View metadata, citation and similar papers at core.ac.uk brought to you by CORE
provided by The International Islamic University Malaysia Repository

Online available since 2012/Oct/08 at www.scientific.net
© (2012) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.576.107

# Surface Roughness Model for High Speed End Milling of Soda Lime Glass Using Carbide Coated Tools with Compressed Air Blowing

M. A. Mahmud[1,a], A. K. M. Nurul Amin[2,b] and M. D. Arif[3,c]

[1]Department of Manufacturing and Materials Engineering

Kulliyyah of Engineering, International Islamic University Malaysia

[a]mahmud_1879@yahoo.com, [b]akamin@iium.edu.my, [c]marif@mtu.edu

**Keywords:** High Speed End Milling, Soda Lime Glass, Carbide Coated Tool, Surface Roughness, ANOVA.

**Abstract.** Glass materials play a vital role in advancement of science and technology. They have found wide spread application in the industry, in laboratory equipment and in micro-gas turbines. Due to their low fracture toughness they are very difficult to machine, moreover there are the chip depositions on the machined surface which affects surface finish under ductile mode cutting conditions. In this research, high speed end milling of soda lime glass is performed on CNC vertical milling machine to investigate the effects of machining parameters i.e. spindle speed, depth of cut, and feed rate on machined surface roughness. Design of experiments was performed following Central Composite Design (CCD) of Response Surface Methodology (RSM). Design Expert Software was used for generating the empirical mathematical model for average surface roughness. The model's validity was tested to 95% confidence level by Analysis of Variance (ANOVA). Subsequent experimental results showed that the developed mathematical model could successfully describe the performance indicators, i.e. surface roughness, within the controlled limits of the factors that were considered.

## Introduction

Lately, there has been an increased interest in the high speed machining due to its ability to improve surface finish. Moreover, high speed machining increases the Material Removal Rate (MRR) while retaining the tool life within acceptable limits [1]. But, even applying high speed machining, end milling of glass is a serious challenge and expensive issue because of glass' inherent brittleness and low toughness. Based on prior studies on glass machining, it has been observed that effective machining of glass can be achieved by utilizing ductile regime machining. Ductile mode machining enables material removal from brittle materials in a ductile manner avoiding fracture or crack propagation. However, such machining mode is only attainable through careful control of machining conditions and parameters. Therefore, the need for developing empirical mathematical equations to model machining processes, especially for brittle materials such as glass, is of paramount importance.

Sajjadi et al. [2] in their study by scratch test showed that higher critical chip thickness was obtained by higher cutting speeds. While, Reddy et al. [3] developed predictive models for surface roughness of ceramic glass under the conditions of 10,000 to 20,000 rpm and 30 mm/min feed rate. They concluded from their model that surface roughness decreased with increase of spindle speed in micro end milling operation. Arif et al. [4] reported on their achievement in ductile mode machining of glass by micro milling process with 2-flute, TiAlN coated, super hard cemented carbide micro end mill tools (diameter: 0.8 mm). They found the critical axial depth of cut (0.4-0.6 μm) for fracture-free slotting in soda-lime glass. Uddin et al. [5] observed that high hydrostatic pressure could be used to deform brittle materials plastically and produce continuous chips. Sai et al. [6] claimed that optimum quality machined surfaces, which depends on roughness, micro hardness, residual stresses and material micro structure, could be obtained by employing high cutting speeds. This work aims at developing empirical mathematical model of surface roughness in high speed end milling of soda lime glass within selected ranges of the cutting parameters.

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of TTP, www.ttp.net. (ID: 210.48.222.12, International Islamic University of Malaysia, Kuala Lumpur, Malaysia-01/07/13,10:48:11)

**Experimental Details**

Experimental tests were executed on Vertical Machining Center (VMC ZPS, Model: MLR 542) having a maximum spindle speed of 8,000 rpm. For increased spindle speed a brushless motor spindle planet (Nakanishi HES510) was attached. The HES510 motor and air turbine spindle require dry, clean, and regulated air, which was provided by the Nakanishi AL-0201 airline kit. The Nakashi HES510 spindle was chosen because of its high rigidity (spindle accuracy: 1 µm), low vibration, and high spindle speed (50000 rpm). The output power (250 W) was controlled by an external E3000 ECU. Compressed air to blow off the chips was obtained from an air compressor. The experimental set-up is illustrated in Fig. 1.

