

Experimental Investigation of Rotary Ultrasonic Face Milling on Float glass and Red granite

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Abstract- The rise in the domestic and industrial applications of granite and float glass which are hard and brittle is forcing manufacturing engineering to develop their precise and cost-effective machining techniques. These materials are used mainly in buildings, decorations, arts and optics industries which require a perfect surface finish and dimensional accuracies. Rotary ultrasonic face milling (RUFM) is preferred among all non-conventional machines for surface grinding. The main objective of this paper is to analyze the effect of process parameters on RUFM on float glass and red granite. The analysis of variance (ANOVA) method was used to find significant factors and determine interaction effects as well. Both the materials were compared for material removal rate (MRR) and surface roughness (SR) as response variables. In addition, SEM (Scanning Electron Microscope) was used for qualitative tool wear analyses and comparison between both materials after milling. The experimental results show that the MRR and SR during RUFM increase with all input parameters. Also, the process parameters have a significant effect on output responses. It was concluded that RUFM can successfully be used for brittle and hard material to obtain a micro-level surface finish with a normal material removal rate. In addition, it is surmised that more hardness of work material reduces the tool life.

Keywords- RUFM, SEM, ANOVA

1. INTRODUCTION

Nowadays, Glasses are the most used material for building decoration, architecture, optics industries and for some projects because of their superior properties like durability, energy efficiency, acoustic insulation, and high safety [1]. The pure form of glass was found around 3600 years back. Rapid use of plain surfaced glasses forces the engineering department and industries to manufacture smooth surfaced glass slabs called float glass. Around the 19th century, float glass comes into the play which breaks the major rapid use of simple glasses inefficiently. On other hand, granite material for its outstanding durability and strength become the most usable rock material for building decorations, floor, kitchen, and room formation. Also, rock drilling and milling are widely used for geoengineering, petroleum engineering, and scientist for sample collection from space or planets [2]. Constant innovation of new devices, aerospace parts, optics

materials, and much more improves the demand for brittle and hard materials. New hard and brittle materials are more challenging to the machine on it for manufacturing engineering [3]. Generally, two types of machining are performed by industries to transform these materials in suitable form i.e., conventional and non-conventional machining. Because of some better results like tool life improvement, precise machining, cost-effective, high range of machining scale force industries to used non-conventional over conventional for the machine on these materials. Rotary ultrasonic machining (RUM) which is an advanced version of ultrasonic machining is preferred over another non-conventional machining [4]. Mostly, rotary ultrasonic machining consists of an ultrasonic vibration unit, coolant system, feed system. Brittle fracture due to hammering action of vibration and removal of workpiece grains due to the grinding action of the diamond impregnated tool is the main cause of material removal during RUM. A simple coolant is used to remove the debris and keep the tool and horn cool. The power supplied in form of electrical signal gets converted into mechanical vibration by a transducer (piezoelectric). That vibration is further amplified by the horn and finally transmitted to the cutting tool. The cutting tool is attached with a horn and stepper motor which rotates at a given revolving speed. The main mechanism behind material removal during RUM is the hammering, grinding, and erosion action caused by the vibrating machine tool. Rotary ultrasonic face milling (RUFM) is an extension of the application of RUM for surface grinding [5]. RUFM is best to use for surface machining as it contains a combination of conventional surface grinding and ultrasonic machining (USM) [6]. Various industries and factories are using RUFM for precise and smooth surface machining on hard and brittle materials especially float glass, granites, and ceramics [7].

2. EXPERIMENTAL SETUP

CNC rotary ultrasonic drilling and slot cut machine is used for the experiment. The machine platform consists of several systems such as feed system, coolant system, ultrasonic system, drive control system. A computer-controlled stepper motor is

used to drive ball screws with three degrees of freedom in the feed system. Basic programming language (G&M codes) is used for process planning. Tool path can be generated manually and automatically as per the convenience of the user, shown in Fig. 1. The ultrasonic power and frequency are controlled by the drive control system. The drive system consists of a piezoelectric transducer that converts electric energy into rotation and vibration which is directly transferred to the attached horn. The machine has a maximum value of ultrasonic power is 1000 Watts (which is considered 100% during the experiment) and a frequency of 25KHz. The tool is soldered with the horn which also gets the vibration effect of the transducer.

