ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 4, Issue 5, May 2019

Experimental Study of Rotary Ultrasonic Machining and Process Optimization of Soda Lime Glass using Taguchi Method

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***Abstract*—Rotary Ultrasonic Machining process is one of the best-suited advance machining processes for machining non-conductive, hard, brittle and non-metallic materials such as glass, alumina, ceramic, ferrite, quartz, zirconium oxide, ruby, sapphire, beryllium oxide, composites, etc. Soda lime glass has a wide range of application in the field of electronics optics and fluidics. In present work, a setup Rotary Ultrasonic Machining (RUM), and the experimental study of rotary ultrasonic machining (RUM) is performed. From innovative research, it is observed that high MRR, low overcut find out. The analysis helps us to analyze the effect of various input parameters like ultrasonic power (70, 80, 90 %W), spindle (1000 rpm), frequency (21.5, 22.5, 25.5 kHz) and abrasive grit number (30, 46, 60) on MRR which help to enhance the productivity of ultrasonic drilling. Taguchi's orthogonal array designs the experiments, Taguchi L9 orthogonal array for three factor-three level design is selected. Rotary ultrasonic machining is conducted by performing experiments work and optimizes output characteristics individually with rotary ultrasonic machining at 1000 rpm. Taguchi method is an approach to optimize the process parameters and improve the quality of machining components that are manufactured. By the help of graphs, optimum parameter values were obtained, and the confirmation experiments were carried out the Taguchi optimization method.**

***Index Terms*— Abrasive Slurry, Grit Size, Taguchi, Rotary Ultrasonic Machining (Rum)**

1. INTRODUCTION

Rotary Ultrasonic Machining (RUM) is a nontraditional manufacturing technique for machining hard and brittle materials such as graphite, glass, carbide, and ceramics. Experimental studies have been reported using RUM for drilling and grinding of various types of materials hard and brittle. Churi et al. [1] Rotary Ultrasonic Machining process for drilling holes in Ti6Al4V alloy and studied the effects of spindle speed, frequency, feed rate, and high power on the cutting force, surface roughness and MRR. Cong et al. [2] Using RUM for drilling holes in carbon fiber–reinforced plastic (CFRP) composites and find out the effect of cutting fluid and cold air on the cutting force, surface roughness, torque, and tool wear. Utilized Ultrasonic Machining process for drilling in K9 glass and compared the results with diamond drilling. [3] Fernando et al. [2018] studied RUM of basalt, marble, and travertine rocks. They have observed that RUM can produce the best quality of holes with less cutting force and about two times faster penetration rate [4]. Anwar et al. [2018] using the effect of main process parameters on RUM. They have observed that ultrasonic power(%), spindle speed(rpm), frequency (kHz) and feed rate are the most significant input parameters during rotary ultrasonic machining for BK7 glass [5] Sometimes, the longitudinal ultrasonic vibration assisted drilling machine with a twist drill is also called as during rotary ultrasonic machining. Due to an ultrasonic vibration utilization on the rotating twist drill [6] This paper focus on the performance analysis of Rotary Ultrasonic Drilling (RUD) of BK7 in terms of output responses (MRR, Surface roughness) under the combined influence of input variables (ultrasonic power, frequency, feed rate and tool rotational speed). Taguchi based L9 array has been used to frame the experimental work and for optimization of individual response. After that, the utility has been executed for simultaneous optimization of output responses. [7, 8, 9, 10, 11].

There are three main objectives in this study.

1. To demonstrate a systematic procedure for using Taguchi’s Parameter design in RUM of Soda-lime glass.
2. To study the optimal process parameters for better process performance
3. To examine the effectiveness of Taguchi method in the optimization of rotary ultrasonic machining process parameters.

