the machined part (surface roughness) and necessity of dimensional steadiness (hole dimensional error) at the same time and streamline the machining parameters as needs be (Bagal, 2012; Jeet et. al, 2019; Dilip, Panda and Mathew, 2020; Pattanayak, Panda and Dhupal, 2020; Ranjan et. al. 2019; Chakraborty, Bhattacharyya and Diyaley, 2019). Amid the present examination, CNC assisted drilling system with carbide drill bit of 1 mm diameter with three different point angles of 118°, 124°, 130°, and 23 mm flute length is used in this investigation. The impact of all the drilling parameters, viz. rotational speed, feed and point angle has been explored on circularity error, thrust force and machining time. In this investigation, tests were completed according to Response Surface Methodology based L_{15} orthogonal array. A comparative analysis has been carried out to find out optimal drilling parameters by using to recent MCDM optimization method i.e. Weighted Aggregated Sum Product Assessment (WASPAS) method and Combined Compromise Solution (CoCoSo) method.

2. EXPERIMENTAL DETAIL AND METHODOLOGY

During the experiment, a plate of PMMA (Poly Methyl Meth-Acrylate) having thickness of 5 mm, length of 85 mm and width of 50 mm was drilled CNC Drill machine (Make: HMT Ltd., Bangalore, India; FANUC controlled) in combination with drill bits of cemented carbide having diameter 1 mm, flute length of 23 mm and three different point angles of 118°, 124°, and 130°. The local circularity error and machining time were measured with the help of JEOL SEM-6480LV machine and stop watch respectively. Table 1 shows the properties of PMMA and Figure 1 shows the experimental set up of the CNC assisted drilling operation (Bagal, 2012; Jeet et. al, 2019). The input factors with three different levels are presented in Table 2.

Table 1. Properties of PMMA

Properties	Value
Compressive strength	83-124 MPa
Elastic Modulus	3300 MPa
Poisson's ratio	0.34-0.4
Modulus of rigidity	1700 MPa
Ultimate tensile strength	45-75 MPa
Modulus of elasticity	5.0 GPa
Refractive index	1.49

Figure 1. Experimental set up of CNC assisted drill

Table 2. Input Factors with three different levels

Factors	Code	Unit	Level 1	Level 2	Level 3
Feed	B	mm/min	20	25	30
Rotational Speed	A	rpm	2000	2500	3000
Point Angle	C	Degrees(°)	118	124	130

Firstly, the work-piece was cut according to mentioned dimension i.e. 85 × 50 × 5 mm by cutter. Then two holes of 8 mm and 12 mm diameter are made by heavy-duty driller to hold the work-piece tightly by the nuts and bolts. After drilling holes in workpiece, it was mounted and fastened on Kistler model 9272A piezoelectric drilling dynamo meter by the help of two bolts and washers. With the aid of G-coding program in a CNC drilling machine, the spindle speed and feed are to be inserted as an input parameter in the micro-drilling operation. The output parameters of thrust force and torque are measured simultaneously which were displayed on monitor of amplifier monitor. The machining time is measured with the care of stop watch. After the micro-drilling process and optimization process, images of holes made by optimal parameter setting were measured by JEOL SEM machine at acceleration voltage of 15 KV and magnification of X50.

2.1. Experimental Design using Response Surface Methodology

Response surface methodology is a collected work of calculated and numerical methods that are compliant for demonstrating and exploration of problems in which output is partial by several input parameters. The investigational values are examined and the scientific model is established which exemplifies the correlation amid the input variable and output response (Jeet et. al, 2019; Bagal, 2012; Jeet et. al, 2018). Equation (i) shows the second-order model which describes the conduct of the method:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i,j=1, i\neq j}^{k} \beta_{ij} X_i X_j + \epsilon \qquad (i)$$

where Y is consistent output response, X_i is response variables, X_{ii}, X_iX_j are squares and collaboration terms in second-order model, respectively. β_0, β_i, β_{ij}, β_{ii} are indefinite regression coefficients and ϵ is error in model.

