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CUTTING EFFECTIVENESS OF DIAMOND BURS ON DENTAL ZIRCONIA

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A THESIS

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ABSTRACT

Monolithic zirconia restorations are popular but removing these crowns is difficult. The purpose of the study is to measure and compare the cutting effectiveness of 10 types of diamond burs through monolithic sintered zirconia.

Ten types of diamond burs (n=8) were compared for the cutting effectiveness in Zirconia (CERCON; DeguDent) using a high speed computer controlled cutting device with water spray (5.45L/min). The turbine used to cut the blocks rotated at 150,000 rpm and with the burs at a depth of 2mm into the zirconia during cutting. A 100 gm load was applied during cutting for each bur which made 2-9minute cuts. In the second part of the experiment, we tested 2 representative diamond burs with the same conditions as described before except the bur rotation was resuced to 40,0000rpm. This part of the experiment was performed to evaluate manufacturer's claims some diamonds are more effective at lower cutting speeds.

After each cut, zirconia blocks were ultrasonically cleaned (10 minutes-acetone), dried in an oven at 200°C for 5 minutes before and after each cut and weighed (OHAUS Discovery Balances). The length of the cut was also recorded with a 3D digital microscope (Keyence VHX6000). The data were analyzed with ANOVA and Turkey/Kramer post-hoc tests (p=0.05). In conclusions the volumetric loss and cutting length of zirconia produced during the first 9 minute cut was significantly greater than the second 9 minute cut for all grit sizes. Zirconia surface chipping increased with increased diamond grit size. Four types of wear patterns were observed on the diamond bur: particle fracture, particle pullout, particle wear and matrix damage. In general, super coarse and coarse diamond produced better cutting effectiveness. Higher cutting efficacy was found with higher motor rotary speed.

Keywords: Cutting Efficacy, Diamond Bur, Dental ceramics, Zirconia

DEDICATION

This thesis is dedicated to the love and memory of my father, Yang-xueng Lin. The forever teacher of my life.

To my family; my mother, Fang-mei Liu; my brother, Hung-fan; my beautiful wife, Hsiu-hsien Chen; my kids, Yu-chuan & Yu-chi: thank you for your unlimited supports and encouragement. With your love, we passed through the challenging years of staying and studying away from home.

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INTRODUCTION

Dentists have used burs for dental treatment for over 100 years. Initially, burs were fabricated from steel. Later tungsten carbide burs were introduced, followed by diamond burs. The first diamond bur was introduced for fixed restorative dentistry in the late 19th century. [1, 2] In 1932, W.H. Drendel established a process for bonding diamond points to stainless steel blanks introduced the modern diamond bur. The first diamond burs to be introduced commercially were cost prohibitive and supplied in limited shapes and sizes. Following advances in bur fabrication technology and improved starting materials, multiple diamond burs in useful shapes and grits were produced.[5] By 1957, the development of high speed handpieces (20,000 to 450,000 rpm) allowed dentists to prepare teeth at lighter cutting pressures and greater efficiency. The improved efficiency produced by diamond burs in high speed handpiece created universal acceptance of diamond burs by the dental profession. [3-5]

Manufacturing Diamond Burs

Diamond burs are made of one or more layers of diamond chips attached to a shank that inserts into the head of a handpiece. The shank is typically fabricated from a high-strength metal such as tool steel, stainless steel or another alloy. The cutting zone of the shank is machined to a specific shape which is designated by the manufacturer as a specific numbering system for the bur. [6] Natural or synthetic diamond chips are added to the machined metal blank by several methods. The most common method is electrolytic codeposition.[7]

Electro Codeposition Method:

The electro codeposition process occurs through several steps. A nonconducting material is applied to the shank of the diamond bur to prevent metal deposition on the shank which prevents the portion of the diamond bur inserted into the hand piece from receiving any electrodeposit. The prepared stainless steel blanks are then plated with a thin nickel coating l, commonly in an acid nickel- chloride solution[8] to remove passive films while slightly etching the exposed blank surface . The electrodeposition process is performed with a nickel- plating solution maintained under carefully controlled pH and temperature.[9] This nickel-plating bath also contains diamond particles. Under electrode agitation , the diamond chips accumulate with the nickel to form a coherent layer on the bur blank. This initial plating process tacks the diamond particles onto the designated cutting portion of the blank. The burs are then transferred to a second nickel-plating bath where they remain until the desired degree of nickel coverage is reached.[6]

Depending on whether the diamond chips are deposited in a single layer or in multiple layers, the overall procedure may take 60 to 90 minutes for a conventional diamond bur. On the other hand, the electroplating process for a single-patient-use diamond bur takes only 20 to 30 minutes due to differences in process conditions and quality control.[6] Ideally, the electrodeposited metal matrix covers 50 to 60 percent of the maximum dimension of the diamond chip, with a number of uncovered facets . The exposed facets provide the cutting action while the matrix-engaged portion of the chip provides stable connection to the bur shank.[10]

The electrodeposition process varies with the deposited metal and the operating conditions, so that the characteristics of the diamond bur vary according to the manufacturer.[6] Quality control of the electroplating process is very important in the manufacturing process and significantly affects the bur-cutting efficiency. Generally, excessive nickel deposition and coverage of the diamond chips decrease the number of exposed diamond facets and reduces cutting efficiency. In contrast, insufficient or poor-quality nickel deposition may cause diamond chips to be pulled out easily with deficient anchorage within the matrix leaking to poor cutting life. [11]

Diamond Particles

Important issues related to the diamond particles used on dental burs include: natural vs. synthetic origin, chip size and shape and individual particle faceting. The effect of these parameters on the cutting efficiency of dental diamond burs, however, is incompletely understood.[12] Natural diamonds are more irregular in shape than synthetics, and it has been thought that this irregularity makes them easier to deposit within the nickel matrix. Because of differences in size of the diamond particles used by every company, the roughness can be very different among burs of the same coarseness from different producers.[6] Bur coarseness is decided by the size of the chips deposited onto the blank. By being filtered in a sieve of a designated grit size or mesh, the chip is selected. The mesh size is related to the diameter of the particles being sieved. The tighter the mesh of the sieve, the smaller (finer) the diamond particles were selected. Typically, a medium-grit diamond bur has 90 to 120 µm chips, which equates to a mesh size of 120 to 140. A coarse-grit bur commonly is fabricated with chips sieved through a mesh size of 80 to 100 and contains 150 to 160 µm diameter particles.[6]

Single-Patient-Use Diamond Burs

As burs can spread infectious diseases (for example, hepatitis B, herpes virus and human immunodeficiency virus) with blood, saliva and soft tissue, the CDC and ADA require complete cleansing and sterilization of multiuse burs.[13, 14] Because these procedures require soaking, hand scrubbing or ultrasonic cleaning, drying, packaging for sterilizing and are time-consuming, companies have developed inexpensive and disposable instruments for single- patient-use.[6] The purchase price of single-use diamond burs is considerably lower than that of multi-use burs, but disposable diamond burs are only available with limited sizes and shapes. The price differential is due to several factors, including a thinner layer of electroplated metal on the disposable burs, fewer diamond-containing layers, restricted availability of bur shapes and lower quality control measures.[6]

Nevertheless, recent studies show that disposable diamond burs have comparable cutting efficacies and provide acceptable clinical service.[12, 15] But, all burs differ widely in appearance and performance.[15] Pilcher et al,[16] measured the volumetric cutting rates of single-patient- use and multiple-patient-use diamond burs . They reported that single-use-patient diamond burs had a significantly lower mean cutting rate after several cuts, compared with multiple-patient-use diamond bur.[16]

Spray Flow Rate

High-speed rotary cutting instruments are efficient but may damage the dental pulp irreparably if used inappropriately. Thermal or non-thermal stimuli applied to dental structures may produce irreversible pulpal responses. Thermal stimuli can produce tissue burning, postoperative sensitivity, and pulpal necrosis.[17, 18] Adequate cooling prevents over-drying, increases in pulpal temperature and raises cutting efficiency.[19, 20]

Water coolant sprays directed at the bur-tooth interface are used to provide pulpal protection during cutting procedures, but evidence for the optimum coolant flow rates for dental cutting is limited. Typical coolant flow rates in the United States range from 15 to 20 milliliters per minute.[21, 22]

Pressure applied

Siegel[23] et al determined that cutting efficiency is influenced by the bur diamond grit and the load applied to the handpiece. Most dentists exert a force of 50 to 150 g when using diamond burs in a high-speed handpiece to prepare teeth for fixed restorations.[12, 24] Tanaka et al and Taira showed that greater applied load reduces cutting speed and cutting volume.[12, 23, 25] The tendency is clearly demonstrated with coarse, medium and fine diamond burs, but super-fine grit diamond burs are least affected. While cutting natural teeth, the decrease of the handpiece rotary speed, or rotations per minute (RPM), is about one third of the free-running speed.[26] If the dentist applies excessive pressure, load dependent decreases in RPM and stalling may occur.

Zirconia Ceramic

Traditionally, the brittle nature of dental ceramics has reduced the popularity of all ceramic restorations. The discovery of transformation toughening capabilities of zirconia (Ceramic steel)[27] and its application in strengthening ceramics has changed this situation.[28] Pure zirconia can exhibit a polymorphic phase transformation.

It has 3 phases.

1. Monoclinic phase: from room temperature to heating to 1,170°C
2. Tetragonal phase:1,170°C to 2,370°C
3. Cubic phase: above 2,370°C till the melting point.

Alloying zirconia with stabilizing oxides, such as CaO, MgO, Y_2O_3 or CeO_2 stabilizes the tetragonal structure to remain stable at room temperature. Stress from propagating cracks can cause phase transformation from the stabilized tetragonal phase to the monoclinic phase with 3-5% local volume expansion which can compress cracks. Crack compression ultimately leads to increasing toughness of the ceramic[29, 30] Therefore, researchers and manufacturers have developed advanced formulas to prevent crack propagation mainly by using yttrium- tetragonal zirconia polycrystals (Y-TZP), commonly known as zirconia.[31-33] It contains yttria (Y_2O_3) as a stabilizer.

Currently, zirconia combined with computer-aided design/computer-aided manufacturing (CAD/CAM) systems has become widespread.[34] The three-dimensional design of Y-TZP frameworks requires a computer and special computer-aided design (CAD) software provided by the manufacturer. After a scanning procedure of the designed work, data are transferred to a computerized manufacturing (CAM) unit that performs a preset production of the zirconia framework.[35] Milling of zirconia blocks can be performed in the partially[36] or fully sintered stage using appropriate cutting diamonds under water coolant if needed. The majority of CAD/CAM systems use partially sintered Y-TZP ceramics, where the milling procedure is performed with the use of carbide burs in a dry environment. Throughout the designing stage, the size of a partially sintered framework is approximately 20% and 25% larger than the original dimensions, due to the shrinkage produced during the final sintering.[37] On the other hand, milling of fully sintered is time-consuming due to the increased hardness of the material, but it does not exhibit any dimensional changes.

Y-TZP ceramics are fully dense with tetragonal grains. Tetragonal to monoclinic transformation is accompanied by volume expansion that produces compressive stress, making crack propagation more difficult. Growth of tiny flaws that form during processing or surface damage generated during service[38, 39] is also obstructed by the compressive stresses in the zirconia. Nevertheless, surface damage and microcracks produced by CAD/CAM milling procedures or hard machining of fully sintered zirconia can still be found.[40 41] These may decrease strength and lead to unexpected failures.[42 43]

Currently, the range of contemporary clinical applications of zirconia include veneers, full and partial coverage crowns, fixed partial dentures (FPDs), posts and/or cores, primary crowns, implants, and implant abutments. In addition, different zirconia-based auxiliary components such as cutting burs and surgical drills, extra-coronal attachments, and orthodontic brackets are also available as commercial dental products.[44]

Information about the abrasive machining of zirconia with dental burs like the surface integrity after machining, the removal rates, and bur life is limited. Generally, most dentists believe coarser-grit diamond burs cut faster and more efficiently than finer-grit diamond rotary instruments.[45] Although the bur shape, diamond distribution and grit size are parameters in cutting efficiency, the bur manufacturer, type of bur and manufacturing method are also strong influences. Studies performed by Siegel et al revealed that coarse and super coarse-grit diamond burs had higher cutting rates during the second and third cuts compared to medium-grit diamond burs. Super coarse-grit diamond bur cut faster than medium-grit diamond bur.[46] Is it still the same in cutting fully sintered zirconia? What is the most efficient or safe way to remove or adjust these zirconia restorations clinically? The purpose of this study is to measure and compare the cutting efficiency of clinically used diamond burs on fully sintered tetragonal zirconia.

HYPOTHESIS AND AIM

The purpose of this study is to compare the volume of fully sintered tetragonal zirconia with different diamond burs.

Specific Aims

1. To compare the cutting effectiveness of diamond cutting instruments with different particle size (grit) on cutting zirconia.
2. To compare the cutting effectiveness of burs between the first and second use.
3. To compare the cutting effectiveness of diamond instruments at different rotational speeds.
4. To measure and compare the roughness of diamond burs before and after cutting zirconia.
5. To examine the surface roughness and edge chipping of cut zirconia and diamond and matrix abrasion of the used burs with a microscope.

Null hypothesis:

There is no significant difference in the cutting effectiveness on fully sintered zirconia with diamonds of similar shape with different grit size, different speed operations, or prior use. Additionally, there is no significant difference between the roughness of different burs and there is no difference in the roughness of burs before and after cutting zirconia.

MATERIALS AND METHODS

The purpose of this *in vitro* study was to evaluate cutting efficacy of 10 types of commercially available diamond burs on the zirconia ceramic blocks. Burs used in this study are listed in Table 1. Burs were selected to provide a range of grits. An attempt was made to select uniform shank size and shape for each bur, however, size and shape could not be standardized due to the difference in shapes produced by different manufacturers. Shank size and the diamond particle size (grit) of each bur was verified using Keyence 3D digital microscope (Keyence VHX 6000 Series, KEYENCE America, USA), at 200X (Figure 2, 7). The surface area of cutting zone (2mm from bur tip) of each bur was measured with a digital caliper (Figure 1) and digital microscope (Keyence VHX 6000 Series, KEYENCE America, USA) (Figure 3, 7) and listed in Table 2.

Figure 1 : Digital Caliper

Table 1: List of Burs

Group No.	Bur No.	Manufacturer	Classification/grit (**µm**)
1	6856DC.31.016	BRASSELER USA	Super Coarse/ 180-250
2	8856DF.31.016	BRASSELER USA	Fine/40-50
3	856DEF.31.016	BRASSELER USA	Extra fine/20-30
4	ZR6850.314.016	KOMET USA	Coarse/green/110-130
5	ZR6881.314.016	KOMET USA	Coarse/green/110-130
6	F4R SC	A&M instruments	Super Coarse/180-230
7	5850.314.016	KOMET USA	Super coarse/180-210
8	S5856.314.016	KOMET USA	Super coarse/180-210
9	6850.314.016	KOMET USA	Super Coarse/160-200
10	770.8VF	PREMIER	Fine/50-60

