Parametric Optimization of Conventional Micro-Drilling Operation of PMMA

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Abstract

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Conventional micro-drilling is an emerging technology to drill micro-holes in all types of materials. This is having a very vital role for micro-drilling electrically non-conducting material, where micro-EDM operation cannot be applied. In the present investigation, parametric optimization of micro-drilling of Polymethyl methanacrylate (PMMA) using HSS drill bit has been carried out using grey-Taguchi method, WPCA and PCA based TOPSIS Method. PMMA is used a potential aerospace material which is electrically non-conducting in nature.

Keywords: Micro drilling, Taguchi method, circularity error, burr height.

1. Introduction

Conventional micro-drilling is a very stable process, unlike other micro-drilling process micro-edm, micro-ecm and laser drilling etc. The added advantage of the process is that any electrically non-conducting material can be drilled by this process. In view of this advantage of the process, a number of investigators have started investigating the conventional micro-drilling process for different tool and work-piece combinations. This process is very essential for aerospace, watch manufacturing, automotive, bio-medical and electronic sectors. Especially drilling plays a predominant role in the industries for assembly related to mechanical fasteners. It is reported that around 55000 holes are drilled as a complete single unit production of the airbus A350 aircraft[1]. With increasing demand for precise micro-components, the importance of micro-hole drilling process is increasing rapidly to achieve a high aspect ratio with minimum hole diameter. Chen W. S. [2] has investigated the performance of micro-drill by examining the wear. The aspect ratio of hole achieved is of the order of 17.5 with minimum diameter as 0.457mm. The printed circuit board was taken as the work-material. Boris Stim et al[3] investigated the burr formation in aluminium alloy and steel using drill bit size , and . The process parameters are drill bit diameter, feed and cutting speed. The judging criteria are burr type and burr size. Dong-woo kim minimized the thrust force in the step-feed micro-drilling process using design of experiment based on orthogonal array. The process parameters considered are feed rate, step-feed and spindle rpm. The 2mm deep hole was drilled and thrust force was measured using a piezoelectric dynamometer of Kistler Make (9257A). Azim Abdul Rahmm et al[4] investigated the effect of machining parameters on hole quality of micro-drilling for brass. The machinability criteria are material removal rate, surface roughness, burr formation and dimensional accuracy. The influence of feed rate, spindle speed and drill bit diameter on machinability criteria are studied. It is observed that spindle speed and feed rate mostly affect the tool wear and size of the burr on the edges of the hole. Hyun-Ho et al[5] investigated the micro-drilling operation of glass using a machine vision system. The carbide and diamond drill bits of 0.3mm diameter are used for drilling the holes in the glass of 1mm thick. The hole quality and the wear of the drill bit has been monitored. PMMA is having high strength, low density and better thermal stability. Conventional mechanical drilling of PMMA has to face increasing physical limitation when hole diameter is decreased. Below some critical dimensions, friction surpass the mechanical strength of the tool and the machining is possible only by choosing specially designed tools made of high modulus material such as diamond and coated carbide. So optimization of process parameters plays a critical role for the drilling of 1mm hole in PMMA strip with HSS as drill bit material.

In the present investigation the optimization of microdrilling operation of PMMA (Polymethylacrylate) has been carried out using full factorial design for different drilling speed and feed.

PMMA is an important amorphous thermoplastic with desirable properties including clarity (the transparency being close to the ultraviolet and infra-red region), chemical resistance, good mouldability, protection against ultraviolet radiation, good weather ability, high strength and dimensional stability[6, 7].

