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Effect of Ultrasonic Machining Parameters on Drilling of Steatite Ceramic Composite

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Abstract: Ultrasonic machining (USM) is the mechanical material removal process. It is used to produce the holes on different type of material like glass, ceramic, Aluminium, titanium, zirconium and many other hard or brittle work Material with using shaped tools, high frequency mechanical motion, pressure, amplitude and abrasive slurry. Material which are very difficult to drill is done by ultrasonic machining. It is conventional machining process. Ultrasonic machining process is non-thermal, non-chemical, creates no change in the microstructure, chemical or physical properties of the work material. The current work aims to study the Effects of Ultrasonic machining parameters on drilling of steatite ceramic composite. In this experiment, Steatite ceramic composite are used as the experimental material. The 5 mm thick steatite ceramic tablet is use as work material which is mostly use in electric insulator, cathode ray tube (CRD), ceramic heaters and burner. The process parameters have been taken as the amplitude, Pressure and different size of abrasive particles. The trial drilling experiments were performed to find out the range of process parameters for detail experiment. Based on the range obtained by trial experiments, three levels of abrasive particle size, Amplitude and pressure were selected for detailed experimentation. Detailed experiment was performs on the basis of full factorial design of experiment method. The response parameter like Material removal rate (MRR), taper and radial overcut (ROC) were measured and analyzed. The main effect plots were generated for find out the effect of process parameter on response parameter at each level. The Analysis of Variance (ANOVA) was performed to find out the percentage contribution of each process parameters on response parameter with using Minitab software.

Keywords*: steatite ceramic composite, ANOVA, DOE, Ultrasonic Machining (USM) Process Parameter, full factorial design of experiment method etc.*

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1. INTRODUCTION

Ultrasonic machining is old machining process whose basis was laid way back in 1927 and was patented by L. Balamuth in 1945.

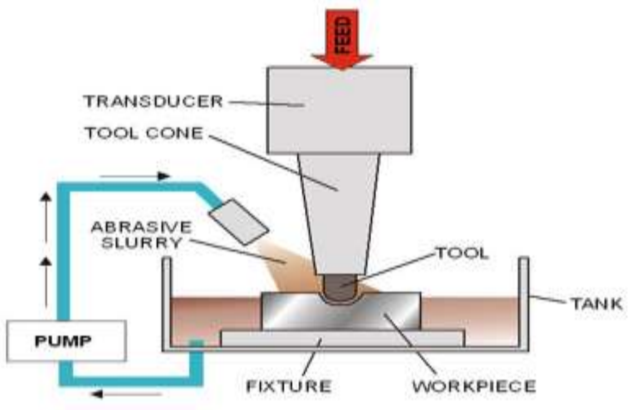

Fig-1: Schematic Diagram of ultrasonic machining

It is a technology that has attained a recognized status in manufacturing technology and found increasing applications in industries including aerospace, optics, and automotive [11]. Ultrasonic machining is manufacturing process that removes material from the surface of a part through high frequency, low amplitude vibrations of a tool against the material surface in the presence of fine abrasive particles Fig. 1 Shows the Schematic diagram of ultrasonic machining. The actual cutting is performed either by abrasive particles suspended in a fluid, or by a rotating diamond-plated tool [3]. Tool of desired shape vibrates at ultrasonic frequency (19 to 25 kHz.) with an amplitude of 15-50 Microns over work piece[12]. USM is used for machining hard and brittle materials. Typical work piece materials being machined in various investigations include glass, silicon, and alumina [3].

2. LITURETURE REVIEW

Guodong Li et al[1] find that surface roughness, could be identify the material removal modes of quartz crystal by micro USM. When the surface roughness is less than 350nm, the machined surface by micro USM is smooth, indicating ductile machining. The machined surface is covered with sharp tips and cracks. Material removal mode is Depend on the material removal mechanism in the machining process. In USM, the material removal is dominated by brittle mode while the ductile mode does exist in machining. To find the material removal mode it is impotent to analyze the monograph. When the roughness value is less than 350mm, the machined surface by micro USM is relatively smooth.

