Experimental Investigation of Surface Roughness and MRR in Rotary-Ultrasonic Machining of Float Glass

Saraswat, Praveen
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan

Joshi, Dheeraj
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan

Manoj Kumar Sain
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan

Sandeep Kumar Bhaskar
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan

https://doi.org/10.5109/7160926

出版情報：Evergreen. 10 (4), pp.2675-2682, 2023-12. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Experimental Investigation of Surface Roughness and MRR in Rotary-Ultrasonic Machining of Float Glass

Praveen Saraswat[1], Dheeraj Joshi[1],
Manoj Kumar Sain[1], Sandeep Kumar Bhaskar[1,*]
[1]Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur 302017 (India)

*E-mail: sandeep.bhaskar@skit.ac.in

(Received March 20, 2023; Revised December 19, 2023; accepted December 19, 2023).

Abstract: Float glass is undoubtedly an important material which is widely used across the globe due to its various favourable mechanical, thermal and optical properties. The increased demand and applications of float glass has motivated the industries to devise more efficient methods so as to enhance the surface smoothness as well as production rate of the products made from the float glass. Rotary ultrasonic machining (RUM) can be identified as a recent method which is a non-conventional hybrid manufacturing process used for drilling holes into brittle and composite material including float glass. The literature reveals that this machining process has proved as an efficient approach for drilling holes in brittle materials without incorporating high cutting forces and improved quality surface finish of machined part. This paper aims to study the float glass machining process and determine the favourable conditions that aid in improvement of surface quality and material removal rate. More specifically, the research has been conducted considering ultrasonic power and feed rate as process variables on machine characteristics namely surface roughness and material removal rate. To analyze the results, a popular statistical technique called response surface methodology (RSM) has been employed. The optimal parametric setting is also determined to decrease the roughness of machined surface along with improved material removal rate for the benefit of practitioners.

Keywords: Hybrid Manufacturing, Float Glass, Response Surface Methodology, Rotary-Ultrasonic Machining

1. Introduction

The modernization of global culture created a huge competitive environment such that every company strives to create and utilize more and more advanced materials. The demand for more advanced and versatile materials has increased dramatically in the present era of globalization. In fact, a number of artificial materials are now available having varied physical, chemical, optical and magnetic properties. However, the traditional machining processes have been found in-efficient to process such materials.[1)] This gave rise to the replacement of traditional machining processes such as Laser beam machining (LBM), Electron beam machining (EBM), electrical discharge machining (EDM), ultrasonic machining (USM) etc. It is well understood that all these processes have their own inherent advantages and limitations. USM has an additional benefit over other process as it does not require material to be electric conductive as in case of EDM and also don't have chemical effect on work piece.[2)]

RUM is the combination of traditional diamond grinding with ultrasonic machining to improve the dimension accuracy and material removal rate on hard-to-machine objects. More specifically, RUM can be identified as one of the advanced version of ultrasonic machining to enhance the metal removal rate in a cost-effective manner. An added advantage in enhanced tool life and machining rate has been observed during RUM in contrast to USM and CG.[3)] A typical RUM unit comprises basically of a feed system, coolant system, and ultrasonic spindle kit. In addition, a rotating diamond-impregnated tool is made to vibrate ultrasonically and is fed at the work piece with uniform feed rate and pressure during machining.[4),5)] The suggestion of combining ultrasonic vibration and drilling was patented by Brown et al. who used very low frequency of vibration i.e. 1 kHz to drill wood only.[6)fig]

