Ultra-precision Dicing Process Separation: Effect of Circumferential and Sidewall Grinding

M. Stompe, S. Cvetkovic, P. Taptimthong, L. Rissing

Institute for Micro Production Technology, Garbsen, Germany

stompe@impt.uni-hannover.de

Abstract

Dicing of hard and brittle materials is still a major challenge for ultra-precision machining. The main goals, in order to rationalize the process as well as to enhance the surface finish and form accuracy, are reducing the tool wear and supporting the removal mechanisms. For this purpose, a profound understanding of the forces generated in the tool-workpiece interface (contact) during the dicing process is required. This can be done by distinguishing the effects of circumferential and sidewall grinding. This paper presents a detailed analysis of these two effects.

1 Introduction

Mechanical micro structuring of hard and brittle materials like Al_2O_3, Al_2O_3-TiC or SSiC is associated with high tool wear [1]. Additionally, the adequate tools are expensive ultra-precision parts. Dicing can be described as a combination of circumferential (peripheral) and sidewall (lateral) grinding mechanisms. To evaluate the influence of these two mechanisms, a concept has been proposed before [2]. It is based on using special sample structures to select either circumferential or sidewall grinding of the dicing blade. To investigate the grinding forces during cutting, the variation of the spindle power is monitored. This setup offers an indirect measurement of the increasing power consumption of the rotating spindle. The cutting force (as well as the spindle power) increases with the higher hardness of the diced material or enhanced wear of the dicing blade.

2 Experimental Procedure

The experiments were performed on a DISCO dicing saw equipped with a DC spindle motor in a Y-Configuration. The test materials are Al_2O_3, Al_2O_3-TiC and SSiC. All the samples are first pre-grooved to achieve the required dicing effect separation. Figure 1 shows the concept for separating the effects into peripheral grinding (A) and lateral grinding (B).

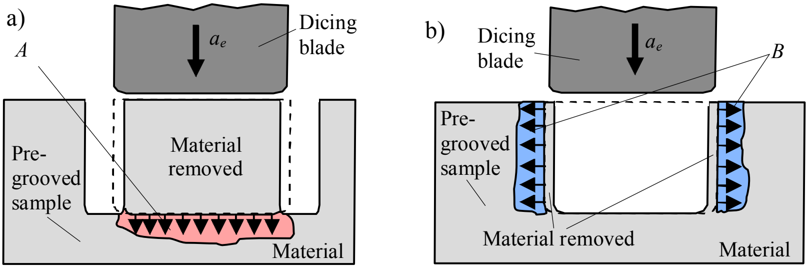

Figure 1: Concept for effect separation a) peripheral and b) lateral grinding [2]

The selected dicing blades are metal-bonded with a diamond grit of 30 µm. All the blades are trued and dressed before testing. The machining is executed with a feed rate of 0.6 mm/s, a cutting depth of 0.4 mm (a_e) and a cutting speed of 58 m/min. The cutting length is set to 30 mm.

The results are analysed applying an optimized power consumption analysis system based on the measuring of the signal amplitude during the dicing process. The energy consumption is measured using a current signal analysis. In order to measure active power, the current is sensed via a current transducer and filtered by a fourth-order Butterworth low pass filter with a cut-off frequency of 600 Hz. The speed of the spindle is held constant at 20.000 rpm. An analogue multiplier AD633 is employed for an I^2 calculation. The result is sent to a PC and analysed by software.

3 Results

Figure 2a shows the distribution of the process forces during grinding pre-grooved dicing grooves to separate the grinding conditions into peripheral grinding (A) and lateral grinding (B). The forces propagate along the peripheral (area A_A, cutting width a_p and geometrical contact length l_g) and lateral surface (Fig. 2b area A_B).