Sandeep Kuriakose et al[2] used metallic glass as the work material. They investigate the effect of over cut, edge deviation, taper angle, MRR and tool wear rate with using the parameter abrasive size, feed rate and constriction of slurry. They measure the edge of the scanning electron micro scope. They find that machining of metallic glass does not change the property of material. Machining of metallic glass is very high with low tool wear rate and also very less over cut and taper is zero.

Manjot S.Cheema et al[3] conduct the work on the borosilicate glass. They study the effect of tool material, abrasive size and feed in micro channels in ultrasonic machining on borosilicate glass. Development of micro channels using ultrasonic micromachining was reported. It is observed that tungsten carbide tool provided a better form of accuracy in comparison to the micro channel machined in stainless steel tool. The tool wear mechanism in both materials is finding out by considering scanning electron micrographs of the tool as evidence. Micro channel width increased with use of larger abrasive particles size. However the depth of the micro channel was mainly dependent upon the step feed of the tool. Tool wear can be dived in three zones like working gap, prevails at the edges of the tool, lateral gap.

Kai Ding et al[4] In this experiment Carbon fibre reinforced silicon carbide matrix (C/Sic) composites is the work material. They investigate the effect of ultrasonic vibration on the tool exit quality and surface roughness. They find that drilling force and torque decrees with increase of spindle speed. Surface roughness is determined by the porosity of ceramic matrix. Lower surface roughness occur similar operating condition.

S.DAS et al[5] investigate effect of process parameter on material removal rat and over cut on top side of larger diameter of hole and smaller diameter of the hall. From the experiment they conclude that abrasive grain diameter and power rating are the most effected parameter on the MRR and overcut. If grain diameter are larger than material removal rate is high and if smaller the grain diameter then MRR is small. If slurry concentration is high then MRR is high and if slurry concentration is smaller than MRR is less.

W. Peia et al[6] In this study, experiments are carried out to investigate the influence of abrasive particles on the profile of machined surface by USM. Difference between the bottom profile of micro-holes and tool diameter, amplitude of ultrasonic vibration and tool feed depth. It was observed that bottom of micro holes are almost convex except the conditions of tool. The number of abrasive particles in the centre of a micro hole increases, resulting in the increase of the material removal When the diameter of a micro tool decreases to the 200μm, bottom profiles of micro-holes become concave, with the exception of conditions using abrasive particles of 3μm in size and tool feed depth of 50μm. It was found that the abrasive particles move towards to the centre of machining area during vibration of tool .When vibration of Amplitude increases, the moving speed of particle increases, resulting in concave bottom shape. Using a tool with a small diameter, the time of a abrasive particle moving to the centre is short than using of large size tool. Profile is affected by amplitude of vibration.

Sreenidhi Cherk et al[7] used silicon wafer as the work material. They investigate that it is the abrasive particles in the slurry which in turn hit the work piece and chip away the material from it. The vibrations given to the work piece is refreshing the slurry so that fresh abrasive particles are in contact with the work piece and also in removing the material from the tool work piece gap. In machining with fine sized grains MRR increases with the increase in the abrasive particles size due to increase in the number of particles involved in the machining. The influence of process parameters such as slurry medium, slurry concentration, and abrasive particle size on the performance of micro USM Material Removal Rate (MRR) and Surface Roughness is observed. From the experimental study that machining with use of water based slurry is suitable only for finer particles sizes with higher concentration or medium particles sizes with medium concentration or coarser particle sizes with lower particles where as machining with oil based slurry is always suitable for all size of the particles with low concentration.