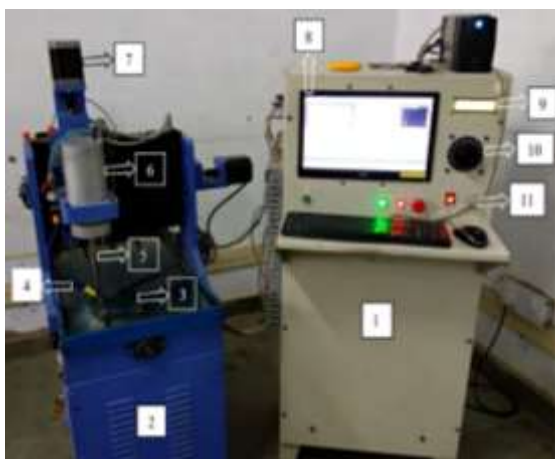


Fig.1 CNC rotary ultrasonic drilling and slot cut machine

A high carbon steel tool that consists of diamond grit implemented at the bottom part is used for the machining. In the coolant system, normal fluid (without abrasives) is used to reduce the temperature and remove debris. The numbers indicated in Fig. 1 indicates the parts of the machine setup labeled as s (1) Drive control system (2) Coolant tank (3) The workpiece (4) Coolant flow (5) Horn (6) Transducer (7) Stepper motor (8) Processing display (9) Ultrasonic freq. display (10) Ultrasonic power control (11) Frequency control.

3. EXPERIMENTAL CONDITIONS AND MEASUREMENT PROCEDURE

3.1 Workpiece selection

After keeping all factors like limited spindle speed, cost-effectiveness, low machinability, and material availability, the two hard and brittle materials selected were float glass and red granite.

3.2 Experimental parameters

As per the literature review, the following parameters are selected for this study:

1. General-

- (a). Slot length and width = 26 mm and 6 mm

- (b). Gap between slots = 6 mm

2. Inputs-

- (a). Spindle speed = 1000 rpm
- (b). Ultrasonic power = 25% and 75%
- (c). Feed rate = 6, 12 and 18 mm/min. for float glass
- (d). Feed rate = 6, 12 mm/min. for red granite
- (e). Depth of cut = 0.5, 1.0 and 1.5 mm

3. Outputs- Surface roughness (SR), material removal rate (MRR), Tool wear (qualitative)

3.3 Output response measurement

Material removal rate (MRR) was measured using the calculation of volume removed from the workpiece and the time taken for each slot cut. A stopwatch was used to calculate the time taken for a slot cut. Surface roughness was measured by a SURFTEST SJ-201 equipment which provides a micron level of Ra value, shown in Fig. 2. Qualitative tool wear was measured or observed by using SEM technology for both tools which were used on both materials.



Fig.2 Surface roughness measurement using SURFTEST SJ-210

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Result analysis for float glass during RUFM

Total 18 experiments were performed after combining all the levels of process parameters. All 18 experimental results on float glass with MRR and SR output response were shown in Table 1.

4.2 Effect of process parameters on MRR and SR during RUFM on float glass

The main effects plot shows that MMR increases with all input parameters. There is very less effect of ultrasonic power on MRR variation compared to feed rate and depth of cut. The maximum MRR was found at 75% of ultrasonic power, 18 mm/min. feed rate and 1.5 mm of depth of cut. On the other side, ultrasonic power shows some effect on SR variation more than in MRR variation. Ultrasonic power and depth of cut were less effective on SR variation compared to feed rate. The best surface finish can find at 25% of ultrasonic power, 6 mm/min. of feed rate and 0.5 mm of depth of cut.

4.3 ANOVA analysis on MRR and SR during RUFM on float glass

ANOVA table for MRR shows that all process parameters are significant factors except ultrasonic power. The contribution of ultrasonic power, feed rate, and depth of cut is 0.04%, 50.50%, and 42.34% on MRR. From the ANOVA table for SR, it is clearly showing that all process parameters are significant factors for SR variation. The contribution of ultrasonic power, feed rate, and depth of cut for SR is 4.60%, 92.10%, and 3.15%.

