# Experimental Investigation of Float Glass in Rotary Ultrasonic Machining for Sustainable Manufacturing

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

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

Joshi, Dheeraj
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/10.5109/7162018

出版情報：Evergreen. 10 (4), pp.2520-2527, 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 Float Glass in Rotary Ultrasonic Machining for Sustainable Manufacturing

Praveen Saraswat[1], Naveen Kumar Sain[1,*], Dheeraj Joshi[1], Sandeep Kumar Bhaskar[1]

[1]Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India

E-mail: naveen.sain@skit.ac.in

(Received March 20, 2023; Revised December 18, 2023; accepted December 18, 2023).

**Abstract**: Sustainable manufacturing focuses on increasing productivity by regulating process parameters through resource optimization. Industries are attempting to use fewer resources in machining of any material in order to improve productivity and sustainability. It can be accomplished by higher Material Removal Rate (MRR) and decreased defective components since enhanced MRR requires less energy usage and material waste can be reduced by manufacturing high-quality products. In the drilling operation of rotary ultrasonic machining (RUSM), this study intends to investigate the effects on material removal rate (MRR) by varying the process parameters and overcut, in order to reduce overcut error, which increased the number of faulty parts (RUSM). For this investigation, the Six Sigma (DMAIC) technique was used. Gauge R&R study was conducted to check the accuracy of measuring instrument by ensuring its measurements are repeatable and reproducible followed by cause and effect analysis to find out possible causes for a specific problem. More specifically, the current study focusses on determining the relative effect of process parameters on overcut and MRR by using a full factorial design. Ultrasonic power control factors and feed rate were chosen as the study's control variables. According to the study's findings, the total gauge R&R was 1.78%, which shows that the part-to-part variance is significant for an overcut error. The results revealed that at 0.6 mm/min feed rate and 75% ultrasonic power, the MRR achieved was maximum. With an ultrasonic power of 50% and 0.6mm/min feed rate, the overcut error was reduced. When using the revised machining conditions, the mean overcut error was reduced by 34.18%, which was a significant reduction. It can be concluded that machining with optimized process parameters leads to economically sound processes and solves persistent problems in terms of improved MRR, reduced overcut defects and increased productivity.

Keywords: DMAIC, Float Glass, MRR, Overcut, RUSM

## 1. Introduction

Ceramics, in recent years, are a must-have material due to their increased and favourable applications in both industrial and domestic sector. This can be attributed to their better chemical stability, increased thermal resistance, good hardness, and insulating characteristics. The ultrasonic machining (USM) has proved to be a crucial technique[1] for achieving high accuracy and precise machining especially for brittle and hard materials. The literature shows that USM exhibits some distinctive and favourable features such as being non-chemical, non-electrical and also non-thermal. It also has no impact on the metallurgical, chemical, or physical qualities of the material being machined.[2]

The non-traditional machining technique known as "rotary ultrasonic machining" (RUSM) combines two popular techniques namely conventional diamond grinding and ultrasonic machining to accomplish the removal of material.[3] This hybrid machining process removes more material from the work piece due to the incorporation of micro-chipping and grinding action of abrasives. As a result, a greater material removal rate (MRR) is also seen.[4, 5] RUSM is typically referred to as a hybrid kind of USM machining in which material is removed using both grinding and erosion mechanisms.[6] To state precisely, RUM has been identified as a cutting-edge machining technique that employs ultrasonic machining (USM) with diamond grinding to get removal of material at a faster pace, with a better surface finish (SR). In addition, the results revealed that hole quality obtained is appreciable than USM processes or diamond drilling alone.[7, 8] Geometrical imperfections in ultrasonic machining are categorised as overcut (dimensional inaccuracy) and conicity (form inaccuracy). It was also stated that abrasive grain size reduction enhances the accuracy of holes drilled by ultrasonic.[9] In another study, the conicity error and overcut for glass material has been found to increase with increasing static load and machining duration. It was also discovered that the overcut error in ultrasonic drilling increases with increasing diameter-length ratio and is maximum at entry.[10]