Zu yuan Yu et al[8] investigate that Ultrasonic Machining (USM) is used to generate micro features in hard and brittle materials. In this paper, low cycle fatigue is identified as the dominant factor causing tool wear in micro USM. A theoretical model is proposed to estimate the tool wear. Experimental results of tungsten and stainless steel 316L is same with the theoretical values. The tool rotation has no most significant influence on tool wear. The difference between the experimental and theoretical results is sensitive to the variance of abrasive particle number in the working zone. A theoretical model was proposed to estimate the rate of tool wear. Experimental results of tungsten and stainless steel 316L as tool materials agree well with the theoretical values. It was also found and prove that in the case of small diameter tool and large sized particles, large errors are easily generated because of the variance of particle numbers in the working area. They are also easily generated due to measurement error of tool wear length when using large diameter tools in micro USM. The tool rotation has insignificant influence on the tool wear.

Chandra Nath et al[9] find that adverse effects of this inherent removal phenomena on the hole integrity such as entrance chipping, wall roughness and subsurface damage. It also presents the material removal mechanism happens in the gap between the tool periphery and the hole wall (called ‘lateral gap’). They also realized that the radial and the lateral cracks formed due to adjacent abrasives, which are under the tool face, extends towards radial direction of the hole resulting in entrance chipping. The angle penetration and the rolling actions of the abrasives, which are at point of the tool, contribute to the entrance chipping. It is also find that size of small grit size increase the good hole quality.

Shri krushna B.Bhosale et al[10] Perform experimental investigation and analysis of material removal rate, tool wear rate, and surface roughness in ultrasonic machining of alumina- zirconium ceramic composite (Al2O3 + ZrO2). The experiments were conducted using full factorial DOE method with an L8 orthogonal array. The effects of amplitude, slurry concentration and slurry type on the above responses were investigated. Analysis of results indicates that the amplitude has significant effect on the MRR and surface roughness .An increase in amplitude causes higher MRR and surface roughness. It is observed that the amplitude and slurry type both have statistically significant effect on the material removal rate (MRR). The slurry concentration has lesser effect on the tool wear rate and amplitude has more significant effect. It is observed that the amplitude has most significant effect on surface roughness. An increase in the amplitude increases the surface roughness. The machined surface show the alterations such as micro cavities, plastically deformed layers and fragments of zirconium present on the surface.

3. EXPERIMENTATION

3.1 Material

For current study, 5 mm thickness steatite ceramic composite was use as the work material. Steatite is a crystalline form of magnesium silicate. It has low loss, low cost, insulating material which can function safely at temperature up to 2000 °F. Steatite ceramic is mostly used for insulation in electrical and electronic Industries. This ceramic has low die electric loss. Steatite ceramic composite has good mechanical strength. Steatite ceramic composite has been also used in aero space application and some automobile parts. And electro technical instrument like cathode ray tube.

Composition	**Al**	**Si**	**Mg**	**O**	**c**	**NA**
Percentage	0.98	27.20	4.33	42.25	24.27	0.97

Table-1: Composition of steatite ceramic composite

3.2 Machine

The experiments have been conducted using 2.0 KW Power Ultrasonic – USP – 2500 / MPS – 2 ultrasonic machines. This Machine also called as ultrasonic drill press. This press is built with welded box structure (sheet steel with welded–in ribs). This press is built with rigidity combined with minimum weight. The base is made of aluminium chill casting incorporating a ribbed design to ensure high stability. The feed unit, precise piston and force sensor is movable over feed–length of 100 mm. At the end of the cylinder is aluminium mounting which holds the converter – booster –sonotrode combination. Amplitude–regulated power system (ARP) based generator is used for generating high frequency supply for the converter. This generator, termed as SG–22, has automatic frequency control ensuring automatic correction for changes. Converter used in this machine is PZT based converter coded as SE–50/40– 4–20 KHz.

Fig-2: Machine Setup

3.3 Experiment Run

Full factorial design of experiment method is used for perform the experiment.Three process parameter (Abrasive size, Amplitude, pressure) was selected for this study. From the result of trail experiment, the three level of abrasive size (220, 320, 500), Amplitude (70, 80, 90) and pressure (4, 4.5, 5 bar) was select. MRR was measure by weighting equipment. Taper and radial over cut measure by measuring microscope.