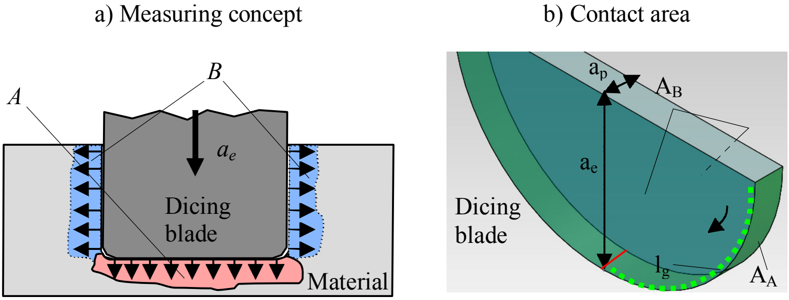
a) Measuring concept
b) Contact area

Figure 2: a) Measuring concept and b) contact area

To calculate the peripheral and lateral contact area the following equations can be used [1]:

$$l_g = \sqrt{a_e \cdot d_s} \tag{1}$$

$$A_A = l_g \cdot a_p \tag{2}$$

$$\frac{A_B}{2} = \frac{a_e^3}{4 \cdot \sqrt{l_g^2 - a_e^2}} + \frac{4 \cdot a_e \cdot (l_g^2 - a_e^2)}{3 \cdot \sqrt{l_g^2 - a_e^2}} \tag{3}$$

The contact length l_g is an empirical determined equation to calculate the contact area. For the parameter used (infeed a_e= 0.4 mm, blade diameter d_s= 55 mm, and the cutting width a_p= 0.21 mm) and after substitution in (1), the geometrical contact $l_g \approx$ 4.69 mm can be calculated. Furthermore, from (2) and (3) the lateral area $A_A \approx$ 0.985 mm² and the peripheral area $A_B \approx$ 4.985 mm² are determined. Thus, the contact area ratio $A_A : A_B$ averages 5 : 1.

Table 1 shows the measured signal value (mV) of the power consumption during full dicing and dicing of pre-grooved samples, as well as the comparison of hardness [3] for the used materials. The required power to cut into a not pre-grooved material is almost equal to the sum of the peripheral (P_A) and lateral power (P_B).

Table 1: Distinction of full, peripheral and lateral grinding

	Al_2O_3	SSiC	Al_2O_3-TiC
Full grinding [mV]	7	10	7
Peripheral grinding [mV]	5	5	5
Lateral grinding [mV]	2	5	2
Hardness [MPa]	1500-1900	2300-2900	1200-1500

Table 2 shows the correlation between the contact area and the power consumption. The required power for lateral and peripheral grinding is equal for Al_2O_3 and Al_2O_3-TiC substrates. The coherence between the total value signals for full grinding is analogous to the material hardness. For SSiC (shown in table 2), the required power consumption for the lateral grinding is higher than for both other materials. This effect can be explained by the following assumption.

Table 2: Correlation between contact area and power consumption in %

	Al_2O_3		SSiC		Al_2O_3-TiC	
	contact area	power consumption	contact area	power consumption	contact area	power consumption
Full grinding	100%	100%	100%	100%	100%	100%
Peripheral grinding	83%	71%	83%	50,00%	83%	71%
Lateral grinding	17%	29%	17%	50,00%	17%	29%

One observed effect is that 17% of the contact area goes along with 50% of the process power consumption (both other materials are comparable). Increased power consumption is a result of higher wear on this surface area. So the wear on the sidewall during dicing SSiC is higher than for dicing Al_2O_3 and Al_2O_3-TiC. This has an influence on the dressing and truing concept for dicing blades.

4 Conclusion and Outlook

The results show a clear correlation between the material hardness and the required spindle energy. With increasing hardness, the energy consumption also increases as well. The relationship between the cutting forces measured by the spindle power on the front edge and the side edge could be clearly shown. These results can be used for modelling the dicing process, as well as for optimizing the dicing blade form and topography. Furthermore, the effects on the dressing and truing of dicing blades after dicing SSiC have to be investigated in detail.

Acknowledgment

This work is sponsored as part of a Project funded by a grant of the German Research Foundation (DFG).

References:

[1] Wenda, A.: Schleifen von Mikrostrukturen in sprödharten Werkstoffen. In: Dissertation, TU Braunschweig, 2002

[2] S. Cvetkovic, H.H. Gatzen: Concept for Distinction Between the Circumferential and Sidewall Effects during Dicing of Single Crystal Silicon. Proc. ASPE 2007 22nd Ann. Meet. 2007, Dallas, Texas, USA, pp. 186-189, 2007

[3] H.H. Gatzen, K.-H Wu, S. Cvetkovic: Dicing Process Optimization for Sapphire and Altic. In: euspen 2008, Zurich, Switzerland, Vol. 1, pp. 121-125, 2008