Unlike other techniques, ultrasonic machining (USM) offers advantages of being fairly capable of machining hard and brittle materials regardless of their chemical and electrical properties.[9), 11] However, it has been noted that sometimes this process may contain certain geometrical inaccuracies which may be attributed to the inclusion of slurry of abrasive particles. The geometrical anomalies are usually defined by hole over size, conicity, and out of roundness are terms used to describe. [9), 12), 13] In USM, the removal of material from the work surface take place by striking it with abrasive particles in the form of slurry.[14),15),16] Further research revealed a clear relationship between feed rate and edge chipping size. The collected data's statistical analysis by ANOVA revealed that the feed rate has a significant impact on edge chipping.[17] In a different study, the use of the central composite rotatable design (CCRD) and the response surface methodology (RSM) was described for modelling and optimising the impact of specific operating variables on the response utilising annova.[18] Surface morphology has shown that components made in a flat orientation have fewer flaws than those made in an edge orientation.[19]

According to another study, the rate of material removal increased during RUFM in comparison to CG. With each level of regulating parameters being increased, the material removal rate (MRR) also rises. With the addition of ultrasonic vibration during RUFM, surface roughness (SR) rises.[20] Focus was said to be placed on the machining of challenging materials, particularly those that are the current hot commodities in a number of industries.[21] RUM, an advanced hybrid machining technique, circumvents a number of drawbacks common to static-type USM and traditional diamond grinding. RUSM has surpassed conventional USM restrictions including out of roundness, overcut, and weak MRR, conicity. Traditional USM offers a lower MRR, whereas RUSM offers a higher MRR. The RUSM has a problem with feed rate; when the feed rate surpasses a critical point, the cutting force quickly increases and the ultrasonic amplitude significantly decreases. RUM's superior performance is nearly gone at this point.[22] In terms of material waste, this can have an impact on the sustainability of machining. In RUSM, the tool may erode the machined hole's wall, reducing accuracy, especially for small holes.[23]

Six Sigma has gained popularity as a quality tool in recent years for improving production efficiency and business performance. The study's efforts to improve quality have been guided by the Six Sigma DMAIC approach.

Different sections of the paper are as follows: In this Section, RUSM is introduced and its advantages discussed over the USM in terms of sustainable manufacturing. Than the research aim and objectives established in Section 2 after conducting a brief literature review pertinent to the RUSM and its process parameter optimization The approach used in this study to achieve the given goals is then introduced and implemented in Section 3. The findings and experimentation results of this investigation are reported in Section 4, finally conclusion have been exhibited in the Section 5.

## 2. Literature Review

In order to ensure a sustainable machining process, a proper attention has to be given to related process parameters which may include tool material and geometry, work piece material, shape and size of component to ne produced as well as auxiliary processes such as cooling and lubrication employed. Improved machining sustainability can then be achieved by selecting optimal machining settings that minimise energy use while maintaining cost efficiency.[24), 25] Because of the multiple environmental benefits of ultrasonic aided machining, it is considered green and sustainable production. The machining process is very energy efficient, economical, and cleaner because the chips are continuous and simple to remove without interfering with it, and it doesn't release any pollutant gases. It has been reported in literature that ultrasonic machining, unlike conventional machining employed for new and advanced materials, offers better machining quality. The particular advantages that are seen include reduction in the burrs, resin peeling, machining forces, wall tearing, tool damage etc.[26), 27] Various other applications also employ the ultrasonic vibrations due to their ability to be ecologically beneficial.[28]

The impact of milling parameters on the cylindricity and perpendicularity of circular pockets during CNC milling operations was examined, and it was suggested that future work could be expanded by taking into account other performance criteria like roundness and pertinent input process parameters like depth of cut, various materials, MRR, etc.[29] Several studies have been found in literature that establish the use and applicability of ultrasonic assisted RUM for grinding and drilling of hard and brittle materials. Researcher studied the effects of feed rate, spindle speed, ultrasonic power on cutting force, MRR and surface roughness during drilling in Ti6Al4V alloy.[30] According to the experimental findings, the values of the optimal MRR depend on the process parameters and their acceptable machining range.[31]

