Optimization of Machining Parameters During Micro Milling Process on PTFE Material

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Abstract - *The Micro milling method is viewed as a non-traditional method to meet growing demands. It is used to optimize machining parameters on polytetrafluoroethylene. To create micro channels on PTFE using a hyper 15 synergy Nano-machine and HSS two flute 0.6 mm diameter end mill. PTFE has excellent chemical resistant, thermal stability, low coefficient of friction, resistance to water properties, making it suitable for use in the automobile, microelectronics, micro fluidic, and aerospace applications. In this paper, optimized machining parameters are considered with proper depth of cut, speed, and feed to examine the impact on the material removable rate, cutting force components, and dimension deviation using the Taguchi approach. In addition, the experimental results were analysed by using ANOVA. Moreover, the MRR raises as the depth of cut and feed rate are increased. The reduction in the parameters such as depth of cut along with feed rate causes decrease in the cutting forces such as Fx, Fy, and Fz. Also, the dimension deviation reduces with a reduction in feed rate.*

Key Words: **polytetrafluoroethylene, micro milling, cutting force, Kistler mini dynamometer, MRR.**

1. INTRODUCTION

The Micro-milling machining method is generally utilized for aerospace, automotive, medical, precision mould, toys, and other industries to produce micro components or parts. Micro milling is a process that makes small-scale phenomenon which makes more complex. Micro milling is a precise and reliable method for producing 3D complex features compared to additive manufacturing, etching, electroplating, and embossing. In this paper, End milling is performed on a vertical milling 'c' frame type centre where 0.6 mm end mill cutter, depth of cut, cutting speed, and feed are input parameters where output terminals MRR, cutting force components, and dimension deviation are output responses. The accuracy and efficiency of micro feature parts are affected by these process parameters. Since accurate milling quality affects tool life, fatigue strength, corrosion resistance, and overall productivity, accuracy is critical for the production of micro channels. According to the research study, a mini Kistler dynamometer and Dino lite digital microscope instruments are used to achieve the best MRR, cutting force elements, and dimension deviation. PTFE (polytetrafluoroethylene) is a flexible polymer that has been used since 1938. Polytetrafluoroethylene gives excellent properties to apply for microelectronics, biomedical, automobile, aerospace, micro fluidic applications. There are many uses of PTFE in industrial and consumer applications. PTFE has a lot of applications for miniature sensors, biomedical engineering, micro-channels, micro-fluidics, and miniature actuators. PTFE is also used to make containers and pipes because it is anti-corrosive and non-reactive.

2. LITERATURE REVIEW

The literature review indicates that very few researchers explored little research work of micro-milling on PTFE material, so Optimization required.

Kim and Park [1] conducted an experiment on PTFE properties. The depth of cut, spindle speed, and feed rate in 1D groove machining are used to obtain the response variables of roughness and straightness. He found that the best combination was 15000 RPM is spindle speed, 172 mm/min is feed rate, and 15μm is depth-of-cut.

Hira and Yoshioka [2] used PTFE to create a micro fluidic machine to use in a Micro-Total Analysis System. He discovered the best machining conditions and a method to avoid burr generation.

I. Justin Antony Raj et al. [3] carried out experiments using a Taguchi L_9 Orthogonal array design on micro-turning with the use of various response parameters, as well as its combinations. For example, cutting depth, cutting speed, and feed as well as optimized, response parameters for metal removal rate.

Ansari et al. [4] studied the turning of PTFE composites and determined the impact of cutting parameters such as insertion radius for machinability measured by parameters such as different cutting forces and roughness value. In addition,

Suhail used a Kastler Piezoelectric Dynamometer and found out leading forces. Also, the results were evaluated by considering the ratio of S/N, evaluation of variance, and grey relational examination.

Warlu G. et al. [7] studied the PTFE is low confident friction, high thermal stability, low load-bearing capacity, high elongation crystalline polymer material and their applications.