2.2. Calculation of Weights Between Criterions by Pair-Wise Comparison

Using geometric mean approach of the analytic hierarchy process (AHP) method, relation significance of output responses was determined. For formulating the pair-wise comparison matrix, Saaty's nine-point preference scale was used as shown in Table 3. Output response weights of the experiments were calculated by using following equations.

$$GM_i = \left(\prod_{j=1}^{n} b_{ij}\right)^{1/n} \qquad (ii)$$

$$w_j = GM_i / \sum_{j=1}^{n} GM_i \qquad (iii)$$

Table 3. Pair-wise comparison table between criterions

	Local Circularity Error	Thrust	Machining Time
Local Circularity Error	1	3	3
Thrust	0.3	1	0.3
Machining Time	0.3	3	1

Output response weights were obtained as w = [0.60, 0.27, 0.13]. For three considered output response criteria, random index of 0.58, consistency index and consistency ratio of 0.037 and 0.064 were obtained, respectively. Consistency index and consistency ratio values shows that determination of output response criteria weights is reasonable since for consistency the value of consistency ratio ⩽ 0.10 (Naik et. al., 2019a; Naik et. al., 2019b). The weights obtained for each quality characteristics will be used in the WASPAS and CoCoSo method for optimization of the process parameters.

2.3. Weighted aggregated sum product assessment (WASPAS) method

The chief technique of WASPAS method for solving MCDM problems are (Naik et. al., 2019).

Step 1. Initial decision matrix is set.

Step 2. Decision matrix normalization using following equations (iv) an (v) for maximization and minimization criteria, respectively:

$$\bar{x}_{ij} = x_{ij} / max_i x_{ij} \qquad (iv)$$

$$\bar{x}_{ij} = min_i x_{ij} / x_{ij} \qquad (v)$$

where x_{ij} is the assessment value of i^{th} alternate with respect to j^{th} measure.

Step 3. Calculation of total comparative significance of i^{th} alternate, based on weighted sum method (WSM) using equation (vi):

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} . w_j \qquad (vi)$$

Step 4. Calculation of total comparative significance of i^{th} alternate, based on weighted product method (WPM) using equation (vii):

$$Q_i^{(2)} = \prod_{j=1}^{n} \bar{x}_{ij}^{w_j} \qquad (vii)$$

Step 5. Calculation of total comparative significance of alternatives is done using equation (viii) and ranked from higher value to lower value:

$$Q_i = \lambda . Q_i^{(1)} + (1 - \lambda) . Q_i^{(2)} \qquad (viii)$$

2.4. Combined Compromise Solution (CoCoSo) Method

The following steps are used to solve CoCoSo decision problem (Barua et. al., 2019; Acharya et. al., 2019):

1) Determination of initial decision-making matrix using equation (ix):

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad \text{(ix)}$$

2) Using compromise normalization equation, normalization of criteria values is done: (2) Using compromise normalization equation, normalization of criteria values is done:

$$r_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \quad \text{: for benefit criterion} \quad \text{(x)}$$

$$r_{ij} = \frac{maxx_{ij} - x_{ij}}{maxx_{ij} - minx_{ij}} \quad \text{: for cost criterion} \quad \text{(xi)}$$

3) Determination of total of weighted comparability sequence and the whole of power weight of comparability sequences for each alternative as S_i and P_i, respectively:

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \quad \text{(xii)}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \quad \text{(xiii)}$$

4) Three appraisal score are used to generate relative weights of other options derived using equation (xiv), (xv), (xvi):

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \quad \text{(xiv)}$$

$$k_{ib} = \frac{S_i}{minS_i} + \frac{P_i}{minP_i} \quad \text{(xv)}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{(\lambda max S_i + (1-\lambda) max P_i)} \quad \text{(xvi)}$$

5) The ranking of all alternatives is determined from higher to lower based on k_i values:

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + (k_{ia} + k_{ib} + k_{ic}) \quad \text{(xvii)}$$

3. RESULTS AND DISCUSSION

Samples are prepared by using Response Surface Methodology (RSM) Box Behnken experimental design shown in Table 4. The experimental results are then analysed using MINITAB 18 software. The experimental results for the local circularity error, thrust and machining time are listed in Table 4. Here, the local circularity error was calculated using following formula:

$$Local\ Cirularity\ Error\ (in\ mm) = \frac{D_{avg} - 1\ mm}{1\ mm} \quad \text{(xviii)}$$

Where,

$$D_{avg}\ (in\ mm) = \frac{D_1 - D_2 - D_3}{3} \quad \text{(xix)}$$

and D1, D2, D3 are the diameter of the hole measured from different directions using scanning electron microscope (SEM) images.