Run	**Abrasive size**	**Amplitude**	**Pressure**	**MRR**	**Radial over cut**	**Taper**
				gm	**mm**	**mm**
1	220	70	4.0	0.0646	0.3530	0.03623

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2	220	70	4.5	0.0467	0.3765	0.04381
3	220	70	5.0	0.0530	0.4200	0.04507
4	220	80	4.0	0.0540	0.1280	0.00631
5	220	80	4.5	0.0654	0.1350	0.03787
6	220	80	5.0	0.0543	0.8680	0.01691
7	220	90	4.0	0.0530	0.4200	0.02184
8	220	90	4.5	0.0916	0.4530	0.01388
9	220	90	5.0	0.0833	0.8815	0.17462
10	320	70	4.0	0.0592	0.4765	0.00088
11	320	70	4.5	0.0681	0.5600	0.00505
12	320	70	5.0	0.0764	0.6150	0.00075
13	320	80	4.0	0.0548	0.5815	0.00921
14	320	80	4.5	0.0598	0.8350	0.12714
15	320	80	5.0	0.0579	0.9115	0.20416
16	320	90	4.0	0.0772	0.9103	0.20744
17	320	90	4.5	0.0688	1.1115	0.01136
18	320	90	5.0	0.0698	0.9200	0.17626
19	500	70	4.0	0.0593	0.7100	0.08005
20	500	70	4.5	0.0589	0.9911	0.21338
21	500	70	5.0	0.0625	1.1600	0.23447
22	500	80	4.0	0.0724	0.7400	0.01174
23	500	80	4.5	0.0933	1.1480	0.26085
24	500	80	5.0	0.0993	1.1810	0.07361
25	500	90	4.0	0.0802	0.6600	0.31237
26	500	90	4.5	0.0842	1.0230	0.04962
27	500	90	5.0	0.1065	1.2150	0.08257

Table-2: Observation Table

Fig-3: Steatite Work Peace after Drilling

4. MAIN EFFECT PLOT

4.1 Main effect plot for MRR

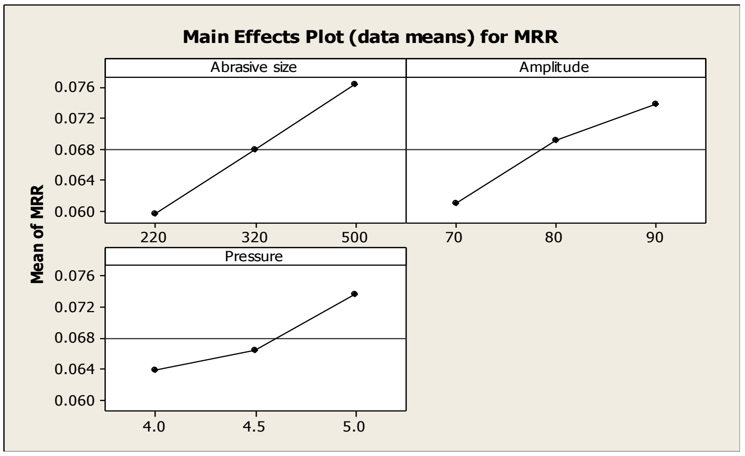

Fig-4: Main effect plot for MRR

From the main effect plot in fig 4 and ANOVA table 3 it is observed that amplitude shows the most significant parameter for material removal rate (MRR). When increase the amplitude MRR increase because higher momentum generated at the abrasive particle and then after string on the work peace that generated the crack on the work peace and MRR increase. Second most significant parameter for MRR is abrasive size. If the abrasive grain size is large than impact force Reduce and MRR decrease. Hear grain size are small because of this MRR is high. Pressure shows less significant effect on MRR. With increase in pressure abrasive particle impact force increase because of this increase the MRR.