In rotary-ultrasonic machines, low frequency electric impulses are translated into higher frequency ones and delivered to a transducer, which converts them into ultrasonic vibrations with a frequency greater than 20 kHz. These vibrations are further transferred to the tool through the horn. The purpose of coolant system is to ensure the heat dissipation from the cutting site. Initially, the material is removal in ultrasonic was achieved by the simultaneous action of extraction and erosion as well as by hammering of the diamond coated tools.[7] In the study RUM was used for performing drilling in a glass plate. Z.J. Pei [8] presented a novel approach with the modified cutting tool design for performing milling operations. In another work, a DOE was employed with 5 variables of 2-level and 4-output responses namely material removal rate, material removal mode, machining force and surface roughness.[9] In addition, machining of difficult materials, like float glass, using RUM technology has also been investigated.[10], [11], [12] Figure 1 illustrates the main components of a typical RUSM. Further, the RSM approach has the capacity to find the optimal input variable structure for selecting the most suitable outputs with the fewest trials. This method is applicable in a variety of domains and it is not constrained by the context in which it is used.[13], [14]

The current research work has been performed to fulfil the following goals:

i. To study the consequence of process parameters and their mutual interactions on machine performance (specifically material removal rate and surface finish).
ii. To analyze the results obtained by experimentation using RSM and ANOVA tools and to optimize the process through desirability function.

Fig. 1: Rotary-ultrasonic machine setup

2. Literature Review

An efficient machine is one which gives high MRR without compromising the quality of surface produced. Debnath et al., investigated drilling operation on reinforced epoxy laminates (glass fiber) and it was found that the material removal rate significantly improves with hollow tool in contrast to solid tool. It was particularly ascertained that the MRR by using hollow tool was approximately 2 times higher than by using solid tool.[15] F. Ning et al., conducted a study on carbon-fiber-reinforced plastic (CFRP). The objective was to carry out the comparisons between rotary ultrasonic machining process with that of conventional grinding. As per the study results, MRR obtained in RUM was higher as compares to conventional grinding. Also the surface roughness for the drilled hole was lower in RUM as compared to conventional grinding.[16] Singh and Singhal, conducted an experimental investigation on quartz ceramic machining characteristics and found that in RUM brittle fracture is responsible for MRR with very low plastic deformation.[17] Kumar and Singh, conducted an experiment on BK7 optical glass for optimization of machining characteristics and the feed rate was identified as prominent deciding parameter for MRR. It was seen that as feed increased surface finish got deteriorated. The highest impact on surface roughness was of feed rate (76.19%). At the same time, it was observed that the contribution of spindle speed and ultrasonic power was 5.48% and 8.81%.[18] D. Sindhu et al., investigated RUSM based machining of a quartz glass using multi-objective optimization. The most critical parameter for MRR was found to be feed rate. Then after, ultrasonic power and rotational speed of tool were having their effect.[19] In a study by Kumar and Singh, RUM assisted drilling operation on optical glass BK-7 was analysed by RSM technique. Feed rate was found to be the most critical parameter in for surface finish and MRR. The processed surface topography by SEM showed that the brittle fracture ascendency along with very less plastic deformation.[20]

Kumar and Singh, conducted an experiment on BK7 optical glass to optimize process parameters in RUM. It was seen from SEM images that plastically deformation occurred at low feed rate whereas brittle fracture became prominent when feed was increased.[21] Sindhu et al., investigated the RUM process parameters for quartz glass and found that there was pullout of the grains due to the cross linking of cracks consequently engraving deeper groves on the surface being machined. It was observed that the surface roughness of machined face increased suddenly by augmentation in feed rate of tool while it decreased at higher RPM and input power.[22]

In another study by Bdo et al., the micro channels were fabricated on zirconium oxide using RUM. To ascertain the effect of RUM input factors on the milling channels, a full factorial experimental design was utilised. Further, the optimal parametric conditions were determined using multi-objective genetic algorithm (MOGA). The results showed that high surface finish can be obtained through high level of frequency and amplitude but at low depth of cut, feed rate and cutting speed.[23]

3. Methodology & experimentation work

This section deals with the methodology and framework of study utilized for research work shown in figure 2.

3.1 Design of experimental procedures

In the present study holes were drilled using RUM in float glass. The process parameters (both constant and variable) used in RUM are stated below:

Constants:

i. Spindle Speed: It can be simply defined as tool rotations per minute. (1000 RPM).
ii. Ultrasonic Frequency: It depicts the rate of vibrational movement of the tool. It is fixed at 20KHz.

