The Effect of Uncut Chip Thickness on Edge Chipping and Grinding Ratio in Groove Grinding of Single Crystal Silicon

1. Introduction

With the growing of the semiconductor and optics industries, demand has increased for enhancing manufacturing quality and reducing machining costs. Most mechanical machining of the semiconductor materials and optic glass requires the use of a diamond-impregnated wheel for grinding. Groove grinding is extensively used for separating small sized components or cutting grooves. Edge chipping is a major issue during the precision groove grinding of brittle materials. The serious edge chipping is a major issue due to the brittleness of the workpiece. In addition, the grinding wheel additionally comprises a majority of the manufacturing cost, because of the large utilization of the diamond wheel during manufacture, and its high unit price. For these reasons, an improved understanding of what happens during the groove grinding process should provide a technologically basis for engineers to enhance the process efficiency enhancement and point way for the equipment manufacturers to future improvement.
Efficient production is achieved in the groove grinding of brittle materials requires the selection of suitable grinding conditions, and by consideration of material properties, in order to maximize the wheel life while controlling edge chipping. The fundamental grinding parameter for in a grinding process is the cutting geometry, which is also called in particular, it is the uncut chip thickness or (also known as the grit depth of cut) [1, 2]. In general, the uncut chip thickness is well known to play an important role relative to the surface finish and the wheel life. For the In regards to the surface finish, controlling the uncut chip thickness by varying through the modification of grit size, grit density, wheel dimension, cutting speed, feed speed, and/or wheel depth of cut can improve the surface roughness [1-7]. In past studies on surface finish, some researchers have undertaken to experiments to investigate experimentally what happen during the effects of changing altering the uncut chip thickness. The surface roughness is indicated in experimental investigations can be improved effectively with by decreasing the feed rate, abrasive grit size and/or increasing cutting speed, as reported by some authors [1-4]. For very hard materials, such as silicon nitride [5], silicon carbide [6] and granite [7], the roughness of the grinding surface also decreases with decreasing the uncut chip thickness decreases. Besides characterizing for surface finish In addition to its effect upon the surface finish, the uncut chip thickness can be a factor to characterize in determining the wheel wear for a cutting process. For instance, it has been experimentally shown that the behavior in during the sawing of granite, there is evidence that suggests a transition in the predominant diamond wear mechanism, from attrition at a smaller uncut chip.
In addition to the uncut chip thickness, the material properties of the workpiece may also be a crucial factor. During the grinding of a brittle material, the material removal process results in brittle fracture and leads to an undesirable decrease of surface roughness. This occurs to a greater degree than would occur in conventional metal cutting. However, if the cutting parameters are chosen adequately, the brittle materials can deform plastically, without brittle fracture, at room temperature under conditions of large hydrostatic compressive stress [8, 9]. Research in scribing [10-12], turning [13], vibration cutting [14], and grinding [15-17] has observed ductile chip formation. In order to ensure a ductile-to-brittle transitional depth during cutting of brittle materials, analysis of fracture mechanics [15, 18] or and dislocation theory [19] further can aid in estimating the transitional depth, that is called the critical depth of cut (CDC). The CDC can be formulated as a function of the geometry of the tool and the material properties of the workpiece [18]. The CDC model for a grinding process has been presented [15].

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grinding of brittle materials (given for consideration for wheel life and groove edge chipping) in groove grinding of brittle materials is still lacking. Although several grinding studies have been reported, a logical methodology for the optimization of the grinding parameters, in order to reduce total manufacturing cost in groove grinding of brittle materials (given consideration for wheel life and groove edge chipping), is still lacking. An experimental investigation of edge chipping and performance in the grinding of a single crystal silicon (SCS) wafer over a range of uncut chip thickness (5 nm – 32 nm) has been undertaken in this study, over a range of uncut chip thickness (5 nm – 32 nm) in this process of a commercial single crystal silicon (SCS) wafer is then attempted in this study. The results show that the edge chipping and wheel performance in a groove grinding process can be characterized by a newly defined value, i.e. the cutting depth ratio (CDR). This dimensionless parameter can be used for explaining the effect of uncut chip thickness on the edge chipping and the grinding ratio during groove grinding of SCS. Evidence derived from both of these approaches provides important insights into the groove and cutoff grinding mechanism for ceramics.

