Grinding: A Pictorial Odyssey, Part II

By Dr. Jeffrey Badger

A further examination of the grinding process through the lens of an electron microscope.

About the Author:

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In February, *Cutting Tool Engineering* published the article "Grinding: A Pictorial Odyssey," a collection of electron-microscope photos and corresponding captions related to grinding, including wheels, chips, dressing tools and workpiece surfaces. The response was positive, with readers writing: "I now have a visualization of something I've been working with for 40 years," "Chips! Just like in turning!" and "Those were cool."

For me the response wasn't surprising. When I present my 3-day "High Intensity Grinding Course," it's the photos that produce the "aha moment" in attendees. Therefore, I dug up more grinding-related photos and present them here. This time I've gone a little deeper, giving longer descriptions of grinding issues, such as residual tensile stresses, the impact of grit size on surface finish and the effect of grinding scratches on tool performance and coating adhesion.

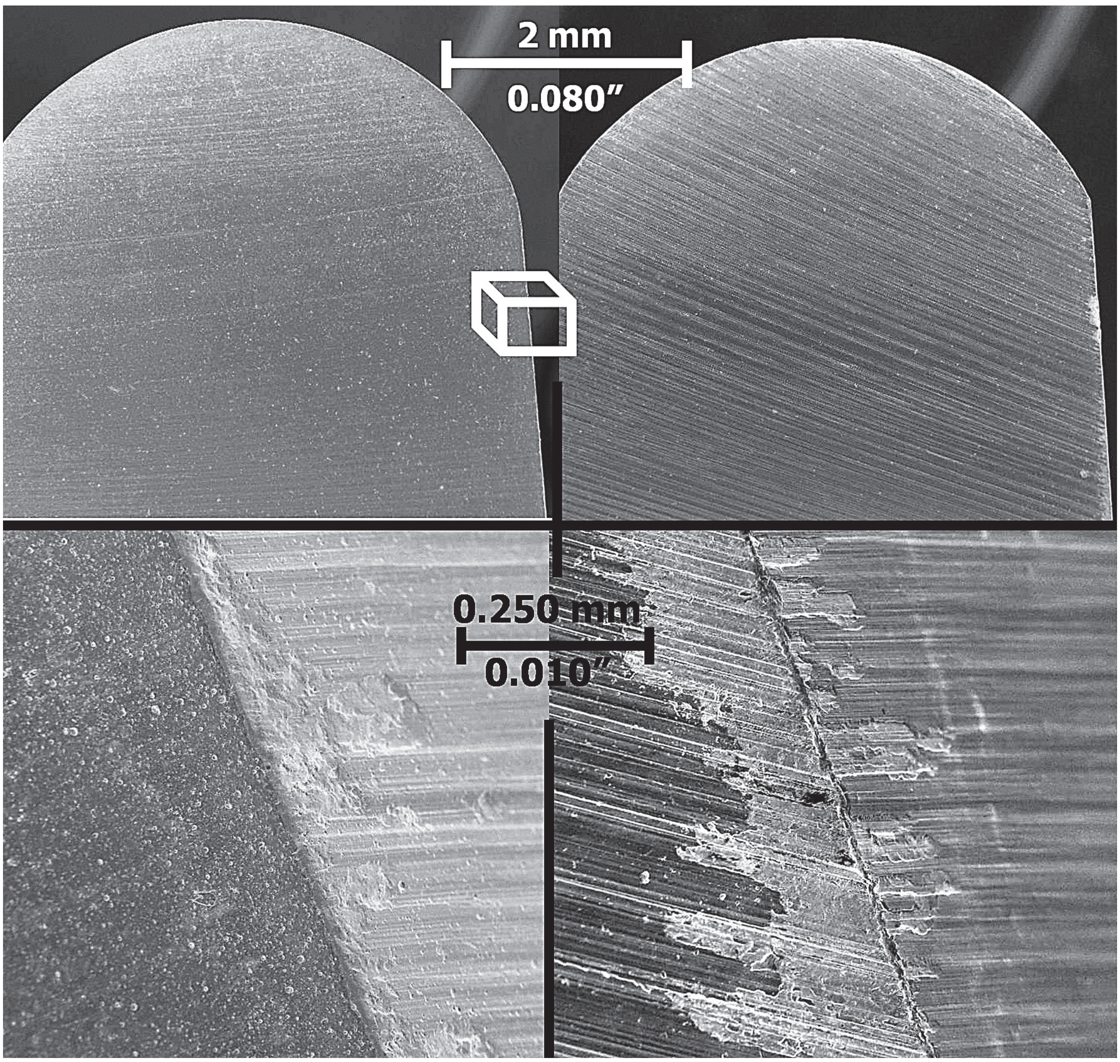

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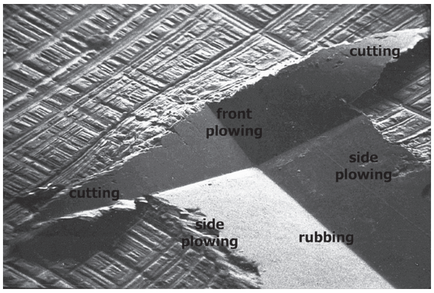
Figure 10: These broaches were produced by the same company on the same machine and, presumably, with the same grinding conditions. However, broach No. 1 (left) has a finer surface finish than broach No. 2 (right). During cutting, broach No. 1 was able to make double the number of cuts before failure. Looking at the cutting edge (bottom) shows how the rough surface caused flaking of the coating in broach No. 2.



Andrew Torrance