Variables:

i. Feed Rate: Rate of the tool approach w.r.t. the specimen in order to complete machining.
ii. Ultrasonic Power: Refers to the quantity of power that is given to the transducer. It corresponds to the amplitude of vibrations delivered to the instrument via the horn assembly.

With reference to the research objectives and literature survey stated in introduction section, the following machine characteristics have been chosen for analyzing optimally process parameters in RUM process:

i. Surface Roughness
ii. Material Removal Rate

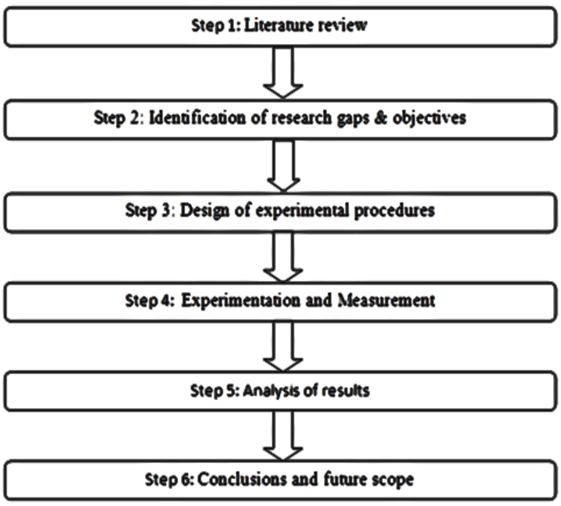


Fig. 2: Flowchart showing the various steps employed in this study

3.2 Experimentation and Measurement

Float glass is heat treated to make it stronger like toughened glass for ceiling, stairs, and flooring applications. Other glasses which can be produced from processing float glass are insulated glass, tinted glass, frosted glass and laminated glass which increases its applicability further.

Float glass has greenish hue colour naturally. It has smooth and flat surface with good transparency. Approx. 87% incident light transmitted through this material. It can handle various chemical changes under different climatic conditions. The significant mechanical properties of float glass of interest have been mentioned in Table 1.

The layout of experimentation generated from the CCD approach is given in Table 3. The experiment is conducted according to run order and experimentally identified values of edge chipping, surface roughness and MRR are entered in their respective column.

Saint Gobain made float glass was used as experimentation material. The properties and composition of float glass are already discussed in section 3.1. Three cuboidal plates of size 150x120x5 mm are taken for experimentation. A total of 39 holes of 6 mm were drilled on these plates as shown in Figure 3.

Table 1: Experiment design for RUM parameters & their levels

Parameters	-α	-1	0	+1	+α
Feed rate (mm per min)	0.59	1	2	3	3.41
Ultrasonic power (%)	15	25	50	75	85

Table 2: Experimental Layout of DOE

Std. Order	Run Order	FR (mm/min)	UP (%)
3	1	1.00	75
6	2	3.41	50
1	3	1.00	25
4	4	3.00	75
11	5	2.00	50
7	6	2.00	15
5	7	0.59	50
10	8	2.00	50
13	9	2.00	50
9	10	2.00	50
12	11	2.00	50
2	12	3.00	25
8	13	2.00	85

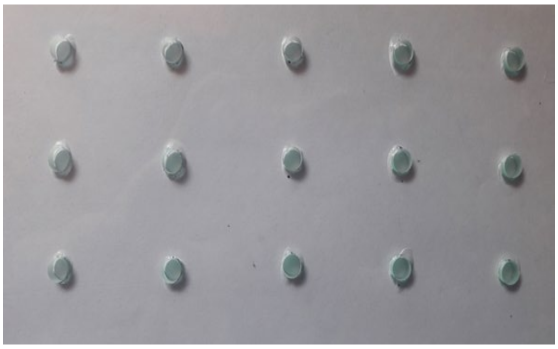


Fig. 3: Float glass plate with drilled hole array

Holes of dimensions 30 x 20 x 5 mm are drilled in 3 glass specimens. There are 5 levels of the 2 control variables namely feed rate of 0.59, 1, 2, 3, and 3.41 mm/min; and ultrasonic power of 15, 25, 50, 75, and 85%.