4.2 Main effect Plot for Radial over cut

From the fig 5 and ANOVA table 4, it is observed that abrasive size shows the most significant effect on the radial over cut. By increasing the abrasive size radial over cut increase because continues flow of abrasive slurry on the tip of tool. This continues flow of abrasive slurry make cavitation on the tool tip and overcut produced. Second significant effect on radial over cut is pressure if we increase pressure its linearly increase the over cut because with increasing pressure impact force of abrasive particle increase that make crake on the work surface and due to this crack radial overcut generate and third significant effect on radial over cut is amplitude if increase the amplitude increase radial over cut because it give higher momentum to abrasive particle before string on the work peace this higher momentum increase the impact energy because of this higher impact energy crack generated and radial over cut produce.

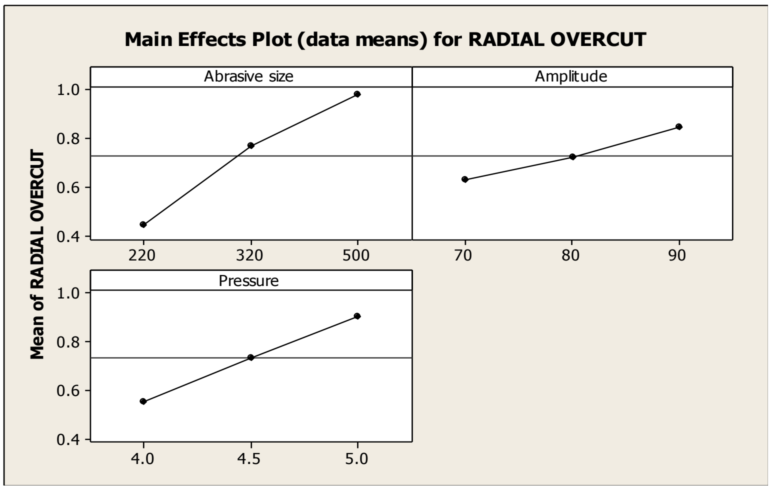

Fig-5: Main effect Plot for Radial over cut

4.3 Main effect plot for Taper

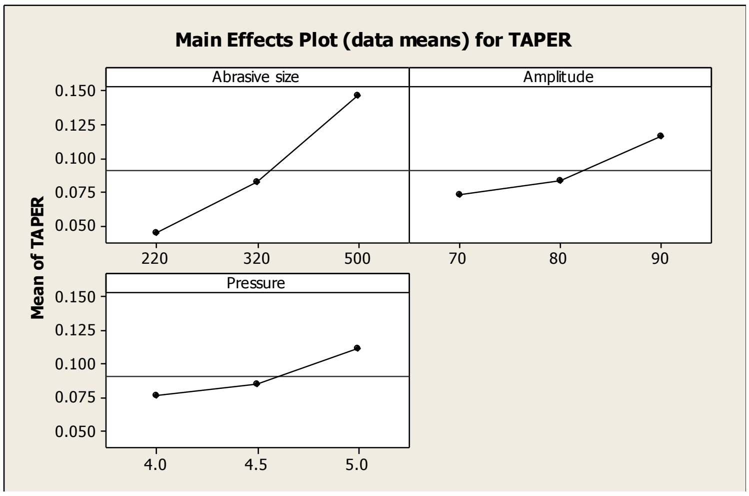

Fig-6: Main effect plot for Taper

From the figure 6 and ANOVA table 5, it is observed that abrasive size has most significant effect on the Taper. If we increase the abrasive size taper also increase. If abrasive grain size are larger than impact force reduced and momentum of abrasive particle are slow because of this taper reduced. If we increase the abrasive grain size than impact force increase and momentum of abrasive also increase because of this taper also increase. Second significant effect is amplitude if we increase the amplitude abrasive particle which are come in contact with tool tip is increase this make increase the energy imparted to the particle on the work peace due to this side cutting occur on surface of the work peace and taper increase. Third significant effect is pressure with increasing the pressure abrasive hammering effect increase and because of this thrust force increase and make side cutting. Because of this thrust force there is difference between top and bottom diameter of the surface and taper generated.