Table 1 Experimental result for RUFM on float glass

Exp. No.	Ultrasonic power (%)	Feed rate (mm/min.)	Depth of cut (mm)	MRR (mm ³ /min.)	S.R (μm)
1.	25	6	0.5	20.51	1.486
2.	25	6	1.0	38.33	1.505
3.	25	6	1.5	56.19	1.520
4.	25	12	0.5	41.01	1.586
5.	25	12	1.0	76.71	1.603
6.	25	12	1.5	112.45	1.617
7.	25	18	0.5	61.78	1.675
8.	25	18	1.0	115.42	1.704
9.	25	18	1.5	169.35	1.718
10.	75	6	0.5	21.41	1.521
11.	75	6	1.0	39.24	1.542
12.	75	6	1.5	57.08	1.549
13.	75	12	0.5	42.78	1.622
14.	75	12	1.0	78.39	1.643
15.	75	12	1.5	114.12	1.654
16.	75	18	0.5	64.56	1.710
17.	75	18	1.0	118.27	1.738
18.	75	18	1.5	171.91	1.758

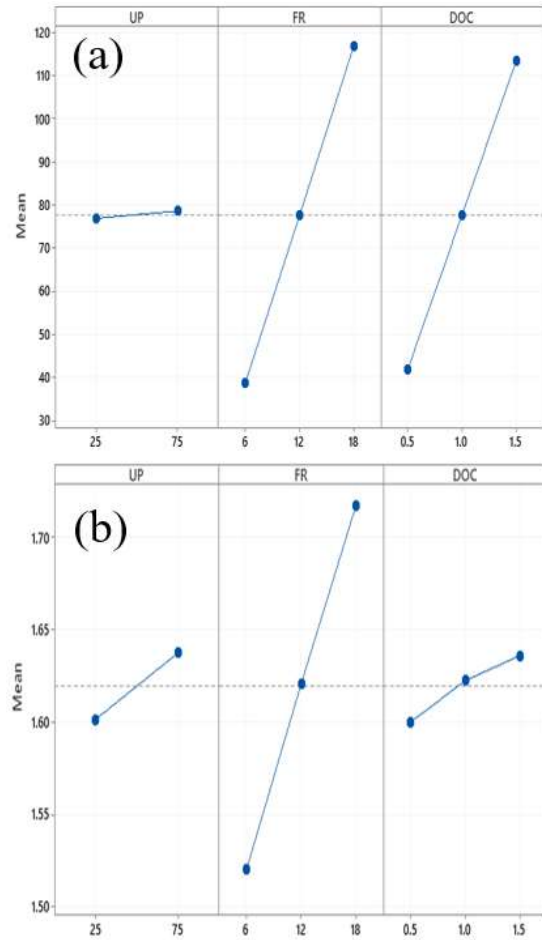


Fig.3 Effect of process parameters on (a) MRR and (b) SR during RUFM on float glass

Table 2 ANOVA for (a) MRR and (b) SR during RUFM on float glass

ANOVA for	Table	MRR				SR			
		SS	MS	F	P	SS	MS	F	P
SOURCE	DOF								
UP	1	14.2	14.24	0.07	0.801	0.0057	0.00579	377.78	0.00
FR	2	18293.6	9146.82	42.56	0.000	0.1160	0.05802	3781.93	0.00
DOC	2	15340.3	7670.17	35.69	0.000	0.0039	0.00198	129.35	0.00
Error	12	2579.1	214.93			0.0002	0.00002		
TOTAL	17	36227.3				0.1259			

4.4 Result analysis for red granite during RUFM

Due to the 2 level of feed rate, the number of experiments gets reduced during red granite compared to float glass. A total of 12 experiments were performed during RUFM on red granite.

4.5 Effect of process parameters on MRR and SR during RUFM on red granite

MRR linearly increases with all process parameters during RUFM on red granite. Ultrasonic power shows less effect on MRR variation compared to feed rate and depth of cut. The maximum MRR can found at 75% of ultrasonic power, 12 mm/min. of feed rate, and 1.5 mm of depth of cut. The main

effects plot for SR variation shows that SR increases with all process parameters. All parameters show a linear effect on SR where feed rate is more effective than ultrasonic power and depth of cut. the best surface finish can find at 25% of ultrasonic power, 6 mm/min. of feed rate and 0.5 mm of depth of cut.

4.6 ANOVA analysis on MRR and SR during RUFM on red granite

ANOVA table for MRR shows that feed rate and depth of cut are significant factors where ultrasonic power is an insignificant factor for MRR variation. The contribution of ultrasonic power, feed rate, and depth of cut is 0.06%, 39.41%, and 54.44% on

MRR. From the ANOVA table for SR, it is clearly showing that all process parameters are significant factors for SR variation. The contribution of ultrasonic power, feed rate, and depth of cut for SR is 6.53%, 87.57%, and 5.72%.

