Advanced Materials Research
ISSN: 1662-8985, Vol. 1115, pp 51-54
doi:10.4028/www.scientific.net/AMR.1115.51

Submitted: 2015-01-09
Accepted: 2015-03-26
Online: 2015-07-20

Effect of Cutter Diameters on Surface Roughness Attained in High Speed End Milling of Soda Lime Glass

A. K. M. Nurul Amin[1,a], A. A. Che Omar[1,b], M. A. Mohammed Kamal[1,c], Mahmoud M. A. Nassar[1,d], N. F. Mohd Zaib[1,e], Muammer D. Arif[1,f]

[1]Department of Manufacturing and Materials Engineering,

Faculty of Engineering, International Islamic University Malaysia (IIUM)

Jalan Gombak, 53100 Kuala Lumpur, Malaysia

[a]email: akamin@iium.edu.my, [b]email: 0913049@gmail.com, [c]email: mohd_rs70@hotmail.com, [d]email: mmn_yota258@hotmail.com, [e]email: fathiahzaib@gmail.com, [f]email: marif@mtu.edu

Keywords: Ductile mode machining, soda lime glass, micro high speed end milling, surface roughness, carbide insert.

Abstract. Soda lime glass is used extensively in camera lens, micro gas turbines, light bulbs, tablewares, optics, and chemical apparatus owing to its high hardness, excellent optical properties, and good corrosion and chemical resistance. Such applications of soda lime glass demand high machining and finishing precision. On the other hand, machining of glass poses significant challenges due to its inherent brittleness. The process of removal of material from glass, if not done in ductile mode, can generate subsurface cracks and brittle fractures which have adverse effects on its functionality. This research investigates the high speed micro-end milling of soda lime glass in order to obtain ductile regime machining. It has been found by other researchers that ductile mode machining can avoid sub-surface cracks and brittle fractures. However, in ductile mode machining, the gummy chips settle permanently on the machined surface affecting adversely the surface finish. In order to avoid such chip settlement, compressed air was directed using a special air delivery nozzle to blow away the resultant gummy chips, thereby preventing them from settling on the machined surface. Response surface methodology (RSM) and a commercial NC end mill were used to design and perform the machining runs, respectively. Machining was done using: high spindle speeds from 30,000 to 50,000 rpm, feed rates from 5 to 15 mm/min, and depth of cuts from 3 to 7 μm. Three different diameter carbide tools were used: 0.5, 1, and 2 mm. A surface profilometer was used to analyze the surface roughness of the resultant machined surface. Subsequently, the data was used for finding the best combination of cutting parameters required to obtain the lowest surface roughness. The results demonstrate that high speed machining is a viable option for obtaining ductile regime machining and generating machined surfaces with very low surface roughness in the range of 0.08μm – 0.22 μm, using 0.5 mm carbide end mill cutter.

Introduction

Soda lime glass is used for plane glass, containers, pressed and blown ware, and lighting products where high chemical durability and heat resistance are not needed. At the same time, it is also used in manufacturing, opto-electronics, and semiconductor industries [1]. However, soda lime glass is considered a difficult-to-machine material as it is susceptible to brittle fracture during machining. To achieve a good surface finish, soda lime glass should therefore be machined in ductile mode [2]. So, in order to obtain ductile regime machining (DRM) along with good surface finish, appropriate machining parameters need to be observed [1].

High speed machining (HSM) is a combination of high speed and high feed rates along with special tools and processes to achieve high efficiency machining operations. It is not simply a machining process which uses high rpms or spindle speeds. Rather, it involves very specific operations which are accomplished with specialized tooling [3], thereby achieving DRM. Thus, high speed machining helps to achieve lower surface roughness and better surface integrity. Also, it can reduce the chances of unstable tool performance. Thus, it is recommended that to increase productivity and surface quality HSM should be used with a combination of high spindle (cutting) speed and large axial depth of cut [4].