Aspects of RUSM's quality include torque, cutting force, MRR, machine quality, hole quality, edge chipping size, and tool wear. Researchers published an article related to determine how process variables affected the quality traits of RUM on CFRP/Ti stacks.[32] Experiments were conducted for a comparison of RUM and twist drilling and it was found that machining parameters such as torque, cutting force, and surface finish are favourable as compared to the twist drilling of carbon fiber-reinforced plastic (CFRP).[33] An another study examined at the hole quality at the exit when feed rate, spindle speed, and other factors were combined.[34] Researcher identified some limitations of the USM which include hole inaccuracies (oversize, conicity, out-of-roundness etc.) and poor MRR.[9] These were rectified by employing RUSM. It was explored how various input variables affected the quality of hole produced during USM of WC-Co composite material.[35] It was concluded that the power rating and abrasive grit size and had the biggest effects on hole quality. Higher cobalt content has been discovered to result in better hole quality, which deteriorated while using coarse grit size. The Taguchi method has been successfully used by numerous researches to optimise the process parameters in RUSM. In another study it was concluded that HF acid concentrations and the types of abrasive have a major impact on MRR. More specifically, polycarbonate bulletproof glass and acrylic heat-resistant glass both saw improvements in the MRR of 34.44 and 29.25 percent, respectively.[36] It was also reported that the input parameters in some predefined ranges had a substantial impact on the drilled hole quality. It was also suggested that the various input parameters could interact with one another.[37] In a study researcher employed a DMAIC method in a tyre manufacturing facility with an objective to reduce process variations in the bead slices that is one of a prominent cause material waste in the process.[38] After experimentation, it was revealed that the standard deviation was decreased from 2.17 to 1.69 after using the DMAIC methodology. Process capability index (Cp) and process performance capability index (Cpk) values increased from 1.65 to 2.95 and 0.94 to 2.66, respectively. Sharma et al. (2018) highlighted a general issue with alloy wheel machining and indicated a need to enhance the procedure for machining A356 aluminium alloy wheels. Improvement tools included the failure modes, Ishikawa diagram and effects analysis, and process monitoring charts. The Cp, Cpk, and Cpm showed signs of progress by using the DMAIC approach, going from baseline values of 0.66, -0.24, and 0.27 to end values of 4.19, 3.24, and 1.41, respectively. Through their experiment on the BK7 model, In a study it was confirmed that a high tool feed rate reduces the quality of drilled holes by widening and tapering the chipping. A superior surface finish was obtained which may be attributed to the low feed rate with ultrasonic power and mixed flow of material.[39] The impact of ultrasonic machining settings on zirconia composite was studied in a study. The findings indicated that while feed rate and taper angle both have an impact on MRR, slurry concentration has an impact on over-cut.[40] With RUM and varied cutting pressures, surface quality, and machining procedures and conditions, In an another study ceramic composites have machined. Due to ductile fracture, material loss in ZrO2-NbC was greater than in ZrO2-WC, where brittle fracture appears to be predominate.[41]

## 3. Research Methodology

The specifics of the implantation procedure used in this investigation are presented in this section. As previously mentioned, this study will employ the Six Sigma methodology to lower the defect rate. It incorporates the following five main steps: define, measure, analyse, enhance, and control, commonly known as DMAIC. The details of these five steps of Six Sigma for addressing the issue at hand are presented in the section that follows.

The following objectives have been defined for the current study:

i. To reduce the overcut error on RUSM during drilling holes in float glass, using DMAIC (six sigma) approach.
ii. To determine the impacts of drilling process variables on MRR and overcut.

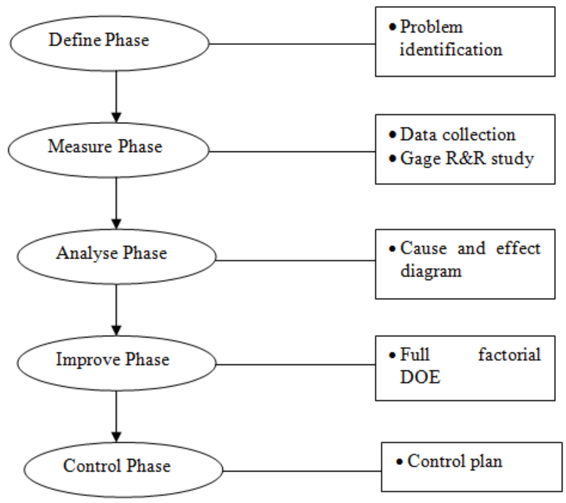


**Fig. 1:** Key steps of the Six Sigma process (DMAIC)

### 3.1 The Define Phase

DMAIC process, which is part of the Six Sigma technique, begins with addressing the scope and objectives of the project improvement in relation to client needs and by identifying the fundamental project procedures that need to be improved.