2. Experimentation

The experiment has been conducted in a radial drilling specimen with the experimental set-up as shown in Fig.1. The technical specifications are as given in Table1. The dynamometer was mounted over machine bed having T-slot with the help of T-bolts of 10mm diameter and 80mm length. PMMA workpiece was mounted on the dynamometer with the help of two bolts having specifications M8 15. The thrust force was measured with the help of dynamometer connected to multi-channel charged amplifier. The circularity and the burr size were measured using scanning electron microscope. The experiments were completed for two parameters and three levels as orthogonal array due to

Fig. 1. Experimental setup

Table 1. Technical specifications

Parameters	Specifications
Drill bit diameter	1 mm
Workpeice	Poly (methyl methacrylate 9530*4 mm)
Dynamometer	Kistler co. (9272 A)
Amplifier	Kistler co. (5070 A)
Feed (mm/rev)	0.12, 0.20, 0.30
Spindle speed(rpm)	80, 150, 300

3. Taguchi method

Taguchi Analysis is one of the efficient tools for manufacturing design. Taguchi's method shows an integration of design of experiments with optimizing of parameters to set the required result. Taguchi's signal to noise ratio (S/N ratio) which are logarithm functions of required output serve as intended functions of optimization. It may be defined as the ratio of mean value (signal) to that of standard deviation (noise).

The objective function is in this work is to maximize the S/N ratio and is defined according to Taguchi method.

$$\frac{S}{N}\text{Ratio} = -10 \log \left[\frac{1}{n}\sum_{1}^{n}\frac{1}{Yi^2}\right] \quad (1)$$

3. Theory of Grey Relational Analysis

Grey-based Taguchi approach for process optimization has been carried out to solve this multi-response optimization problem.

Steps In Grey relational analysis are as follows:

Step1: Finding out the experimental Data Table.

Step-2: Generation of Grey Relational. That means normalized the values ranging from 0-1 using the formula

$$Xi(k) = \frac{\max yi(k) - yi(k)}{\max yi(k) - \min yi(k)} \text{ for Lower the better}$$

$$Xi(k) = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min yi(k)} \text{ For higher the better}$$

………. (2)

where Xi(k)= Value after Grey relational generation

Min Yi(k)= minimum of Yi(k) for kth Response

Max Yi(k)= maximum of Yi(k) for kth Response

Step-3: Calculation of Grey relation Co-efficient using formula:

$$\epsilon_i(k) = \frac{\Delta min + \varphi\Delta max}{\Delta 0i(k) + \varphi\Delta max}$$

\ (3)

where = Δ0i(k) = |xo(k) – xi(k)| =Difference between absolute Values of xo(k) and xi(k).

Step-4: Finding out the grey Relational grade (mean of grey Co-efficient of each variable at ith run).Now the overall performance of multiple response process depends upon the calculated grey relational grade. This approach converts a multiple response optimization situation with the objective function in overall grey relational grade.

Step-5: Evaluation of optimal parametric combination which would result maximum overall grey relational grade. The optimal factor setting for maximum overall grey relational grade can be performed by the Taguchi's method.

$$\text{S/N ratio} = -10 \log \left[\frac{1}{n}\sum_{1}^{n}\frac{1}{yi2}\right] \text{ for LB} \quad (4)$$

Step-6: Then plotting the response table and response graph we can find out the optimum settings of different parameters

4. Results and discussion

In the experiment for micro-drilling operation the thrust force, circularity error and burr size are measured by varying the RPM and feed in three levels. Total nine sets of experiments have been conducted. The values of cutting speed and feed as taken in three levels are indicated in Table 2.

Table 2. Cutting speed and feed

Factors	Notation s/unit	Code	Level of factors		
			1	2	3
Feed	S(mm/ rev)	A	0.1 2	0.2 0	0.30
Spindle speed	N(rpm)	B	80	150	300

The normalized experimental data for thrust force, circularity error and burr size are given in Table 3. For all the three performance characteristics, lower the better (LB) has been selected. Grey relational co-efficient for each performance characteristics have been evaluated using equation 4.

