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Structure Integrity Analysis on Nickel–Diamond Blade in Dicing of Hard-brittle Ceramic Die

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Abstract

Dicing operation in cutting hard-brittle ceramic die using nickel–diamond blade causes cracked or chipped die, accelerated tool wear and, ultimately, shortage of blade lifetime. This study aims to analyse the structural integrity of dicing blade in terms of tool wear, surface roughness, microstructure and elements during dicing. The measurements of wear blade on the blade are made by confocal microscope, whereas surface and elemental analyses are carried out with EDX SEM. Results show that the volumetric wear rate of blade is 20%, similar to roughness. The microstructure of the blade changes with occurrence of Aluminium owing to abrasive wear mechanism during cutting.

Keywords: dicing; structural integrity; nickel–diamond blade

1. Introduction

In the last four decades, the use of silicon in the microelectronic industry has fuelled the production of precision grinding and dicing processes in fragile materials. The advancement of dicing technology opens the door to new applications and encourages the improvement and production of various items. Precision dicing is now known for its high efficiency and consistency, which is attributed to the increasingly smaller sizes and tolerances of the cut pieces [1]. Integrated circuit, camera windows, infrared filter modules and electromechanical components all use hard-brittle materials like silicon, silicon carbide, sapphire and alumina ceramics.

Dicing blade uses thin blades as the cutting element, and is one of the most popular methods for cutting hard-brittle thin wafers [2]. Metal-sintered diamond blades, resin-bonded diamond blades and nickel-bond diamond blades are the three most common forms of current dicing blades. Metal-sintered diamond blades have a longer blade lifespan because of their thermal conductivity and better mechanical properties of the binder material [1]. Resin-bonded diamond blades are used in applications where smooth finish and minimal chipping are needed. Nickel-bond diamond blades have high diamond concentration and produce less heat, allowing for a freer, faster cutting operation [3].

Tool wear means the tool loses its volume and geometrical properties, leading to the gradual failure of the cutting tool. Tool wear causes the tool to lose its original shape, and it occurs due to regular operation. Once the cutting tool starts cutting a workpiece, it will gradually fail. In ceramic cutting, the friction between the dicing blade and ceramic workpiece causes tool wear and other damages to the cutting tool such as chipping, thermal damage and mechanical crack [2,3]. Various types of tool wear can occur during machining. However, types of tool wear vary depending on type of machining, cutting parameters, nature (types) of cutting tool and workpiece material [4].

The diamond dicing blade's wear process impacts how long it lasts, how much it costs to cut, and even which cutting method is used. Controlling tool wear may result in significant gains in cutting efficiency and cost savings. Wear reduces the cutting rate whilst increasing the cutting energy, resulting in severe diamond fracture and microchipping [5]. Despite all these, the wear mechanism of diamond tools has received little

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attention. Wear develops on the diamond particle, which is subjected to high force and temperature during the cutting procedure. The contact surface area and force on the grit continuously increase as the diamond particle wears [6-8]. At the same time, the diamond grit's bond support is steadily eroding. The diamond particle is fractured or extracted from the matrix when the wear process reaches a critical stage, that is, the bond can no longer tolerate the high contact force. The diamond dicing blade's wear process is a complicated system that is influenced by a number of elements. Understanding the cutting action and manner of wear on the dicing blades, as well as attempting to analyse which properties impact the operation, is required to estimate cutting ability using any approach. Many complex and interconnected elements influence the kind and degree of wear [9].

In this study, nickel-bond dicing blade is used as the dicing blade for cutting ceramic. Nickel-bond diamond blades feature high diamond concentration and produce less heat, allowing for a freer, quicker cutting action. Diamonds have a greater protrusion ratio, which allows them to stay on the cut's surface longer, enabling faster material removal [4,7,8]. Nickel-bond dicing blades are commonly used for cutting wafers and thin substrates because they can keep great shape and sharpness. Nickel-bond dicing blades also have a lower wear rate, a longer life, and a low amount of chipping on a wide range of materials. Therefore, the wears of the nickel-bond diamond blade such as radial wear are investigated, the surface roughness is measured and the surface microstructures are observed.