IFERP
ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 4, Issue 5, May 2019

2. EXPERIMENTAL SET-UP

The main parts of a rotary ultrasonic machine are as follows:

1. Ultrasonic Transducer
2. Sine wave generator
3. Velocity transformer (horn) with a tool
4. RPM regulator

Ultrasonic Transducer

The transducer is a device which converts energy from one form to another. In the case of a transducer for USM, electrical energy is converted to mechanical motion. There are two types of transducers used for ultrasonic machining based on two different principles of operation.

a. Piezoelectric Transducer
b. Magnetostrictive Transducer

The piezoelectric transducer works based on piezoelectric effect according to which when a piezoelectric material such quartz or lead zircon natetitanate is compressed, it generates a small electric current. Similarly, when an electrical signal is applied to one of these materials, the material changes the length and return to original position when current is removed. A piezoelectric transducer, by nature, exhibits an extremely high electro-mechanical conversion efficiency (up to 96%), which eliminates the need for water cooling of the transducer. These transducers are available with power capabilities up to 900W [12].Magnetostrictive Transducer is usually constructed from a laminated stock of nickel or nickel alloy sheets which, when influenced by a strong magnetic field, will change length. Magnetostrictive transducers are rugged but have electro-mechanical conversion efficiencies ranging from 20 to 30%. The lower efficiency results in need to water cool magnetostrictive devices to remove the waste heat. Magnetostrictive transducers are available with power capabilities up to 2400W. The strength of transducer material limits the magnitude of the length change that can be achieved by both piezoelectric and magnetostrictive transducer. In present work, a piezoelectric transducer is selected as per the specification is given below:

Sandwich type piezoelectric transducer prestress bolt M12
Piezoelectric element – 50*20*6 mm ring type Grade PZT4

Selection of Sine wave generator

In present work, sine wave generator as per the following specification is used for USM.
Input voltage – 220 V, 50 Hz
Output frequency – 22 kHz +/- 10%
Output power – 0-150 W

Velocity Transformer (Horn)

The velocity transformer has got several names like concentrator, horns, a mechanical focusing device, shank, horn, amplifier, tool cone, transformer stub or convergent wave-guide, etc. It amplifies and focuses the automaticthe energy produced by the transducer and imparts this to work-piece in such a way that energy utilization is optimum.

Fig.1: Horn with tool

Horn may be of different shapes or configurations. Some typical shapes are exponential (circular), Exponential (wedge), Exponential (annular), Straight conical, Stepped (symmetrical), Stepped (unsymmetrical), Gaussian profile, etc.
In the present work, the velocity transformer (horn) used is as follows:

Type – Stepped type
Material – EN-8 (tool steel)
Threading – 3/8”
The diameter of the tool – 2 mm

RPM regulator

An rpm regulator, capable of varying the rpm from 0-1500 rpm is selected for providing different spindle speed of RUM.

Fig.2: Setup of rotary ultrasonic machining

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

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3. WORK MATERIAL

In this paper, a soda lime glass plate with dimensions 20×20×3 mm was selected as workpiece material. The chemical composition and mechanical properties of soda-lime glass in shown in table I & II respectively.

I. Chemical composition of soda lime glass

Element	Percentage (%)
SiO2	69-74
Na2O	10-16
CaO	5-14
MgO	0-6
Al2O3	0-3
Others	0-5

II. Mechanical properties of soda lime glass

Density	2500 Kg/m^3
Young's Modulus	70 MPa
Poisson's ratio	10-16
Shear Modulus	30 MPa
Knoop Hardness	6 GPa

III. Experimental observation by L_9 Taguchi orthogonal array

Taguchi Method

The Full Factorial Design needs a large number of experiments to be carried out as stated above. It is difficult and complicated, and the number of factors increases. To overcome this problem, Taguchi suggested a specially designed method called the use of an orthogonal array to study all the parameter space with lesser number of experiments to be conducted. The Taguchi, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further converted into signal-to-noise (S/N) ratio. Usually, there are three categories of performance characteristics to analyze the S/N ratio. They are as, larger-the-better, and smaller-the-better, nominal-the-best.

Three independent input parameters namely ultrasonic power, the frequency also abrasive size are selected for experimental study whereas material removal rate (MRR) and overcut are selected as response parameters. The possible range of input parameters is chosen based on preliminary experiments. For each input parameter, three level values from the possible range are selected for conducting the pilot study. Rotary ultrasonic machining is done by performing the experiments with rotary ultrasonic machining at 1000 rpm. The input parameters and their level values are shown in Table III.