Amin et al. [5] reported that DRM of soda lime glass was obtained by using high spindle speed in a vertical end mill using conventional uncoated tungsten carbide (WC) cutters. They obtained very low surface roughness and claimed that the high local heating due to friction at large cutting speeds was enough to ensure DRM. There was no need for negative rake angles. They also optimized the process using RSM.

This work uses high speed end milling to machine soda lime glass using uncoated WC tools of three different diameters to determine the effect of cutter diameter on DRM.

Experimental Details

A 5-axis DMU 35M Deckel Maho NC mill was used to conduct the machining runs. Fig. 1 below shows the schematic diagram for the experimental setup of high speed micro-end milling of soda lime glass using uncoated tungsten carbide tool. A NSK Planet 550 high speed attachment with spindle speed range from 40,000 rpm to 60,000 rpm was attached to the spindle and connected to the air supply via the Nakanishi AL-0201 Air Line Kit. Compressed air was needed to control the high speed attachment. Another compressed air supply was required for the air blower.

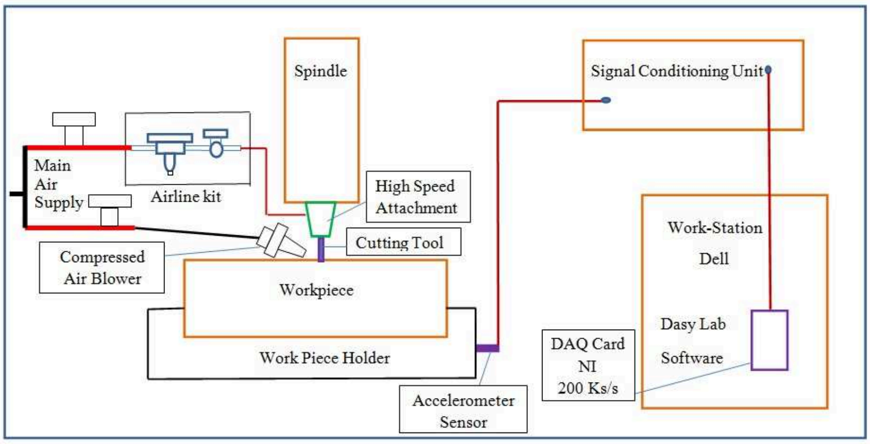
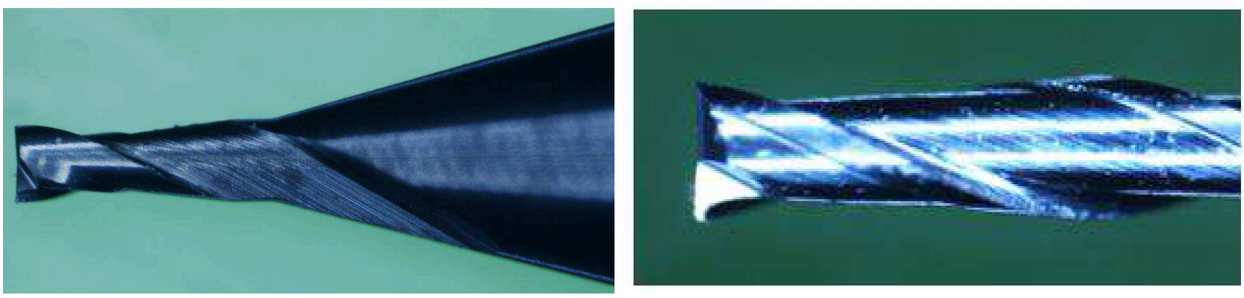


Fig. 1: Experimental setup used for HSM of soda lime glass with air blower system.

Three different diameters (0.5, 1, and 2 mm) of uncoated tungsten carbide tools with two flutes were used. Fig. 2 shows their geometry. Rectangular work specimens of soda lime glass measuring 20 mm x 15 mm x 5 mm were used in this study. Before running the experiment, the work-piece was placed at a slightly higher level than the aluminum clamping plates of the fixture to facilitate grinding using a diamond grinding wheel (for leveling prior to machining). The surface roughness values were measured after machining using a SurfTest SV-500 surface profiler.