2. Methodology

Dicing is a technique to cut a wide variety of materials such as semiconductor compounds, ceramics, different glass forms and other composites, in part (scribing) or entirely (singulation). A variety of new types of dicing blades, such as hybrid-bond diamond blades and ceramic-bond diamond blades, are created to adapt to the cutting of various materials. DISCO, ADT, K&S, UKAM, Ceiba and Shanghai Sinyang are the most famous companies engaged in the production of dicing blades. Hot press sintering is often used to create metal-sintered diamond blades and resin-bonded diamond blades. Photopolymerizable resins can also be used to make resin-bonded diamond blades [6]. In most cases, nickel-bond diamond blades are manufactured primarily using nickel technology [9].

Dicing blades have diamond particles embedded in a bond matrix, holding together either resin (soft strength), a sintered metal bond (medium strength) or a nickel bond (hard strength) with a binder. Every diamond particle embedded in the blade gradually breaks/shatters as it grinds away material from the substrate. New particles caught in the matrix continue to give new sharp points until the blade wears out. The concentration and size of diamond particles, along with the shape and thickness of the matrix, ensure that the blades are organised and have a direct impact on the cutting job's finishing efficiency. As a result, the materials to be cut have a significant impact on the form of dicing blades selected. Figure 1 shows the schematic of cutting process, including the blade rotation (w), depth of cut (p) and feed speed (v). Table 1 shows the experimental conditions for the dicing of hard ceramic die using nickel–diamond blade.

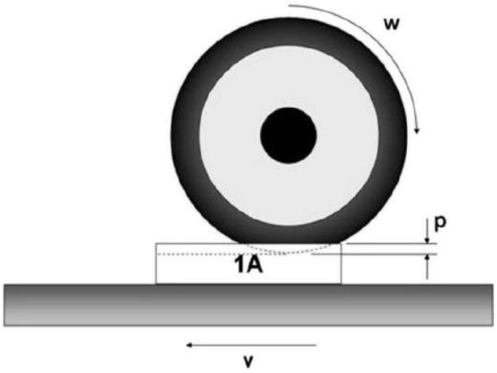


Fig. 1 Dicing blade cutting process

Table 1 Experimental setting conditions

Equipment	Blade dicing machine ADT 7900
Blade material	Nickel–diamond blade
Die material	Alumina, 50 mm long and 20 mm wide
Cutting depth	50 µm
Cutting length	20 mm
Workpiece feedrate	1 mm/s
Blade rotation	166.6 rev/s
Blade diameter	101.6 mm

This experiment is carried out to investigate the radial wear of the dicing blade after cutting the workpiece so as to determine the surface roughness and surface microstructure of the dicing blade. To carry out the experiment, the cutting tool and workpiece material are first selected. Ceramic is chosen as the workpiece material ceramic. Nickel-bond dicing blade is chosen as the cutting tool because it has high diamond concentration and performs a freer, faster cutting action with minimum heat generation when cutting the ceramic.

The experiment involves dicing a ceramic cutting. The cutting distance for this experiment, which is 1000 mm, is kept constant. Nickel-bond dicing blade is used as the cutting tool as it provides longer blade life and lower wear rate together with the abrasive, making this blade the perfect choice for soft material application such as ceramic (Figure 2). In this case, the dicing is carried out using three different tools with the life remaining of worn blades as 1, 2 and 3. A new dicing blade is also used to observe the wear, surface roughness and surface microstructure. The radial wear as average wear of the blades are examined by observing the cutting tool condition using 3D measuring laser microscope (Olympus laser confocal scanning microscope, see Figure 3). Surface roughness and surface microstructure are also examined using the laser microscope. The data from the experiment are collected and then evaluated to determine the best solution for reducing wear and improving tool life. The tools are measured using their images generated by SEM and EDX machine.

