Research Paper

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Investigation of Tool Life & Surface Roughness During Single Point Diamond Turning of Silicon.

Engineering

KEYWORDS : tool life, surface roughness, silicon, diamond turning

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ABSTRACT

In the present study investigation was done to analyze the tool life by analyzing the change in surface roughness with time during machining of silicon (infrared crystal) at optimized parameters with a single crystal diamond tool. Silicon has low mass density, low cost & low coefficient of thermal expansion. Due to these properties it is used in micro-electro, micro-mechanical & weight sensitive infrared applications where surface roughness is a major criteria for the acceptance of the fabricated part. A contact type mechanical profilometer was used to measure the surface roughness of silicon.

INTRODUCTION

It is sometime difficult to achieve nanaometric level surface roughness on silicon due to its brittle nature. Jiwang yan *et al.* have performed the ductile mode cutting of silicon and observed micro cracks on the surface. This happen when the transition changes from ductile to brittle mode. These micro fractures dramatically increase the surface roughness of the machined part. They also mentioned that negative rake tool performs better while cutting silicon [1]. SEM image of micro fractures is shown in Figure1.

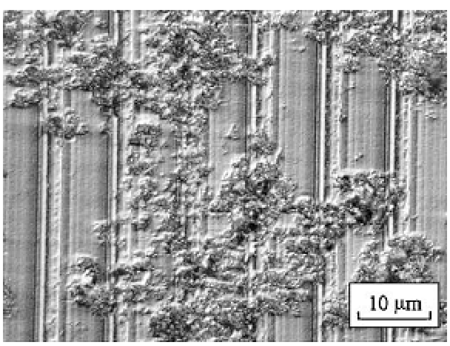

Figure 1: SEM images of micro-fractures of machined surface of silicon
Source: Research paper [1]

J. Paoli Devim & Francisco Mata have worked on optimization of surface roughness parameters for fibre-reinforced plastics on diamond turning equipment. They concluded that surface roughness increases with the feed rate and decreases with cutting velocity [2]. An experimental investigation was done in the past by Birhan Işık to find the effect of machining parameters on surface roughness during turning of glass fibre reinforced plastic composites. They concluded that the surface roughness decreases if the tool nose radius is increased & increase in depth of cut has no effect on surface roughness [3]. Zhou Zhimin et al. have analyzed the effect of machining parameters on the surface roughness during single point diamond turning of steel. They concluded that machining vibrations becomes very high when the surface roughness degrades. They also mentioned that the feed rate has the most significant effect on the surface texture among all the machining parameters [4]. Experimental investigation has been done by Young Kug Hwang et al. on AISI 1045 for the optimization of cutting parameters for best surface finish. They suggested that minimum quantity of lubrication should be used to achieve best surface finish during machining [5]. A. Pramanik et al. have studied the effect of tool wear on surface roughness & cutting forces. They optimized the cutting parameters & phosphorus contents. They observed that the surface roughness increases with the increase in cutting distance. And cutting forces increases with the increase in spindle speed, depth of cut & feed rate & decrease with the phosphorus content in the work piece. They have found the tool life in terms of kilometers [6]. M. Sharif Uddin et al. have studied the performance of single crystal diamond tool in ductile mode cutting of silicon. They also studied the change in surface roughness with the propagation of tool wear. They observed that the tool wear is a major cause of the degradation of the surface finish. At higher cutting distances tool flank wear affects the surface quality [7]. Philippe Revel et al. optimized the machining parameters for best surface finish during diamond turning of aluminium alloys. They mentioned that the single crystal diamond is the most powerful tool, which makes it possible to reach the surface roughness of a few nanometers [8]. J. Yan & T. Kuriyagawa has proposed the tool swinging method of machining to reduce the surface roughness & tool wear [9]. In the present study the tool life was found in terms of minutes. Single crystal negative rake diamond tool was used for the turning of silicon. Contact type mechanical profiler was used to measure the surface texture of the component. Brittle mode dry machining was done to analyze that how the surface quality changes with time.

EXPERIMENTAL

- **Experimental setup**

Taylor Hobson Nanoform-250 is a versatile 2-axis ultra precise machine with real time operating system designed for single point diamond turning, grinding and precision machining. The typical SPDT setup is shown in Figure 2. It consist of very stiff and stable (vibration isolated) machine base on which the number of components can be placed. These components are generally consists of gas or liquid – bearing precision slide ways, liquid or gas bearing spindle, appropriate drive mechanism, precision position and environmental sensing system and control processors to guide the machine motion, including the diamond cutting tool. These components form the complete machine capable of part accuracies in one micron range

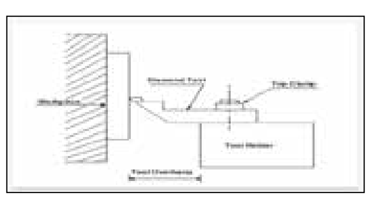

Figure 2: SPDT Set up
Source: SPDT Manual

- **Metrology**

Surface roughness of the machined components is measured through Talysurf PGI-120. Schematic of the mechanical profiler is shown in Figure 3. The stylus moves over the surface at a constant speed. And an electrical signal is produced by the transducer. The stylus is provided with the diamond tip with a cone angle of 60º to 90º and a tip radius in the range of 1-10μm. These electrical signals are amplified and undergo analog to digital conversion. The resulting digital file is stored in the computer & can be analyzed subsequently for roughness and waviness parameters.