(a) (b)

Fig. 2: Photo micrograph of tungsten carbide tool with diameters (a) 0.5 mm and (b) 1 mm.

Response surface methodology in Design-Expert software (version 8.0.7.1) was employed to design the experimental runs using Face Centered Central Composite Design (FC-CCD) model. Three input variables at three levels and one response variable (surface roughness 'R_a') were used for modeling. The input parameters were: spindle speed (30,000-50,000 rpm), axial depth of cut (3-7 μm), and feed rate (5-15 mm/min). In addition, compressed air was used to blow the chips from the machined surface with an air pressure of 0.35 MPa. The same experimental runs were conducted with the three different diameters in order to generate the required surface roughness data for modeling.

Results and Discussions

The average surface roughness (Ra) of the machined soda lime glass achieved by machining with the three different cutters at different cutting conditions are listed in Table 1. It is observed from the table that the surface roughness is the lowest for the 0.5 mm diameter tool (highlighted column), except for run 3 where the Ra is slightly higher at 0.19 μm compared to 0.15 μm obtained using 1 mm diameter tool. The second lowest values are achieved for the 1 mm diameter tool and the worst results are for the 2 mm diameter tool.

Table 1: Experimental sequence with surface roughness values

Runs	A: Spindle Speed (rpm)	B: Axial Depth of Cut (μm)	C: Feed Rate (mm/min)	Surface Roughness (μm) under 0.5 mm diameter tool	Surface Roughness (μm) under 1 mm diameter tool	Surface Roughness (μm) under 2 μm diameter tool
1	40000	5	10	0.08	0.18	0.25
2	40000	5	10	0.11	0.17	0.26
3	50000	7	5	*0.19*	0.15	0.26
4	50000	3	15	0.11	0.18	0.27
5	40000	3	10	0.09	0.17	0.25
6	40000	5	10	0.1	0.16	0.25
7	30000	5	10	0.18	0.18	0.34
8	30000	3	5	0.22	0.3	0.33
9	40000	7	10	0.1	0.19	0.29
10	30000	7	15	0.12	0.28	0.25
11	40000	5	10	0.1	0.17	0.27
12	40000	5	5	0.2	0.33	0.32
13	40000	5	15	0.11	0.16	0.22
14	50000	5	10	0.1	0.17	0.27
15	40000	5	10	0.09	0.16	0.28

Fig. 3 is a graph of the surface roughnesses obtained above. The graph clearly indicates that Ra of workpiece machined with 0.5mm diameter tool is minimum and varies between 0.08μm and 0.22 μm. Fig. 4 shows the scanning electron microscope (SEM) pictures of machined surfaces obtained in run number 11 using the three different cutter diameters. It can be observed that there are no subsurface damage or cracks. Also, there is evidence of ductile streaks. These indicate that DRM was accomplished using high speed micro-end milling of soda lime glass and that the resultant surfaces have good surface integrity and finish.