Table 3. Grey Relational Generations

Run Order	**Thrust Force**	**Circularity**	**Burr Size**
Ideal Sequence	1	1	1
1	0.636	0.857	0.571
2	0.697	0.857	0.381
3	1	0.857	1
4	0.151	0.571	0.524
5	0.697	1	0.857
6	0.939	0.857	0.714
7	0	0.857	0.904
8	0.935	0.571	0.714
9	0.151	0	0

The Grey relational co-efficient of each performance characteristics (with ψ=0.5) is given in Table 4.

Table 4. Grey relational coefficient of each performance characteristics (with ψ=0.5)

Run Order	Thrust Force	Circularity	Burr Size
Ideal Sequence	1	1	1
1	0.578	0.777	0.538
2	0.622	0.777	0.447
3	1	0.777	1
4	0.371	0.538	0.512
5	0.622	1	0.777
6	0.891	0.777	0.636
7	0.333	0.777	0.839
8	0.885	0.538	0.636
9	0.370	0.333	0.333

The multiple response optimizations are converted into a single objective function in overall grey relational grade. The results are tabulated in Table 5.

Table 5. Grey relational grades

Run Order	Grey relational grade
1	0.631
2	0.615
3	0.925
4	0.473
5	0.799
6	0.768
7	0.649
8	0.686
9	0.345

Higher the value of grey relational grade, the corresponding combination is close to the optimum one. The mean response table is shown in Table 6 and graphs are shown in Fig. 3.

Table 6. Response table (mean) for overall Grey relational grade

Factor	**Grey Relational Grade**		
	Level 1	**Level 2**	**Level 3**
Feed(S)	0.793	.681	.489
Speed(N)	.680	.65	.633
Total Mean Grey relational grade=0.654			

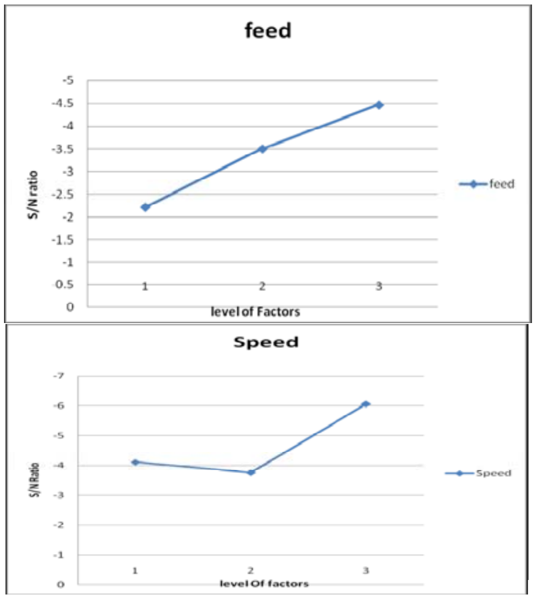

Fig.3. S/N ratio plot for overall Grey relational grade

5. WPCA ANALYSIS

Table 7 Response Table for Means

Level	feed	speed
1	-0.6582	-0.5461
2	-0.6413	-0.6370
3	-0.4290	-0.5455
Delta	0.2292	0.0915
Rank	1	2

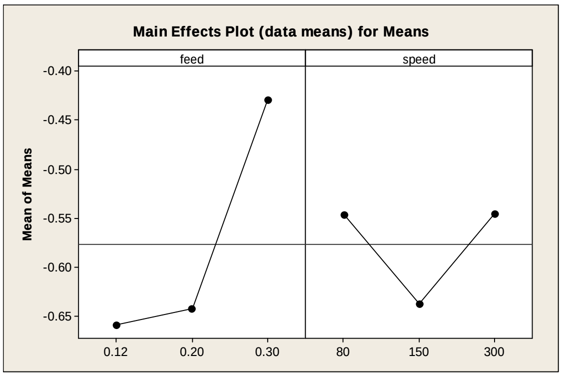

Fig4.mean effect plot

6. PCA combined with Grey Taguchi Analysis

Table 8 Response Table for Means

Level	feed	speed
1	0.6432	0.4541
2	0.5948	0.6280
3	0.4898	0.6456
Delta	0.1533	0.1916
Rank	2	1