Figure 2: A soft material after a hard grit has been pushed through it. The image shows the three types of contact in grinding: rubbing, plowing and cutting. Rubbing occurs when the grit simply rubs against the workpiece, generating heat but not displacing or removing material. Plowing takes place when the grit pushes material to the sides and in front of the grit. Heat is generated but material is not removed. Front plowing generates a burr, and side plowing causes grinding scratches. Cutting, or chip formation, occurs when chips are formed to the sides of the grit. Heat is generated and material is removed. Dull grits rub and plow more, whereas sharp grits cut more. More aggressive grinding conditions—deeper cuts, faster work speeds, slower wheel speeds—produce more cutting and less rubbing.

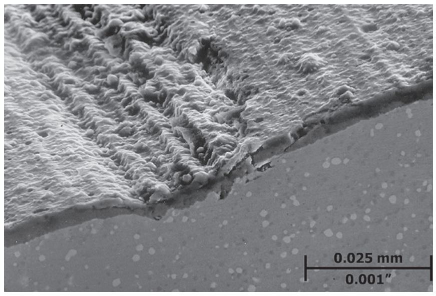


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Figure 9: A coated HSS tool after sectioning. As coatings become more sophisticated, the requirements for the substrate's surface finish below the coating are becoming more stringent. A state-of-the-art coating on a rough surface will quickly flake away. Therefore, companies looking to improve tool performance are investing in more sophisticated finishing techniques to decrease R_a values. The coating on the tool shown was deposited on a poor surface finish. Even if the coated surface was "cleaned up" with a post-coating finishing operation, stress concentrations would be present below the surface, increasing the risk of flaking.

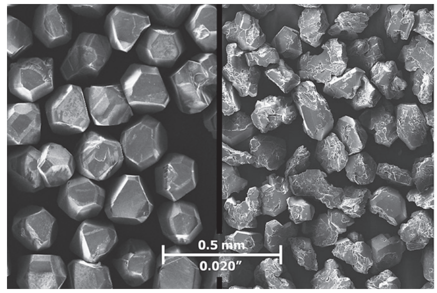

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Figure 14: The diamond grits on the left are "blocky." The diamond grits on the right are "angular." Blocky grits tend to wear less, impart a finer surface finish and generate more heat. Angular grits attack the workpiece at a more aggressive angle. They tend to fracture more easily, causing more wheel wear but facilitate a more self-sharpening wheel. Angular grits also produce a rougher surface finish and generate less heat. Unfortunately, most superabrasive wheel manufacturers don't indicate what type of grit is in the wheel.