3. METHODOLOGY

3.1 Experimental Setup

The micro-machining setup of synergy nano 'c' column vertical center is used to experiment with micro-milling on PTFE shown in Fig 1. Fig 2 shows the micro-milling setup with dynamometer.

Fig 1. Experimental micro milling setup

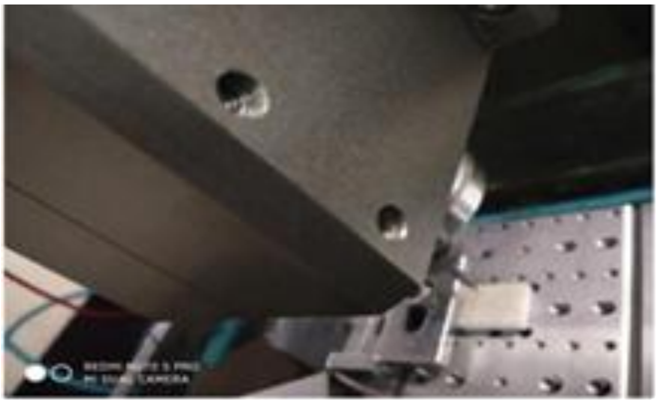

Fig 2. Actual performance image

The workpiece is placed on top of the stationary dynamometer, which is located on the machine tool table. The workpiece is bolted directly onto the dynamometer to reduce the mass on the dynamometer and thereby mitigate the negative impact on its dynamics. 50*50*5mm workpiece select for experimentation.

3.2 Trial Experimentation

According to trial experimentation, generating burr during micro milling process is mentioned in Table 1.

Table -1: Trial experiment

Sr.No	Work Piece	Dino lite Images	Burr Generation
1			Large amount
2			Less amount

Table -2: Results of the trial experiment

Expt. No.	Speed (rpm)	Feed (mm/ min)	DoC (mm)	MRR (mm³/ min)	Cutting force (N)			Dim. Deviation (mm)
					Fx	Fy	Fz	
1	900	10	0.05	0.31	0.365	0.405	1.431	0.032
2	1800	50	0.15	5.42	0.681	0.816	3.600	0.124
3	1500	85	0.05	2.67	0.618	1.053	0.464	0.029
4	2000	90	0.15	8.24	0.054	0.018	0.895	0.011
5	2500	95	0.1	5.78	0.031	0.101	0.057	0.009

Table 2. Shows that hands-on trial experiment readings. It is noticed that whenever feed rate was higher inside means above 90 mm/min, then burr generation reduced. Also, MRR increases when the depth of cut increases. Fx component is less contribute, accordingly Fy and Fz is most contributing for micro-milling. Here with speed and feed increase, dimension deviation was decreases. When the depth of cut increases, a slightly change in width and also cutting force increases.

3.3 Experimental technique:

i. Parameter selection

According to research study and trail experience parameter levels and parameters selected, mentioned in Table 3.

Table -3: Parameter selection

Sr.No	Input	1	2	3
1	**Speed (rpm)**	900	1800	2700
2	**Feed (mm/min)**	10	50	90
3	**Depth of cut(mm)**	50	100	150

ii. Tool selection

PTFE is a one of the plastic material, 6mm “HSS” ‘2 Flute’ type end mill cutter mostly used because of spiral type chips are created when experimentation and these are not easily come out from tool tooth’s.

iii. Design of experiment

DoE is a statistical procedure for process design improvement and solving problems occurring during the production of parts. Design of Experiments is an experimental strategy for examining the effect of multiple factors on the output. Taguchi has formulated a systematic method to the Design of Experiments method to improve the product quality and processes shown in Table 4.

iv. L_9 orthogonal array:

Table -4: Taguchi L_9 Array

Sr. No.	Speed (rpm)	Feed (mm/min)	DoC (mm)
1	900	10	0.05
2	900	50	0.10
3	900	90	0.15
4	1800	10	0.10
5	1800	50	0.15
6	1800	90	0.05
7	2700	10	0.15
8	2700	50	0.05
9	2700	90	0.10