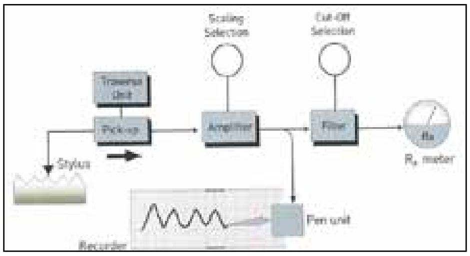

Figure 3: Schematic of contact type mechanical profiler
Source: Equipment Manual

- **Cutting conditions & material**

Optimized machining parameters were used to perform this experiment. Unused diamond tool was set on the tool post & was not removed till the end of the experiment. The work piece was removed from the chuck in between the experiment to measure the surface roughness. On-Machine measurement system was used to check the decentring error of the tool. The decentring error was checked at different stages of machining to make sure that the tool is not changing its point of contact with the work piece.

Table-1
CUTTING CONDITIONS & MATERIAL

Tool	Single crystal diamond tool
Rake angle	-10º
Work material	Silicon(Infrared crystal)
Clearance angle	10º
Shank clearance	50º
Tool nose radius(mm)	0.5
Depth of cut(μm)	2.5
Feed rate(μm/rev)	3
Spindle speed(rpm)	2000
Cutting environment	Dry
Work piece diameter	16mm
Controlled Environment	20º

RESULTS & DISCUSSION

Silicon and diamond both are brittle materials. Due to the brittle nature of the material & friction between the tool-work piece interface, micro fractures occurred on the surface of the material & cutting edges of the tool. So large cutting forces occurred between the tool-work piece interface .This happened because flank wear is the dominating wear while cutting silicon with a diamond tool. During machining most of the surface of the work material has been damaged by micro-fractures. When the cutting forces decreased the surface roughness of the work material also decreased with a large difference. During the first 110 Minutes of machining when the tool was new & unused, the surface roughness of silicon varied between 0.0342μm-0.0658μm. During 110th-165.6th minutes of machining, the surface roughness values varied between 0.0806μm-0.146μm. Tool wears at a very fast rate during machining of silicon due to which the surface roughness increased simultaneously. During 179.4th-234.6th minutes of machining, the surface roughness increased due to increase in the cutting forces & micro fractures on the surface. The surface roughnesses during this region varied between 0.208μm-0.276μm. Micro cracks were clearly visible on the surface. The surface roughness of silicon decreased during 262.2th-331.2th minutes of machining due to decrease in micro fractures on the surface. Surface roughness during this region varied between 0.122μm-0.173μm. When the tool completed the 345th minute of machining the surface roughness value increased dramatically to 0.324μm.Due to worn out tool surface roughness increased due to the tool marks on the surface of the material. When further machining continued up to 372th minute the surface roughness came down to 0.054μm. At this stage, due to high cutting force and friction between tool and work piece the tool was deflected from its position. Due to which the new cutting point of tool came in contact with the work piece and the surface roughness decreased. Figure 4, Figure 5 & Figure 6 are the surface roughness values taken at different stages from contact type mechanical profilometer (Talysurf PGI-120).

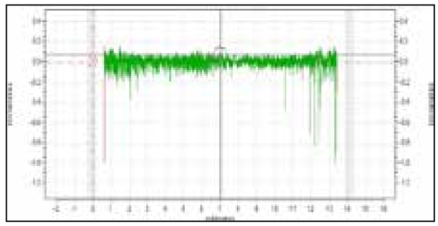

Figure 4: Surface roughness after 48mins-0.0342μm

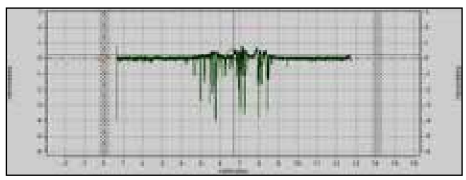

Figure 5: Surface roughness after 165mins -0.152μm

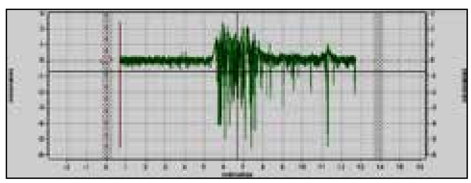

Figure 6: Surface roughness after 345mins - 0.338μm
Source: Generated by Talysurf PGI-120

Following is a graph showing the relationship between Time v/s surface roughness.

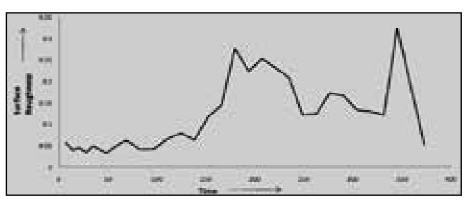

Figure 7: Time v/s surface roughness

CONCLUSIONS

1. The best surface finish can be achieved during first 110 minutes of machining. After that the tool starts degrading the surface finish.
2. After 110 minutes of machining, the tool can be used for roughing purpose. Because surface roughness above 0.060μm is not acceptable for optical quality.
3. Micro fractures increase the surface roughness dramatically.
4. Total life span of a diamond tool during diamond turning of silicon is around 370 minutes.

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