Table 4. RSM based Box-Behnken design for experimental runs and results

Run No.	A	B	C	Hole diameter, mm				Local circularity error, mm	Thrust, N	Machining time, sec
				D_1	D_2	D_3	D_{avg}			
1	20	2000	124	1.021	1.023	1.016	1.02	0.02	6.14	23.34
2	30	2000	124	1.030	1.029	1.031	1.03	0.03	9.71	19.29
3	20	3000	124	1.009	1.010	1.011	1.01	0.01	8.29	18.17
4	30	3000	124	1.009	1.010	1.011	1.01	0.01	6.36	14.38
5	20	2500	118	1.021	1.023	1.016	1.02	0.02	4.63	20.47
6	30	2500	118	1.050	1.047	1.053	1.05	0.05	5.05	16.45
7	20	2500	130	1.021	1.023	1.016	1.02	0.02	1.95	23.10
8	30	2500	130	1.009	1.010	1.011	1.01	0.01	3.18	17.15
9	25	2000	118	1.061	1.060	1.059	1.06	0.06	8.74	16.62
10	25	3000	118	1.021	1.023	1.016	1.02	0.02	3.59	9.03
11	25	2000	130	1.021	1.023	1.016	1.02	0.02	2.00	16.82
12	25	3000	130	1.021	1.023	1.016	1.02	0.02	5.86	12.18
13	25	2500	124	1.029	1.029	1.032	1.03	0.03	3.53	18.16
14	25	2500	124	1.031	1.029	1.030	1.03	0.03	3.57	18.23
15	25	2500	124	1.030	1.029	1.031	1.03	0.03	3.61	18.66

3.1. Optimization using WASPAS method

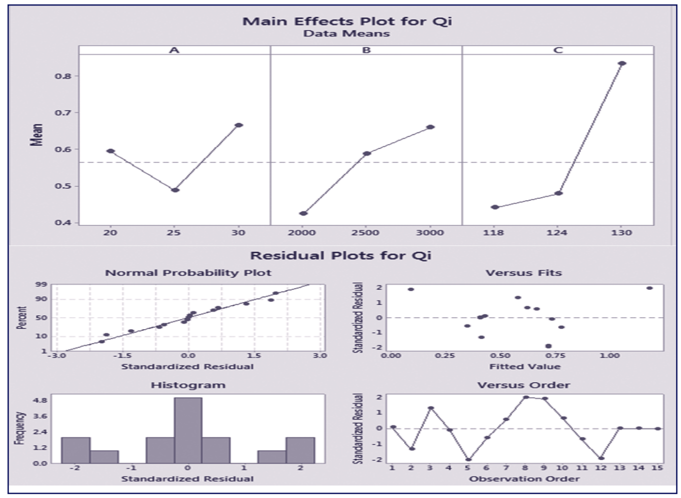
Since semantic terms, employed to express the responses, have already been converted into crisp (real) values, the application of the WASPAS method starts with normalization of the decision matrix by applying equation (iv) since the output has to be maximized. Consequently, total relative significance of alternatives based on WSM and WPM are designed by using equations (vi) and (vii), respectively. Lastly, combined condition of optimally of WASPAS method is calculated by using equation (viii). Table 5 shows the computational particulars of all alternatives using WASPAS method for a λ value of 0.5. The ranking of total comparative significance of alternatives was carried out with respect to its corresponding values.