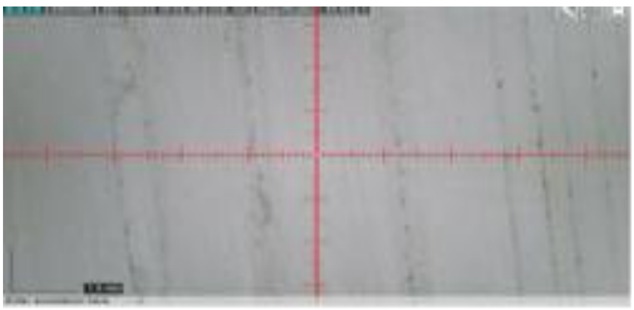

Fig 3. After experiments and dino lite image

After The experimentation the workpiece checked by the Dino lite and check width of the channels for calculating dimension deviation shown in Fig 3.

4. RESULTS AND ANALYSIS

Table -5: Results of the L_9 array experiment

Array	Feed	Speed	DoC	Cutting forces			MRR	Dim. Deviations
	mm/min	rpm	mm	Fx (N)	Fy (N)	Fz (N)	mm^3/min	%
1	10	900	0.05	0.36	0.40	1.43	0.349	5.5
2	50	900	0.10	0.73	0.50	2.31	3.95	5
3	90	900	015	0.89	0.69	4.10	8.424	4
4	10	1800	0.10	0.83	0.57	2.52	0.643	7.1
5	50	1800	0.15	0.68	0.81	3.11	4.13	13
6	90	1800	0.05	0.35	0.41	2.72	2.97	10
7	10	2700	0.15	0.72	0.85	2.50	0.957	6
8	50	2700	005	0.38	0.44	2.47	1.577	6.3
9	90	2700	0.10	0.53	0.5	3.18	5.841	10

5. RESULT AND DISCUSSION

In this trial experiment, nine experiments completed using Taguchi L_9array. Results were obtained for MRR, cutting force and dimension deviation (Ref. Table 5). In addition, in this experiment, Minitab is used, which is statistical software. The statistical analysis of all the outcomes of trial runs was analyzed using ANOVA.