The issue addressed in this study is one that arises throughout the Rotary Ultrasonic Machining (RUSM) process. Figure 2 illustrates the usage of CNC RUSM to drill holes in a workpiece made of float glass plate that is 10 mm thick. The machine has 1000 rpm of continuous spindle speed, 25 kHz of top frequency, and ultrasonic power of 1000 Watts. In this procedure, a rotary high carbon steel tool employed, bonded with diamond abrasives to it. The work piece is fed with the tool using ultrasonic vibration. In order to lower the temperature and transport the waste, a flood-type cooling system is employed. In this procedure, 5mm holes are drilled into a glass plate, and it is seen that when the parameters are adjusted in accordance with the instructions, the diameter of the holes is overcut. At 178 microns, the overcut is typically detected. Low MRR while drilling these holes is another issue.

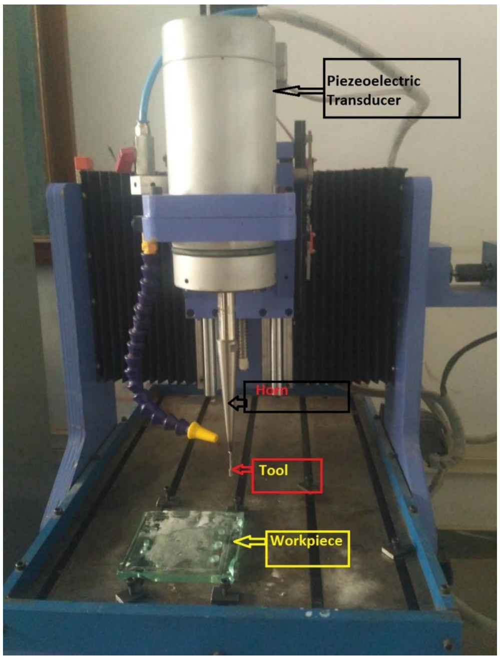


**Fig. 2:** Experimental set-up of RUSM

### 3.2 The Measure Phase

The techniques and tools for recording measurement data are discussed in this phase. Data recording requires the use of precise instruments and the selection of appropriate techniques. A measurement system analysis, including studies on gauge repeatability and reproducibility (Gage R&R), was carried out in the current study. The Gauge R&R study's objective is to confirm the measuring system's statistical validity. The overcut error will be measured by three observers. Five parts were chosen as the sample size, and three operators were selected to measure the overcut on each piece. two replicated measurements were also taken into account, for a total of 30 measurements. The measurement was performed using the profile projector having 0.01 least count, as shown in figure 3. The Minitab software was used to perform the Gauge (R & R) investigation.

**Fig. 3:** Profile Projector

Table 1. Study evaluation of the Gauge (R & R).

| Variance components | SD (Standard Deviation) | Variance in percentage(%) |
|---|---|---|
| Total Gauge R&R | 1.26350 | 1.78 |
| Reproducibility | 0.56140 | 0.79 |
| Repeatability | 1.13190 | 1.59 |
| Operator(s) | 0.56140 | 0.79 |
| Part-to-Part | 71.00060 | 99.98 |
| Total Variation | 71.01180 | 100.00 |

The difference from part to part is 99.98%, as shown in Table 1. Total Gage R&R was determined to be 1.78%. The table makes it apparent that part-to-part variation is the cause of variation in measurement.

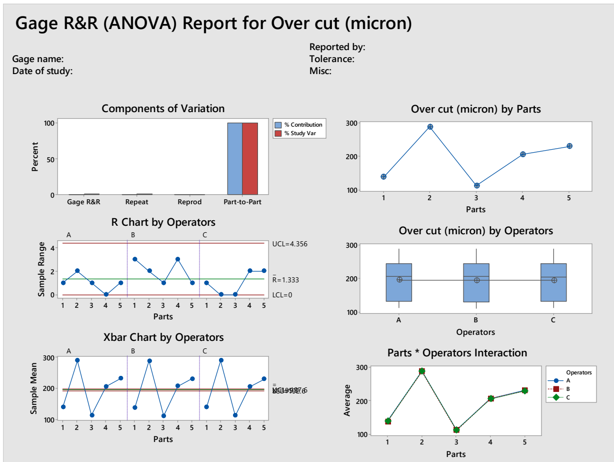


**Fig. 4:** Gage R & R overcut error ANOVA report

The overall gauge R&R ANOVA report for overcut error is shown in Figure 4. According to the figure, the percentage of the part to part component in the variation graph is considerably higher as compared to the components, this clearly indicates the differences between the parts. In addition, the R Chart emphasises the accuracy of the measurements considering different operators. It indicates inconsistent measurements of parts by Operator B and C.