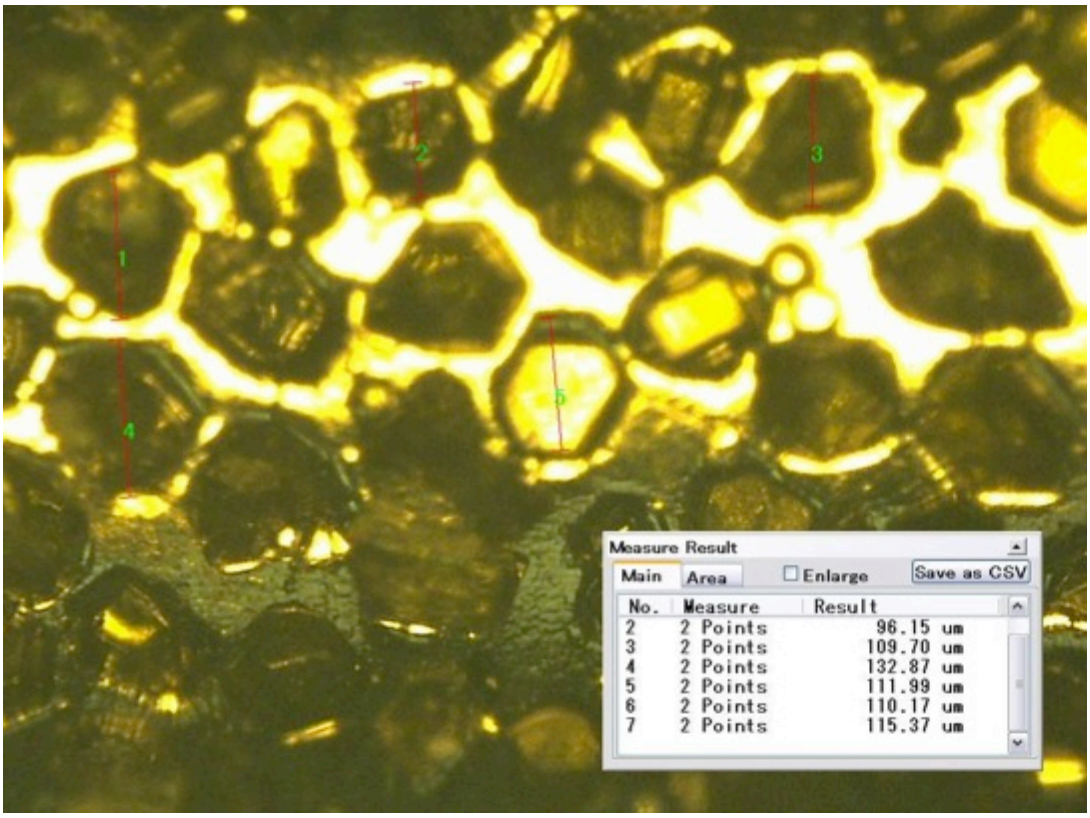


Figure 2: Grit size measured with the Keyance Digital Microscope

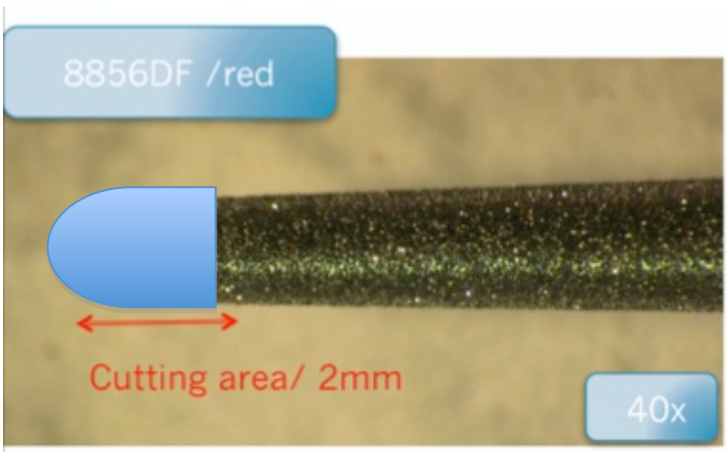
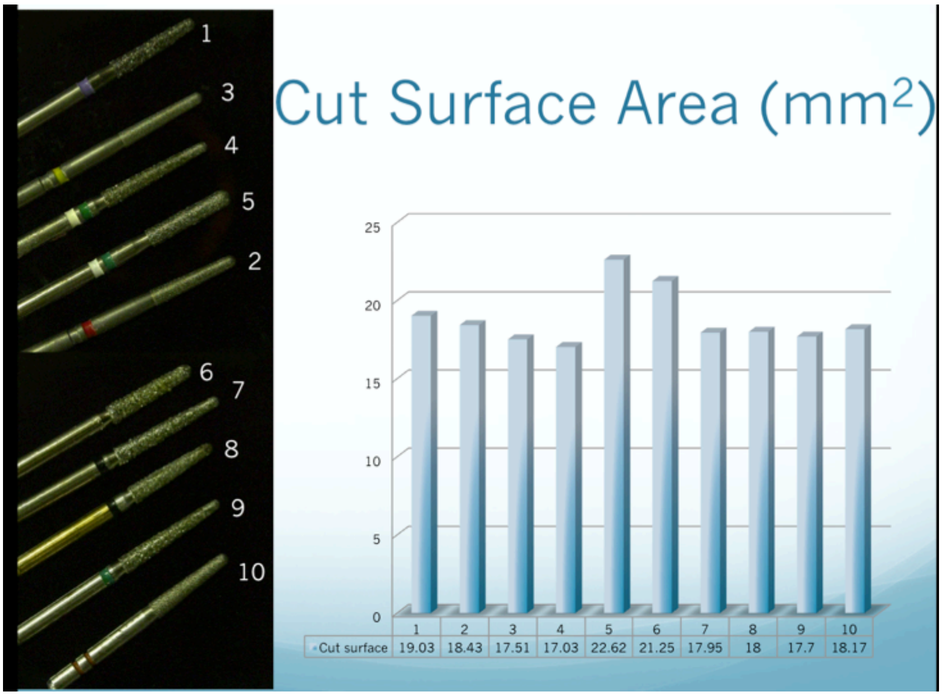


Figure 3: the cutting zone surface area measurement with digital microscope

Table 2: Cut Surface Area of Each Bur

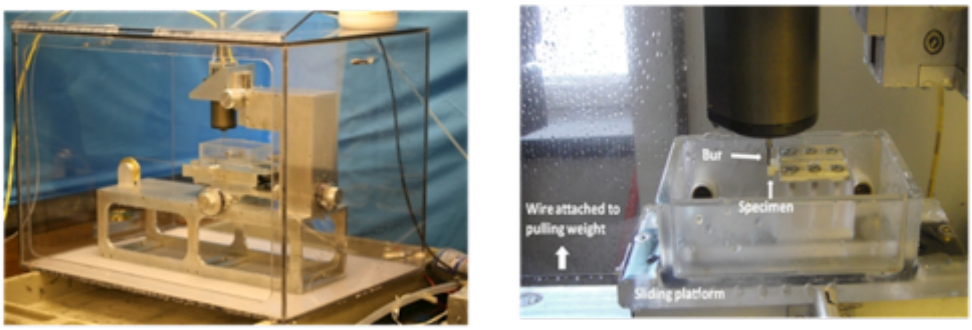


96 sintered Cercon® blocks were cleaned in acetone in an ultrasonic bath (BRANSON 1200, CT, USA) for 10 minutes and dried in an oven at 200°C for 5 minutes. The blocks were then weighed in an OHAUS digital scale (OHAUS Corporation, NJ, USA) (Figure 4) and divided randomly into 12 groups (n=8).

Figure 4: OHAUS Digital Scale

Cutting Procedure 1

All cutting tests were performed in a customized milling apparatus (Nakanishi EM25-5000, Kanuma, Japan) designed and fabricated at UAB. The milling machine was connected to a computer which controlled bur revolution per minute (rpm) and quantity of lubricating water spray (percentage of pump capacity). A pump was connected to the system to vacuum solution from the water tower. (Figure 5)



Custom Milling Machine

Computer controlled milling head under water spray

Figure 5: UAB Milling Machine

In this study, 10 kinds of burs (Table 1) were used to cut the zirconia blocks. Burs cut at a rate of 150,000 rpm and a depth of 2 millimeters for 9 minutes using an apparatus that pulls a moveable table at a load of 100 grams. The sliding table holds the block and pulls it against a bur held in the milling head (Figure 5). The lubricating spray was ejected at 5.45L/min. Each bur was used for 2 cuts on each block, total 2 cuts on each block (Figure 6). All burs were ultrasonically cleaned in acetone for 10 minutes after each cut.

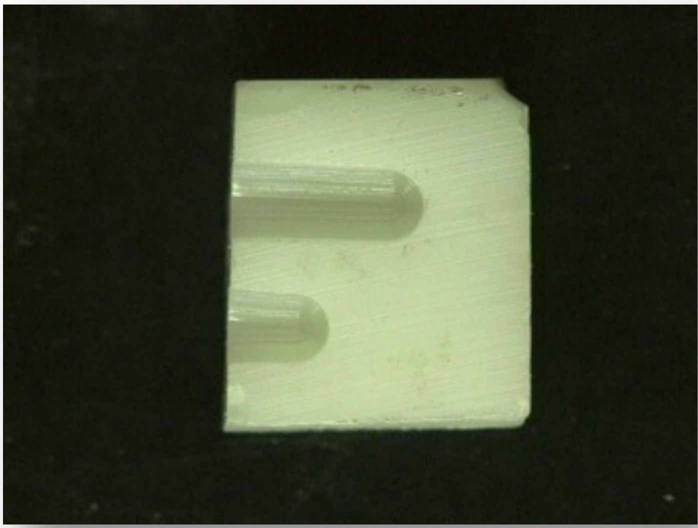


Figure 6: Zirconia block, total 2 cuts on each block

Cercon® blocks were cleaned in ultrasonic bath with acetone (BRANSON 1200, CT, USA) for 10 minutes and dried in an oven at 200°C for 5 minutes, and weighed after each cut to evaluate the loss weight for every cut. Also, the length of each cut was measured using Keyence 3D digital microscope (Keyence VHX 6000 Series, KEYENCE America, USA), at 10X (Figure 7).

Figure 7: Keyence 3D digital microscope

Cutting Procedure 2

In the second part of the experiment, we tested 2 representative diamond burs with the same conditions as described before except the bur rotation was reduced to 40,000rpm. This part of the experiment was performed to evaluate manufacturer's claims some diamonds are more effective at lower cutting speeds. 2 kinds of burs (6856DC.31.016, BRASSELER USA and ZR6850.314.016, KOMET USA) were selected to cut the blocks at different operation speed (n=8).

Cuts were produced with a rotational speed of 40,000 rpm and depth of 2 millimeters for 9 minutes using an apparatus that pulls a moveable table at a load of 100 grams. The lubricating spray was ejected at 5.45L/min. Cercon® blocks were cleaned and weighed following the same procedure to evaluate the loss weight for every cut.

Diamond Bur Surface Roughness

Burs were ultrasonically cleaned for 10 minutes in acetone and dried at room temperature for 24 hours before scanning. A 0.2×4mm^2 area of the cutting surface of each bur was scanned (Proscan 2000, Scantron industrial products Ltd, England) for surface roughness (Ra). (Figure 8,9) Scanning was followed by ISO 4288 for cut-off and evaluation length (0.8/4mm) using a 3500μ sensor and 0.003 mm step size and discarding 0.4mm at first and last ends. Diamond burs were scanned prior to use and following each cut following the same standard. After the final cutting tests the burs were cleaned in an ultrasonic bath for 10 min in acetone to remove machining debris. They were then observed with a digital light microscope to determine modes of diamond wear in 200x & 400x magnification

Figure 8: Proscan 2000 (Scantron) for surface roughness (Ra),

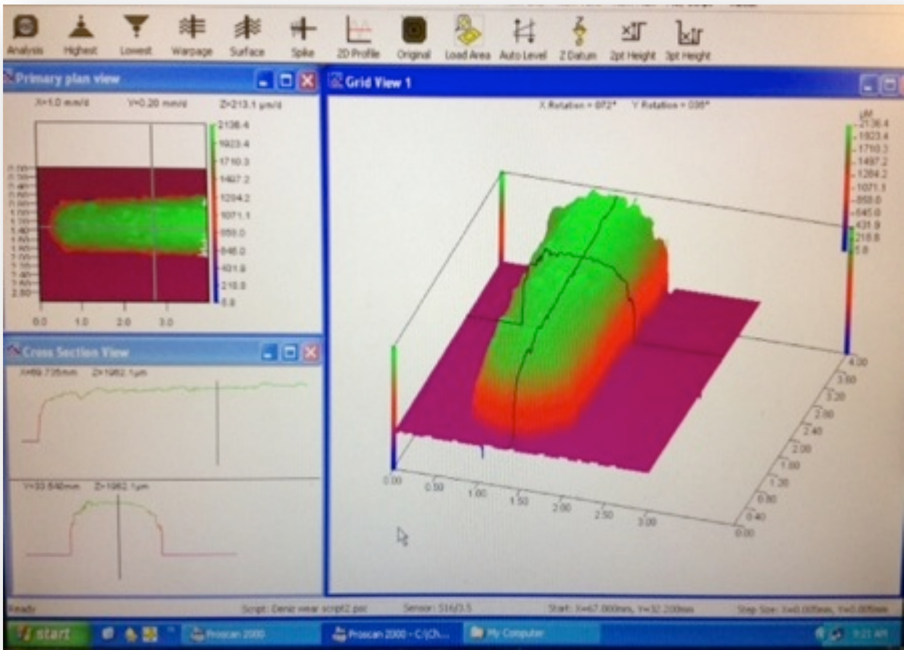


Figure 9: Diamond Bur Surface Roughness (Ra)Scan

One-way ANOVA were used to compare data. All statistical tests were performed at the 1% significance level and p-values less than or equal to 0.05. Post-hoc comparisons were made using Tukey's test. Statistical analyses were conducted using the SAS® computer software system, release 9.1 (SAS Institute Inc., Cary, NC, USA). Temperature and humidity were recorded during the study.

RESULTS

The results of this study are described as A; Block weight loss after each cut, B; Cutting length produced after each cut, C; Wear of diamond burs and D; Zirconia removal mechanisms

Block Weight Loss

Table 3 and Figure 10 show the mean zirconia weight loss after the first, second, and combined (combination of first and second) cuts with each bur at 150,000 RPM. The weight loss/cutting area was determined for each cut by dividing the zirconia weight loss by the cutting surface area of the bur used to produce the cut. Table 4 and Figure 11 show the mean zirconia weight loss/cutting area after the first 9 minute cut, the second 9 minute cut, and combined (18 minute) cuts with each bur at 150,000 RPM. The amount of block weight lost per cut was significantly different for the different types of bur ($p<0.05$). In the over all statistic analysis, Group 5 bur (ZR6881.314.016/ KOMET USA) produced the best performance of all groups with significantly greater cutting effectiveness than all other diamonds ($p<0.05$) difference in the first cut, the second cut and total amount. After analyzing the volume loss by dividing with diamond cutting surface area, the Komer bur (ZR6881.314.016/ KOMET USA) still produced the best performance ($p< 0.05$)of all groups with the significant difference in the first cut and total amount, but not so clear in the second cut. There was a significant decrease in the amount of zirconia volume removed between the first and second cut ($p<0.05$). Other 2 groups we need to notice are Group10 (770.8VF ZIRCONIA/ PREMIER) & Group6 (F4R SC/ A&M instruments). Group10 is a fine zr bur. Group6 is a super coarse single use bur. Both them do a comparable performance with other groups.

Table 3 : Block Weight Loss (mg)

Bur No./ Manufacturer	1^{st} Cut /mg	2^{nd} Cut/mg	Total
6856DC.31.016/ BRASSELER USA	$39.99 \pm 8.4^{c,d}$	$22.93 \pm 2.3^{c, d}$	$62.9^{b,c}$
8856DF.31.016/ BRASSELER USA	$12.58 \pm 2.5^{a,b}$	$7.56 \pm 2.4^{a, b}$	20.1^{a}
856DEF.31.016/ BRASSELER USA	7.2 ± 1.4^{a}	6.5 ± 5.9^{a}	13.7^{a}
ZR6850.314.016/ KOMET USA	$30.59 \pm 7.1^{a,b,c}$	$22.28 \pm 4^{c,d}$	$52.9^{b,c}$
ZR6881.314.016/ KOMET USA	98.68 ± 32.5^{e}	24.48 ± 7.6^{d}	123.2^{d}
F4R SC/ A&M instruments	61.21 ± 25.5^{d}	$16.7 \pm 7.9^{b,c,d}$	77.9^{c}
5850.314.016/ KOMET USA	$36.13 \pm 6.3^{b,c}$	$18.01 \pm 5.6^{c,d}$	$54.1^{b,c}$
S5856.314.016/ KOMET USA	$33.23 \pm 8.4^{b,c}$	$14.76 \pm 7.6^{a,b,c}$	48.0^{b}
6850.314.016/ KOMET USA	$29.2 \pm 7.7^{a,b,c}$	$18.26 \pm 8.0^{c,d}$	47.5^{b}
770.8VF ZIRCONIA/ PREMIER	$41.4 \pm 12.0^{c,d}$	$21.1 \pm 3.81^{c,d}$	$62.5^{b,c}$

Items with the same superscript are not statistically different. (Mean ±SD) (n=8)