3.3 Test Measurements Procedure

Surface roughness is the irregularity or projection present on a surface. It can be calculated by different means. Most of the researchers computed average surface roughness for measurement purpose. For this purpose, various equipment's are used like optical surface profiler, contact type surface profilometer, Talysurf stylus etc. According to the application desirability, surface roughness tester (Mitituyo Surftest SJ-201) is employed for ascertaining the surface roughness of float glass surface obtained after machining as seen in Figure 4. For measurement, evaluation length of 4mm is taken with 0.8mm as cut-off length. Due to small size of drilled hole diameter the hole is cut down into half. The reading is taken two times at single drilled hole at 180^0 to each other. The average of two values taken provides surface roughness measurement at that hole.

Fig. 4: Measurement of surface roughness using Mitituyo Surftest SJ-201

4. Results and Discussion

4.1 Effect on Surface Roughness

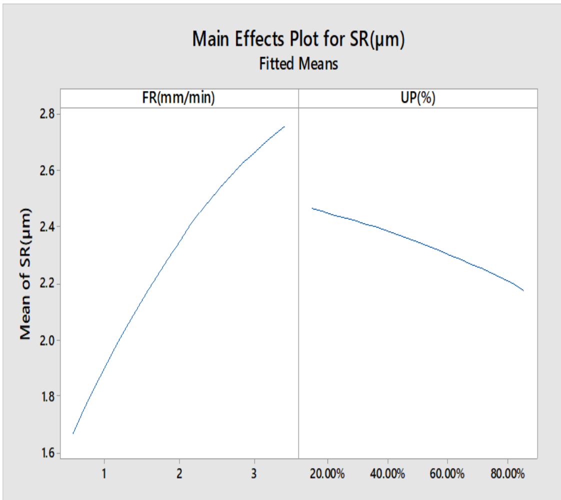
The variance analysis (ANOVA) is used to determine whether model is suitable. Measurements of the process variables are used to calculate the regression relevant towards each responder.[24),25)]

Table 3 displays result for the response variable surface roughness (SR) using ANOVA.

Table 4 demonstrates that ultrasonic power, feed rate, and the second order component of feed rate have a substantial influence on the size of edge chipping. This is because the P- values for these factors are less than 0.05, indicating that the null hypothesis is false. Further, the P-value obtained for lack of fit is 0.967, (higher than 0.05), demonstrates that the null hypothesis is accurate and there is no lack of fit Thus, all essential terms are present and there are no missing higher-order words. The effect of feed rate to surface roughness is 88.83%, indicating that edge chipping is highly dependent on feed rate. It was found that the effect of ultrasonic power and second order feed rate term is 6.14 and 2.34 percent, respectively. Figure 5 depicts a Pareto chart of standardized effect, which demonstrates the significance and size of process parameters. Equation 1 demonstrates the regression equation for surface roughness (SR). It is the constructed model in equation form that demonstrates the response's dependence on model terms.

$$\text{SR } (\mu\text{m}) = 1.420 + 0.676 \text{ FR (mm per min)} - 0.133 \text{ UP } (\%) - 0.0687 \text{ FR (mm per min)} * \text{FR (mm per min)} - 0.214 \text{ UP } (\%) * \text{UP } (\%) - 0.030 \text{ FR (mm per min)} * \text{UP } (\%)$$

\- Equation (1)