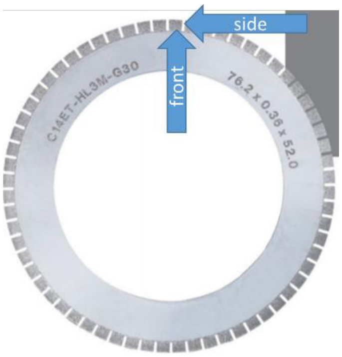
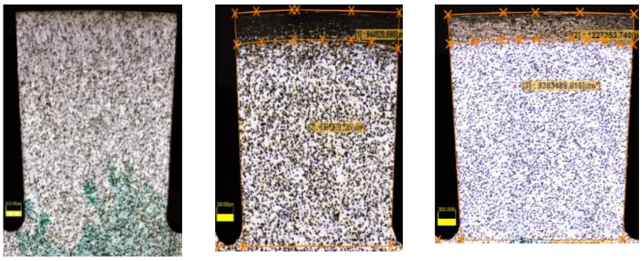


Fig. 2 Dicing blade

Fig. 3 Olympus laser confocal scanning microscope

3. Results

In Figure 4, the wear area can be determined by comparing a new tool and worn tools. The wear area of the dicing blade for worn blade 2 is higher than worn blades 3 and 4 (Figure 5). This is because the tool life remaining for worn blade 1 is lower than those for worn blades 2 and 3. The reduction of the blade size due to wear happens during dicing.



a) New blade b) Worn blade 1 c) Worn blade 2

Fig. 4 Average roughness measurement for dicing blades

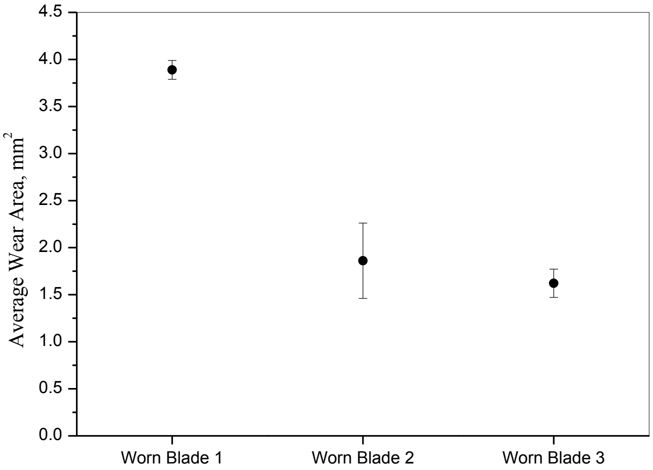
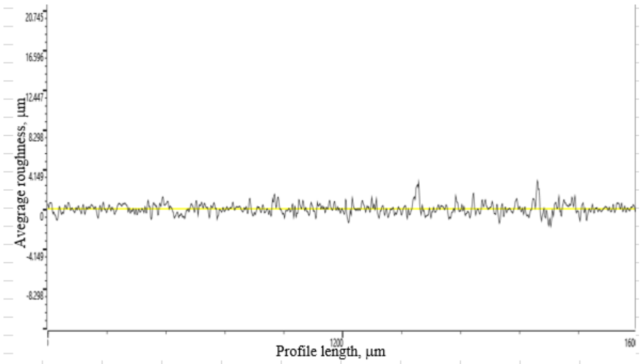
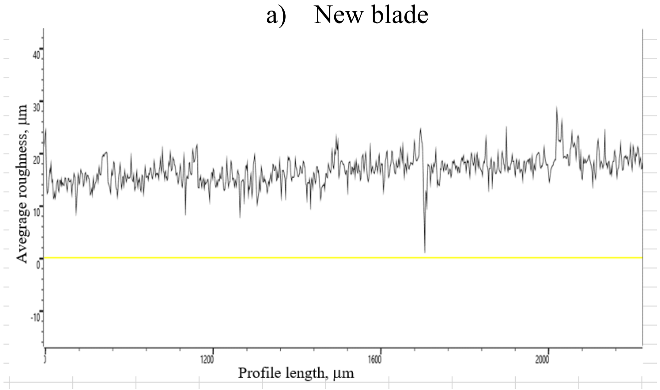


Fig. 5 Wear area comparison between a new blade and worn blade.