### 3.3 The Measure Phase

In the analysis phase, numerous issues that arise in the process are tracked down to their root causes. An overcut cause-and-effect diagram has been produced in order to pinpoint potential causes of the overcut error.

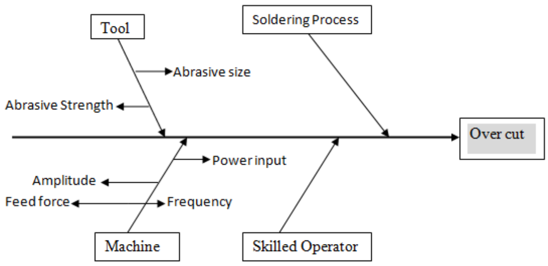


**Fig. 5:** Overcut cause and effect diagram

Overcut cause and effect diagram shown in Figure 5. The tool is used for two reasons: first, the abrasive size; second, the abrasive strength. The diamond-coated tool was used in the RUSM method. Diamond particles ranged in size from 80 to 90 microns. The particle adhesion with the tool is determined by the abrasive strength. The overcut also needs to be improved in the perfect soldering process since inadequate soldering gives less power to the tool and can cause it to begin bucking about its axis. For the operation, skilled manpower is also necessary. The main causes of the overcut were found in the categories of machine, which include frequency, feed force, ultrasonic, and power output amplitudes The primary causes of the overcut may be attributed to the type of machine having varying frequency, amplitudes, ultrasonic power output and feed force.

### 3.4 The Improvement Phase

In accordance with the cause-and-effect diagram and following the analysis phase, the control factors were identified. The feed rate and ultrasonic power were the selected as control factors that have an impact on the response. A full factorial design of experiments did not take into account the factors impacting response variables, such as abrasive strength, abrasive size as process parameters. At 1000 rpm, the spindle speed remained constant.

The control factors with their corresponding levels have been exhibited in Table 2.

Table 2. Control factors with their levels.

| Variables | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Ultrasonic Power (%) | 25 | 50 | 75 |
| Feed Rate (mm/min) | 0.2 | 0.4 | 0.6 |

The experiments were designed using a full factorial approach. The experiments, which have two control factors, three levels, and nine runs, were set up by using a 32 three-level design. The response variables selected were overcut and MRR. Overcut error is measured by using a profile projector. Plotting the graph between process variables and the mean of responses enabled researchers to examine how process factors affect overcut and MRR.

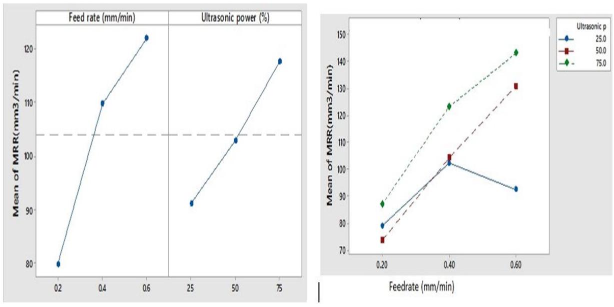


**Fig. 6:** Individual and interaction effects of process variables for MRR

Figure 6 illustrates how feed rate, ultrasonic power, and a few other process variables affect the MRR. It shows that, in comparison to ultrasonic power, an increase in feed rate increases the MRR. At 75% ultrasonic power and 0.6 mm/min feed rate, the MRR reaches to its maximum value.

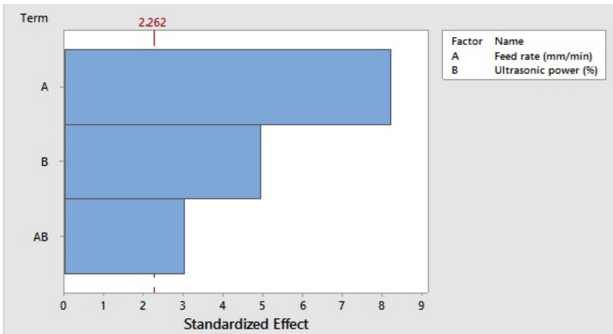


**Fig. 7:** A Pareto chart of standardized effects for MRR

As presented in figure 7, the Pareto chart indicates the absolute values of the standardized effects for individual process variables and their interaction. It clearly shows the factor feed rate has much significant effect on the MRR as compared to other variables. It gives another information that feeds rate, ultrasonic power, and their interaction have statistically significant because all the variables crossed the reference line.