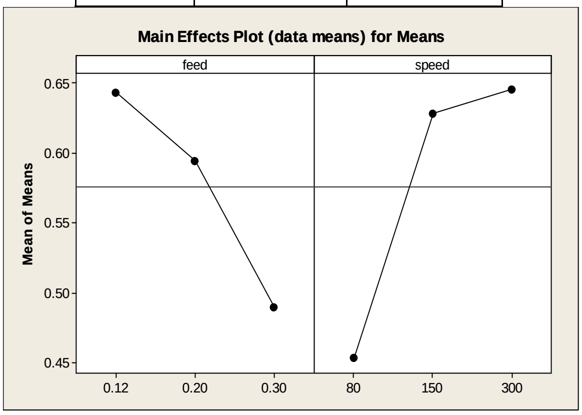

Fig5. Main effects plot for data mean

7. PCA based TOPSIS method

Table 9 Response Table for Means

Level	feed	speed
1	0.3284	0.4385
2	0.3584	0.3403
3	0.5462	0.4542
Delta	0.2178	0.1139
Rank	1	2

Referring to Fig.4 and Table 7 (weighted principal component analysis) the optimization parameters for minimizing burr size, thrust force and circularity error are same as the grey taguchi method (feed =0.3mm/rev and N=300RPM). Referring to Table 8 and Fig.5 the optimum value of feed as per grey Taguchi combined with PCA reduces to 0.12mm/rev. As per PCA based TOPSIS method referring to Fig6 and Table 9 the optimum parameters are same as earlier.

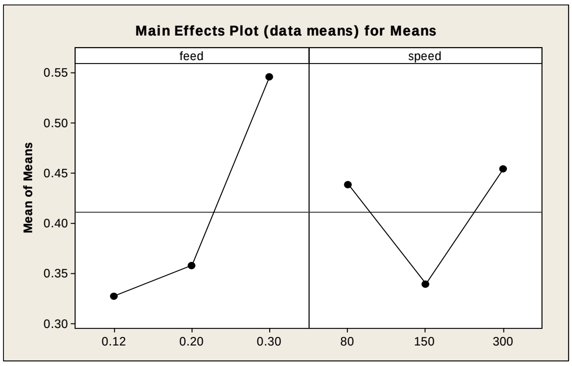

Fig.6 Main effects plot for data mean

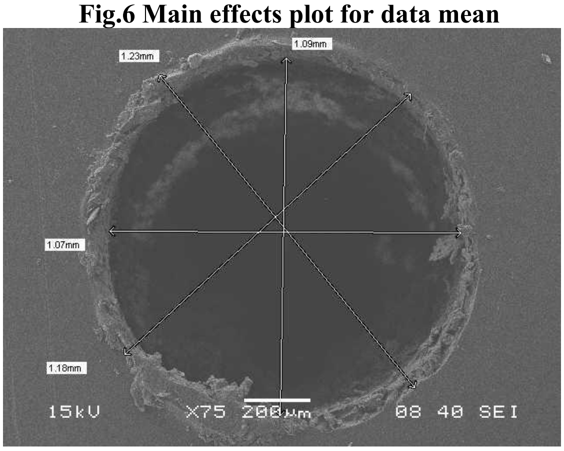

Fig. 3.1 (Micro hole at Feed=0.20mm/rev Speed= 300 rpm)