The next step in this experiment is determining the surface roughness of the dicing blade. Owing to wear, the roughness of the dicing blade changes in the frontal area. Figure 6 shows the roughness profile for the new blade after dicing the ceramic. The average roughness measured is Ra = 2.935 µm. Figure 7 shows the roughness profile for worn dicing blades wherein three different dicing blades are observed. Referring to Figure 3, the average surface roughness data of the dicing blades are compared between a new blade and three worn ones. The average roughness for worn blades is 50% higher than for a new tool because of wear during dicing.



a) New blade



b) Worn blade

Fig. 6 Average roughness measurement for dicing blade

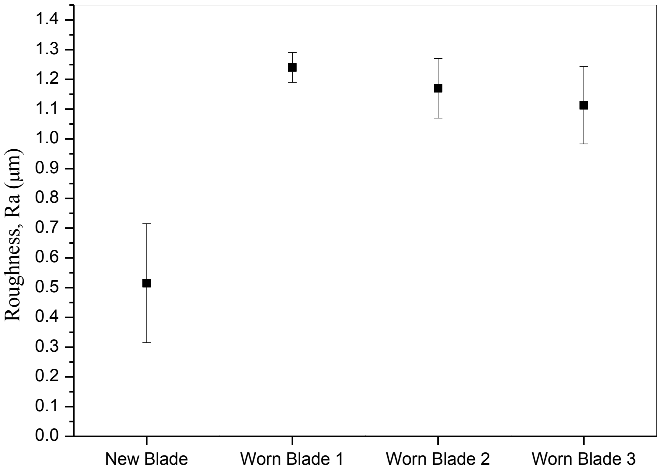
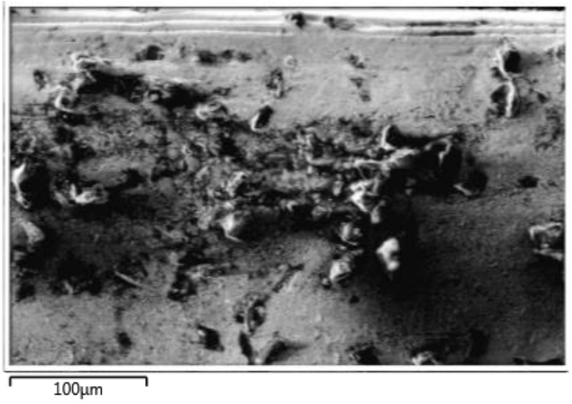
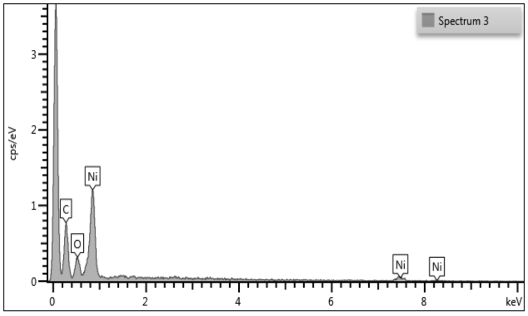


Fig. 7 Average roughness comparison between a new blade and worn blade.