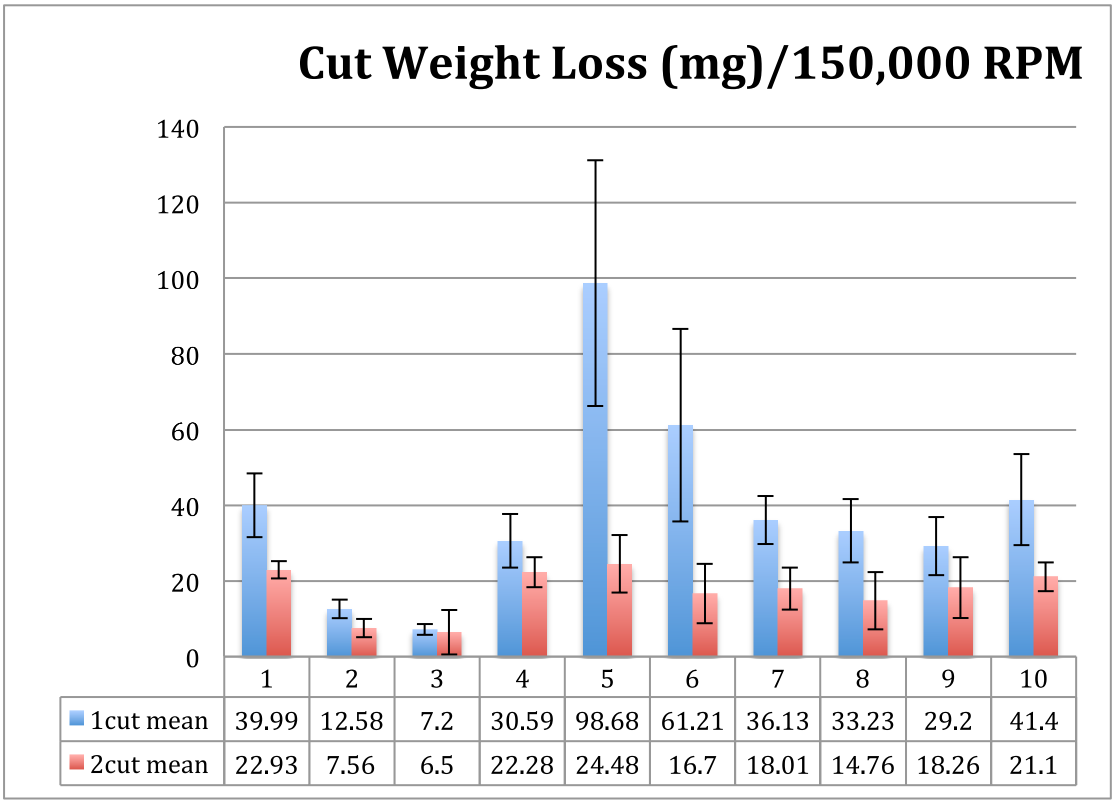


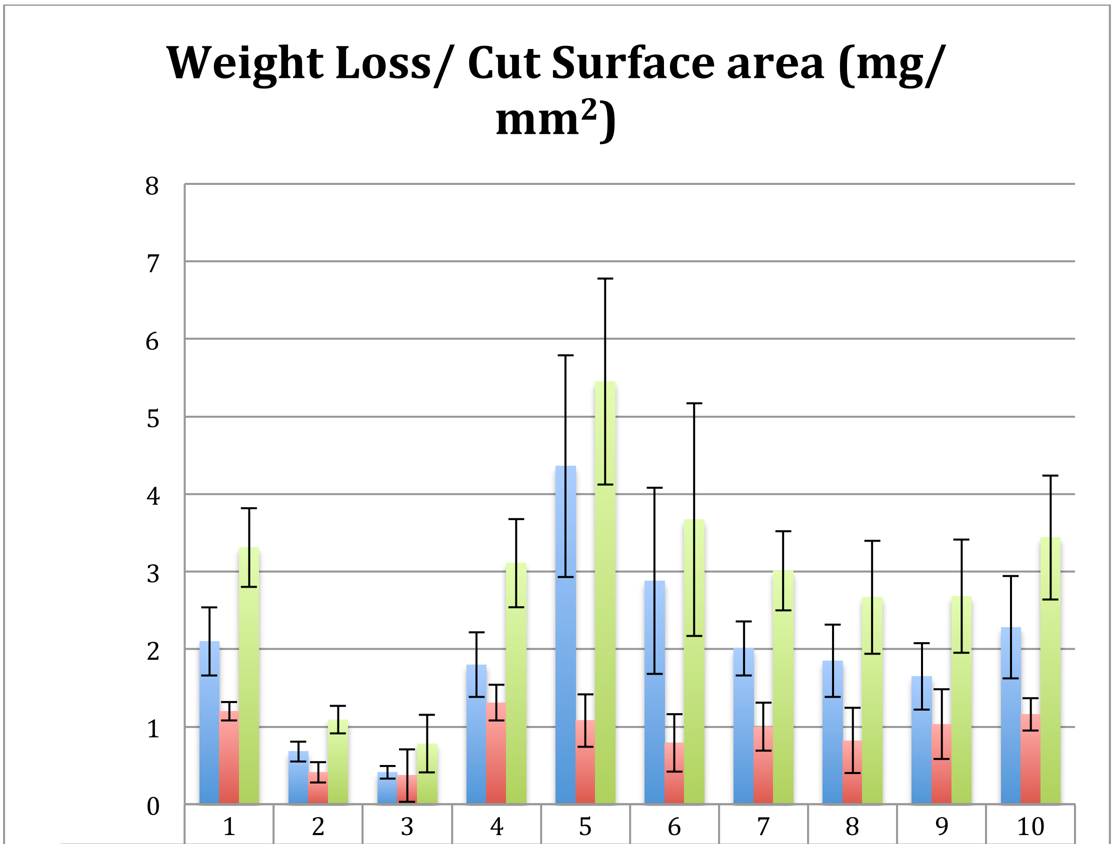
Figure 10 : Cut Weight Loss at 150,000 RPM

Table 4: Block Weight Loss /Cutting Surface Area (mg/mm^2)

Bur No./ Manufacturer	1^{st} Cut /mg	2^{nd} Cut/mg	Total
6856DC.31.016/ BRASSELER USA	$2.1 \pm 0.44^{c,d}$	$1.2 \pm 0.12^{b,c}$	3.31 ± 0.51^{b}
8856DF.31.016/ BRASSELER USA	$0.68 \pm 0.13^{a,b}$	$0.41 \pm 0.13^{a, b}$	1.09 ± 0.18^{a}
856DEF.31.016/ BRASSELER USA	0.41 ± 0.08^{a}	0.37 ± 0.34^{a}	0.78 ± 0.37^{a}
ZR6850.314.016/ KOMET USA	$1.8 \pm 0.42^{b,c,d}$	1.31 ± 0.23^{c}	3.11 ± 0.57^{b}
ZR6881.314.016/ KOMET USA	4.36 ± 1.43^{e}	$1.08 \pm 0.34^{b,c}$	5.45 ± 1.33^{c}
F4R SC/ A&M instruments	2.88 ± 1.2^{d}	$0.79 \pm 0.37^{a,b}$	3.67 ± 1.5^{b}
5850.314.016/ KOMET USA	$2.01 \pm 0.35^{c,d}$	$1 \pm 0.31^{b,c}$	3.01 ± 0.51^{b}
S5856.314.016/ KOMET USA	$1.85 \pm 0.47^{c,d}$	$0.82 \pm 0.42^{a,b,c}$	2.67 ± 0.73^{b}
6850.314.016/ KOMET USA	$1.65 \pm 0.43^{b,c}$	$1.03 \pm 0.45^{b,c}$	2.68 ± 0.73^{b}
770.8VF ZIRCONIA/ PREMIER	$2.28 \pm 0.66^{c,d}$	$1.16 \pm 0.21^{b,c}$	3.44 ± 0.8^{b}

Items with the same superscript are not statistically different. (Mean ±SD) (n=8)

Surface is mis spelled I corrected use this draft for the all edits



	1	2	3	4	5	6	7	8	9	10
1st cut	2.1	0.68	0.41	1.8	4.36	2.88	2.01	1.85	1.65	2.28
2nd cut	1.2	0.41	0.37	1.31	1.08	0.79	1	0.82	1.03	1.16
Total	3.31	1.09	0.78	3.11	5.45	3.67	3.01	2.67	2.68	3.44

Figure 11: Cut Weight Loss /Cutting Surface Area (mg/mm^2)

In the second part of the experiment, we tested 2 representative diamond burs with the same conditions as described before except the bur rotation was reduced to 40,000rpm. This part of the experiment was performed to evaluate manufacturer's claims some diamonds are more effective at lower cutting speeds. Group 1& 4 (6856DC.31.016, BRASSELER USA and ZR6850.314.016, KOMET USA) were selected to cut the blocks at a different operation speed (40,000 rpm) followed the same protocol. The result and comparison are presented in Figure 12.

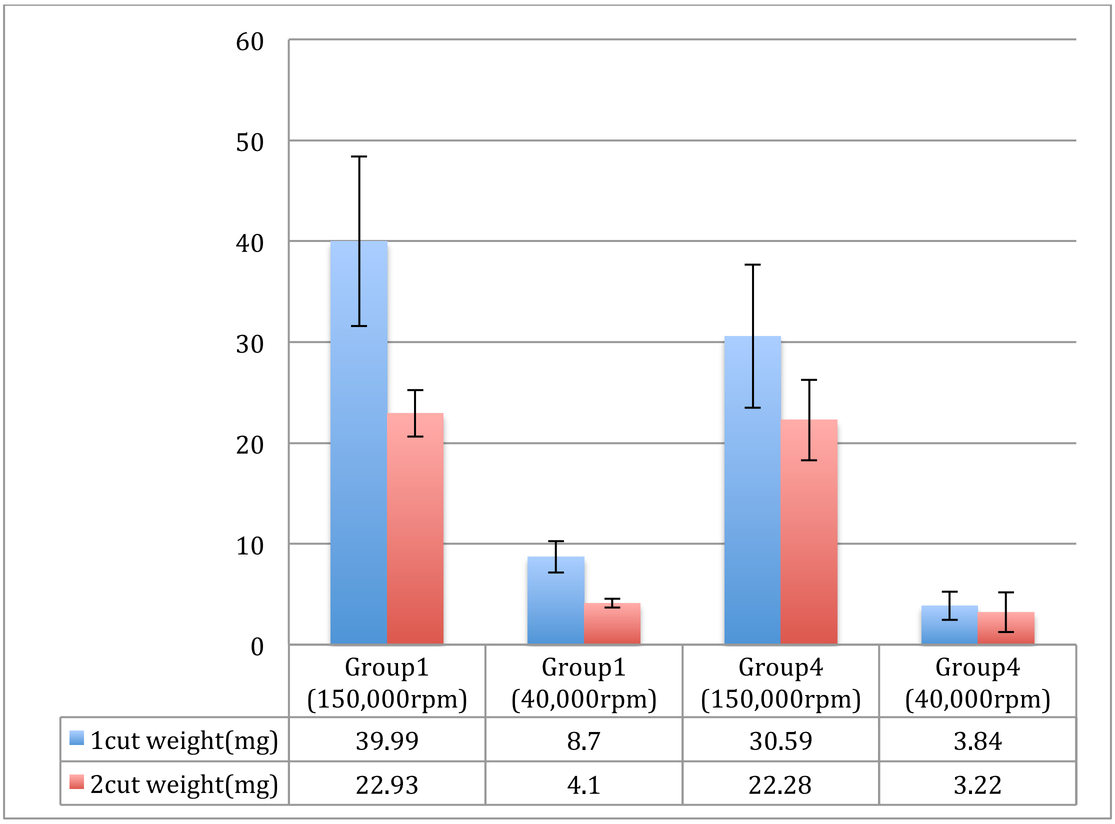
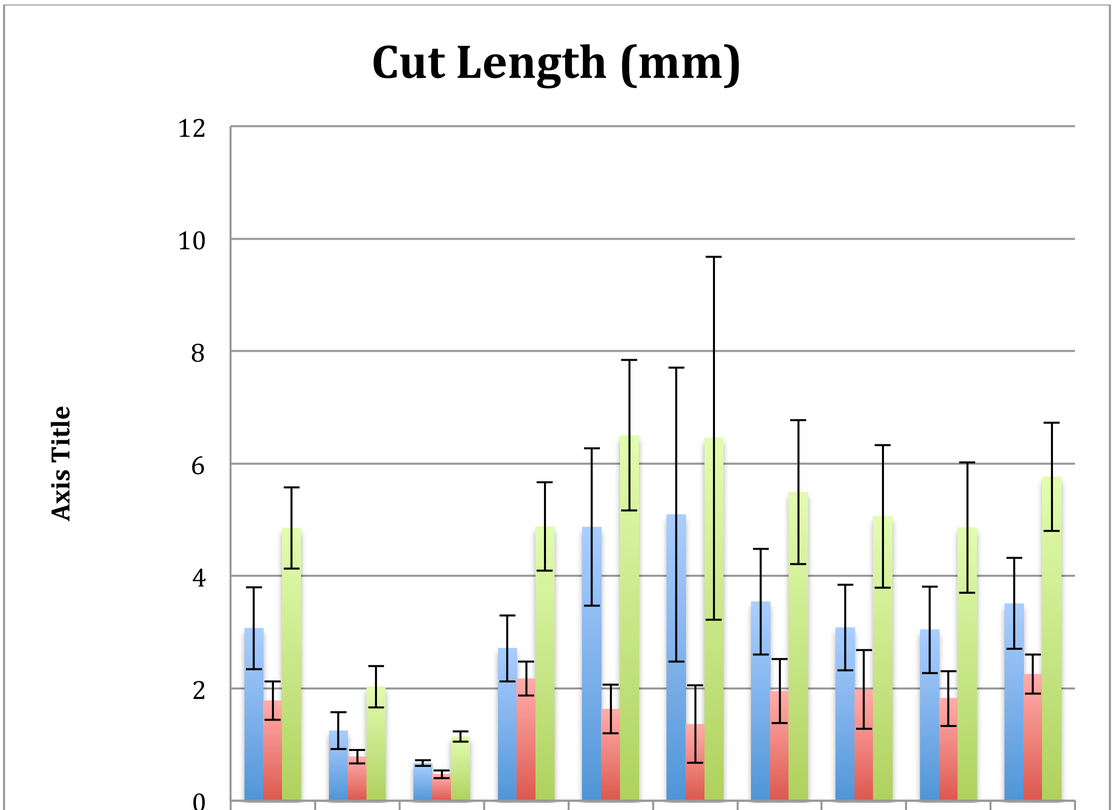


Figure 12: Cut Weight Loss at 150,000 RPM & 40,000 RPM

Cutting length

Table 5 and Figure 13 show the mean cutting length of block after the first, second, and combined (combination of first and second) cuts with each bur at 150,000 RPM. The cutting length was significantly different between the different diamond bur at both the first and second cut ($p<0.05$). With the statistic analysis, the advantage is not so clear. Group 6 bur (F4R SC/ A&M instruments) produced the longest cuts of all groups ($p<0.05$) with the significant difference during the first cut which decreased in the second cut. In cutting length, the Group 2 (8856DF.31.016/ BRASSELER USA) and Group3 (856DEF.31.016/ BRASSELER USA) bur produced the least cutting length of all groups with the significant difference in the first cut, the second cut and total amount. There was a significant decrease in the cutting length for all diamonds on average between the first and second cut ($p<0.05$).



	1	2	3	4	5	6	7	8	9	10
1cut length	3.07	1.25	0.67	2.71	4.87	5.09	3.54	3.08	3.04	3.51
2cut length	1.78	0.78	0.47	2.17	1.63	1.36	1.95	1.98	1.82	2.25
total length	4.85	2.03	1.14	4.88	6.5	6.45	5.49	5.06	4.86	5.76

Figure 13: Cut Length

Table 5 : Bur Cut Length (mm)

Bur No./ Manufacturer	1^{st} Cut /mm	2^{nd} Cut/mm	Total/mm
6856DC.31.016/ BRASSELER USA	3.07±0.73 [b,c,d]	1.78±0.34 [c,d]	4.85±0.72 [b]
8856DF.31.016/ BRASSELER USA	1.25±0.33 [a,b]	0.78±0.12 [a,b]	2.03±0.37 [a]
856DEF.31.016/ BRASSELER USA	0.67±0.05 [a]	0.47±0.07 [a]	1.14±0.09 [a]
ZR6850.314.016/ KOMET USA	2.71±0.59 [b,c]	2.17±0.3 [d]	4.88±0.79 [b]
ZR6881.314.016/ KOMET USA	4.87±1.4 [c,d,e]	1.63±0.43 [c,d]	6.5±1.34 [b]
F4R SC/ A&M instruments	5.09±2.62 [e]	1.36±0.69 [b,c]	6.45±3.23 [b]
5850.314.016/ KOMET USA	3.54±0.94 [c,d,e]	1.95±0.57 [c,d]	5.49±1.28 [b]
S5856.314.016/ KOMET USA	3.08±0.76 [c,d]	1.98±0.7 [c,d]	5.06±1.27 [b]
6850.314.016/ KOMET USA	3.04±0.77 [b,c]	1.82±0.49 [c,d]	4.86±1.16 [b]
770.8VF ZIRCONIA/ PREMIER	3.51±0.81 [c,d,e]	2.25±0.35 [d]	5.76±0.96 [b]

Items with the same superscript are not statistically different. (Mean ±SD) (n=8)

Wear of diamond burs

Figure 16 shows the mean surface roughness (Ra) of burs as received and following each cut. Significant differences were measured between the Ra of each bur ($p<0.05$). The Ra values decreased significantly after the first cut ($p<0.05$) except for Group 10 (770.8VF ZIRCONIA/ PREMIER).

After checking the burs in the digital microscope (Keyence VHX 6000) (Figure 17-26), four types of wear damage were observed: diamond dislodgment, diamond particle fracture, wear facet, and matrix abrasion. The amount and type of damage were different for each bur.

Diamond particle fracture (Figure 14A), was found to be the major wear process. Some diamond particles were found to contain wear facets (Figure 14B), where the grit edges had worn producing small flat surfaces. Abrasion damage to the matrix was also observed (Figure 15B). Diamond grit dislodgment was the failure mechanism usually found (Figure 15A), when machining zirconia with finer burs.