Table 5. Computational particulars of all alternatives using WASPAS method

Run No.	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i	Rank
1	0.4361	0.4279	0.4320	9
2	0.3151	0.3038	0.3094	13
3	0.7281	0.6178	0.6730	5
4	0.7644	0.6840	0.7242	3
5	0.5712	0.5583	0.5647	8
6	0.3090	0.2902	0.2996	14
7	0.7208	0.6939	0.7074	4
8	1.4343	1.2225	1.3284	1
9	0.2400	0.2215	0.2308	15
10	0.6767	0.6650	0.6709	6
11	0.7331	0.7182	0.7256	2
12	0.5862	0.5603	0.5732	7
13	0.4136	0.4023	0.4080	10
14	0.4119	0.4010	0.4064	11
15	0.4088	0.3986	0.4037	12

From total relative significance values of alternatives, it was detected that investigational results obtained in experiment number. 8 is the best result according to the ranking.

Figure 2. Main effect plot with factors and their levels and Residual Plots for Q_i



Now, the total relative importance of alternatives was used to plot mean effect. Based on this study, one can select a mixture of the levels that provide the smaller average response. In Figure 2, the combination of A2 B1 C1 shows the smallest value of the main effect plot for factors A, B and C respectively. Therefore, A2 B1 C1 i.e. feed of 25 mm/min, rotational speed of 2000 rpm and point angle of 118° is the optimum input parameter combination for micro drilling operation on PMMA.

3.2. Optimization using Combined Compromised Solution

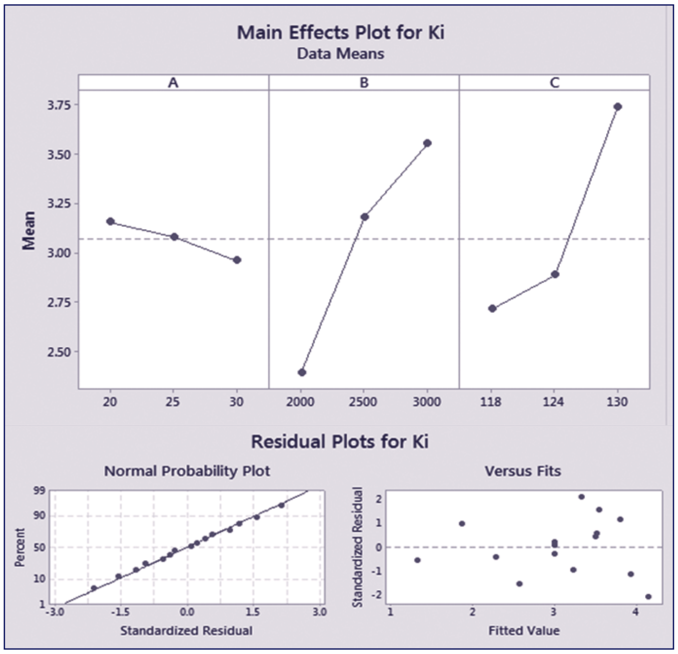
The first step demonstrates forming of the normalized decision-making matrix (using compromise equation (max–min)), which is shown in Table 6. The further step is to generate the comparability sequence matrix. In this process, the weights of decision-making criteria are involved in the algorithm. The S_i and P_i vectors must be generated using formulas (xii) and (xiii), respectively. The values of K_a, K_b, and K_c are calculated using equations (xiv), (xv) and (xvi). Equation (xvii) used to calculate the ranking score by k_i shown in Table 6.

Table 6: Weighted comparability series (S_j), Exponentially weighted comparability sequence (P_i), Final aggregation and CoCoSo ranking of the alternatives