The EDX analysis results of blades before and after dicing are presented in Figures 8 and 9. A new dicing blade is without wear at top surface, whereas a worn blade reduces the nickel element for 20% wear. Increasing carbon and oxygen content needs to be investigated, and the results are provided in Table 2. The analysis results show that the composition of oxygen decreases by 5.54%. For a worn blade, the existing Al element decreases by 1.41% due to wear from the ceramic dices containing AlN. Similarly, the nickel content as resin in blade element is reduced by 2% after dicing.



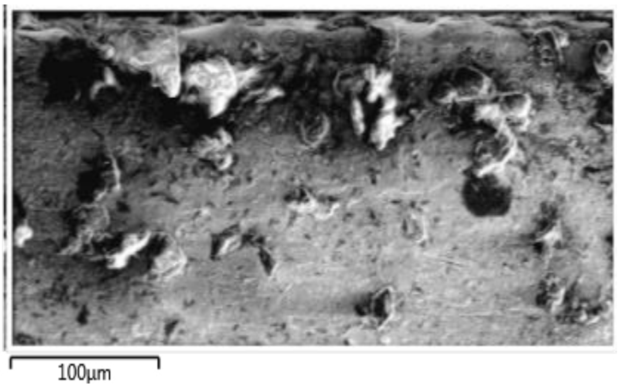
a) SEM



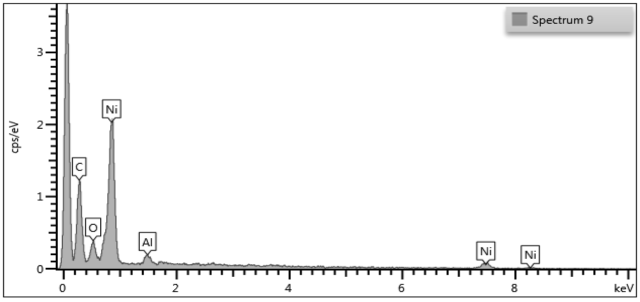
b) EDX

Fig. 8 SEM image and EDX of a new blade before cutting in dicing process

a) SEM b) EDX



a) SEM



b) EDX

Fig. 9 SEM image and EDX of a worn blade after cutting in dicing process

Table 2 Elemental composition for new blade and worn blade

Element (weight %)	New blade	Worn blade
Carbon, C (%)	30.20	32.66
Oxygen, O_2(%)	5.54	3.78
Nickel, Ni (%)	64.25	62.14
Aluminum, Al (%)	0	1.41

4. Discussions

As shown in the comparison in Figure 5, worn blade 3 is more abraded than worn blades 1 and 2 when dicing ceramic. This comparison indicates that worn blade 3 has a larger abrasion ratio than worn blades 1 and 2. The experiment is continued by observing the abraded areas for dicing blades. During dicing, the blade continuously abrades the aluminium and removes the ceramic debris. As ceramic is brittle and hard, the dicing blade wears during dicing. To understand the blade surface conditions, the blade surface is examined. Figures 4a and 4b show four abraded areas on the new blade and worn blade 1, respectively, whereas Figure 4c shows three abraded areas on worn blade 2.

The experiment conducted includes three types of tools with the life remaining for the worn blades as 1, 2 and 3 and a new dicing blade. The workpiece materials involved are ceramic. During the wafer dicing, the dicing blades gradually wear. The radial wear of the dicing blade is analysed by measuring the reduction of the outer diameter of the dicing blade.

5. Conclusion

Ceramic dicing blade radial wear, surface roughness and microstructure are investigated. The results are from the interaction of tool wear and material properties. The tool life remaining for dicing blades after dicing ceramic influences the radial wear, surface roughness and microstructure. The radial wear for the tool life remaining of worn blade 1 is the highest followed by those of worn blades 2 and 3. Therefore, worn blades 2 and 3 can maintain their form longer whilst dicing the workpiece. The relationship between the tool life remaining for the dicing blade and the wear is measured by observing its surface roughness and surface microstructure. The results obtained help understand the tool life of the dicing blade which can be meaningful in the use of the dicing blade.

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