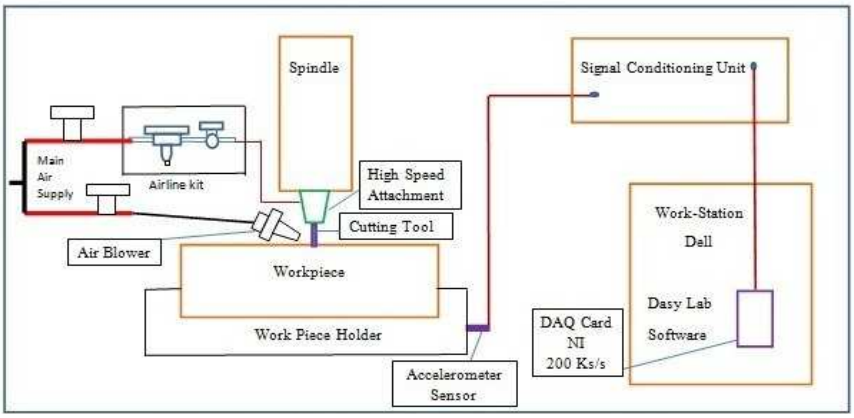


Fig. 1: Experimental set up for high speed end milling of glass

A micro-grain cemented carbide tool with plasma CVD coating (dia: 4 mm, flute no: 2) was used for machining soda lime glass (dimensions: 20 mm x 15 mm x 5 mm, composition: 73% $SiO_2$, 14% $Na_2O$, 9% CaO, 4% MgO, 0.15% $Al_2O_3$). The tool overhang was fixed at 15 mm from the collet chuck for all cutting conditions. The posterior surface of the work-piece was strongly clamped by Aluminium fixtures. At the beginning, the glass work-piece was leveled by an abrasive diamond grinder wheel. Experimental runs were designed using the DESIGN-EXPERT Software 6.0 based on a Central Composite Design (CCD) model in Response Surface Methodology (RSM). The input parameters were: spindle speed (30,000-50,000 rpm), depth of cut (50-100 µm), and feed rate (6-18 mm/min). Compressed air (0.35-40 MPa) was used for air blowing. Finally, after machining, the work-piece (cleaned with acetone) was analyzed for surface roughness using 3-D optical profiler (VeecoWyko) and SurfTest SV-500. Table 1 lists the experimental results.

Table 2 includes the results of the Fit and Summary Test and Table 3 is the ANOVA analysis. The Model F-value of 22.17 implied that the model was significant. There was only a 0.01% chance that a "Model F-Value" this large could occur due to noise. The "Lack of Fit F-value" of 1.47 implied that the lack of fit was not significant relative to the pure error. There was a 35.16% chance that a "Lack of Fit F-value" this large could occur due to noise. Therefore, the 2FI model with a confidence level of more than 95% was selected for modeling the surface roughness (Eq. 1, below).