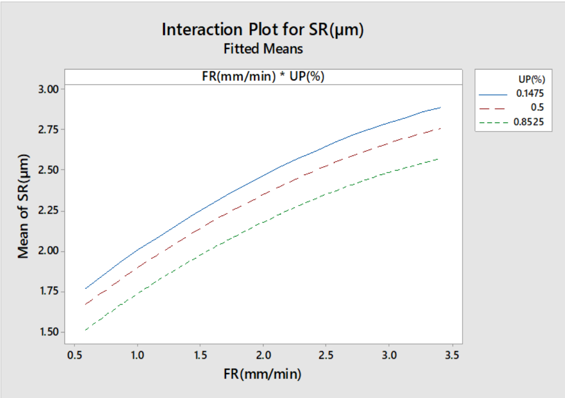


Fig. 5: Main and interaction plots for SR

Figure 5 demonstrates the impact of ultrasonic power and feed rate on the surface roughness of the machined part. It is evident from this graph that with the increment in feed rate, there is also an increment in surface roughness. It is interesting to note that effect of ultrasonic power on surface roughness is exactly the reverse as compared to feed rate. As ultrasonic power increases, there is a reduction in surface roughness. The nonparallel lines represent an interaction impact of machine settings on surface roughness.

Table 3: Analysis of Variance (ANOVA) table for Surface roughness (SR)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F Value	P Value
Model	5	1.30719	97.42%	1.30719	0.26144	52.83	0.000
Linear	2	1.27429	94.97%	1.27429	0.63714	128.75	0.000
FR(mm/min)	1	1.19189	88.83%	1.19189	1.19189	240.85	0.000
UP(%)	1	0.08240	6.14%	0.08240	0.08240	16.65	0.005
Square	2	0.03268	2.44%	0.03268	0.01634	3.30	0.098
FR(mm/min)*FR(mm/min)	1	0.03145	2.34%	0.03253	0.03253	6.57	0.037
UP(%)*UP(%)	1	0.00123	0.09%	0.00123	0.00123	0.25	0.634
2-Way Interaction	1	0.00022	0.02%	0.00022	0.00022	0.05	0.837
FR(mm/min)*UP(%)	1	0.00022	0.02%	0.00022	0.00022	0.05	0.837
Error	7	0.03464	2.58%	0.03464	0.00495		
Lack-of-Fit	3	0.00196	0.15%	0.00196	0.00065	0.08	0.967
Pure Error	4	0.03268	2.44%	0.03268	0.00817		
Total	12	1.34183	100.00%				

Table 4: Table of Variation Analysis (ANOVA) for Material Removal Rate (MRR)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F Value	P Value
Model	5	3.11665	98.89%	3.11665	0.62333	124.50	0.000
Linear	2	3.07088	97.44%	3.07088	1.53544	306.69	0.000
FR(mm/min)	1	3.04164	96.51%	3.04164	3.04164	607.54	0.000
UP(%)	1	0.02924	0.93%	0.02924	0.02924	5.84	0.046
Square	2	0.03674	1.17%	0.03674	0.01837	3.67	0.081
FR(mm/min)*FR(mm/min)	1	0.03670	1.16%	0.03582	0.03582	7.16	0.032
UP(%)*UP(%)	1	0.00003	0.00%	0.00003	0.00003	0.01	0.937
2-Way Interaction	1	0.00903	0.29%	0.00903	0.00903	1.80	0.221

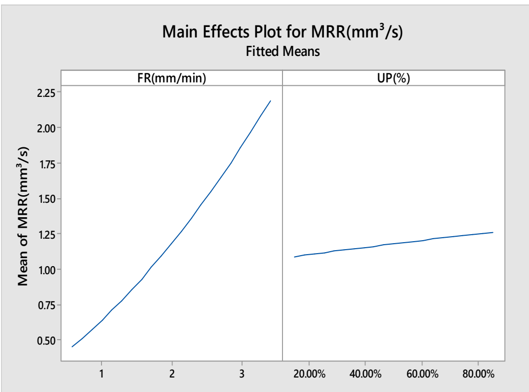
FR(mm/min)*UP(%)	1	0.00903	0.29%	0.00903	0.00903	1.80	0.221
Error	7	0.03505	1.11%	0.03505	0.00501		
Lack-of-Fit	3	0.02409	0.76%	0.02409	0.00803	2.93	0.163
Pure Error	4	0.01096	0.35%	0.01096	0.00274		
Total	12	3.15169	100.00%				