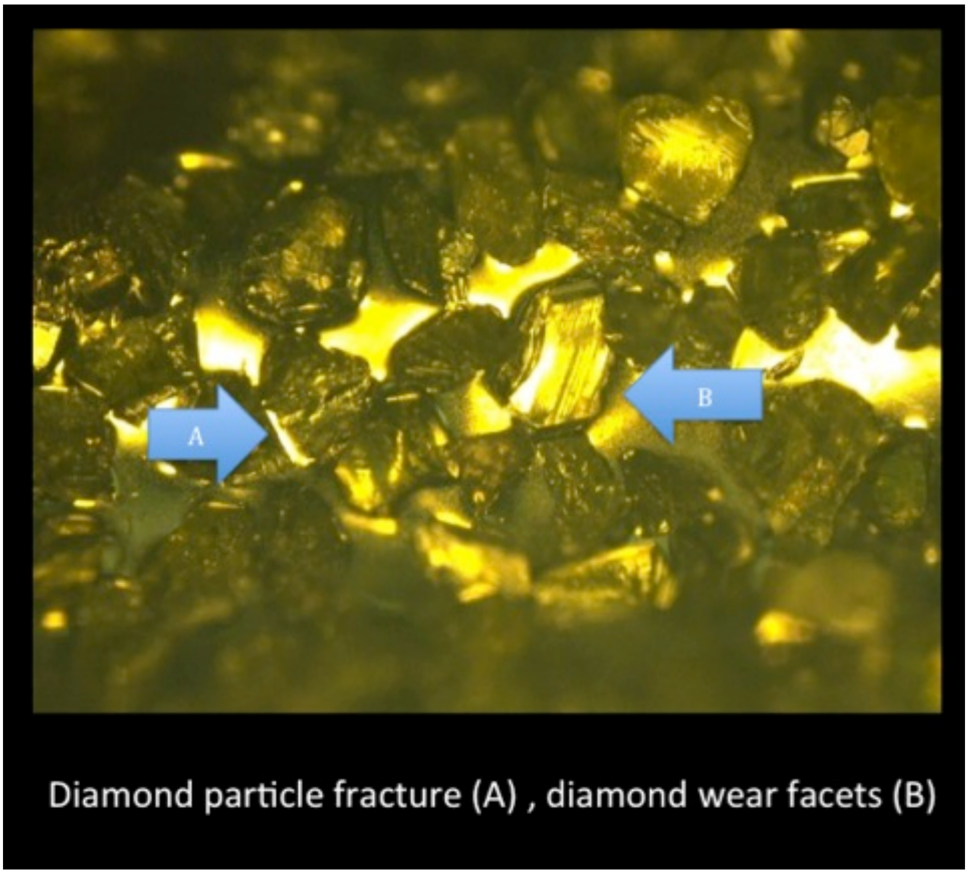


Figure 14: Diamond particle fracture (A) , wear facets(B)

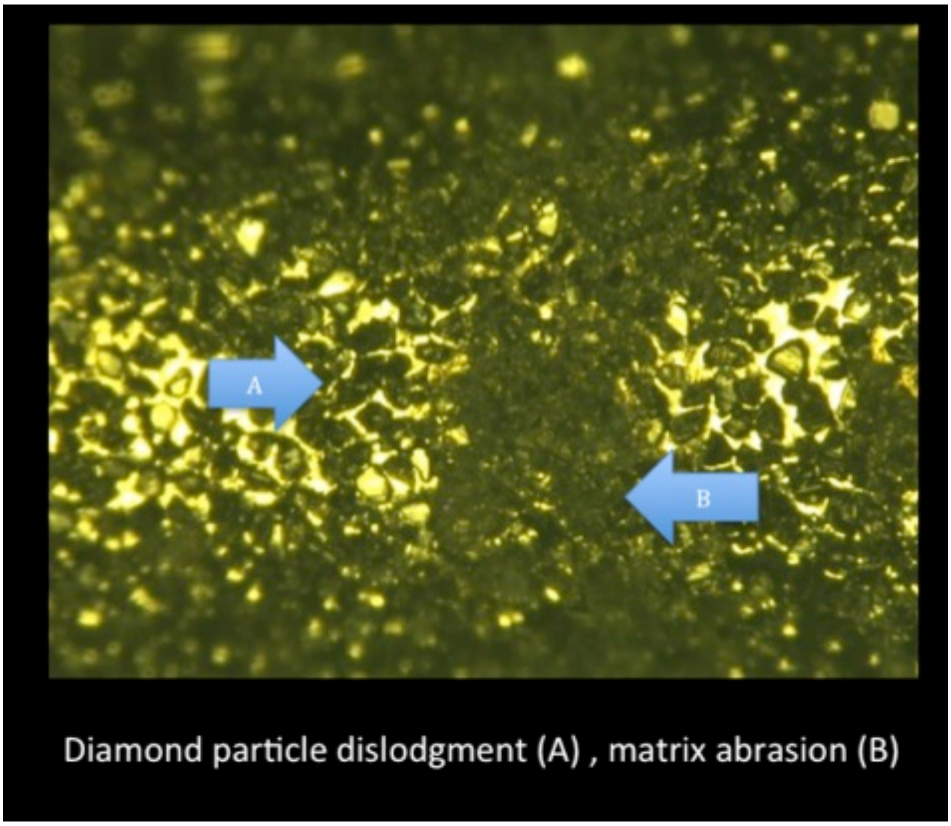
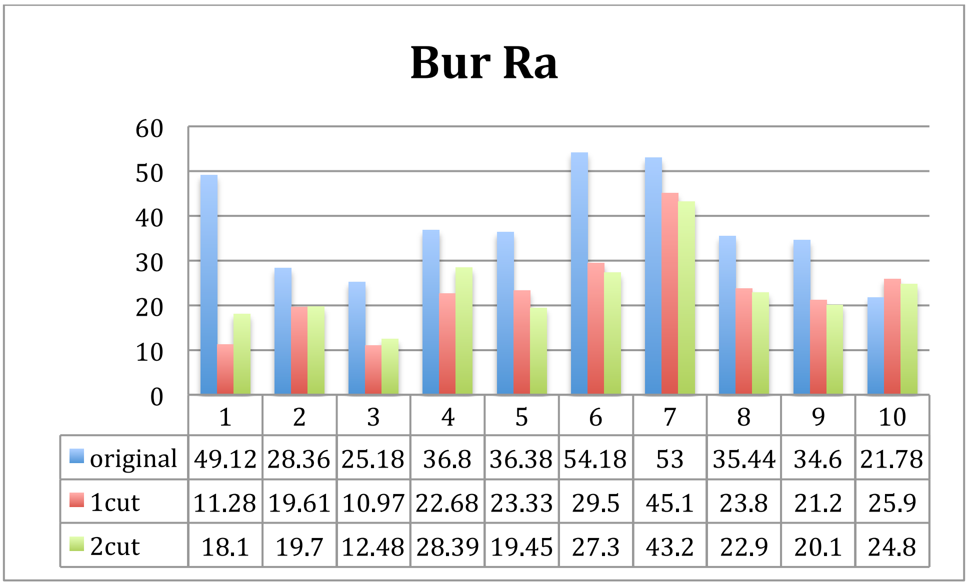


Figure 15: Diamond grit dislodgment (A) , matrix abrasion (B)



	1	2	3	4	5	6	7	8	9	10
original	49.12	28.36	25.18	36.8	36.38	54.18	53	35.44	34.6	21.78
1cut	11.28	19.61	10.97	22.68	23.33	29.5	45.1	23.8	21.2	25.9
2cut	18.1	19.7	12.48	28.39	19.45	27.3	43.2	22.9	20.1	24.8

Figure 16: Diamond Bur Surface Roughness

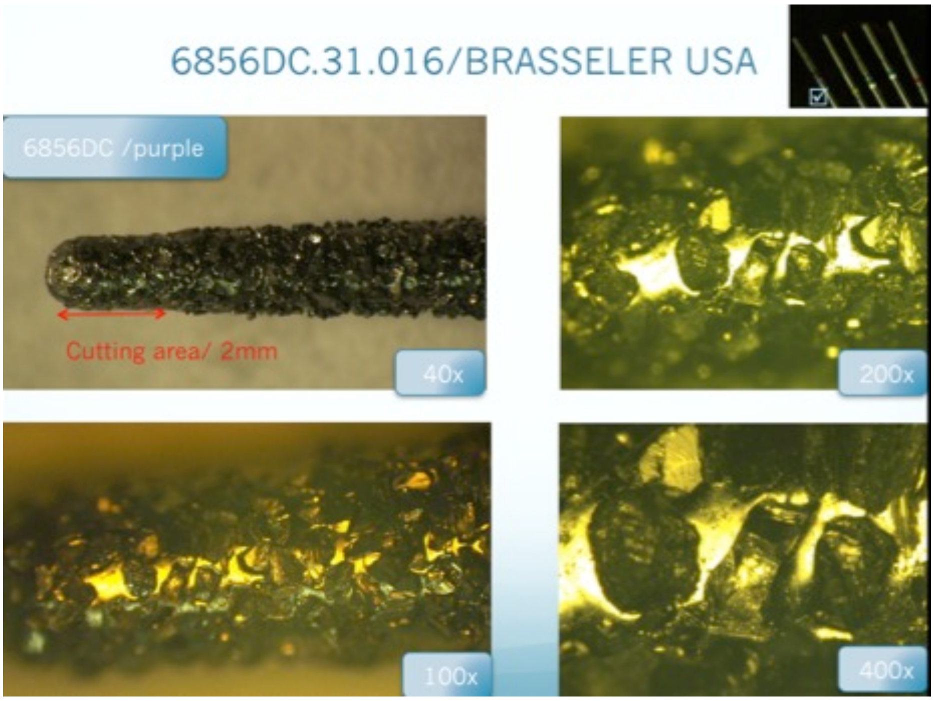


Figure 17: Group1 diamond wear after second cut.

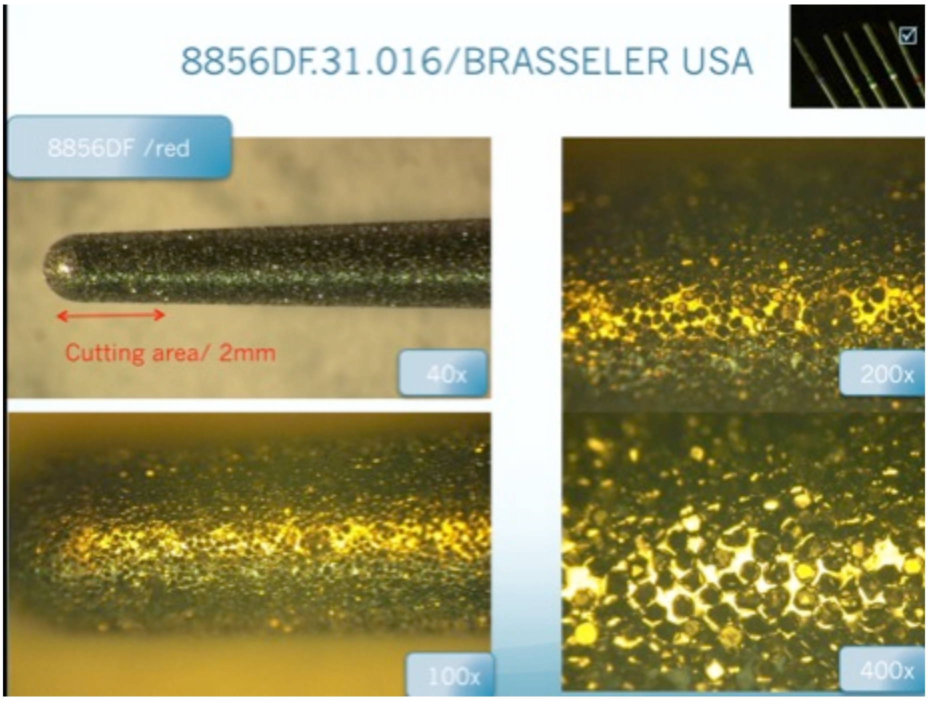


Figure 18: Group2 diamond wear after second cut.

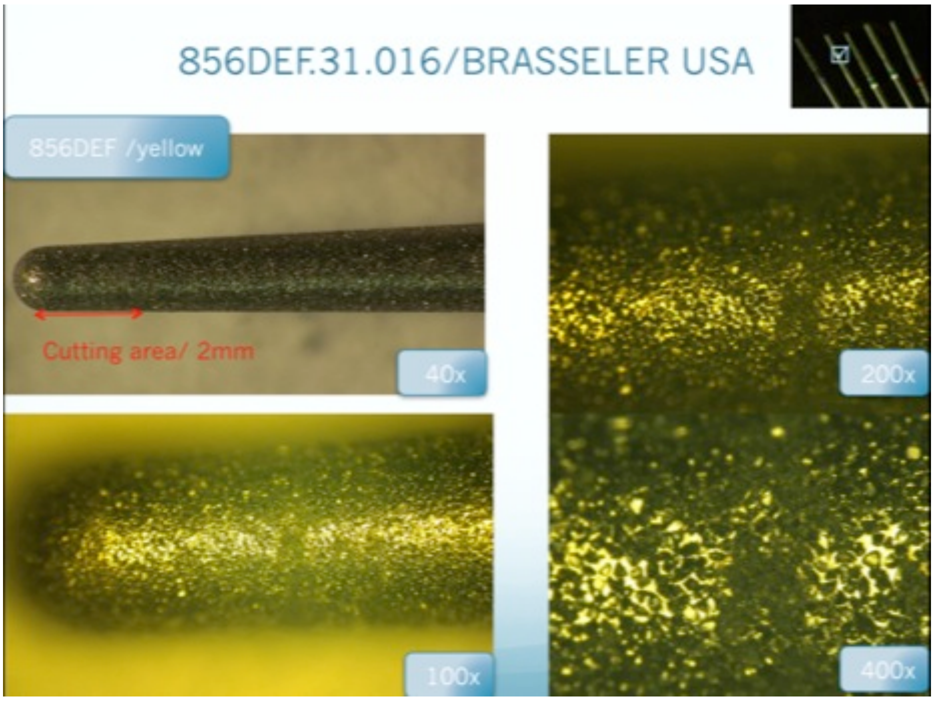


Figure 19: Group3 diamond wear after second cut.

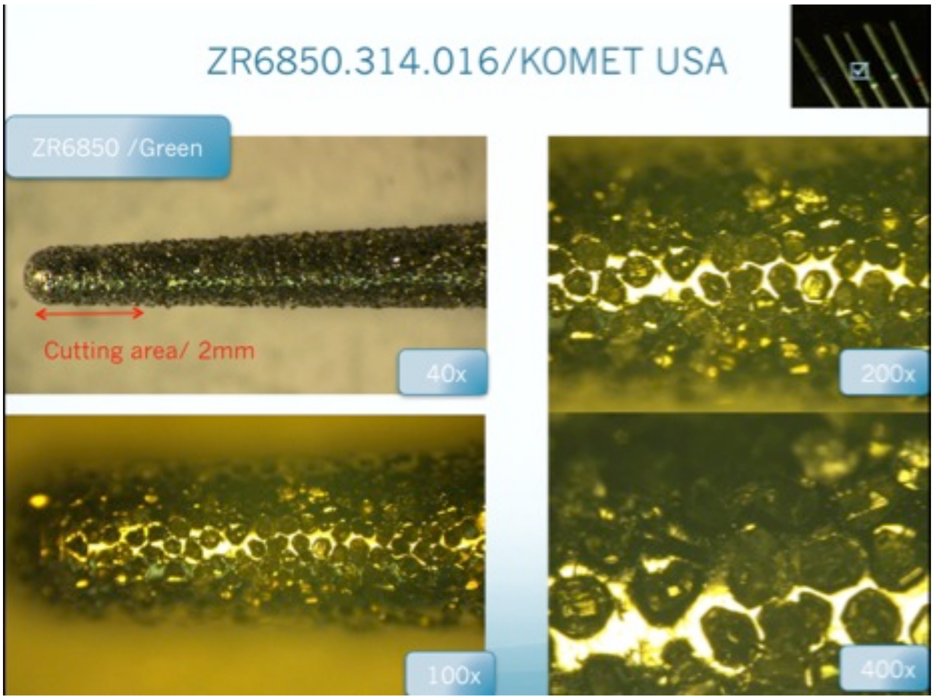


Figure 20: Grou4 diamond wear after second cut.

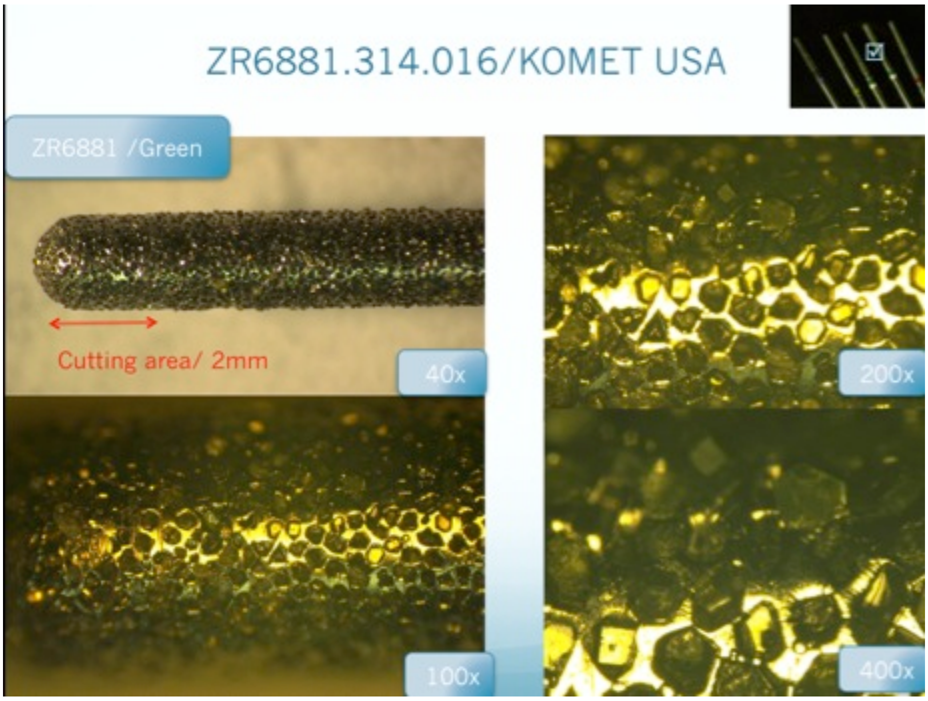


Figure 21: Group5 diamond wear after second cut.