Table 1: Experimental sequence with independent and response variables

| Run | Factor 1 | Factor 2 | Factor 3 | Response 1 | | Run | Factor 1 | Factor 2 | Factor 3 | Response 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| | A:Spindle Speed (RPM) | B:Depth of Cut µm | C:Feed Rate mm/min | Surface Roughness µm | | | A:Spindle Speed (RPM) | B:Depth of Cut µm | C:Feed Rate mm/min | `Surface Roughness nm |
| 1 | 40000 | 75 | 12 | 239.87 | | 11 | 40000 | 75 | 12 | 248.3 |
| 2 | 50000 | 75 | 12 | 276.22 | | 12 | 30000 | 50 | 6 | 171.37 |
| 3 | 30000 | 100 | 18 | 287.66 | | 13 | 40000 | 75 | 12 | 285.58 |
| 4 | 30000 | 50 | 18 | 156.37 | | 14 | 50000 | 50 | 6 | 413.63 |
| 5 | 40000 | 50 | 12 | 296.81 | | 15 | 30000 | 75 | 12 | 184.46 |
| 6 | 40000 | 75 | 18 | 266.06 | | 16 | 40000 | 75 | 12 | 259.26 |
| 7 | 50000 | 50 | 18 | 322.86 | | 17 | 50000 | 100 | 18 | 200 |
| 8 | 40000 | 100 | 12 | 210.215 | | 18 | 30000 | 100 | 6 | 224.88 |
| 9 | 40000 | 75 | 12 | 221.57 | | 19 | 50000 | 100 | 6 | 261.41 |
| 10 | 40000 | 75 | 6 | 220 | | 20 | 40000 | 75 | 12 | 261.32 |

Table 2: Fit and summary test for surface

| Source | Sum of Squares | DF | Mean Square | F Value | Prob > F | |
|---|---|---|---|---|---|---|
| Mean | 1253926 | 1 | 1253926 | | | |
| Linear | 23663.07 | 3 | 7887.69 | 3.127363 | 0.0551 | |
| 2FI | 32869.07 | 3 | 10956.36 | 19.02809 | < 0.0001 | Suggested |
| Quadratic | 635.4524 | 3 | 211.8175 | 0.309225 | 0.8183 | |
| Cubic | 4017.787 | 4 | 1004.447 | 2.127952 | 0.195 | Aliased |
| Residual | 2832.151 | 6 | 472.0252 | | | |
| Total | 1317943 | 20 | 65897.16 | | | |

Table 3: Analysis of variance for surface roughness model

| Source | Squares | DF | Square | Value | Prob > F | |
|---|---|---|---|---|---|---|
| Model | 54756.92 | 4 | 13689.23 | 22.1733 | < 0.0001 | significant |
| A | 20194.24 | 1 | 20194.24 | 32.70987 | < 0.0001 | |
| B | 3128.477 | 1 | 3128.477 | 5.067388 | 0.0398 | |
| AB | 26436.2 | 1 | 26436.2 | 42.82036 | < 0.0001 | |
| AC | 4998 | 1 | 4998 | 8.095572 | 0.0123 | |
| Residual | 9260.618 | 15 | 617.3746 | | | |
| Lack of Fit | 6909.155 | 10 | 690.9155 | 1.469118 | 0.3516 | not significant |
| Pure Error | 2351.463 | 5 | 470.2926 | | | |
| Cor Total | 64017.54 | 19 | | | | |

$$\text{Surface Roughness} = 250.39 + (44.9*A) - (17.68*B) - (57.48*A*B) - (24.99*A*C). \qquad (1)$$

Where, A is spindle speed, B is Depth of Cut, and C is Feed Rate. Fig. 2 (a) represents the interaction effect of spindle speed (A) and depth of Cut (B) on surface roughness. It was observed that the surface roughness increased with the increase in spindle speed. However, in case of increased depth of cut again surface roughness increased when there were deviations from the reference point of C = 12 mm/min. Fig. 2 (b) is the residual plot showing that there was good clustering of the data.