Run no.	S_i	P_i	P_i+S_i	k_{ia}	k_{ib}	k_{ic}	k_i	Rank
1	0.6043	1.6857	2.2900	0.0876	4.9650	0.5948	2.5196	9
2	0.3967	1.5846	1.9813	0.0758	3.5609	0.5146	1.9016	13
3	0.6965	2.5086	3.2051	0.1226	6.0795	0.8324	3.1977	5
4	0.7979	2.7379	3.5357	0.1352	6.8787	0.9183	3.5929	3
5	0.7430	2.6424	3.3854	0.1295	6.4643	0.8793	3.3939	8
6	0.4048	2.2664	2.6712	0.1022	4.0433	0.6938	2.2724	14
7	0.8121	2.5253	3.3374	0.1277	6.8367	0.8668	3.5216	4
8	0.9436	2.9103	3.8539	0.1474	7.9283	1.0009	4.0792	1
9	0.1549	1.7284	1.8832	0.0720	2.0906	0.4891	1.3031	15
10	0.8830	2.8767	3.7597	0.1438	7.5158	0.9765	3.8968	6
11	0.8675	2.8399	3.7074	0.1418	7.3928	0.9629	3.8356	2
12	0.7753	2.7344	3.5097	0.1342	6.7305	0.9115	3.5295	7
13	0.6219	2.5524	3.1744	0.1214	5.6259	0.8245	3.0164	10
14	0.6201	2.5495	3.1695	0.1212	5.6118	0.8232	3.0097	11
15	0.6148	2.5379	3.1526	0.1206	5.5703	0.8188	2.9892	12

From Table 6, for a particular values of input parameter in experiment number 8 has the highest k_i value. Therefore, experiment number 8 is an optimal parameter combination for micro drilling of PMMA according to CoCoSo technique optimization.

Figure 3. Main effect plot with factors and their levels and Residual Plots for K_i



Now the k_i values of alternatives were used to plot mean effect. Based on this study, one can select a mixture of the levels that provide the smaller average response. In Figure 3, the combination of A3 B1 C1 shows the smallest value of the main effect plot for factors A, B and C respectively. Therefore, A3 B1 C1 i.e. feed of 30 mm/min, rotational speed of 2000 rpm and point angle of 118° is the optimum input parameter arrangement for micro drilling operation on PMMA.

3.3. Most influential factor

Table 7 gives the results of the Analysis of Variance (ANOVA) for the local circularity error, thrust and machining time using the calculated values from the total relative importance of alternatives of Table 5. According to Table 7, factor C, point angle with 30.21 % of contribution, is the most significant controlled parameters for the CNC micro drilling followed by factor B, rotational speed with 10.92 % and factor A, feed with 0.99 % of contribution if the minimization of local circularity error, thrust and machining time are simultaneously considered.

S=0.151481, R-sq=88.73 %, R-sq (adj)=68.45 %, R-sq (pred)=0.00 %

Table 7. ANOVA result for Q_i

Source	DOF	Adj SS	Adj MS	F-test	P-test	% Contribution
Model	9	0.9033	0.1003	4.37	0.059	88.73
Linear	3	0.4289	0.1429	6.23	0.038	42.13
A	1	0.0101	0.0101	0.44	0.536	0.99
B	1	0.1112	0.1112	4.85	0.079	10.92
C	1	0.3075	0.3075	13.40	0.015	30.21
Square	3	0.1827	0.0609	2.66	0.160	17.95
A*A	1	0.0850	0.0850	3.71	0.112	8.35
B*B	1	0.0019	0.0019	0.09	0.781	0.19
C*C	1	0.1032	0.1032	4.50	0.087	10.14
2-Way Interaction	3	0.2916	0.0972	4.24	0.077	28.64
A*B	1	0.0075	0.0075	0.33	0.591	0.74
A*C	1	0.1962	0.1962	8.55	0.033	19.27
B*C	1	0.0877	0.0877	3.82	0.108	8.61
Error	5	0.1147	0.0229			11.27
Lack-of-Fit	3	0.1147	0.0382	8096.14	0.000	11.27
Pure Error	2	0.0000	0.0000			0.00
Total	14	1.0180				

Table 8 gives the results of ANOVA for the local circularity error, thrust and machining time using the calculated values from the k_i of alternatives of Table 6. According to Table 7, factor B, rotational speed with 31.75 %, is the most significant controlled parameters for the CNC micro drilling followed by factor C, point angle with 24.61 % of contribution and factor A, feed with 0.99 % of contribution if the minimization of local circularity error, thrust and machining time are simultaneously considered.