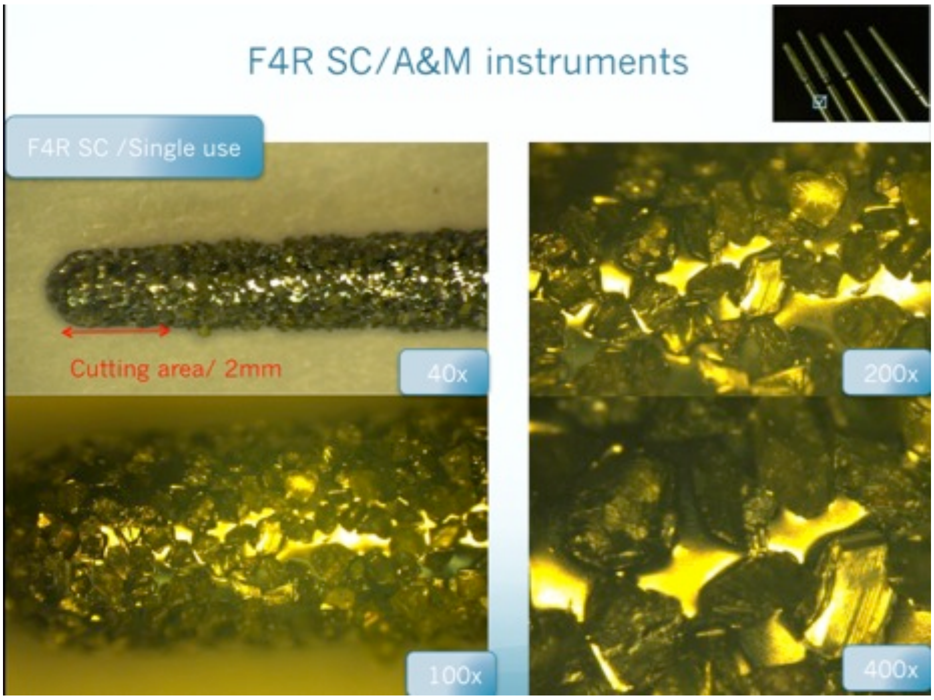


Figure 22: Group6 diamond wear after second cut.

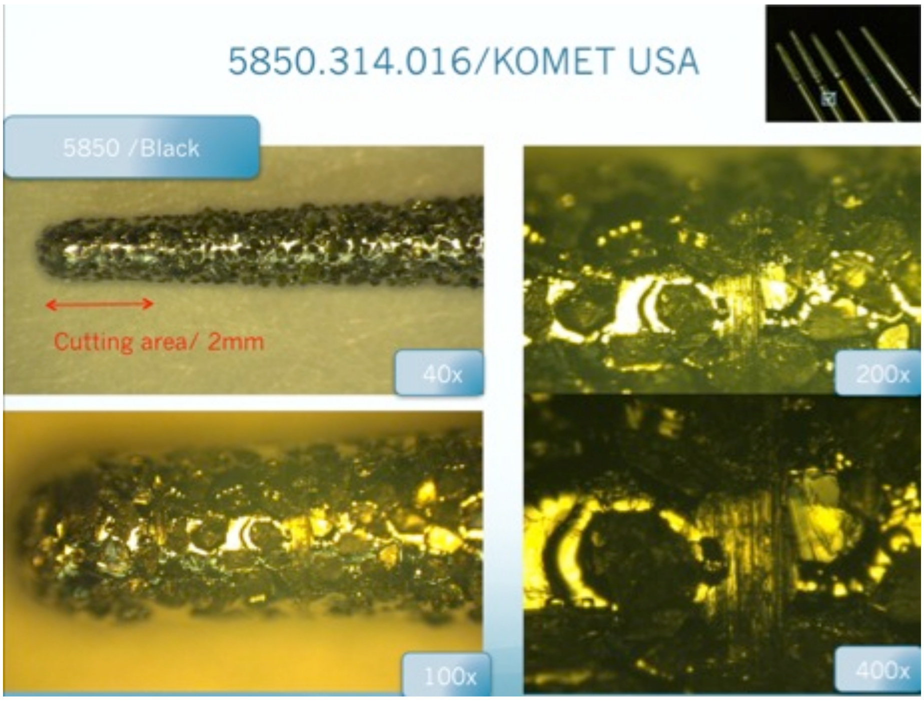


Figure 23: Group7 diamond wear after second cut.

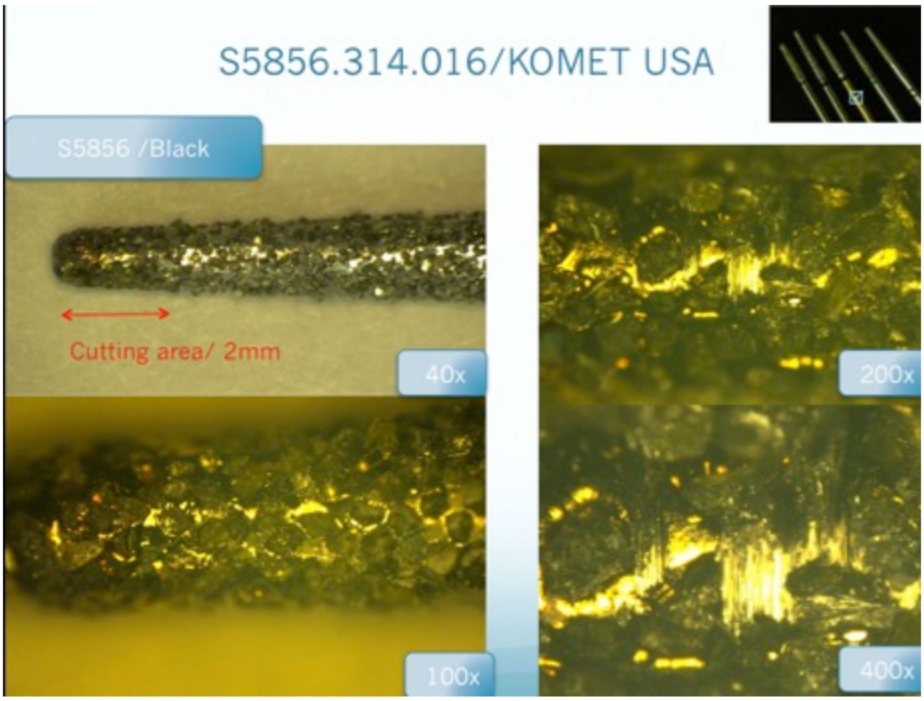


Figure 24: Group8 diamond wear after second cut.

Figure 25: Group9 diamond wear after second cut.

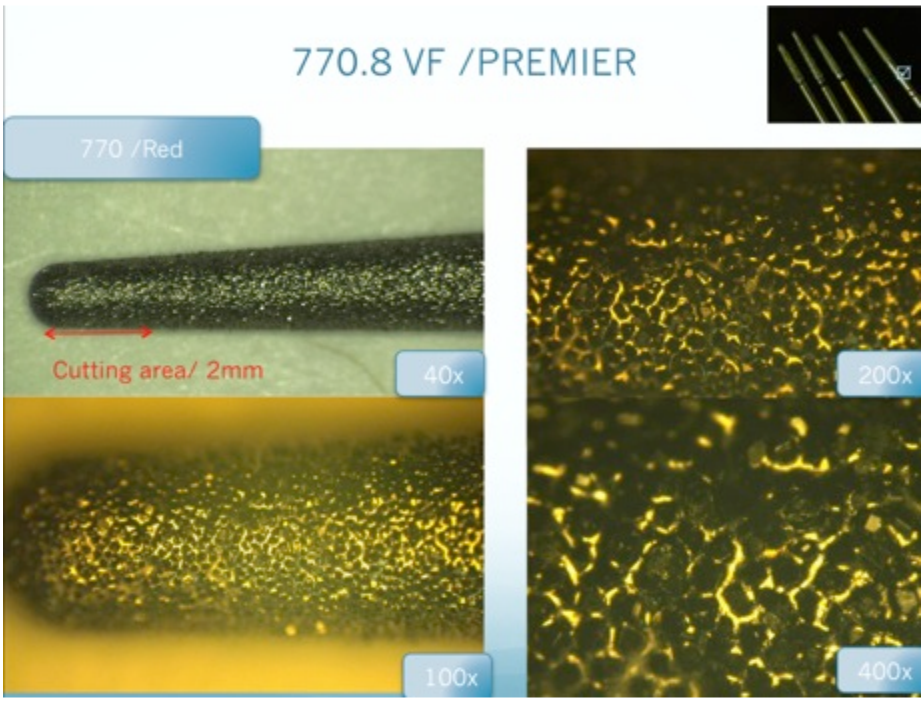


Figure 26: Group10 diamond wear after second cut.

Zirconia removal mechanisms

Examination of the machined grooves in the zirconia was performed with a digital microscope (Keyence VHX 6000) at 100x magnification. (Fig. 27) No chipping damage was observed with the ultrafine and fine burs (Fig. 29,30,37), and relatively large chipping areas were observed along the edges with the coarse burs (Fig. 28,31-36). The cut zirconia surfaces consisted mostly of a series of parallel scratches (Figs. 38). The width of these scratches appeared to be formed by plastic deformation and increased as the diamond grit size increased [47]. We can find the plastic flow, delamination of deformed layer, and side flow across the scratches on the zirconia surfaces machined with the coarse and super coarse burs (Fig. 38). With decreased grit size found in fine diamonds, similar features were seen on the zirconia surfaces, but fewer microfractures were present.

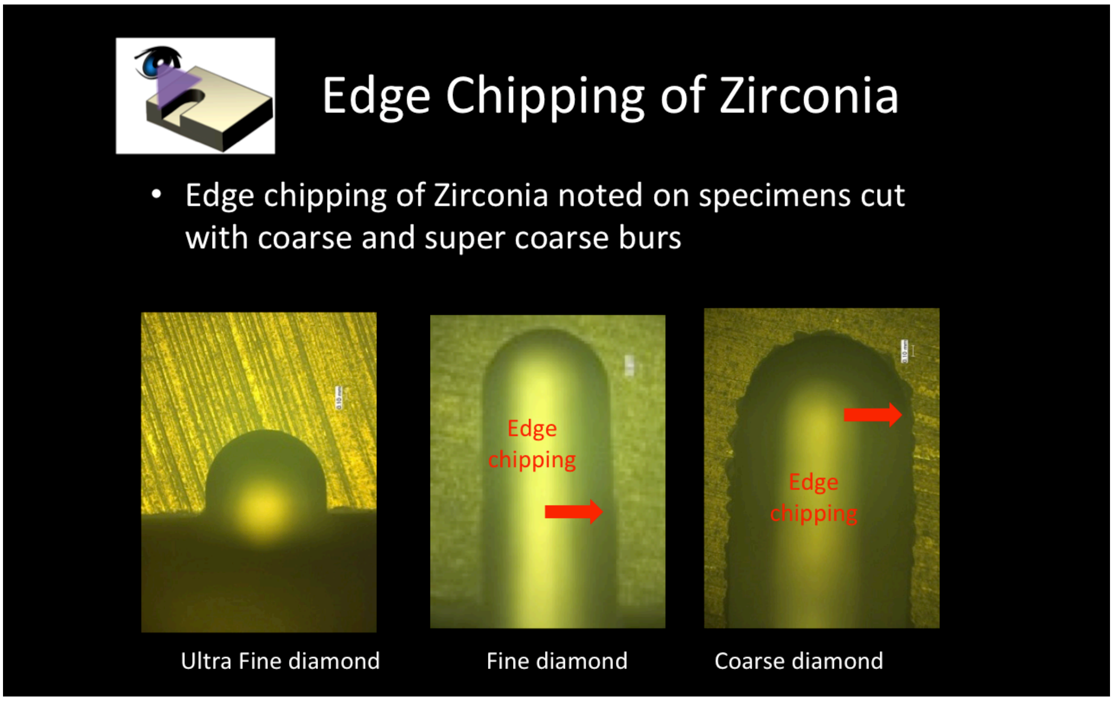
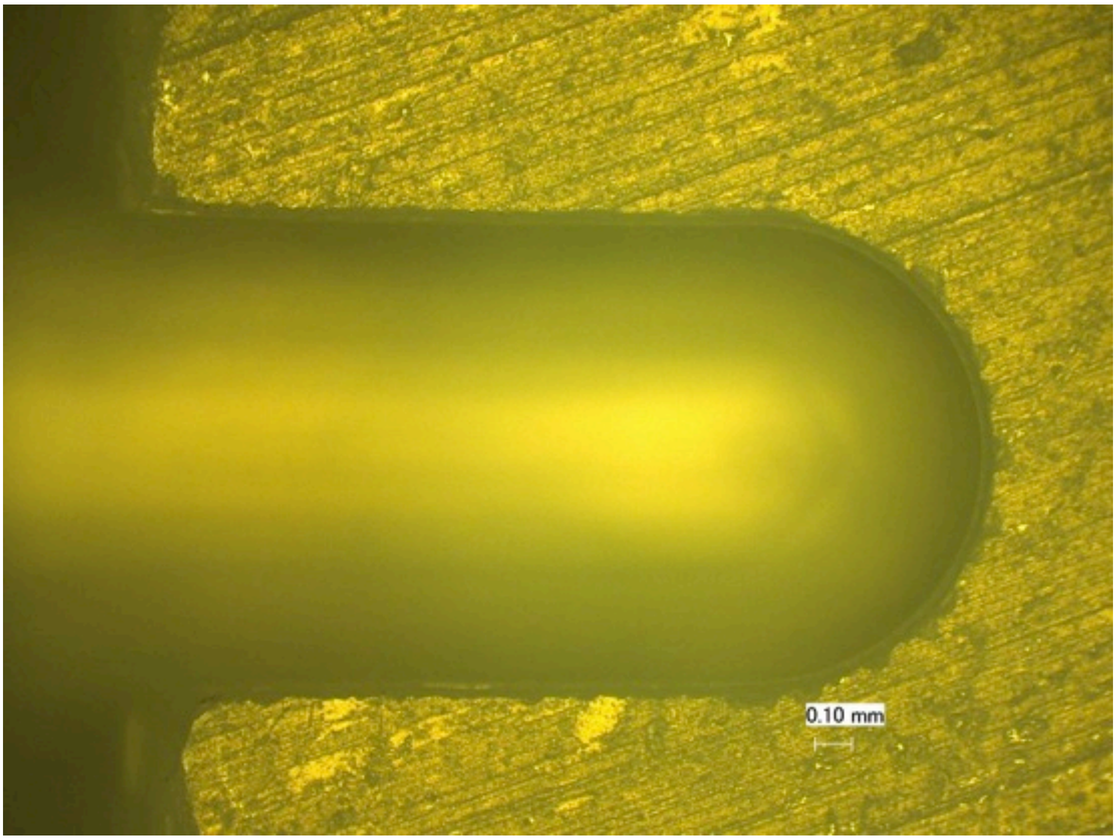


Figure 27: Edge chipping on zirconia at 100x magnification



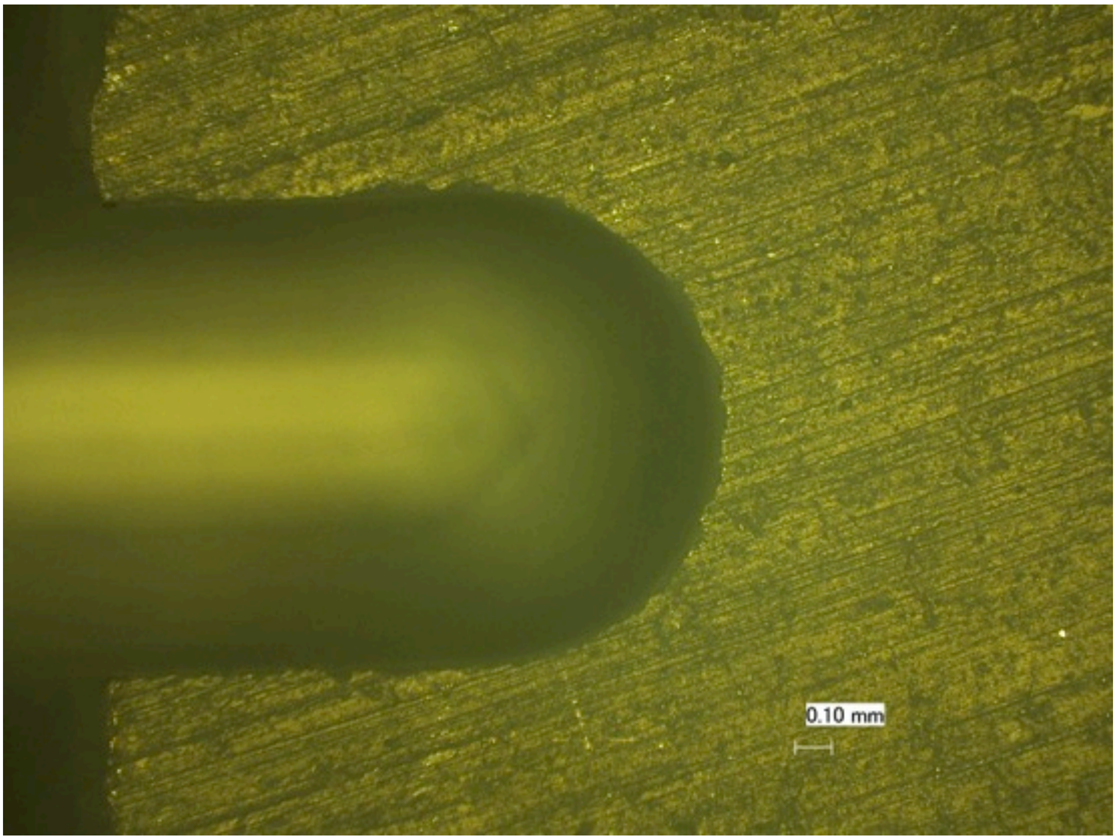


Figure 28: Zirconia with Group1 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(6856DC.31.016/ BRASSELER USA/Super Coarse/ 180 -250µm)