Table 3 Experimental result for RUFM on red granite

Exp No	Ultrasonic power (%)	Feed rate (mm/min)	Depth of cut (mm)	MRR (mm ³ /min.)	S.R (μm)
1.	25	6	0.5	18.72	1.373
2.	25	6	1.0	36.56	1.386
3.	25	6	1.5	54.37	1.398
4.	25	12	0.5	37.44	1.450
5.	25	12	1.0	73.14	1.469
6.	25	12	1.5	108.88	1.475
7.	75	6	0.5	19.62	1.398
8.	75	6	1.0	37.45	1.410
9.	75	6	1.5	55.28	1.417
10.	75	12	0.5	39.21	1.470
11.	75	12	1.0	75.89	1.486
12.	75	12	1.5	110.58	1.497

4.7 Comparison between float glass and red granite for MRR and SR during RUFM

Comparative graphs on MRR and SR between both materials are mentioned in Fig. 5. MRR during RUFM on float glass is more than red granite because one level of feed rate was not performed on red granite for tool safety. Also, red granite is a more hard and less brittle material than float glass which generates more milling resistance and causes more tool wear than float glass. In the 2nd graph, the value of surface roughness is more than red granite. This means the surface finish on red granite is comparatively better than float glass. It is because of the same reason that float glass is a more brittle material than red granite, due to which vibration on float glass cause more sub-surface damage.

Table 4 ANOVA for (a) MRR and (b) SR during RUFM on red granite

ANOVA Table for		MRR				SR			
SOURCE	DOF	SS	MS	F	P	SS	MS	F	P
UP	1	6.6	6.63	0.07	0.796	0.001344	0.001344	251.45	0.00
FR	1	4149.3	4149.29	45.34	0.000	0.018019	0.018019	3370.99	0.00
DOC	2	5731.1	2865.54	31.31	0.000	0.001176	0.000588	110.00	0.00
Error	7	640.6	91.51			0.000037	0.000005		
TOTAL	11	10527.6				0.020576			

4.8 Tool wear analysis

Two new tools were used for both materials during RUFM. Tool wear analysis performed on both tools using SEM technology. Fig. 6 showing the magnified image of the tool and its abrasives grains which was used on float glass during RUFM. A similar pattern of tool wear was found at the maximum area of the tool bottom. The tool which was used on float glass for milling was magnified to 7082x for clear analysis. Tear-out of diamond

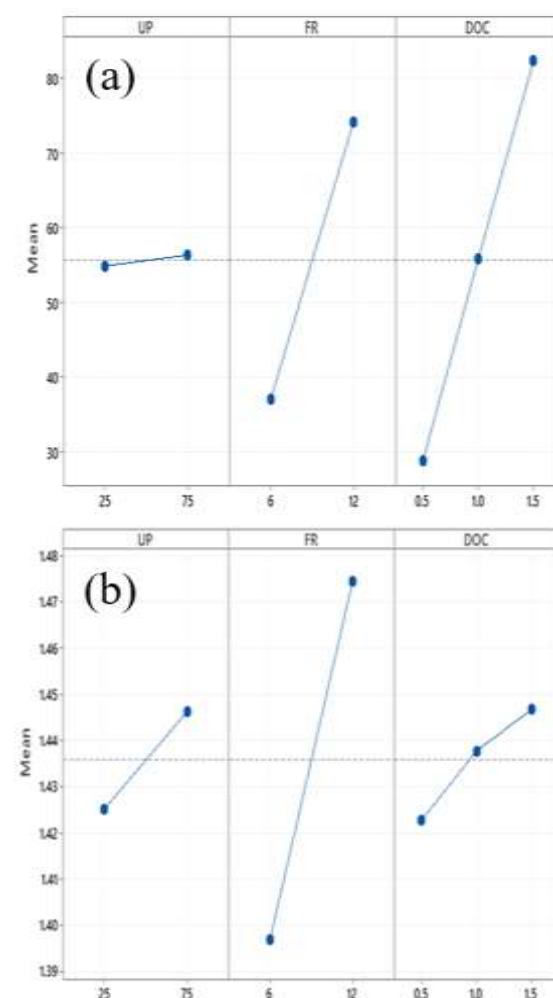


Fig.4 Effect of process parameters on (a) MRR and (b) SR during RUFM on red granite

abrasives was found on the tool because of high milling resistance during machining on float glass.

Another tool that was used for milling on red granite was magnified to 1082 to analyse the similar pattern of tool wear on it. A diamond (abrasive) grain pulled out was found. Complete pull-out of abrasive grain crates voids on the tool surface due to which the internal (main) material of tool started contacting with the surface of the workpiece during

machining. Also, the pull-out of abrasive grain makes the tool surface smooth (less rough than the new tool) which makes it less effective. It may one of the reasons for less MRR on red granite.