4.2 Effect on Material Removal Rate

Table 4 displays the experimental results for the response MRR. It is evident that the feed rate and ultrasonic power as well as second order component of feed rate demonstrate a substantial influence on the metal removal rate, since the p-values for these terms are less than 0.05, indicating that the likelihood of the null hypothesis is false with 95% certainty. The fact that the p-value for lack of fit is 0.163, which is larger than 0.05 indicates correctness of null hypothesis. This also proves about the absence of lack of fit. Thus, all essential terms are present and there are no missing higher-order words. The contribution of feed rate to material removal rate is 96.51%, indicating that edge chipping is highly dependent on feed rate. The influence of second-order feed rate term and ultrasonic power is 1.16 percent and 0.93 percent, respectively. The MRR regression equation presented in Equation 2 illustrates dependence of response on model variables.

MRR (mm^3/s) = 0.295 + 0.234 FR (mm per min) - 0.102 UP (%) + 0.0721 FR (mm per min) * FR (mm per min) - 0.036 UP (%) * UP (%) + 0.190 FR (mm per min) * UP (%)

- Equation (2)



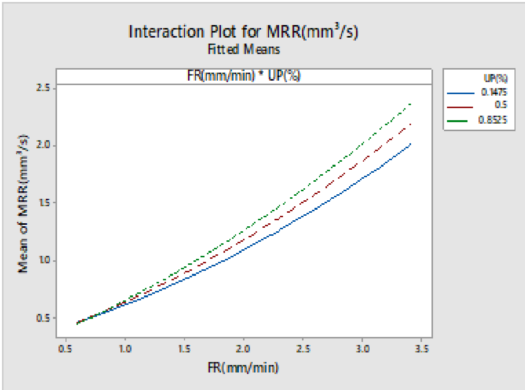


Fig. 6: Factorial Plots for MRR (mm3/s) showing main and interaction effects

The effect of ultrasonic power and feed rate on metal removal rate has been illustrated in Figure 6. It is evident from that with increase in the feed rate, the MRR also increases. Further, that surface roughness does not show considerable effect on ultrasonic power, and as ultrasonic power increases, material removal also increases interaction impact of ultrasonic power and feed rate. The non-parallel lines illustrate that the ultrasonic power and feed rate interactions that affect the MRR.

5. Conclusion and Future Scope

In this paper an extension of ultrasonic machining popularly termed as rotary ultrasonic machining (RUM) was utilised to investigate the influence of machining settings on three response variables, namely edge chipping size, surface roughness, and MRR with the goal of process optimization. A central composite design (CCD) approach of RSM methodology was thereby employed to accomplish the analysis on data obtained after machining. Subsequently, a statistical model is created through response surface method so as to provide comprehensive understanding of the results and optimize the machining parameters. Following points presents a summary of the results as obtained in this study:

i. It has been discovered that process factors, such as ultrasonic power and feed rate have a substantial effect on the machining properties, such as MRR, edge chipping size and surface roughness.
ii. It was also observed that MRR is nearly in direct correlation to the ultrasonic power and feed rate.

Additionally, the surface roughness (SR) have shown an increase with the increase in feed rate of tool, but gradually reduces due to increment in ultrasonic power.

iii. ANOVA results demonstrates that the feed rate has a prominent effect on the parameters under study with. 88.83% contribution on surface roughness while for MRR it is 61.96% and 96.51% respectively.

iv. In the experimental study, the multi-response optimization approach, Desirability function, optimises the response at an ideal feed rate of 1.39 mm per min, The ultrasonic power (UP) for this is found to be 76%. The value at these optimal setting is found as 0.7850 mm^3/s for MRR, 1.92 µm for SR and 1.58 mm for ECS.

v. The individual optimization for maximum value of MRR suggest optimal parameter setting as feed rate 3.41 mm/min and ultrasonic power 85% which give material removal rate of 2.37 mm^3/s. The optimal parameters values for minimizing surface roughness are feed rate 0.59 mm per min and ultrasonic power 85% that provide surface roughness as 1.51 µm. The least amount of edge chipping, 0.95mm, was found when the feed rate and UP supplied to the tool were 0.59 mm/min and 72 percent, respectively.