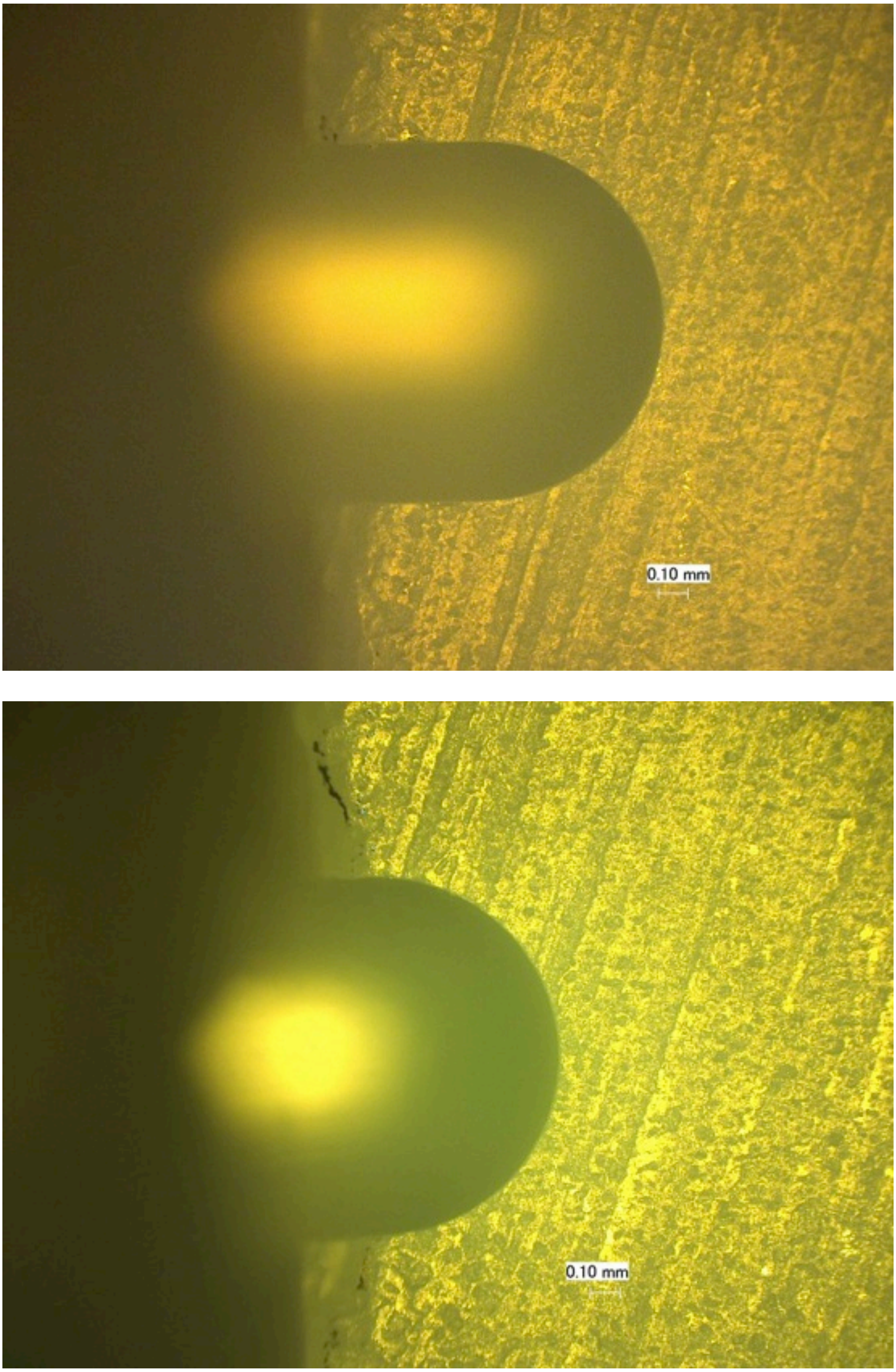


Figure 29: Zirconia with Group2 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(8856DF.31.016/ BRASSELER USA/Fine/40-50μm)

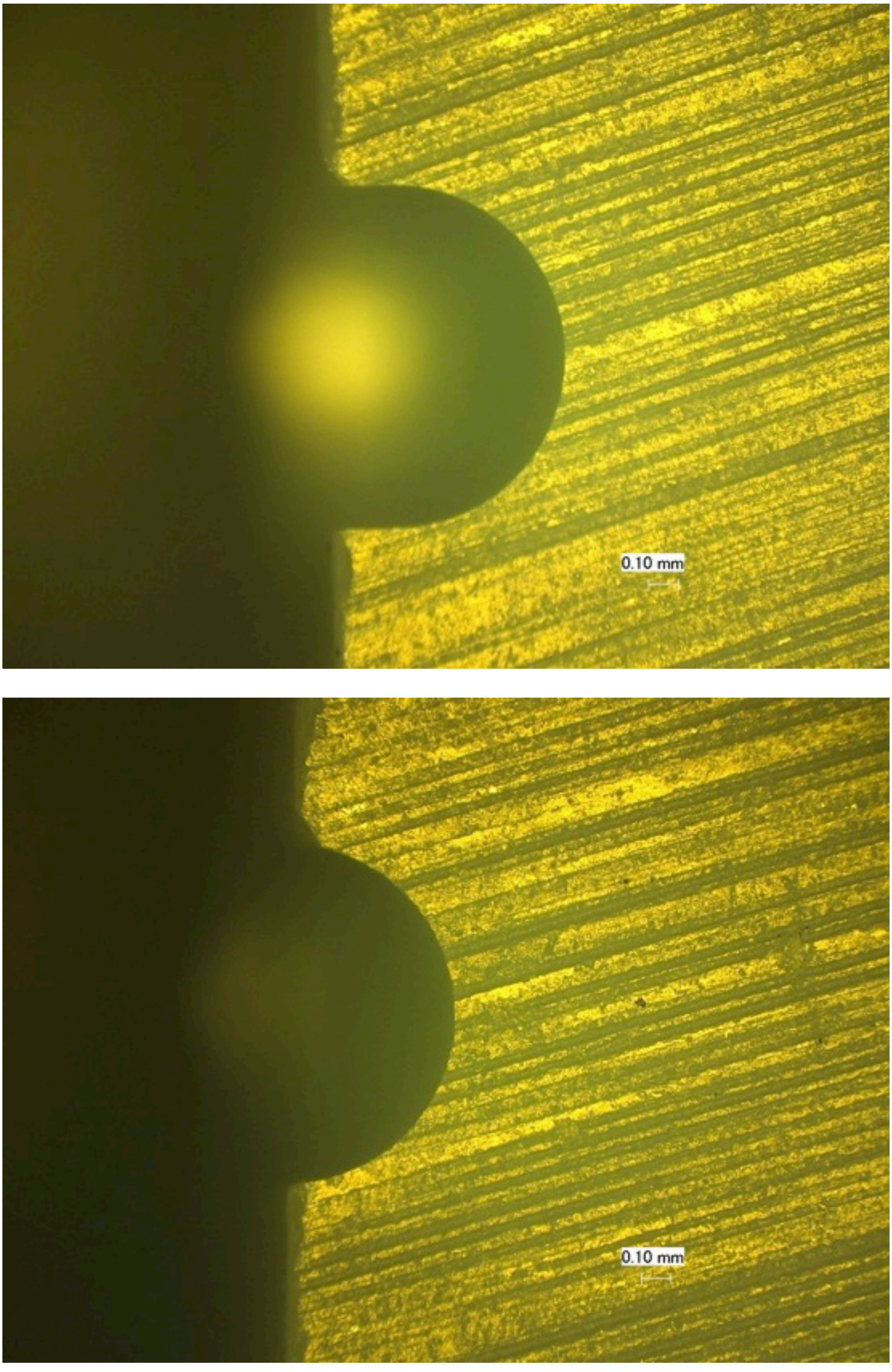
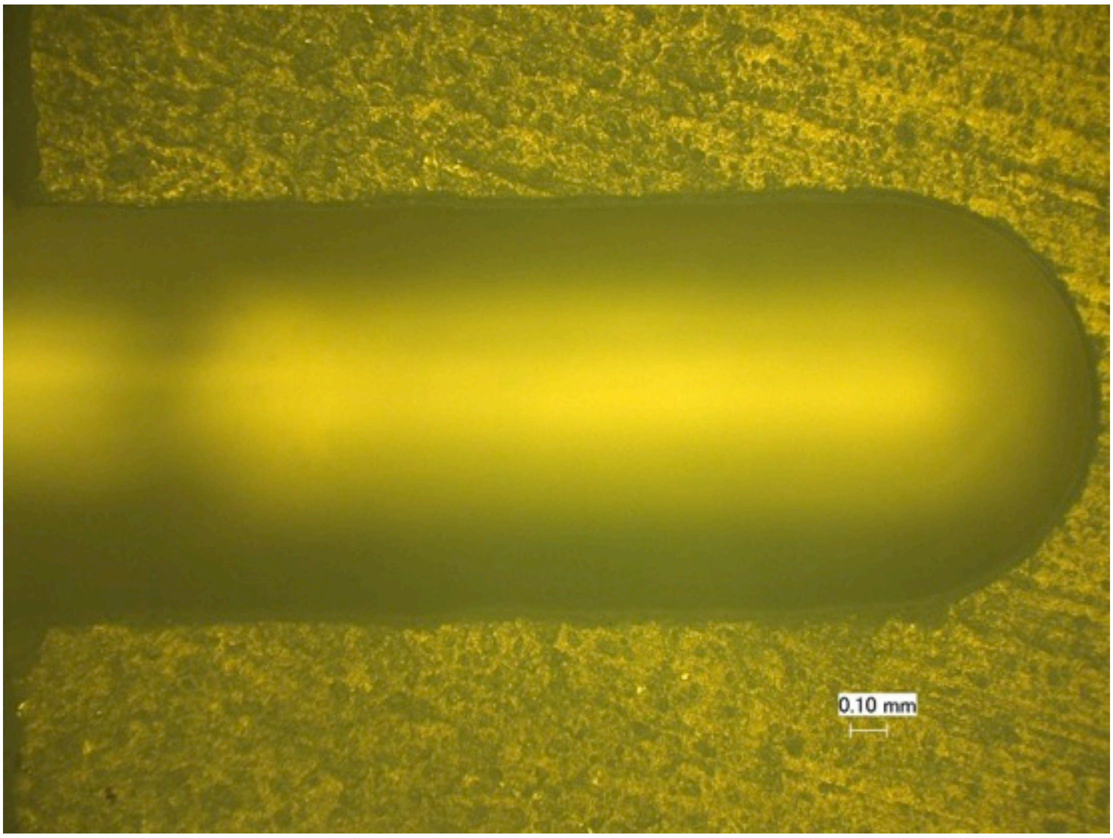


Figure 30: Zirconia with Group3 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(856DEF.31.016/ BRASSELER USA/Extra fine/20-30µm)



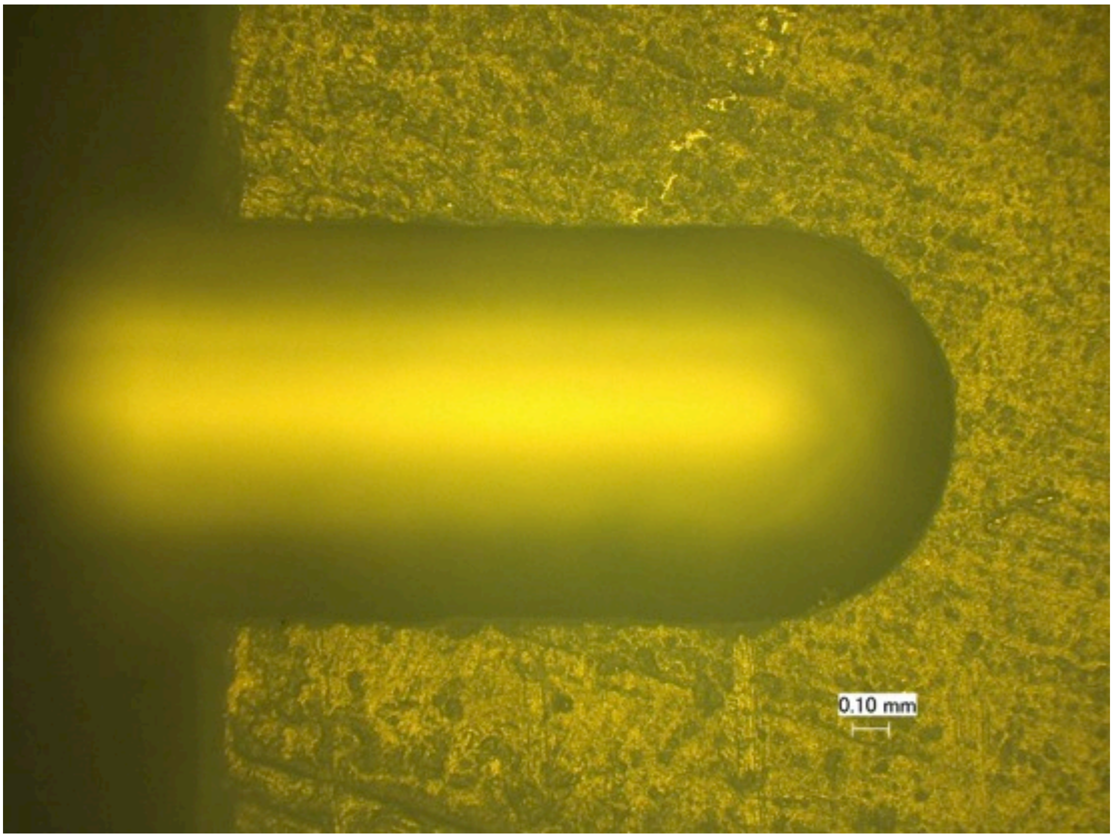


Figure 31: Zirconia with Group 4 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(ZR6850.314.016/ KOMET USA/Coarse/green/110-130μm)

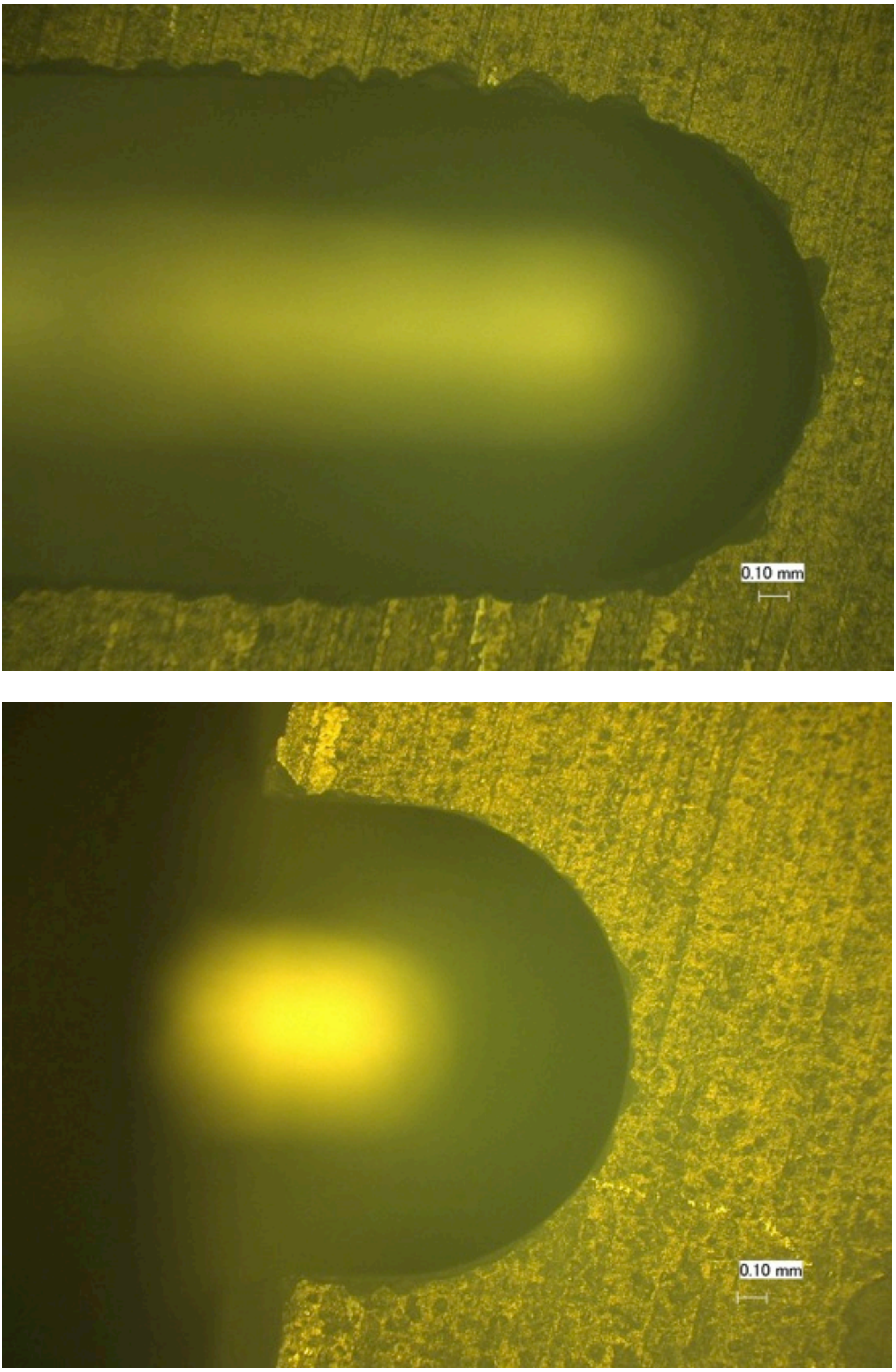


Figure 32: Zirconia with Group 5 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(ZR6881.314.016/ KOMET USA/Coarse/green/110-130μm)