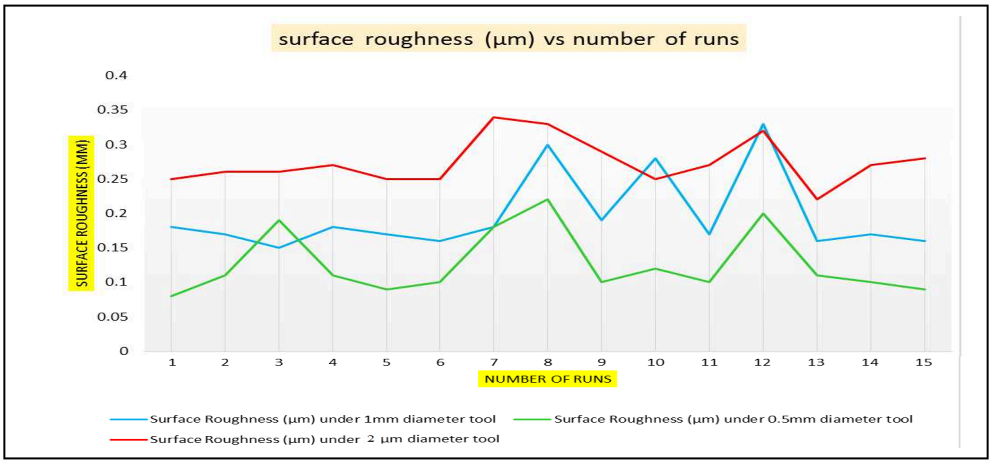
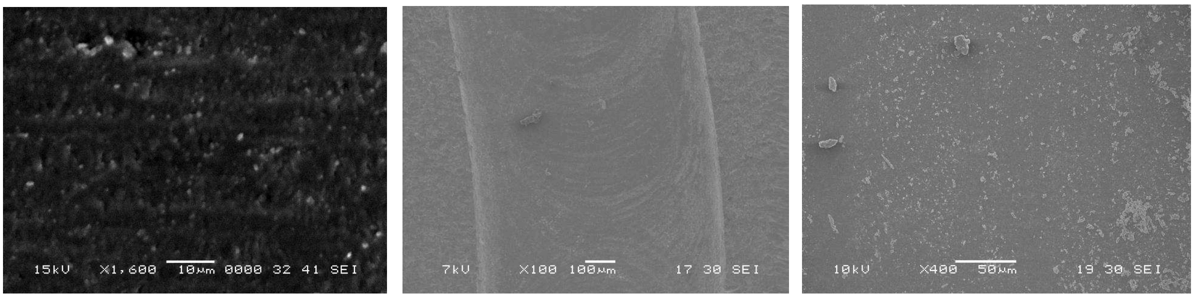


Fig. 3: Graph of surface roughnss attained for different cutter diameters and run numbers.



(a) (b) (c)

Fig. 4: SEM of machined surfaces using (a) 2 mm, (b) 1 mm, (c) 0.5 mm diameter tool.

Conclusions

The results demonstrate that high speed micro-end milling of soda lime glass using 0.5 mm tungsten carbide tool and compressed air blowing is the most viable machining approach for DRM.

Surface roughness achieved in machining soda lime glass with 0.5 mm diameter tool are within 0.08µm – 0.22 µm and the minimum roughness is obtained at cutting conditions of 40,000 rpm spindle speed, 5 µm axial depth of cut, and 10 mm/min feed rate.

SEM pictures indicate that there are no subsurface cracks on the machined surface.

References

[1] M. Arif, M. Rahman and W.Y. San: Ultraprecision ductile mode machining of glass by micromilling process, *Journal of Manufacturing Processes*, Vol. 13(1) (2011), p. 50-59.

[2] E. Al-Regib, E. Ni and S.H. Lee: Chatter control by spindle speed variation in high-speed milling, *International Journal of Machine Tools and Manufacture,* Vol. 43(12) (2003), p. 1229-1240.

[3] H. Schulz and T. Moriwaki: High-speed machining, *CIRP Annals-Manufacturing Technology,* Vol. 41(2) (1992), p. 637-643.

[4] A.K.M.N. Amin, M.M.A. Nassar and M.D. Arif: Optimization of surface roughness in micro-high speed end milling of soda lime glass using uncoated tungsten carbide tool with compressed air blowing, *Advanced Materials Research*, In Press.

[5] A.K.M.N. Amin, M.D.M. Ismail, High Speed End Milling of Single Crystal Silicon Wafer, LAP Lambert Academic Publishing, 66111 Saarbrücken, Germany, ISBN 978-3-8443-8111-5/2011/USA, UK, 80p.

Advances in Manufacturing and Materials Engineering
10.4028/www.scientific.net/AMR.1115

Effect of Cutter Diameters on Surface Roughness Attained in High Speed End Milling of Soda Lime Glass

10.4028/www.scientific.net/AMR.1115.51