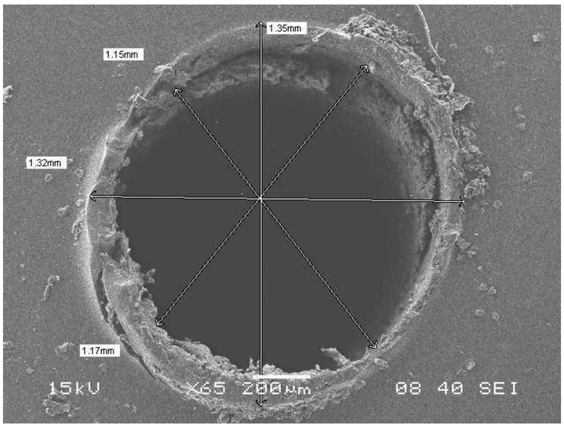

Fig. 3.2 (Micro hole at Feed=0.20mm/rev Speed= 150 rpm)

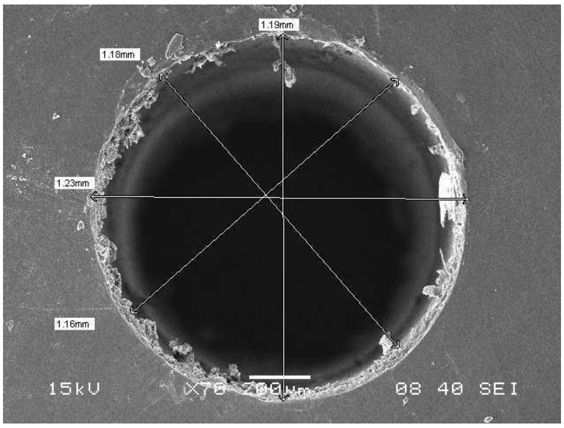

Fig. 3.3 (Micro hole atFeed=0.12mm/rev
Speed= 300 rpm)

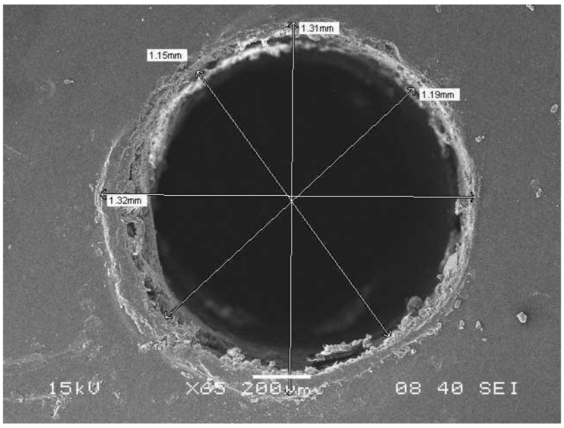

Fig. 3.4 (Micro hole atFeed=0.30mm/rev
Speed= 80 rpm)

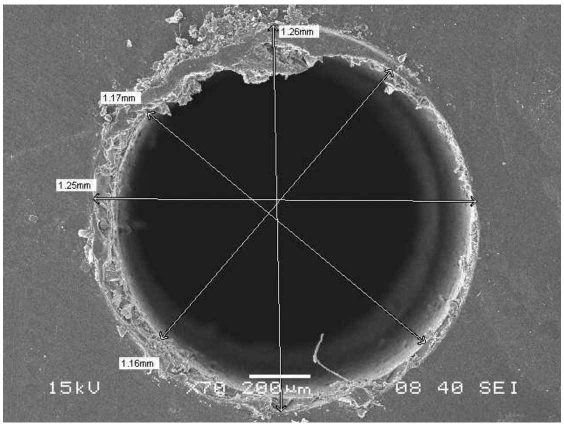

Fig. 3.5 (Micro hole atFeed=0.20mm/rev
Speed= 80 rpm)