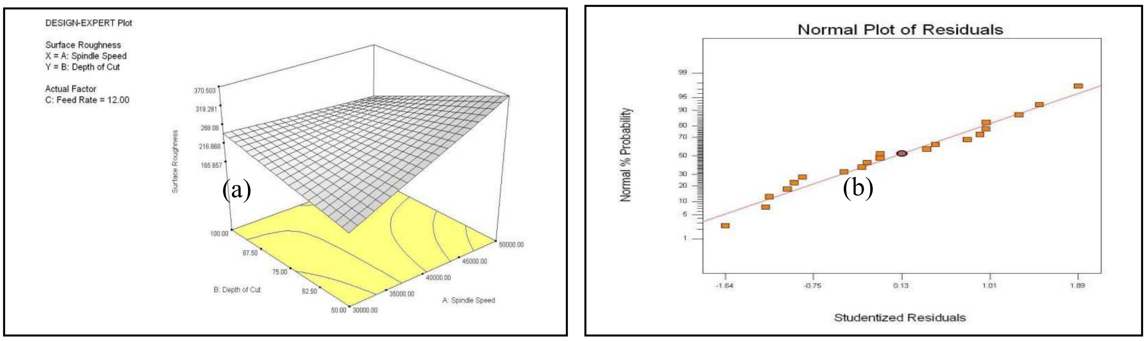


Fig. 2: Analysis plots (a) interaction plot against spindle speed and depth of cut, (b) normal plot of residuals.

## Conclusion

The following specific conclusions have been drawn on the research work:

1. Response surface methodology has been proven as a good method for modeling the cutting parameters in high speed end milling of soda lime glass using carbide coated tools with compressed air blowing.
2. According to the developed model, the spindle speed and the depth of cut have more significant effect on surface roughness in high speed end milling of soda lime glass.
3. Also, a combination of low spindle speed and depth of cut offers the lowest surface roughness.

## References

[1] H. Schulz, T. Moriwaki, High speed machining, CIRP Ann, 41:2 (1992) 637-642.

[2] M. Sajjadi, Md. Malekian, S.S. Park, B.G.J. Martin, Investigation of mico scratching and machining of glass, Proceedings of the 2009 ASME International Manufacturing Science and Engineering Conference, (2009).

[3] M.M. Reddy, A. Gorin, K.A. Abou-El-Hossein, Predictive surface roughness model for end milling of machinable glass ceramic, 2011 IOP Conf. Ser. Mater. Sci. Eng. 17, No. 01 (2002).

[4] Md. Arif, M. Rahman, W.Y. San, N. Doshi, An experimental approach to study the capability of end-milling for microcutting of glass, Int. J. Adv. Manuf. Technol. 53 (2011) 1063-1073.

[5] M.S. Udding, K.H.W. Seah, X.P. Li, M. Rahman, K. Liu, Effect of crystallographic orientation on wear of diamond tools for nano-scale ductile cutting of silicon, Wear, 257 (2004) 751-759.

[6] W.B. Sai, N.B. Salah, J.L. Lebrun, Influence of machining by finishing milling on surface characteristics, Int. J. of Mach. Tools Manuf. 41 (2001) 443-450.

**Advances in Manufacturing and Materials Engineering**
10.4028/www.scientific.net/AMR.576

**Surface Roughness Model for High Speed End Milling of Soda Lime Glass Using Carbide Coated Tools with Compressed Air Blowing**

10.4028/www.scientific.net/AMR.576.107

**DOI References**

[1] H. Schulz, T. Moriwaki, High speed machining, CIRP Ann, 41: 2 (1992) 637-642.
doi:10.1016/S0007-8506(07)63250-8
[2] M. Sajjadi, Md. Malekian, S.S. Park, B.G.J. Martin, Investigation of mico scratching and machining of glass, Proceedings of the 2009 ASME International Manufacturing Science and Engineering Conference, (2009).
doi:10.1115/MSEC2009-84038
[3] M.M. Reddy, A. Gorin, K.A. Abou-El-Hossein, Predictive surface roughness model for end milling of machinable glass ceramic, 2011 IOP Conf. Ser. Mater. Sci. Eng. 17, No. 01 (2002).
doi:10.1088/1757-899X/17/1/012002
[4] Md. Arif, M. Rahman, W.Y. San, N. Doshi, An experimental approach to study the capability of end-milling for microcutting of glass, Int. J. Adv. Manuf. Technol. 53 (2011) 1063-1073.
doi:10.1007/s00170-010-2893-y