S=0.0669844, R-sq=99.74 %, R-sq (adj)=99.26 %, R-sq (pred)=95.86 %

Table 8. ANOVA result for k_i

Source	DOF	Adj SS	Adj MS	F-test	P-test	% Contribution
Model	9	8.5147	0.9460	210.85	0.000	99.74
Linear	3	4.8892	1.6297	363.22	0.000	57.27
A	1	0.0773	0.0773	17.24	0.009	0.91
B	1	2.7109	2.7109	604.19	0.000	31.75
C	1	2.1009	2.1009	468.24	0.000	24.61
Square	3	0.5617	0.1872	41.74	0.001	6.58
A*A	1	0.0006	0.0006	0.15	0.718	0.01
B*B	1	0.1316	0.1316	29.34	0.003	1.54
C*C	1	0.3899	0.3899	86.91	0.000	4.57
2-Way Interaction	3	3.0637	1.0212	227.60	0.000	35.89
A*B	1	0.2566	0.2566	57.20	0.001	3.01
A*C	1	0.7048	0.7048	157.09	0.000	8.26
B*C	1	2.1022	2.1022	468.52	0.000	24.62
Error	5	0.0224	0.0044			0.26
Lack-of-Fit	3	0.0220	0.0073	36.57	0.027	0.26
Pure Error	2	0.0004	0.0002			0.00
Total	14	8.5371				

3.4. Confirmatory experiment

To confirm the enhancement of output quality features after finding the best level of input parameters, a confirmatory experiment is performed. The total relative importance of alternatives estimated using the formulae given in equation (xx).

where a_{2m} and b_{1m} are specific mean values of both Q_i and k_i with optimal equal values of each constraints and μ_{mean} is the total mean of total Q_i and k_i of alternatives.

$$\mu_{predicted} = a_{2m} + b_{1m} - 3\mu_{mean} \quad \text{(xx)}$$

Table 9. Initial and optimal level performance

Optimum input parameter setting	Predicted Ideal range	Predicted Optimum value*	Experimental Optimum value*
A2B1C1	$-0.2492 < Q_i < 0.4252$	0.0879	0.2308
A3B1C1	$2.1370 < k_i < 2.4353$	2.2862	2.2740
*Significant at 95 % confidence interval			

4. CONCLUSION

The properties of input parameters i.e. feed, rotational speed and point angle experimentally studied throughout micro drilling of PMMA using CNC drilling process. Two different optimization methods i.e. WASPAS and CoCoSo methods based on the RSM table was employed to improve the micro-drilling process parameters. Based on the outcomes of the present study, the following inferences are shown:

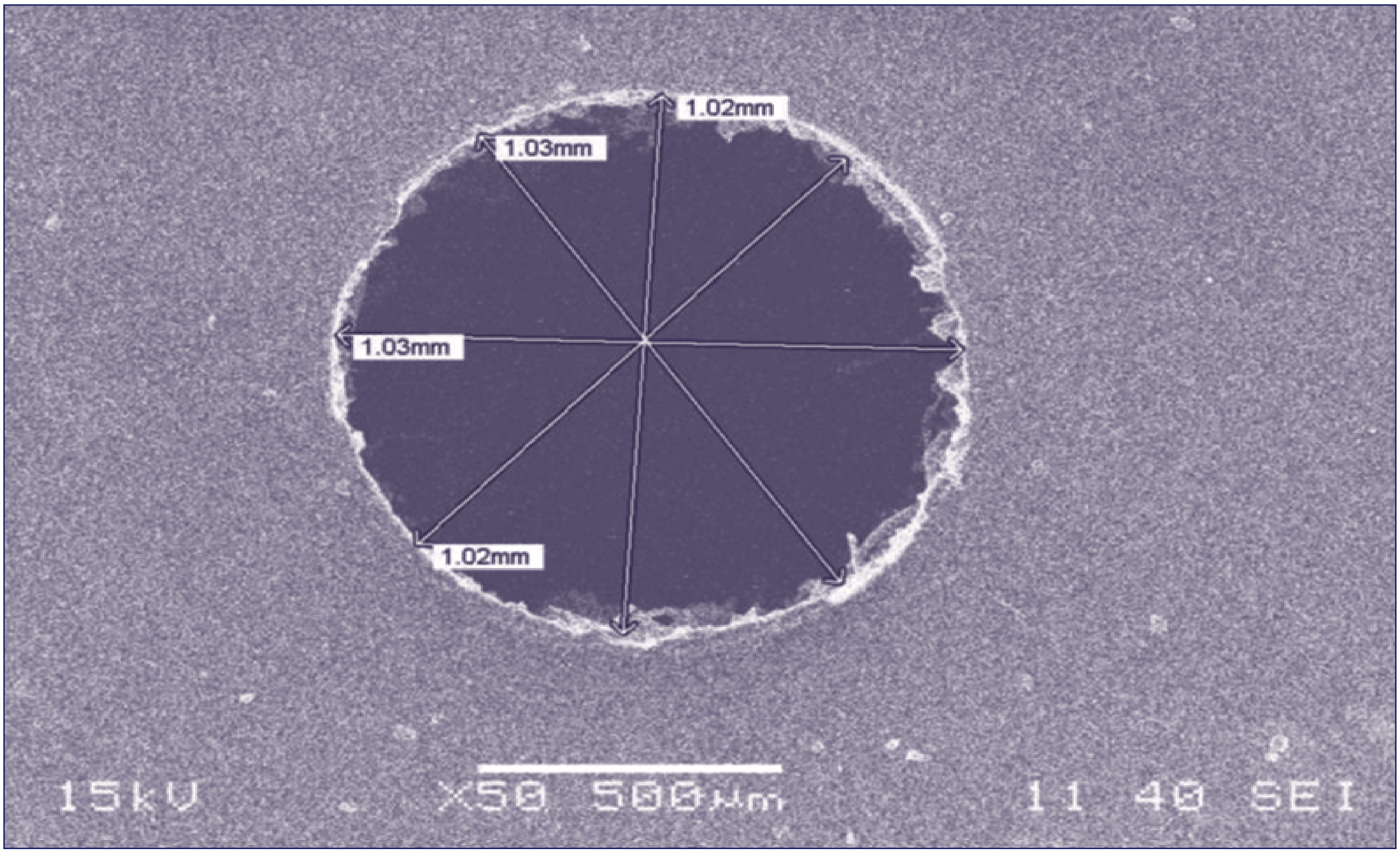
•The optimal setting of input parameters for turning using different approaches are shown in Table 10.

Table 10. Optimal factor setting using different optimization techniques

Algorithm	A	B	C
WASPAS	30 mm/min	2500 rpm	130^0
RSM-WASPAS	25 mm/min	2000 rpm	118^0
CoCoSo	30 mm/min	2500 rpm	130^0
RSM- CoCoSo	30 mm/min	2000 rpm	118^0

• Based on the ANOVA result it is found that RSM- CoCoSo method gives the optimal factor since R-square value is about 99 %, which is higher than the R-square value of RSM-WASPAS method. Figure 4 shows the SEM image of micro hole at feed 30 mm/min, speed 2000 rpm and point angle 118°.

Figure 4. SEM image at feed 30 mm/min, speed 2000 rpm and point angle 118°



- From ANOVA analysis for RSM- CoCoSo method, rotational speed with 31.75 %, is the most significant controlled parameters for the CNC micro drilling followed by point angle with 24.61 % of contribution and feed with 0.99 % of contribution if the minimization of local circularity error, thrust and machining time are simultaneously considered.
- Confirmatory experiment was done at feed rate of 30 mm/min, spindle speed of 2000 rpm and point angle of 118° which mollifies the actual necessities of the determined ideal settings in micro-drilling operation of PMMA.