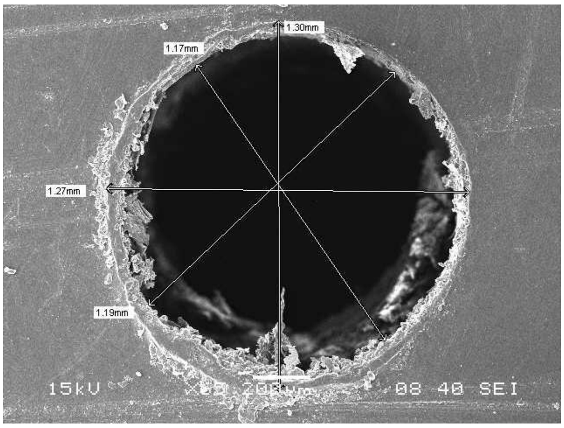

Fig. 3.6 (Micro hole at Feed=0.12mm/rev
Speed= 80 rpm)

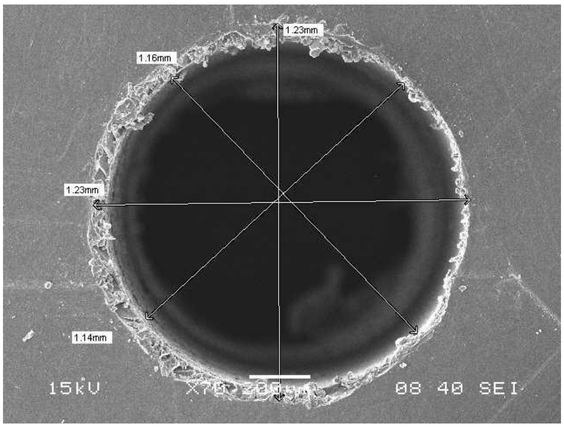

Fig. 3.7 (Micro hole at Feed=0.30mm/rev
Speed= 150 rpm)

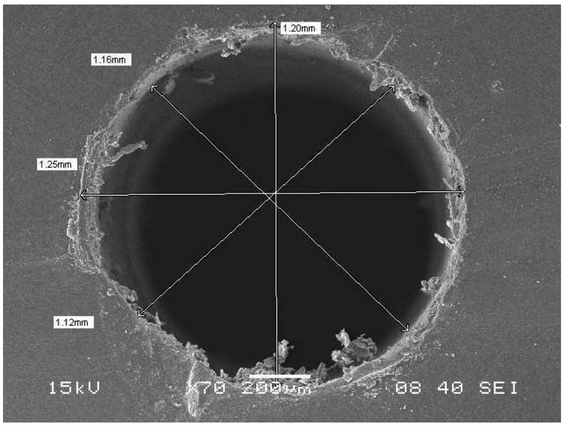

Fig. 3.8 (Micro hole at Feed=0.12mm/rev
Speed= 150 rpm)

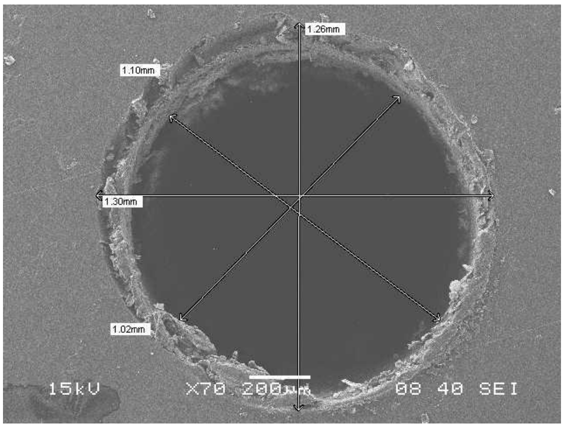

Fig. 3.9 (Micro hole at Feed=0.30mm/rev Speed= 300 rpm)

8. Conclusions

1. The micro-drilling of PMMA work-material has been carried out using a HSS drill bit of 1mm size.
2. The minimization of drilling thrust, circularity error and reducing the burr size has been carried out using Grey taguchi method , weighted principal component analysis, Grey Taguchi combined with PCA and PCA based TOPSIS method considering feed and rpm of spindle.
3. The optimal value of process parameters is found to be 0.3mm/rev and 300rpm. But in case og grey Taguchi combined with PCA the optimum value of feed reduces to 0.12mm/revolution.

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