Steps Involved in quality loss function 0f the Taguchi Method

a) Set the material and objective parameters.
b) Select the factors influencing the set objective.
c) Select the number of levels for the identified factors.
d) Select the suitable orthogonal array (OA).
e) Allocate the factors to the columns of the selected OA.
f) Conduct the experiments as per these selected OA.
g) Estimate loss function.
h) Normalize the loss function.
i) Assign a weight to the response variables.
j) Estimate Multi Response Signal to Noise (MRSN) Ratio.
k) Find out the combination of factor levels to optimize the objective parameters.

3. MACHINING PARAMETERS AND THEIR LEVELS

Sr.	Input parameter	Unit	Value		
			Level 1	Level 2	Level 3
1.	Ultrasonic Power	%	70	80	90
2.	Frequency	kHz	21.5	22.5	25.5
3.	Abrasive size	μm	30	46	60

On the other hand, hole overcut is measured by optical zoom. In the present study, universal clip-type LED cell phone microscope also known as optical zoom, which is compatible with mobile software, is used for measuring the actual size of the machined hole. Then, overcut is measured by subtracting tool diameter from the actual size of the machined hole.

Fig 3: Overcut by rotary USM at 1000 rpm and measurement of hole diameter with optical zoom

4. L9 OA EXPERIMENTAL DATA ROTARY USM (1000 RPM)

Sr. No.	Ultrasonic Power (%)	Frequency (kHz)	Abrasive Size (μm)	MRR (mg/min)	Overcut (μm)
1.	70	21.5	30	2.80	344.91
2.	70	22.5	46	2.40	473.63
3.	70	25.5	60	9.04	405.63
4.	80	21.5	46	9.07	91.56
5.	80	22.5	60	5.15	791.64
6.	80	25.5	30	2.67	205.57
7.	90	21.5	60	13.31	347.14
8.	90	22.5	30	3.62	346.78
9.	90	25.5	46	14.66	279.87

Fig 4: Holes machined by rotary USM at 1000 rpm

Calculation Quality Loss for Each Response Parameters

The observed quality characteristics are MRR and Overcut. The MRR is high "Higher-the-better" (HB) type characteristics, and the Overcut is "Smaller-the-better" (SB) type characteristics. The equation for calculating the quality loss for "Higher-the-better" (HB) and "Smaller-the-better" (SB) type characteristics are;

1. **Objective function:** Higher-the-better (HB), quality loss for this function is:

$$L_{HB} = \frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^2}$$

2. **Objective function:** Smaller-the-better (SB) quality loss for this function is

$$(L_{ij})_{SB} = \frac{1}{n}\sum_{j=1}^{n} y_{ij}^2$$

5. QUALITY LOSS FOR DIFFERENT RESPONSE PARAMETERS

Sr. No.	MRR (mg/min)	Overcut (μm)	Quality loss	
			MRR (HB) (mg/min)	Overcut (SB) (μm)
1	2.80	344.91	0.1275	118962.90
2	2.40	473.63	0.1736	224325.37
3	9.04	405.63	0.0122	164535.69
4	9.07	91.56	0.0121	8383.23
5	5.15	791.64	0.0377	626693.88
6	2.67	205.57	0.1402	42259.02
7	13.31	347.14	0.0056	120506.17
8	3.62	346.78	0.0763	135998.68
9	14.66	279.87	0.0046	78327.21

Calculation of normalized quality loss for each response parameters

The normalized quality loss for different parameters is presented in the table. Each quality feature has a different measurement; it is necessary to quality loss. The normalized quality loss can be identified using by:

$$\text{Normalized quality loss } (y_{ij}) = \frac{Lij}{Li\,max}$$

Where, $L_{i\ max}$ = Maximum quality for the i_{th} quality feature among all the experiments runs. Therefore, normalized quality loss varies from a minimum of one.