5.1. Graph of the MRR

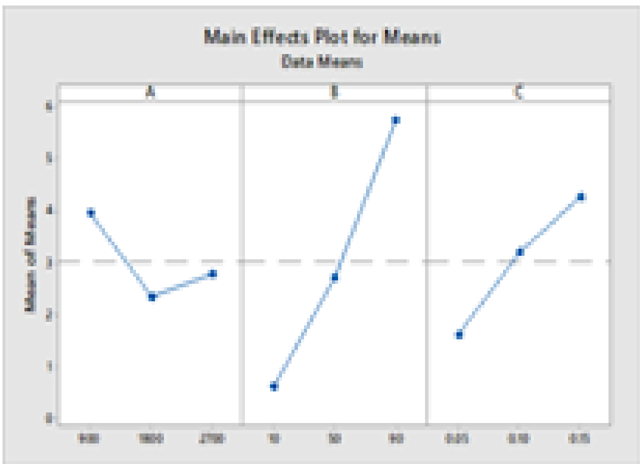

Fig 4. MRR, Main effect plots

5.2. Graph of the cutting force Fx

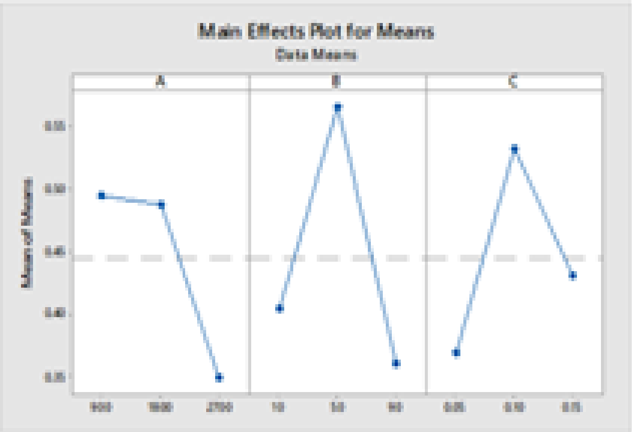

Fig 5. Cutting Force Fx

5.3. Graph of the Fy:

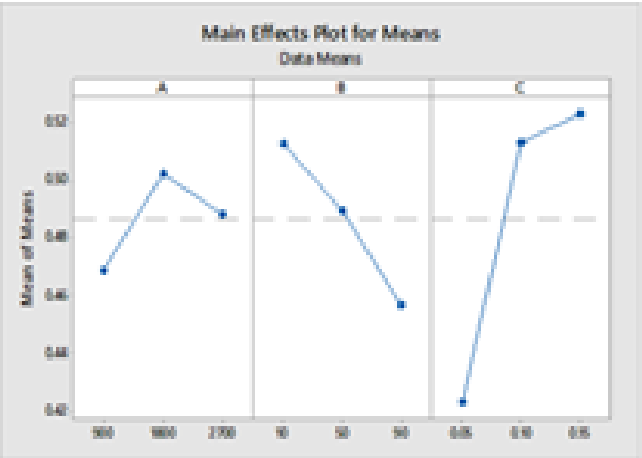

Fig 6. Cutting Force Fy

5.4. Graph of the Fz:

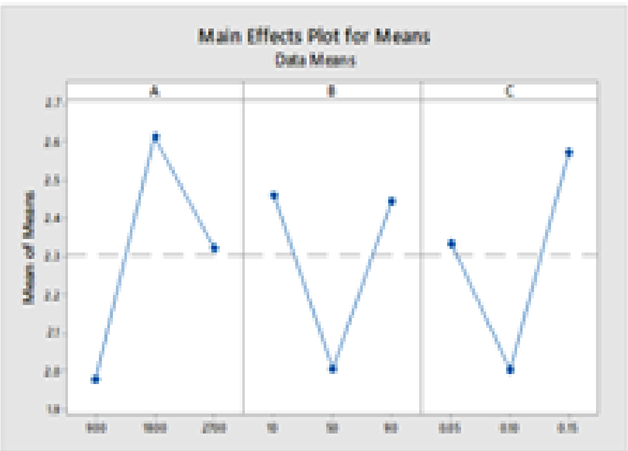

Fig 7. Cutting Force Fz,

5.5. Graph of the dimension deviation

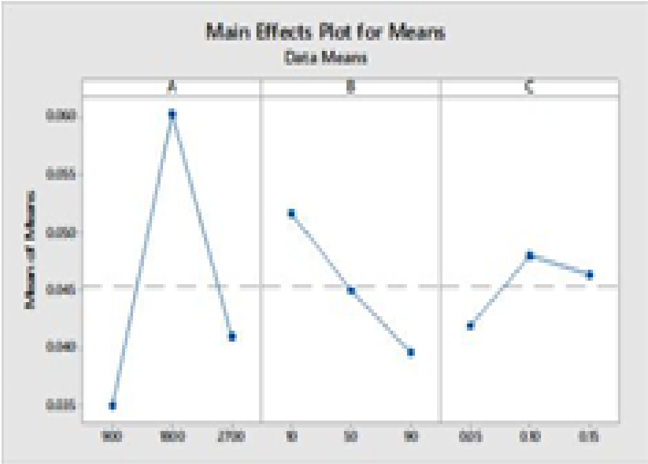

Fig 8. Dimension deviation, Main Effect Plot

Table -6: ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed (A)	2	4.171	2.086	1.85	0.237
Feed (B)	2	39.602	19.801	17.59	0.038
DOC (C)	2	10.645	5.322	4.73	0.107
Error	2	2.251	1.126		
Total	8	56.668			

Fig.4 shows the main effect plot for MRR. The trend observed for feed rate is increasing MRR increases. According to ANOVA (Table 6.), the most significant factor observed is Feed Rate. According to MRR, the formula of Q is directly proportional to the depth of cut, the width of the channel, and Feed. Thus, the value of MRR rises with rise in feed rate and depth of cut. Optimum set is Feed=90mm/min, Depth of Cut=0.15mm, Speed = 900 rpm

Table -7: ANOVA for cutting force component Fx

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed (A)	2	0.040891	0.020445	15.76	0.060
Feed (B)	2	0.070371	0.035185	27.12	0.036
DOC (C)	2	0.040967	0.020483	15.79	0.060
Error	2	0.002595	0.001297		
Total	8	0.154824			

The decrease in cutting depth and speed of the spindle reduces, the force Fx. According to the ANOVA table (Ref.