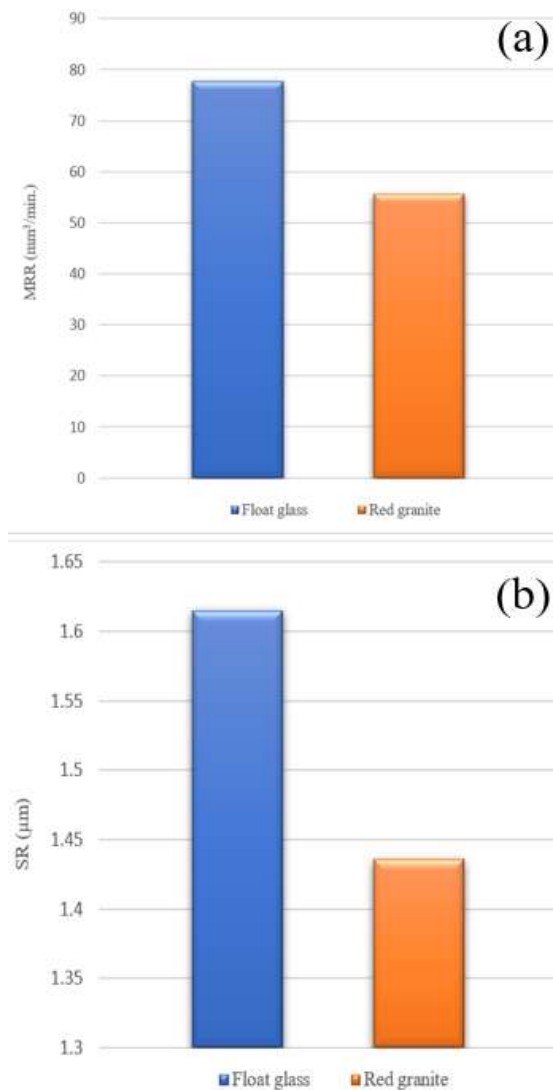


Fig.5 Comparison of float glass and red granite on output responses

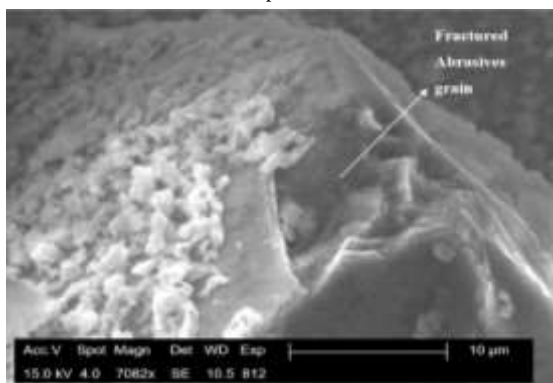


Fig.6 Cavity showing complete removal of abrasive grain (the tool used on red granite)

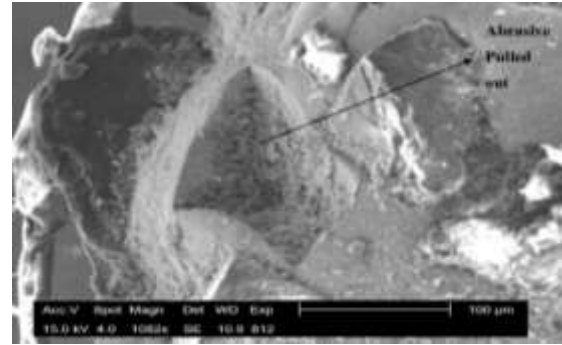


Fig.7 Cavity showing complete removal of abrasive grain (the tool used on red granite)

5. CONCLUSION

1. MRR during RUFM on both materials linearly increases with all process parameters. Ultrasonic power was always found less effective than feed rate and depth of cut. Also, all process parameters were significant factors for MRR variation except ultrasonic power for both materials.
2. SR during RUFM on both materials increases with all parameters. Feed rate was more effective than ultrasonic power and depth of cut in SR variation. All process parameters have a significant effect on SR variation during RUFM on both materials.
3. MRR during RUFM on float glass was more than red granite. Where better surface finish was found on red granite.
4. Red granite causes more milling resistance which causes complete removal of abrasive grains and reduces tool life. Abrasive grain tear was found on the tool which was used on float glass which was comparatively less tool wear than the tool used on red granite. Tool life for milling is more on float glass than red granite.

6. REFERENCES

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