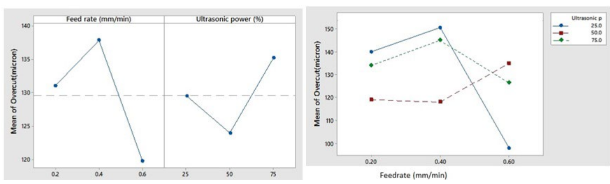

**Fig. 8:** Effects of process factors alone and in combination for overcut

Figure 8 depicts how the overcut first grows as the feed rate increases before rapidly decreasing. When it comes to ultrasonic power, overcut first increases and then decreases. When using 50% ultrasonic power and a feed rate of 0.6 mm/min, the overcut is reduced to its lowest value.

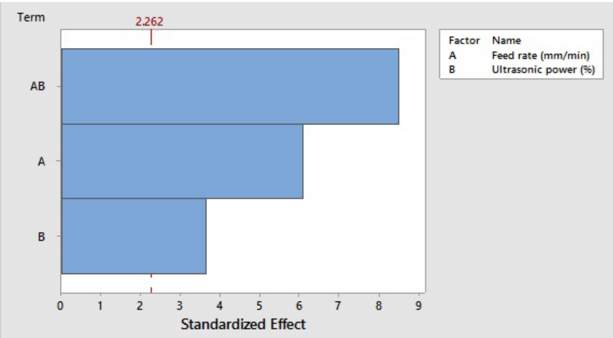


**Fig. 9:** Pareto chart of standardized effects for overcut

Figure 9 depicts that the overcut was significantly impacted by the interaction factor of ultrasonic power and feed rate. Ultrasonic power and feed rate were also statistically significant.

### 3.4.1 The Confirmation Test

One of a popular statistical technique for ascertaining the inter-relationship between input parameters and output responses is the regression model. In this investigation, the Overcut and MRR output variables, which were predicted and experimental output variables, were used to test the validity of the regression model. With a 95% confidence level, the experimental and projected values are compared using the two-sample t-test.

The regression equation for MRR:

MRR($mm^3$/min) = 73.4 - 5.2 Feed rate - 0.414 Ultrasonic power + 2.430 Feed rate * Ultrasonic power

The overcut regression equation:

Overcut in micron = 174.6 - 117 Feed rate - 0.653 Ultrasonic power + 1.70 Feed rate * Ultrasonic power

The findings of regression analysis indicate that no statistically significant variation or difference exists between experimental and projected values. The regression model is validated as there is no difference between the means and the p-values for both equations are greater than 0.05.

### 3.4.2 Improvement in Overcut error

The RUSM process's ideal control factor setting for increasing MRR and lowering overcut was discovered. Ten trial runs were carried out with these settings (50% ultrasonic power and 0.6 mm/min feed rate), and overcut error was calculated.

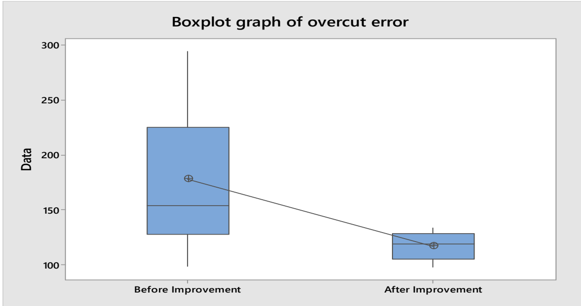


**Fig. 10:** Comparisons of the mean overcut error data before and after improvement

In Figure 10 shown above, the mean overcut error before and after improvement have been compared. 117.1 microns is the mean of improved overcut. Prior to improvement, it was 177.9 micron. The figure also makes it evident that the range of overcut error has been decreased. For the two-sample t-test The p-value is 0.000, which indicates that the difference between the means is statistically significant.

### 3.5 The Control Phase

The outcomes discovered during the improvement phase are fruitful and achieve the intended objectives. Maintaining the gains from the improvement phase is the primary objective of the control phase. Standardization of the procedure will enable further development. This can be achieved by standardization and documentation of the control parameters.