Table 7) Feed rate is the most significant factor. Cutting forces overcome the resistance to rotations, so the depth of cut was low then less energy consumed, and also low frictional forces coming on the tool when the speed and feed increase. According to the main effect plot, optimum set is speed= 2700 rpm, feed = 90 mm/min, and the depth of cut is 0.05 mm.

Table -8: ANOVA for cutting force component Fy

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed (A)	2	0.004604	0.002302	1.63	0.054
Feed (B)	2	0.012162	0.006081	4.30	0.124
DOC (C)	2	0.001336	0.000668	0.47	0.003
Error	2	0.002827	0.001413		
Total	8	0.020928			

The decrease in depth of cut and speed of the spindle reduces the force Fy. According to ANOVA table (Ref. Table 8), the depth of cut is most important factor. Also, the cutting force decreases when the cutting depth and speed was decreases, according to the dynamometer axis direction, Fy is feed force. Fy direction frictional force increases when increases DoC. Optimum set is depth of cut=0.05mm, speed=900rpm, and feed=90mm/min.

Table -9: ANOVA for cutting force component Fz

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed (A)	2	0.004604	0.002302	1.63	0.380
Feed (B)	2	0.12162	0.006081	4.75	0.189
DOC (C)	2	0.001336	0.000668	3.47	0.679
Error	2	0.002827	0.001413		
Total	8	0.020928			

The decrease in the feed rate and depth of cut causes reduction in force component Fz. According to ANOVA table (Ref. Table 9), a significant factor has been not found. In addition, whenever a larger DOC value is given, cutting force increases. This might affect machining performance and causes vibration. So, higher forces observed in Fz component, the optimum set is speed =900 rpm, feed =50 mm/min, and DOC is 0.10 mm

Table -10: ANOVA for dimension deviation

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed (A)	2	0.001052	0.000526	1.04	0.491
Feed (B)	2	0.000217	0.000108	0.21	0.824
DOC (C)	2	0.000058	0.000029	0.06	0.946
Error	2	0.001014	0.000507		
Total	8	0.002340			

When spindle speed and feed decrease, decrease dimension deviation. The significant factor has been not found. Increases feed and speed results on the channel, width increases. Due to spindle vibration and soft material properties as compared to metal, dimension deviation increases. Also, optimum set is speed =900 rpm, depth of cut= 0.05mm and feed =90 mm/min.

6. CONCLUSION

1. The research was concluded the optimization of machining parameters on the MRR, cutting force, dimension deviation during micro milling on PTFE. The main effect plot for MRR and ANOVA shows, the value of MRR raises when feed and DOC increases and optimum combination set is depth of cut 0.15mm, the feed rate 90 mm/min, and the spindle speed 900 rpm.

2. According to the main effect plot and ANOVA analysis, Fx cutting force component increases when there is increase in feed rate. Optimum set found was DOC 0.05 mm, feed rate 90 mm/min and speed of the spindle 2700 rpm. Fy component is increases when there is increase in depth of cut. Optimum set found was the depth of cut 0.05 mm and feed rate 90 mm/min and spindle speed of 900 rpm. The cutting force component Fz could not found a significant factor. The optimum set observed was depth of cut 0.10mm, feed rate 50 mm/min and spindle speed 900 rpm.

3. According to the main effect plot for dimension deviation, the optimum set is depth of cut 0.05mm, and feed rate 90mm/min and speed 900rpm.

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