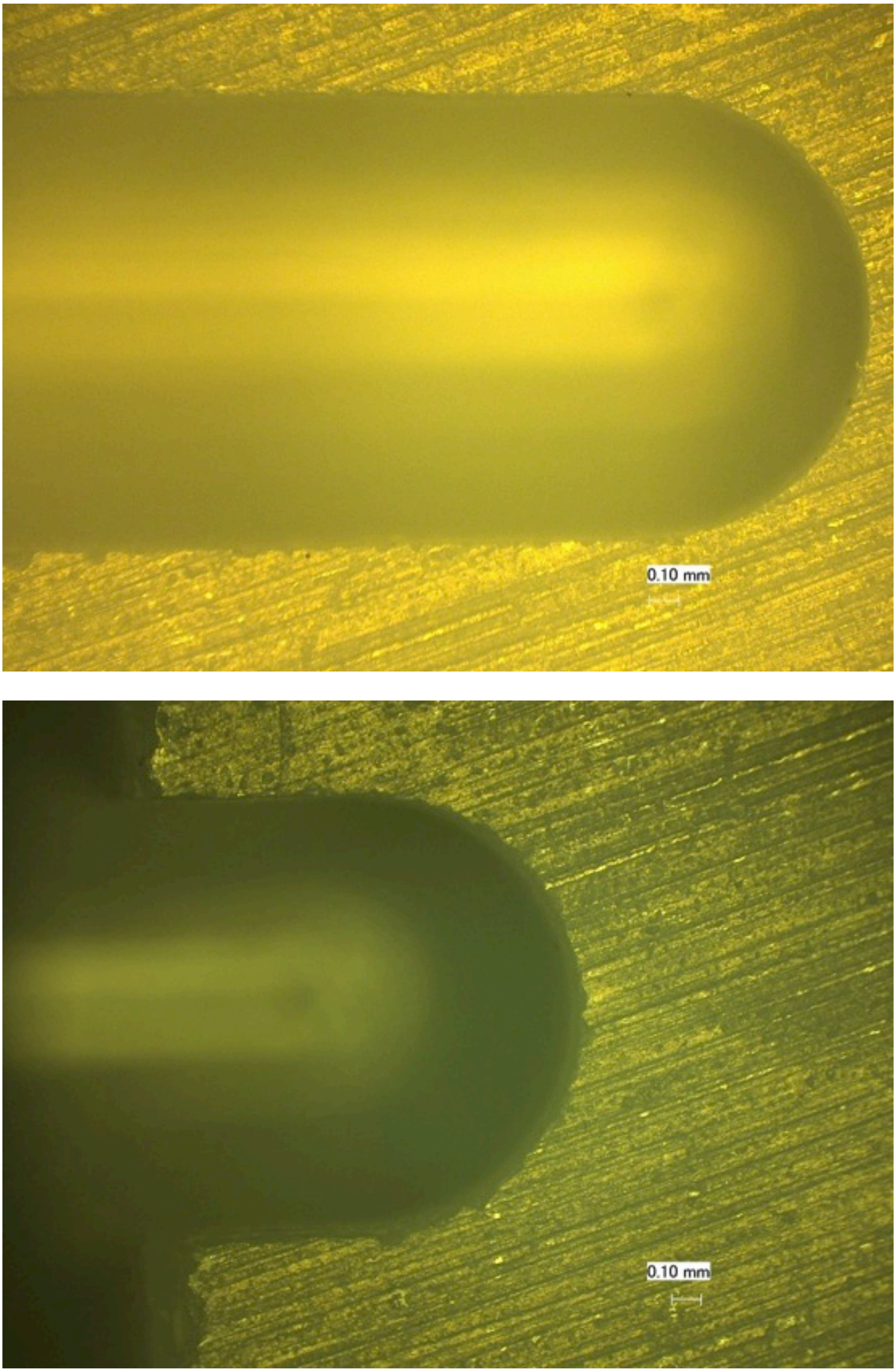


Figure 33: Zirconia with Group 6 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x (F4R SC/ A&M instruments/Super Coarse/180-230µm)

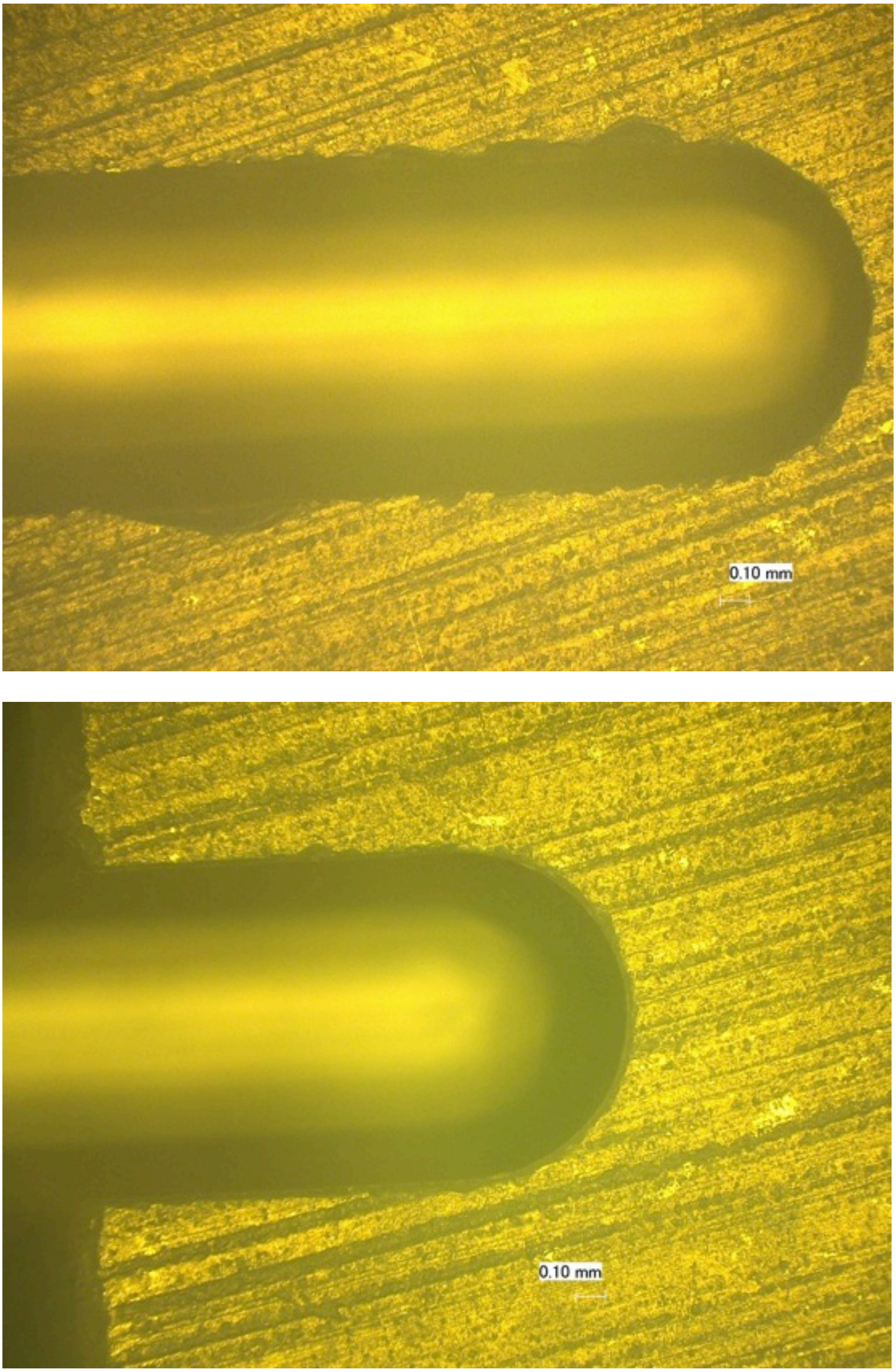
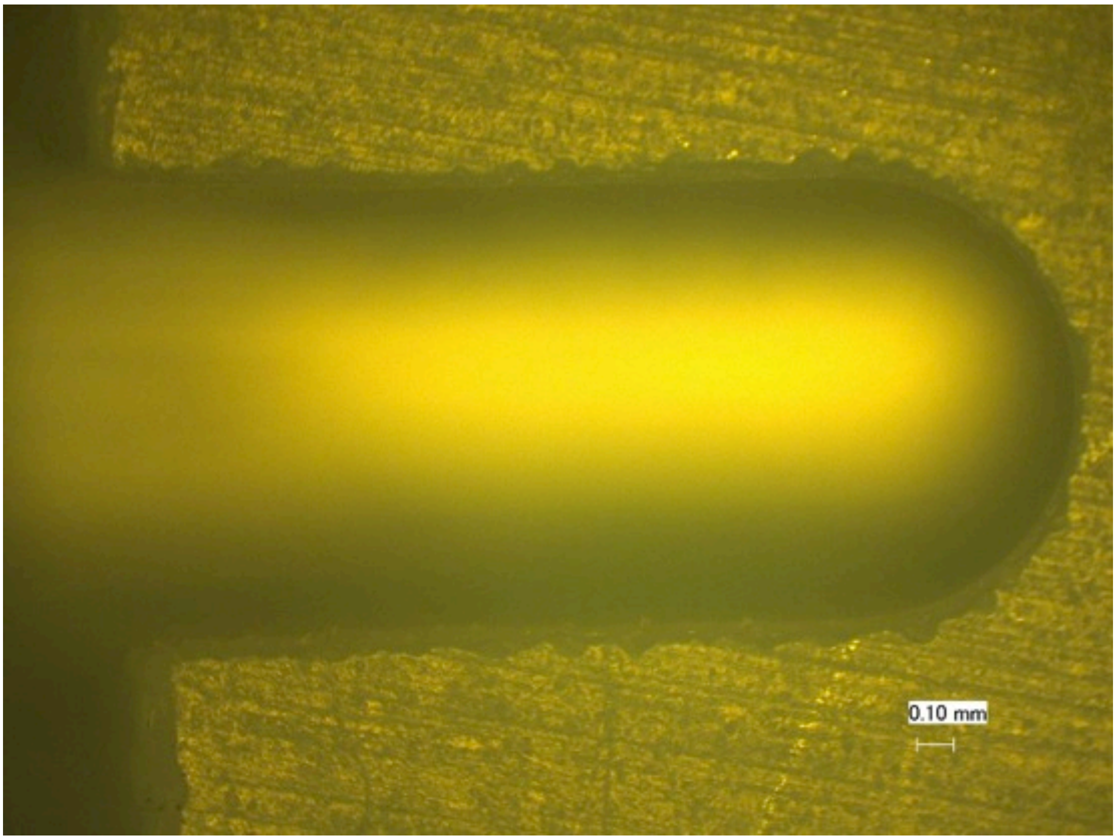


Figure 34: Zirconia with Group 7 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(5850.314.016/ KOMET USA/Super coarse/180-210μm)



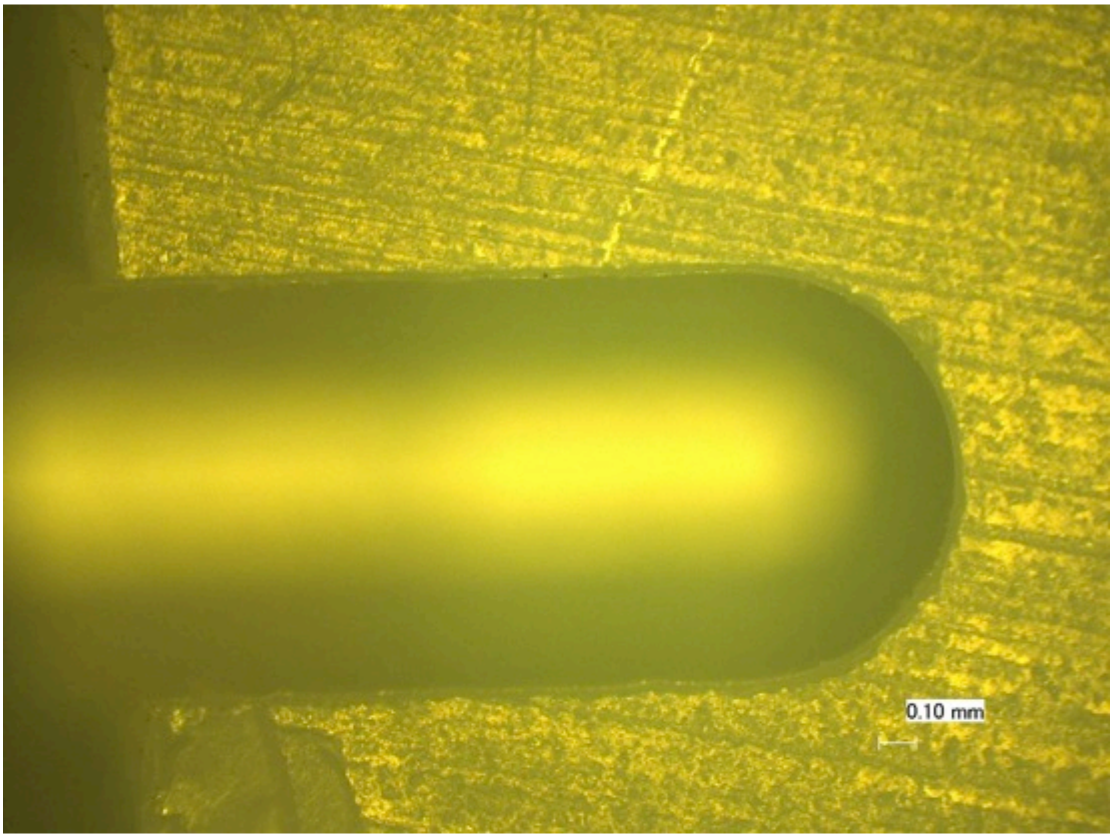


Figure 35: Zirconia with Group 8 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(S5856.314.016/ KOMET USA/Super coarse/180-210μm)

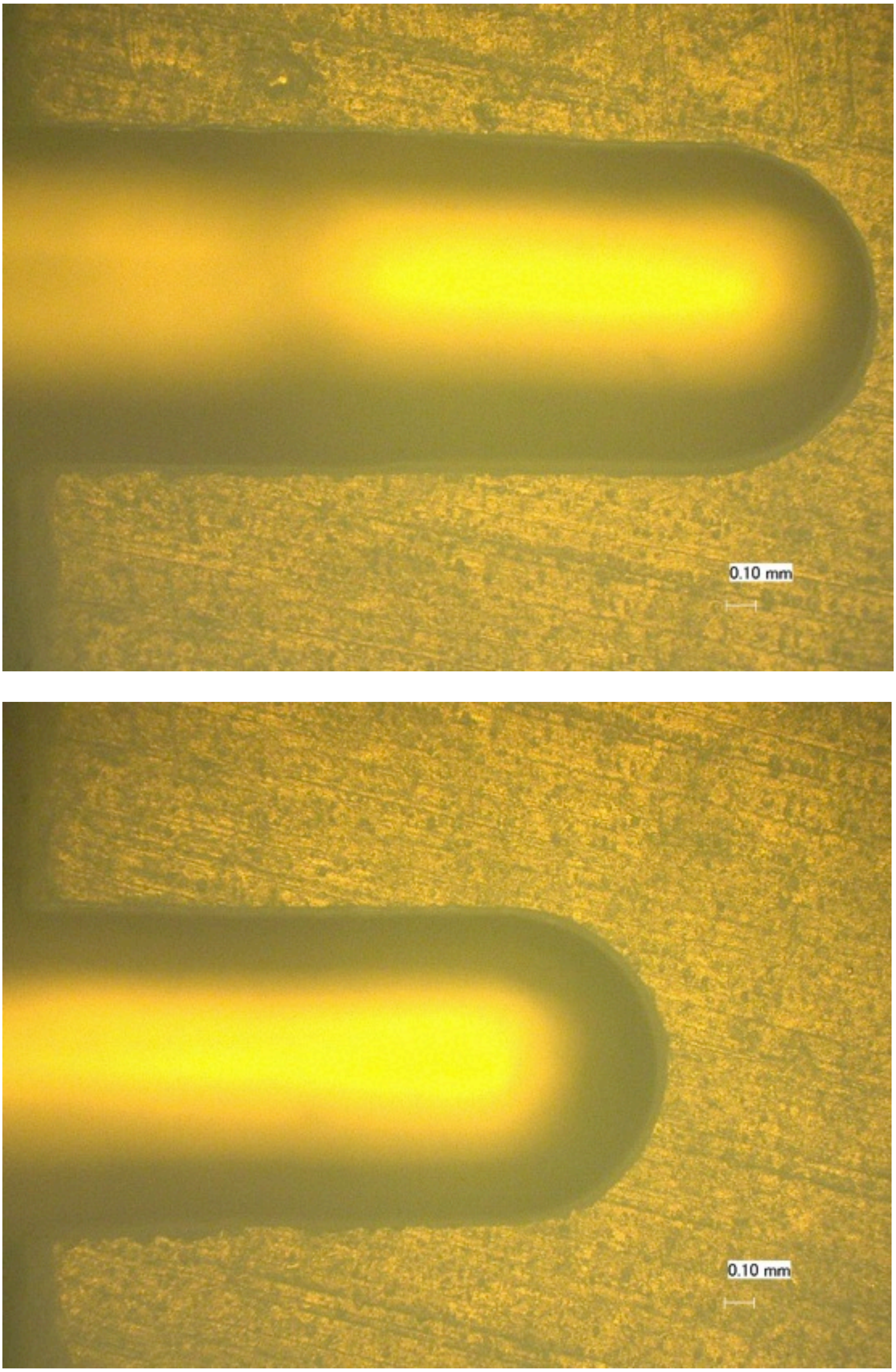
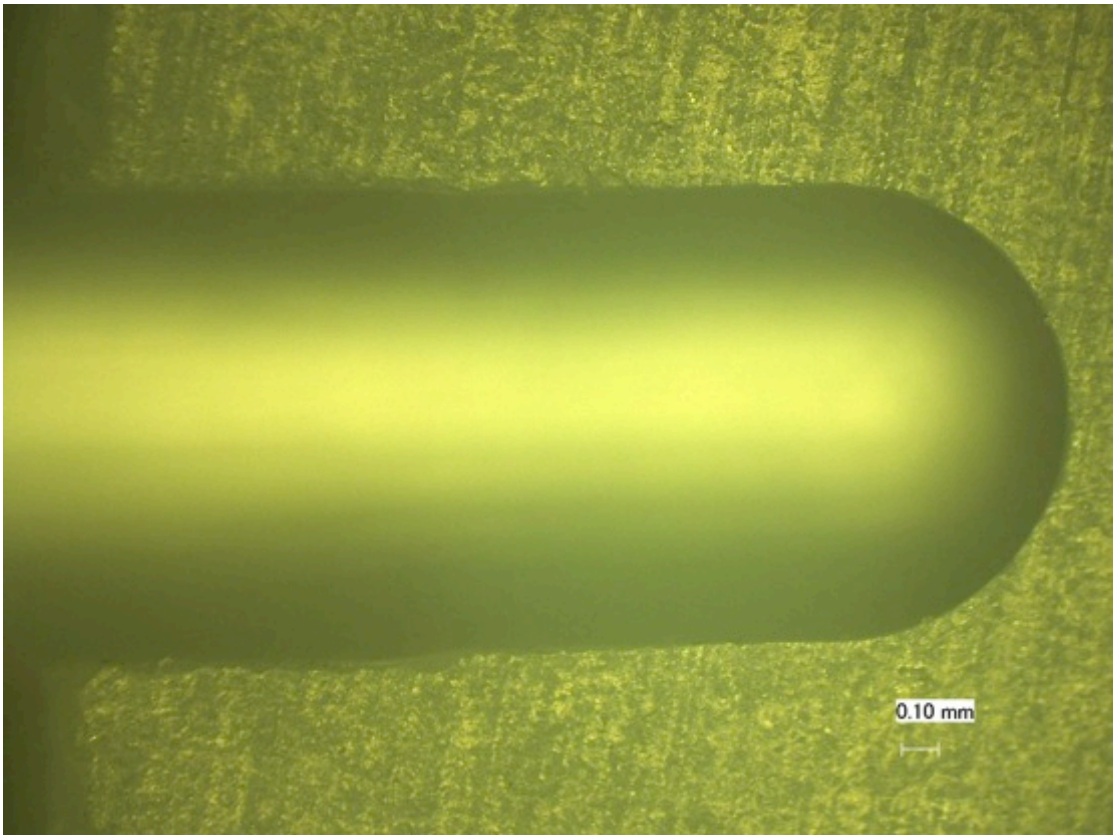