5. REFERENCES

[1] *Bagal, D.K. (2012) 'Experimental investigation and modelling micro drilling operation of aerospace material', B. Tech Dissertation. National Institute of Technology, Rourkela, Odisha, p1-47.*

[2] *Jeet, S., Barua, A., Bagal, D.K., Pattanaik, A.K., Agrawal, P.K. and Panda, S.N. (2019) 'Multi-parametric optimization during drilling of aerospace alloy (UNS A97068) using hybrid RSM-GRA, GA and SA', International Journal of Management, Technology and Engineering, 9(2), p2501-2509.*

[3] *Dilip, D.G., Panda, S. and Mathew, J. (2020) 'Characterization and parametric optimization of micro-hole surfaces in micro-EDM drilling on Inconel 718 superalloy using Genetic Algorithm', Arabian Journal for Science and Engineering, p1-18. https://doi.org/10.1007/s13369-019-04325-4.*

[4] *Pattanayak, S., Panda, S. and Dhupal, D. (2020) 'Laser micro drilling of 316L stainless steel orthopedic implant: A Study', Journal of Manufacturing Processes, 52, p220-234.*

[5] *Jeet, S., Barua, A., Parida, B., Sahoo, B.B. and Bagal, D.K. (2018) 'Multi-objective optimization of welding parameters in GMAW for stainless steel and low carbon steel using hybrid RSM-TOPSIS-GA-SA approach', International Journal of Technical Innovation in Modern Engineering & Science, 4(8), p683-692.*

[6] *Ranjan, J., Patra, K., Szalay, T., Mia, M., Gupta, M.K., Song, Q., Krolczyk, G., Chudy, R., Pashnyov, V.A. and Pimenov, D.Y. (2020) 'Artificial Intelligence-based hole quality prediction in micro-drilling using multiple sensors', Sensors 20(885), p1-41.*

[7] *Chakraborty, S., Bhattacharyya, B. and Diyaley, S. (2019) 'Applications of optimization techniques for parametric analysis of non-traditional machining processes: A Review', Management Science Letters, 9(3), p467-494.*

[8] *Bagal, D.K., Barua, A., Jeet, S., Satapathy, P. and Patnaik, D. (2019) 'MCDM optimization of parameters for wire-EDM machined stainless steel using hybrid RSM-TOPSIS, Genetic Algorithm and Simulated Annealing', International Journal of Engineering and Advanced Technology, 9(1), p366-371.*

[9] *Naik, B., Paul, S., Barua, A., Jeet, S. and Bagal, D.K. (2019) 'Fabrication and strength analysis of hybrid jute-*

glass-silk fibre polymer composites based on hybrid Taguchi-WASPAS Method', International Journal of Management, Technology and Engineering, 9, p3472-3479.

[10] *Naik, B., Paul, S., Mishra, S.P., Rout, S.P., Barua, A. and Bagal, D.K. (2019) 'Performance analysis of M40 Grade concrete by partial replacement of Portland Pozzolana cement with marble powder and fly ash using Taguchi-EDAS method', Journal of Applied Science and Computations 6, p733-743.*

[11] *Barua, A., Jeet, S., Bagal, D.K., Satapathy, P. and Agrawal, P.K. (2019) 'Evaluation of mechanical behavior of hybrid natural fiber reinforced Nano SiC particles composite using hybrid Taguchi- CoCoSo Method', International Journal of Innovative Technology and Exploring Engineering, 8(10), p3341-3345.*

[12] *Acharya, K.K., Murmu, K.K., Bagal, D.K. and Pattanaik, A.K. (2019) 'Optimization of the process parameters of dissimilar welded joints in FSSW welding process of aluminum alloy with copper alloy using Taguchi optimization technique', International Journal of Applied Engineering Research, 14(13), p54-60.*

6. ACKNOWLEDGEMENTS

The Author would like to thank to Dilip Kumar Bagal and Central Workshop of National Institute of Technology, Rourkela, Odisha for helping in preparation of specimen and measurement of outcomes for completion of this research.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

8. AUTHOR CONTRIBUTIONS

Dulu Patnaik contributed to designing, analysing and drafting the manuscript.

9. DATA AVAILABILITY

The working data set used for this study has been cited in this article.

10. ETHICAL APPROVAL

The author commits the ethical approval for this article.

11. FUNDING

There is no funding for this study.

AUTHOR

Dr. Dulu Patnaik, Principal-Cum-Professor, Department of Electrical Engineering, Government College of Engineering, Kalahandi, Bandopala Post-Risigaon, Bhawanipatna – 766 002, (Odisha)
Email: dulupatnaikgcek@gmail.com / patnaik_d@yahoo.com