## 4. Conclusion

The rotary ultrasonic is used to drill holes in materials made of glass plate. The six Sigma DMAIC method has been used to examine the MRR and overcut. Today, six sigma is utilised across the globe to address issues related to component quality. Full factorial design and statistical calculation software (Minitab) have been used to analyse the impact of process factors on overcut and MRR. The overcut and MRR are significantly impacted by feed rate. There is no statistically significant difference between the experimental and anticipated responses, according to tests of the established regression equations' accuracy for overcut and MRR. The optimum process parameters were 75% ultrasonic power and 0.6 mm/min feed rate for increased MRR and ultrasonic power as 50% and 0.6 mm/min as feed rate for reduced overcut. Overcut error have seen a substantial improvement. Overcut error was reduced on mean by 36.7%. Such studies will be helpful to the glass industries because glass machining is a sophisticated process that requires greater precision and accuracy. Present study came to the additional conclusion that the six Sigma DMAIC approach is a highly helpful method for examining and enhancing the component's quality.

## References


1) P.L. Guzzo, A. H. Shinohara, and A. A. Raslan. "A comparative study on ultrasonic machining of hard and brittle materials." Journal of the Brazilian Society of Mechanical Sciences and Engineering 26 (2004): 56-61.
2) D.C., Kennedy and R.J., Grieve “Ultrasonic machining: a review” Product. Eng., 54(9), 1975, 481–486.
3) R.P. Singh and S. Singhal, “Rotary Ultrasonic Machining: A Review” J. Manuf. Process., 31(14), 2016, 1795-1824.
4) Z.J. Pei, and P.M. Ferreira, “An experimental investigation of rotary ultrasonic face milling” Int. J. Mach. Tools Manuf., 39 (8), 1999, 1327-1344.
5) Y. Jiao ; W. J. Liu.; Z.J. Pei; X.J. Xin; C.Treadwell, “Study on edge chipping in rotary ultrasonic machining of ceramics: an integration of designed experiments and finite element method analysis” J Manuf Sci Eng., 127(4), 2005, 752-758.
6) K. J. Singh, I.S. Ahuja and J. Kapoor, “Ultrasonic, chemical-assisted ultrasonic and rotary ultrasonic machining of glass: a review paper”. World Journal of Engineering, 15(6), 751-770, 2018.
7) V. Kumar, H. Singh, “Rotary ultrasonic drilling of silica glass BK-7: microstructural investigation and process optimization through TOPSIS”. Silicon 1–15, 2018.
8) W Gu, Z Yao, X Liang, “Material removal of optical glass BK7 during single and double scratch tests”, Wear 270:241–246, 2011.
9) J. Kumar, “Ultrasonic machining- a comprehensive review” Machining Science and Technology, 17 (3), 2013, 325-379.
10) M. Adithan; V.C. Venkatesh, “Parametric influence on tool wear in ultrasonic drilling”, Tribol. Int. 1974, 7, 260–264.
11) J. Deng; T. Lee, “Ultrasonic machining of alumina based ceramic composites”, Journal of the European Ceramic Society 2002, 22 (8), 1235–1241.
12) V.K. Jain, Advanced Machining Processes; Allied publishers private limited: New Delhi, India, 2013.13)
13) R. Kataria; J. Kumar; B.S. Pabla, “Experimental investigation and optimization of machining characteristics in ultrasonic machining of WC-Co composite using GRA method”, Materials and Manufacturing Processes 2015, 0, 1–9.
14) H. Hocheng; K.L.Kuo; J.T. Lin, “Machinability of zirconia ceramics in ultrasonic drillin”, Materials and Manufacturing Processes 1999, 14 (5), 713–724.
15) R.S.Jadoun; P. Kumar; B.K. Mishra; R.C.S. Mehta, “Manufacturing process optimization for tool wear rate in ultrasonic drilling of engineering ceramics using the taguchi method” International Journal of Machining and Machinability of Materials 2006, 1 (3–4), 94–114.
16) R. V. Rao; P.J. Pawar; J.P. Davim, “Parameter optimization of ultrasonic machining process using nontraditional optimization algorithms”, Materials and Manufacturing Processes 2010, 25 (10), 1120–1130.
17) 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.
18) 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.
19) N. K. Maurya, V. Rastogi and P. Singh, “Experimental and Computational Investigation on Mechanical Properties of Reinforced Additive Manufactured Component”, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy., 6(3) 207-214 (2019). doi:10.5109/2349296
20) 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.
21) A. M. Rosli, A. S. Jamaludin, M. N. Muhd Razali, “Recent Study on Hard to Machine Material – Micromilling process” EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 8(2), 445-453 (2021). doi:10.5109/4480727
22) J. Wang, P. Feng, J. Zhang, W. Cai, H. & Shen, “Investigations on the critical feed rate guaranteeing the effectiveness of rotary ultrasonic machining.” Ultrasonics, 74, 81–88, 2017.
23) W. Cong & Z. Pei (2013). Process of Ultrasonic Machining. Handbook of Manufacturing Engineering and Technology, 1–19
24) J.R. Duflou, J.W. Sutherland, D. Dornfeld, C. herrmann, J. Jeswiet, S. Kara, M. Hauschild, K. Kellens, “Towards energy and resource efficient manufacturing: a processes and systems approach” CIRP Ann: Manufacturing Technology 2012; 61: 587–609.
25) F. Pusavec and J. Kopac, “Achieving and implementation of sustainability principles in machining processes” J Adv Prod Eng Manag 2009; 3: 58–69.
26) FA Rabiei, AR Rahimi, M. Hadad, “Performance improvement of eco-friendly MQL technique by using hybrid nanofluid and ultrasonic-assisted grinding”, The International Journal of Advanced Manufacturing Technology. 2017, 3(1):1001-15.