Figure 36: Zirconia with Group9 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(6850.314.016/ KOMET USA/Super Coarse/160-200µm)



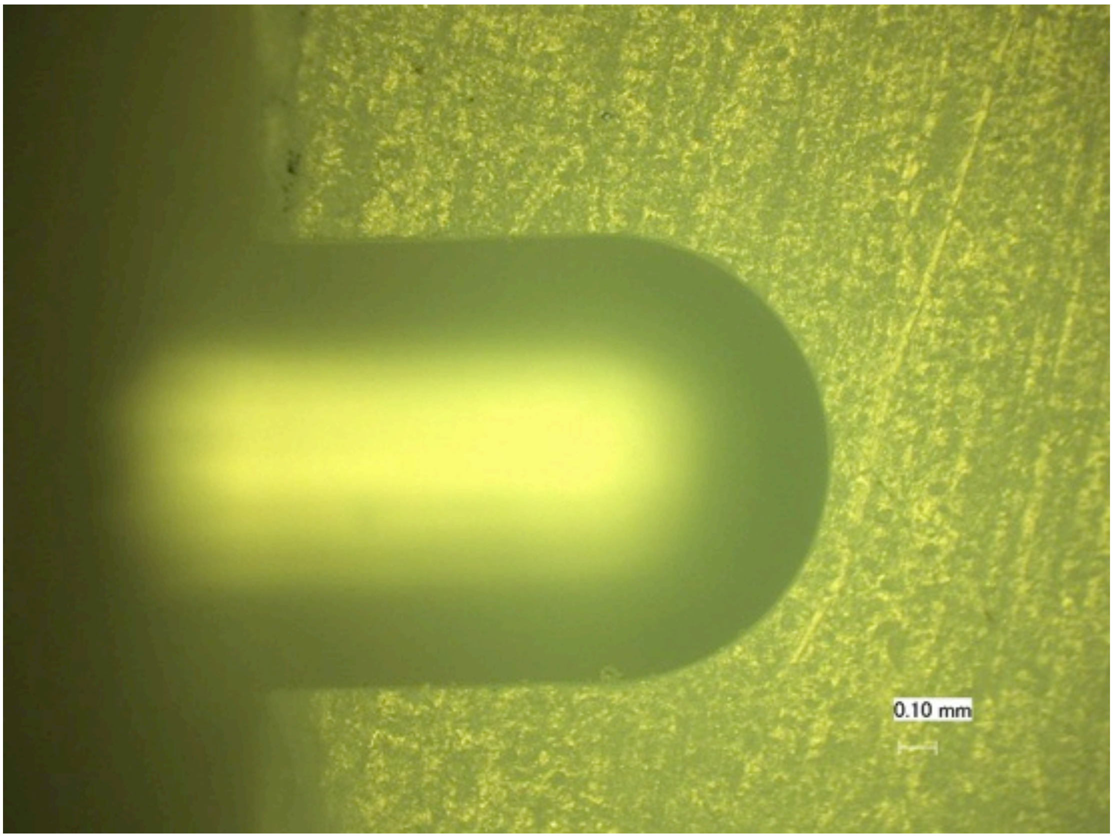


Figure 37: Zirconia with Group10 bur (Upper :1st Cut, Lower: 2nd Cut) at 100x

(770.8VF ZIRCONIA/ PREMIER/Fine/50-60μm)

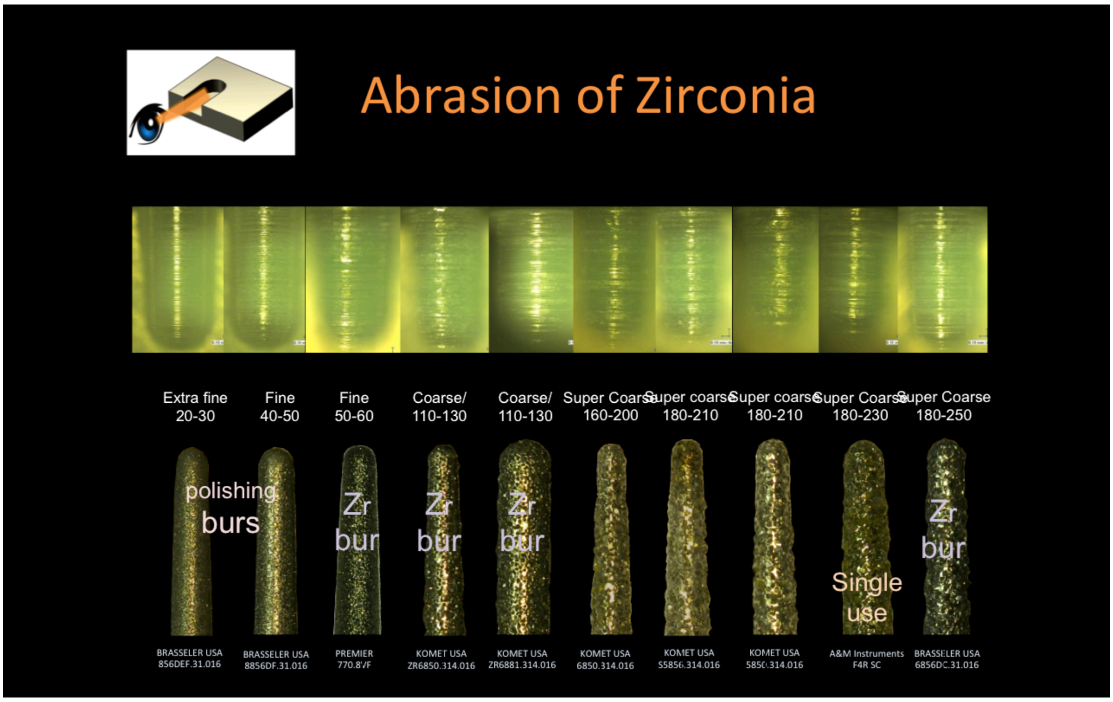


Figure 38: The scratch on the zirconia wall from lateral view at 100x magnification.

DISCUSSION

Using a highly biocompatible zirconia ceramic material that is resistant to long-term thermal, chemical, and mechanical influence produced in the oral environment is an excellent choice for durable wear resistant esthetic dental restorations. However restorations must be adjusted for proximal and occlusal fit, caries may cause replacement of the restoration or an endodontic access opening may be required which requires efficient cutting of zirconia. There is limited clinical data demonstrating the effectiveness of different diamond cutting instruments on zirconia. In this study, we selected 10 kinds of commercially available diamond burs. Four of them (6856DC.31.016/ BRASSELER USA, ZR6850.314.016/ KOMET USA, ZR6881.314.016/ KOMET USA, 770.8VF ZIRCONIA/ PREMIER) are designed specifically for zirconia cutting as well as the disposable super coarse diamond (F4R SC/ A&M instruments) is also designed for zirconia cutting. Three of these diamonds (5850.314.016/ KOMET USA, S5856.314.016/ KOMET USA, 6850.314.016/ KOMET USA) were multiple-use super coarse diamond bur. Two diamonds (8856DF.31.016/ BRASSELER USA, 856DEF.31.016/ BRASSELER USA) are finishing burs added as a control. The purpose of this study was to evaluate cutting efficacy of the 10 kinds diamond burs on zirconia blocks.

Published data on cutting efficiency of diamond instruments are conflicting, possibly because many studies were conducted 30 to 40 years ago before ultra-high-speed handpieces were widely available.[48-53] In this study, cutting was completed using controlled water spray rate, bur rotation and applied load for a standardized time of cutting. The rotating diamond was placed on the free edge of the block with the diamond 2mm below the top edge of the zirconia. The substrate was leveled before each run to produce a uniform cut with a depth of 2 mm.

In clinical settings, the force applied by the dentist is dictated by tactile sense and such factors as the type of dental hard tissue, tooth vitality, vision needed restorative material used and the degree of tooth calcification. Nevertheless, reports in the literature indicate that a handpiece load of about 147.5g-that is, 91.5g at the bur tip- is an average for most clinicians.[12, 24, 54] In our study, an applied controlled 100 gram load was used to move the zirconia specimens against the rotating diamond bur.

The null hypothesis of the study was that there was no significant difference in the cutting effectiveness of diamonds of similar shape with different grit size, or with different speed operations. The final data support rejection of the null hypothesis regarding the cutting efficacy of the bur. Two dependent variables were used to evaluate cutting efficacy of the diamond burs with different grit in this study, cutting length and block weight loss. The results of this study for both factors showed statistically significant ($p<0.05$) differences in bur cutting efficiency between different burs. (Fig. 10,11,13)

Diamond grit size plays an important role in abrasive machining. In general, higher removal rates can be achieved with coarser grit burs, and therefore, coarse burs are often used for gross tooth reduction[6]. But the weight of zirconia removed during cutting with diamonds of different grit size was not clear.[55] In this study, the zirconia cutting bur group (6856DC.31.016/ BRASSELER USA, ZR6850.314.016/ KOMET USA, ZR6881.314.016/ KOMET USA, 770.8VF ZIRCONIA/ PREMIER) didn’t have the dominant advantage over other coarse burs. As Siegel et al [46] reported, the coarse and super coarse-grit diamond burs had higher cut rate for the second cut compared to medium-grit diamond burs. In addition, super coarse-grit diamond bur cuts faster than medium-grit diamond bur.[46] Our study supports the findings of Siegel et al, since the finishing bur group (8856DF.31.016/ BRASSELER USA/ fine diamond, 856DEF.31.016/ BRASSELER USA /ultrafine diamond) had removed the least zirconia and produced the shortest cutting length. But the difference between the coarse and super coarse group is not significantly different.

Coarse burs substantially increased the extent of chipping damage along the edges of the grooves cut in glass-ceramics porcelains[55] . The zirconia ceramic, unlike porcelain[47], did not exhibit severe edge chipping with coarse diamonds in our study but some chipping was present (Fig27-37). Since chipping is undesired at the restoration margins when making refinements on the final restorations, the potential loss of surface/edge integrity must be avoided and so use of finer diamonds for contouring restoration margins is recommended. is the thing we need to care when we use the coarse burs the high-removal rates. The use of coarse burs could also increase the propensity for generating of subsurface cracks with concomitant strength degradation[56]. The strength reduction due to machining-induced damage is, however, material-dependent. The yttria-stabilized tetragonal zirconia is less sensitive to machining damage compared to many other polycrystalline ceramics[57]. When we cut with the same size of diamond burs, an increase in the grit size means a decrease in the amount of diamond particles[55]. Therefore, if we apply the same load on the bur, the coarser particle will bear a much higher load than the finer one. The higher bearing load causes an increased grit penetration into the ceramic with a higher removal rate but with more subsurface cracks. It depends upon what you are trying to do- crown removal for example is not a problem with crack generation- however adjusting the occlusion and proximal contact could be a problem.

The properties that control deformation and fracture of the ceramics, like hardness and toughness, influence the removal rate[58], and the mode of material removal, like brittle fracture versus plastic deformation[56]. The removal mechanisms for zirconia were primarily plastic deformation and microcutting, as evidenced by the smooth furrows on the machined surfaces point out these in the micrographs (Fig. 6).

Like Yin L et al study [47], we discovered that grit fracture, grit pullout, wear flat generation (the worn grit edges making some flat surfaces)or attrition wear, and matrix damage with worn diamonds. The wear mechanisms in diamond burs can also be influenced by grit size. Finer diamond particles are stronger than the larger ones due to the lower flaw population in smaller diamonds as the original flaws in the large particles are eliminated by fracture when finer grit diamonds are produced by crushing coarse diamond particles[59]. Therefore, less grit fracture is expected for finer burs. However, it is easy to find matrix damage of the fine bur due to the limited space for debris removal. The machining debris caused abrasion damage on the metal matrix used to grasp the diamond particles on the bur, weakening the connection between the diamond particles and the matrix, and making grit loss. Therefore, grit loss is a more major wear type for finer burs.

The disposable or single-patient diamond burs employed in the present study are chosen by clinicians to minimize cross-contamination risks of bloodborne pathogens[15]. It is likely that such burs would be used no more than a few minutes before being discarded. However, our results indicate that these single-patient burs can be used for several minutes without a significant loss of cutting efficiency. Siegel and Naylor's reported that [12, 60], the disposable bur demonstrated comparable cutting efficacies, similar to our result. The performance of the disposable coarse diamond bur (F4R SC/ A&M instruments) is comparable other multiple-use coarse diamond burs. Our results also were verified by Pilcher[16], who reported that the single-use-patient diamond burs had a significant decrease of cutting rate in the second cut.

Some companies claimed that their bur will perform better on zirconia when using a lower rotary speed. We selected 2 kinds of zirconia cutting burs (6856DC.31.016/ BRASSELER USA, ZR6850.314.016/ KOMET USA) to test under 40,000 rpm with other settings unaltered. The result demonstrated that the Brasseler bur performed slightly better than the Komet bur at both rpms or just at 40,000 rpm, but there was no statistically significant difference ($p>0.05$). The cutting efficiency of both burs at 40,000 rpm was much less than the efficiency at 150,000rpm ($p<0.05$). Hence, we rejected the null hypothesis stating that there is no significant difference in the cutting effectiveness of diamonds of similar shape with different speed operations. Higher rotation rate leads to higher cutting effectiveness.

Another important result is the cutting efficiency in both weight loss and cutting length of the first cut is much greater than in the second cut. There is the same tendency found in roughness (Ra) change in the bur or the zirconia or both. The observed grit fracture and smoother zirconia cutting edge helps explain the reduced cutting efficiency. The strength of the zirconia ceramic causes wear and dislodgement of the diamonds on the bur. Clinically, these results suggest replacing the diamond bur frequently when cutting or adjusting a zirconia ceramic restoration.

CONCLUSIONS

1. The removal rate produced during the first 9 minute cut was significantly greater than in the second 9 minute cut all grit sizes.

2. The zirconia surface chipping increased with increasing diamond grit size.

3. Four types of diamond wear patterns were observed for the diamond bur were shown: grit fracture, grit pullout, wear flat generation and matrix damage with worn diamonds.

4. Higher rpm increase the cutting efficacy.

5. With the study, if you want to do the crown removal and don't carry about the edge chipping, the coarse diamond bur komet zr6881 can do the best performance. If we worry about the crack will damage the zirconia structure, the fine diamond bur premier 770 can do a comparable performance and make less edge chipping.

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