The further study can be steered in the undermentioned areas:

i. The effect of coolant and its pressure along with ultrasonic frequency on the response variable (i.e. edge chipping size, MRR and surface roughness can be further investigated.

ii. The use of different type of tool can be considered to investigate their effect in the process parameter optimization.

iii. Edge chipping is a main concern to design accuracy which needs to be measured or reduced by even more efficient method.

References

1) A. Saha, S. Chatterjee and G. K. Bose, "Investigation of effect of CNC milling parameters on cylindricity and perpendicularity of milled circular pockets using CMM," EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy., 9(3), 745-751 (2022). doi:10.5109/4843108.
2) T. B. Thoe, D. K. Aspinwall, and M. L. H. Wise, "Review on Ultrasonic Machining", International Journal of Machine Tools and Manufacture, 38 (4) 239-255 (1998). doi:10.1016/S0890 6955(97)00036-9
3) V. Singh, P. Saraswat and D. Joshi, "Experimental investigation of edge chipping defects in rotary ultrasonic machining of float glass", Materials today: Proceedings, 44 (2021) 4462-4466. doi:10.1016/j.matpr.2020.10.719.
4) M. M. Sundaram, A. Sarwade, K. Rachuri, and K. P. Rajurkar, "Micro Rotary Ultrasonic Machining", Transactions of North American Manufacturing Research Institution of SME, 37 621-628 (2009). https://experts.nebraska.edu/en/publicatins/microrotaryultrasonicmachining/fingerprints/
5) V. Kumar, P. Saraswat and A. Kumar, "Experimental investigation of rotary ultrasonic face milling on red granite: A comparison with conventional grinding", Materials today: Proceedings, 58 (2022) 27-32. Doi: 10.1016/j.matpr.2021.12.575.
6) Na Qin, Z. J. Pei, C. Treadwell, and D. M. Guo, "Physics-Based Predictive Cutting Force Model in Ultrasonic-Vibration-Assisted Grinding for Titanium Drilling", Journal of Manufacturing Science and Engineering, 131 (4) 1-9 (2009). doi:10.1115/1.3159050.
7) F. Ning, and W. Cong, "Rotary Ultrasonic Machining of CFRP: Design of Experiment with a Cutting Force Model", Proceedings of ASME International Manufacturing Science and Engineering Conference. 1 (2015). V001T02A040. doi:10.1115/MSEC2015-9227.
8) Z. J. Pei, P. M. Ferreira, S. G. Kapoor, and M. Haselkorn, "Rotary Ultrasonic Machining for Face Milling of Ceramics", International Journal of Machine Tools and Manufacture, 35 (7) 1033–1046 (1995). doi:10.1016/0890-6955(94)00100-X.
9) Z. J. Pei, and P. M. Ferreira, "An Experimental Investigation of Rotary Ultrasonic Face Milling", International Journal of Machine Tools and Manufacture, 39 (8) 1327-1344 (1999). doi:10.1016/S0890-6955(98)00093-5.
10) A. Sharma, V. Jain and D. Gupta, "Comparative analysis of chipping mechanics of float glass during rotary ultrasonic drilling and conventional drilling: For multi-shaped tools", Machining Science and Technology, 23 (4) 547-568 (2019). doi:10.1080/10910344.2019.1575402.
11) A. Sharma, V. Jain and D. Gupta, "A noval investigation study on float glass hole surface integrity & tool wear using chemical assisted rotary ultrasonic machining", Materials Today: Proceedings, 26 632-637 (2020). doi:10.1016/j.matpr.2019.12.202.
12) A. Sharma, V. Jain and D. Gupta, "Multi-shaped tool wear study during rotary ultrasonic drilling and conventional drilling for amorphous solid", Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 233 (3) 551-560 (2019). doi:10.1177/0954408918776724.
13) S. Choudhary, A. Sharma, K. Srivastava, H. Purohit and M. Vats, "Read range optimization of low frequency RFID system in hostile environmental conditions by using RSM approach," EVERGREEN

Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy., 7(3), 396-403 (2020). doi:10.5109/4068619.