27) C. Ni & L. Zhu, (2020). Investigation on machining characteristics of TC4 alloy by simultaneous application of ultrasonic vibration assisted milling (UVAM) and economical-environmental MQL technology. Journal of Materials Processing Technology, 278, 116518.
28) M. Mukherjee, S. Goswami, P. Banerjee, S. Sengupta, P. Das, P. K. Banerjee & S. Datta, (2019). Ultrasonic assisted graphene oxide nanosheet for the removal of phenol containing solution. Environmental Technology & Innovation, 13, 398-407.
29) 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.
30) N.J. Churi; Z.J. Pei; C. Treadwell, "Rotary ultrasonic machining of titanium alloy: Effects of machining variables", Mach. Sci. Technol. 2006. DOI:10.1080/10910340600902124
31) 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
32) W.L. Cong; Z.J. Pei; C. Treadwell, "Preliminary study on rotary ultrasonic machining of CFRP/Ti stacks" Ultrasonics, 54 (6), 2014, 1594-1602.
33) W.L. Cong; Z.J. Pei; Q. Feng; T.W. Deines; C. Treadwell, "Rotary ultrasonic machining of CFRP: a comparison with twist drilling" J. Reinf. Plast. Compos., 31(5), 2012, 313-321.
34) K. Ding; Y. Fu; H. Su; Y. Chen; X. Yu; G. Ding, "Experimental studies on drilling tool load and machining quality of C/SiC composites in rotary ultrasonic machining" J. Mater. Process., 214(12), 2014, 2900-2907.
35) R. Kataria; J. Kumar; B.S. Pabla, "Experimental investigation into the hole quality in ultrasonic machining of WC-Co composite" Mater. Manuf. Process., 30(7), 2015, 921-933.
36) K.J. Singh; I.S. Ahuja; J. Kapoor, "Optimization of material removal rate in ultrasonic machining of polycarbonate bulletproof glass and acrylic heat-resistant glass by Taguchi method" Multidiscip. Model. Mater. Struct, 13(4), 2017, 612-627.
37) S. Anwar; M.M. Nasr; S. Pervaiz; A. Al-Ahmari; M. Alkahtani; A. El-Tamimi, "A study on the effect of main process parameters of rotary ultrasonic machining for drilling BK7 glass" ADV MECH ENG, 10(1), 2018, 1–12.
38) V. Gupta; R. Jain; M.L. Meena; and G.S. Dangayach, "Six-sigma application in tire-manufacturing company: a case study", J Ind Eng Int, 14, (2018), 511–520
39) V. Kumar & H. Singh, "Rotary ultrasonic Drilling of Silica Glass BK-7: microstructural investigation and process optimization through TOPSIS". Silicon, 11(1), 471- 485, 2019.
40) J.H. Biswas, Jagadish and A. Ray, 'Experimental investigation and optimisation of ultrasonic machining parameters on zirconia composite', Int. J. Machining and Machinability of Materials, Vol. 21, Nos. 1/2, pp.115–137, 2019.
41) A. Sandá and C. Sanz, 'Rotary ultrasonic machining of ZrO2-NbC and ZrO2-WC ceramics', Int. J. Machining and Machinability of Materials, Vol. 22, No. 2, pp.165–179, 2020.