6. NORMALIZED FOR EACH RESPONSE PARAMETER

Exp. No.	MRR (mg/min)	OVERCUT (μm)
1	0.7346	0.1898
2	1.0000	0.3579
3	0.0704	0.2625
4	0.0700	0.0113
5	0.2171	1.0000
6	0.8078	0.0674
7	0.0325	0.1922
8	0.4395	0.2170
9	0.0267	0.1249

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Calculation of total normalized quality loss (TNQL)

The TNQL can be identified using.

$$Y_j = \sum_{ij}^{q} W_{ij} y_{ij}$$

If The w_i represents the weighting factor for the i^{th} quality feature, q is the number of quality features, and y_{ij} is the loss function associated with the i^{th} quality features at the j^{th} trial condition. In this case q = 2 and assuming unequal weight i.e for $w_1 = 0.6$ for MRR, $w_2 = 0.4$ for overcut.

7. NORMALIZED QUALITY LOSS (TNQL)

Exp.NO	Total normalized quality loss (TNQL)
1	0.5155
2	0.0858
3	0.1472
4	0.0473
5	0.5302
6	0.5116
7	0.0963
8	0.3505
9	0.0659

Calculation of multiple S/N ratio (MSNR)

The MSNR can be identified by using the following formula: $\eta_m = -10\log_{10} y_j$
The overall mean multiple S/N ratio (η_m) value of the experimental region defined by the factor levels is determined according to this fallowing formula:

$$\eta_m = \frac{1}{9}\sum_{j=1}^{q} \eta_j$$

8. MULTIPLE S/N RATIOS (MSNR)

Exp. No.	Multiple S/N ratios (MSNR)
1	2.8684
2	10.6651
3	8.3209
4	13.2513
5	2.7556
6	2.9106
7	10.1637
8	4.5531
9	11.8111

Determination of significant parameter effect and optimal settings

The S/N ratio for the individual control factors are determined as given below:
$Su1=(\eta_1+\eta_2+\eta3)$,$Su2=(\eta4+\eta5+\eta6)$&$Su3=(\eta7+\eta8+\eta9)$
$Sf1=(\eta_1+\eta4+\eta7)$,$Sf2=(\eta2+\eta5+\eta8)$&$Sf3=(\eta3+\eta6+\eta9)$
$Sa1=(\eta_1+\eta5+\eta9)$, $Sa2=(\eta2+\eta6+\eta7)$&$Sa3=(\eta3+\eta4+\eta8)$
For selecting the values of η_1, η2, η3, etc. and to calculate Su1, Su2 & Su3 see table η_k is the S/N ratio corresponding to Experiment k.

Average S/N ratio corresponding to ultrasonic power at level 1 = Su1/3
Average S/N ratio corresponding to ultrasonic power at level 2 = Su2/3
Average S/N ratio corresponding to ultrasonic power at level 3 = Su3/3
j is the corresponding level each factor. Similarly, Sfj and Saj are calculated for Frequency andAbrasive size. The average of the signal to noise ratios is shown in the table. Then S/N ratios can be calculated for other factors.
Next step is to define the average effect of all parameter on quality characteristic at different levels. The parameters levels corresponding to the maximum average effect are decided as optimum level. The average parameters effect has been conferred in the table and the response plot is shown in the table in fig 5. the optimum setting of parameters is A3B1C2.

9. EFFECT OF LEVEL ON MULTIPLE S/N RATIO (MSNT)

Sr. No.	Input parameter	Unit	Mean multiple S/N Ratio		
			Level 1	Level 2	Level 3
1.	Ultrasonic Power (A)	%	7.2848	6.305	8.8426*
2.	Frequency(B)	kHz	8.7611 *	5.9912	7.6808
3.	Abrasive size(C)	µm	3.444	11.909*	7.080

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the optimum parameters level is A3B1C2.

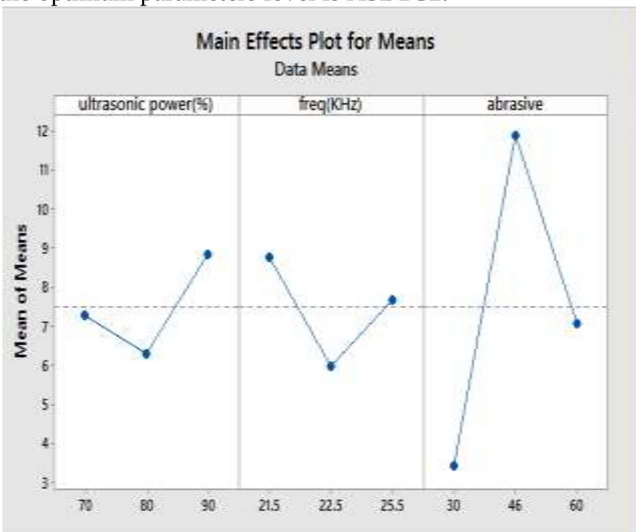

Fig 5. Main Effects plot multiple S/N Ratio(MSNR)