14) A. K. Srivastava, M. Maurya, A. Saxena, N. K. Maurya and S. P. Dwivedi, “Statistical optimization by response surface methodology of process parameters during the CNC turning operation of hybrid metal matrix composite,” EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy., 8(1), 51-62 (2021). doi:10.5109/4372260
15) K. Debnath, I. Singh, and A. Dvivedi, “Rotary mode Ultrasonic Drilling of Glass Fiber-Reinforced Epoxy Laminates”, Journal of Composite Materials, 49 (8) 949-963 (2015). doi:10.1177/0021998314527857.
16) F. D. Ning, W. L. Cong, Z. J. Pei, and C. Treadwell, “Rotary Ultrasonic Machining of CFRP: A Comparison with Grinding”, Ultrasonics, 66 125-132 (2016). doi: 10.1016/j.ultras.2015.11.002.
17) R. P. Singh, and S. Singhal, “Experimental investigation of Machining Characteristics in Rotary Ultrasonic Machining of Quartz Ceramic”, Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 232 (10) 870-889 (2018). doi: 10.1177/1464420716653422.
18) V. Kumar, and H. Singh, “Machining optimization in Rotary Ultrasonic Drilling of BK-7 through response surface methodology using desirability approach”, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 40 (2) (2018). doi:10.1007/s40430-017-0953-z.
19) D. Sindhu, L. Thakur, and P. Chandna, “Multi-objective Optimization of Rotary Ultrasonic Machining Parameters for Quartz Glass using Taguchi-Grey Relational Analysis (GRA)”. Silicon, 11 (4) 2033-2044 (2019). doi:10.1007/s12633-018-0019-6.
20) V. Kumar, and H. Singh, “Regression Analysis of Surface Roughness and Micro-Structural Study in Rotary Ultrasonic Drilling of BK7”, Ceramics International, 44, (14) 16819-16827 (2018). doi:10.1016/j.ceramint.2018.06.117.
21) V. Kumar, and H. Singh, “Optimization of Rotary Ultrasonic Drilling of Optical Glass using Taguchi Method and Utility approach”, Engineering Science and Technology, an International Journal, 22 (3) 956-965 (2019). doi: 10.1016/j.jestch.2019.02.004.
22) D. Sindhu, L. Thakur, and P. Chandna, “Parameter Optimization of Rotary Ultrasonic Machining on Quartz Glass Using Response Surface Methodology (RSM)”, Silicon, 12 (2) 629-643 (2020). doi:10.1007/s12633-019-00160-2.
23) B. M. A. Abdo, A. El-Tamimi, and H. Alkhalefah, “Parametric Analysis and Optimization of Rotary Ultrasonic Machining of Zirconia (ZrO2) Ceramics”, IOP Conference Series: Materials Science and Engineering, 727 (1) (2009). https://iopscience.iop.org/article/10.1088/1757-899X/727/1/012009/meta.
24) M. Maurya, N. K. Maurya and V. Bajpai, “Effect of SiC Reinforced Particle Parameters in the Development of Aluminium Based Metal Matrix Composite,” EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 6(3), 200-206 (2019). doi:10.5109/2349295.
25) H. Sosiati, Y. A. Shofie and A. W. Nugroho, “Tensile Properties of Kenaf/E-glass Reinforced Hybrid Polypropylene (PP) Composite with Different Fiber Loading,” EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy., 5(2), 1-5 (2018). doi:10.5109/1936210.