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TUTOR: - word choice:
Incorrect: “form” is a noun used for a number of things, such as appearance.
Correct: "from" is a preposition used to indicate a starting point.
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Processing Modeling

The block diagram for a groove grinding system can be illustrated in Fig. 1. A variety of input parameters directly affect the grinding mechanisms and their influence on the resulting edge chipping and wheel performance. This study reduces these input parameters to two characteristic parameters, the uncut chip thickness and the critical depth of cut (CDC). Assuming that the thermal effect in the fracture removal process is negligible compared to the cutting force effect, this study therefore groups and reduces these input parameters into two characteristic parameters, uncut chip thickness and CDC. The following section defines the uncut chip thickness and the CDC. Introducing uncut chip thickness, CDC, and how to define new characteristic parameters are described detailed in the following section.

2.1 Uncut chip thickness

The uncut chip thickness of grinding processes can be formulated as a function of the grinding conditions and the geometry of the wheel. The essential parameter variables includes the cutting speed, feed rate, depth of cut, contact length of cutting, abrasive grit size, and active grit density, as shown in Fig. 2. The average uncut chip thickness is given by the following equation [1]

$$T = \left( \frac{V}{VCr} \right)^{0.5} \left( \frac{d}{l} \right)$$

(2)

where $C$ is active grit density (grits/mm²); $V$ is cutting speed (m/sec); $v$ is feed rate (mm/sec); $d$ is cutting depth (μm); $l$ is contact length of cutting (μm) and $r$ is the ratio of the mean scratch width to the mean

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2.2 Critical depth of cut

The ductile to brittle deformation transition has been shown to occur during the indentation and in the cutting process of brittle materials, as reported by some researchers [8-17]. This transitional depth is called as the critical depth of cut. An analytical model has been presented to predict the theoretical critical depth of indentation [18]; this model was later modified to estimate the CDC in the grinding of a brittle material and is given by [15]

$$d_c = \alpha \frac{E K_c}{H^2}$$

(1)

where $E$, $H$ and $K_c$ are the Young’s modulus, hardness and fracture toughness respectively. $\alpha$ is the grinding tool factor representing the combined effect of the tool geometry and the cutting conditions.

2.3 Cutting depth ratio

The removal mechanism in the cutting of brittle materials is deeply affected by the CDC of the work material and the uncut chip thickness. For this reason, the following investigation is further then combining the CDC model of the work materials with the average uncut chip thickness in order to discuss the groove edge chipping and the life of wheel lifespan. The cutting process is then characterized by a newly defined value, the cutting depth ratio (CDR), or $\gamma_c$. The CDR is defined as the ratio of the maximum uncut chip thickness and to the CDC. As the depth of the cut is very far smaller than the diameter of the wheel, the maximum uncut chip thickness is notably around twice the average uncut chip thickness [1]. The CDR can be written as
\( \chi \triangleq \frac{t_{\text{max}}}{d_c} \frac{T}{d} \)

where \( t_{\text{max}} \) is the maximum uncut chip thickness, \( d_c \) is the cutting depth, and \( T \) is the average uncut chip thickness.
3. Experimentation

3.1 Set up and cutting parameters

The experiments were carried out using a grinding machine tool incorporating a diamond-grinding wheel. A commercial single crystal silicon wafer was used as the work material. Fig. 3 shows the schematic illustration of the groove grinding experiment, where \( d \) is the depth of cut and the wheel width is \( 43 \) \( \mu \)m. The diameter of the wheel is \( 55.56 \) mm. Fig. 4 shows the distribution of the participating grits for the wheel. Subsequently, using the abrasive grit size (#2000), diameter of wheel, and the distribution of the participating grits, the active grit density could be estimated, which is \( 23885 \) grits/mm\(^2\).

Table 1 summarizes the experimental conditions used for studying the edge chipping and the performance. The experimental parameters were the depth of cut, feed rate and cutting speed. The cutting length of every experiment was \( 120 \) m. At the restricted range of experimental parameters, the average uncut chip thickness lies between 5.5 nm to 32 nm, as listed in Table 2.
As shown in Fig. 5, the method of digital imaging was used to quantify the magnitude of groove edge chipping. A CCD camera was used to catch edge chipping images off-line. Each experiment took at minimum of 50 pictures least. The pixel array was 640X480, the size of each image was 300X225 μm, and the mode of image acquisition card was IMAQ PCI-1408. As stated above previously, the resolution of the images was 300/640 μm.