5. ANALYSIS OF VARIANCE (ANOVA)

The analysis of variance (ANOVA) is the statistical technique most commonly applied to the results of the experiments to determine the percentage contribution of each factors.

5.1 Analysis of Variance for MRR

Factor	Degree of Freedom (DF)	Seq. Sum of Squares (Seq. SS)	Adjusted Sum of Squares (Adj. SS)	Mean Square Value MSV= Adj. SS/DF	F exp = MSV/MS Ve	P-Value	Contrib ution (%)
Abrasive size	**2**	**0.0014510**	**0.0014510**	**0.0007255**	**11.28**	**0.032**	**22.89**
Amplitude	**2**	**0.0021556**	**0.0021556**	**0.0001077**	**1.67**	**0.013**	**34.00**
Pressure	**2**	**0.0014441**	**0.0014441**	**0.0007220**	**11.22**	**0.034**	**22.78**
Error	**20**	**0.0012863**	**0.0012863**	**0.0000643**			
Total	**26**	**0.0063390**					

Table 3 ANOVA for MRR

P value less than 0.0500 indicate that parameters are significant. Values greater than 0.1000 indicate the parameters are less significant. From ANOVA table 3, it is observed that all parameters show most significant parameter for material removal rate. The percentage Contribution of Abrasive size, Amplitude, Pressure on MRR are 22.89%, 34.00%, 22.78% respectively.

5.2 Analysis of Variance for Top radial over cut

Factor	Degree of Freedom (DF)	Seq. Sum of Squares (Seq. SS)	Adjusted Sum of Squares (Adj. SS)	Mean Square Value MSV= Adj. SS/DF	F exp = MSV/MSVe	P-Value	Contribution (%)
Abrasive size	2	1.29413	1.29413	0.64706	48.00	0.000	47.25
Amplitude	2	0.60814	0.60814	0.30407	22.55	0.044	22.20
Pressure	2	0.56654	0.56654	0.28327	21.01	0.001	20.68
Error	20	0.26970	0.26970	0.01348			
Total	26	2.73851					

Table-4: Analysis of Variance for radial over cut

From Table 4, the percentage Contribution of Abrasive size, Amplitude, Pressure on radial over cut are 47.25%, 22.20%, 20.68% respectively. Here Abrasive size has highest contribution parameter on radial over cut.

5.3 Analysis of Variance for Taper

Factor	Degree of Freedom (DF)	Seq. Sum of Squares (Seq. SS)	Adjusted Sum of Squares (Adj. SS)	Mean Square Value MSV= Adj. SS/DF	F exp = MSV/MSVe	P-Value	Contribution (%)
Abrasive size	2	0.168222	0.0168222	0.084111	20.96	0.013	43.79
Amplitude	2	0.069310	0.069310	0.034655	8.63	0.042	18.04
Pressure	2	0.066299	0.066299	0.033149	8.26	0.044	17.26
Error	20	0.080239	0.080239	0.004011			
Total	26	0.384070					

Table-5: Analysis of Variance for Taper

From Table 5, the percentage Contribution of Abrasive size, Amplitude, Pressure on radial over cut are 43.79%, 18.04%, 17.26% respectively. Here Abrasive size shows most significant parameter on taper.

6. CONCLUSION

(1) From some trial experiment it was found that steatite ceramic composite drill in high range Pressure. For smooth drilling of steatite ceramic composite Pressure range is 4 bar to 5 bar.
(2) From the main effect Plot and ANOVA table it is found that MRR is increase with increase in abrasive size, amplitude and Pressure.
(3) Abrasive mesh size has most significant effect on steatite ceramic. If we increase the abrasive particle size than MRR also increase and machining of material also increase.
(4) From main effect plot and ANOVA table it is found that Radial over cut and taper is also increase with increase in control parameter.

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