X. OPTIMUM VALUES OF FACTORS AND THEIR LEVELS

Parameter	Optimum value
Ultrasonic power (%)	90
Frequency (kHz)	21.5
Abrasive size	46

CONCLUSIONS

Taguchi's method reduces the total number of experiments to be completed without much loss of information. The experimental design using Taguchi's orthogonal array, provide mean effects of parameters on response variables. The following conclusions can drown the above results:

1. The Taguchi quality loss function can be used to optimize multiple quality characteristics.
2. This paper illustrates the analysis of various parameters by the help of experimental observation for soda lime glass and optimizes the response parameters by plotting the Multiple S/N ratio.
3. It is determined that the parameter design of the Taguchi method provides a systematic, efficient and easy methodology for optimizing the process parameter.
4. The optimum values for the machining soda lime glass are Ultrasonic power (%)-90, Frequency (kHz)-21.5, Abrasive size-46.

The recommended parameter combination for MRR and Overcut is A3B1C2.

REFERENCES

[1] Churi NJ, Pei ZJ and Treadwell C. Rotary ultrasonic machining of titanium alloy: effects of machining variables. Mach Sci Technol 2006; 10: 301–321.
[2] Cong WL, Feng Q, Pei ZJ, et al. Rotary ultrasonic machining of carbon fiber-reinforced plastic composites: using cutting fluid vs. cold air as coolant. J Compos Mater 2012; 46: 1745–1753.
[3] Zhang C, Cong W, Feng P, et al. Rotary ultrasonic machining of optical K9 glass using compressed air as coolant: a feasibility study. Proc IMechE, Part B: J Engineering Manufacture 2014; 228: 504–514.
[4] Fernando PKSC, Zhang M and Pei Z. Rotary ultrasonic machining of rocks: an experimental study. J Advances in Mechanical Eng 2018; 10(3): 1-9.
[5] Anwar S, Nasr MM, Pervaiz S, Al-Ahmari A, Alkahtani M, and Tamimi AE. A study on the effect of main process parameters of rotary ultrasonic machining for drilling BK17 glass. J Advances in Mechanical Eng 2018; 10(1): 1-12.
[6] S. Thirumalai Kumaran, T.J. Ko, C. Li, Z. Yu, M. Uthayakumar, Rotary ultrasonic machining of woven CFRP composite in a cryogenic environment, J ALLOY COMPD, 698(2017) 984-993.
[7] A. Goswami, J. Kumar, Optimization in wire-cut EDM of Nimonic-80A using Taguchi's approach and utility concept,Eng. Sci.Technol.Int. J. 17 (2014) 236–246,
[8] C.P. Mohanty, S.S. Mahapatra, M.R. Singh, An intelligent approach to optimize the EDM process parameters using utility concept and QPSO algorithm, Eng.Sci. Technol. Int. J. 20 (2017) 552–562,
[9] P. Antil, S. Singh, A. Manna, Electrochemical discharge drilling of SiC reinforced polymer matrix composite using Taguchi's Grey relational analysis, Arab. J. Sci.Eng. (2017),
[10] R.S. Walia, H.S. Shan, P. Kumar, Multi-response optimization of CFAAFM process through Taguchi method and utility concept, Mater. Manuf. Process. 21 (2006) 907–914,
[11] J. Kundu, H. Singh, Friction stir welding of AA5083 aluminum alloy: multiresponse optimization using Taguchi-based grey relational analysis, Adv.Mech. Eng. 8 (2016) 1–10.
[12] El-Hofy, Hassan Abdel-Gawad, "Advanced machining processes, Non-traditional and Hybrid machining processes", Tata Mc Graw-Hill.