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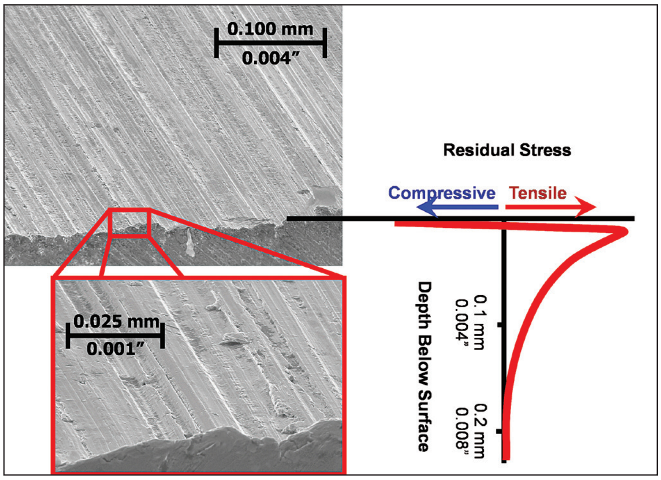

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Figure 6: Residual stresses are formed during grinding of ductile materials. At the surface are residual compressive stresses. These are usually only a few microns deep and are caused by the plastic deformation of the material—i.e., plowing the workpiece material with the abrasive grits. Compressive stresses are usually beneficial to part performance. Below that are residual tensile stresses. These are caused by restricted thermal expansion at high temperatures, and the higher the temperature, the higher the tensile stress. Tensile stresses are detrimental to part performance, particularly in parts subject to fatigue loading. In extreme cases, they cause immediate cracking.

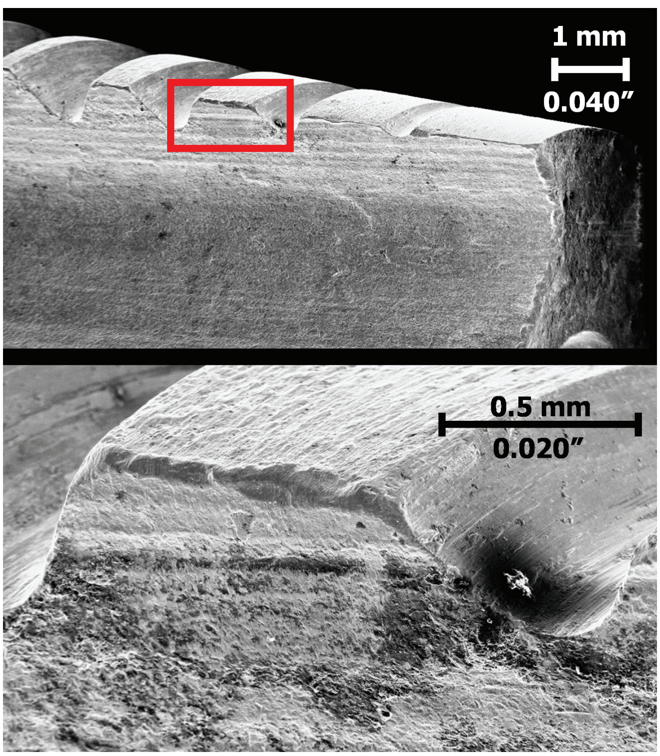

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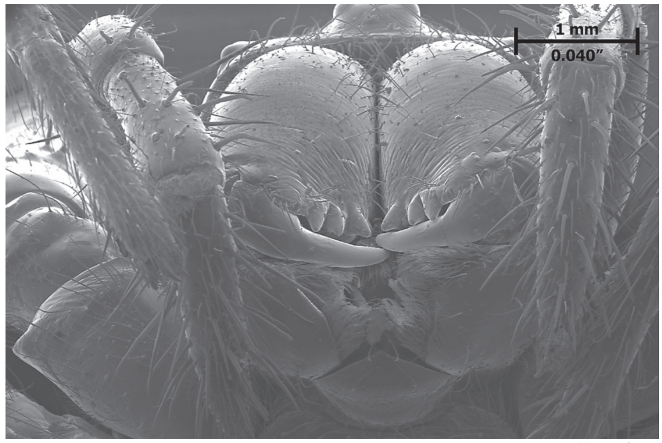
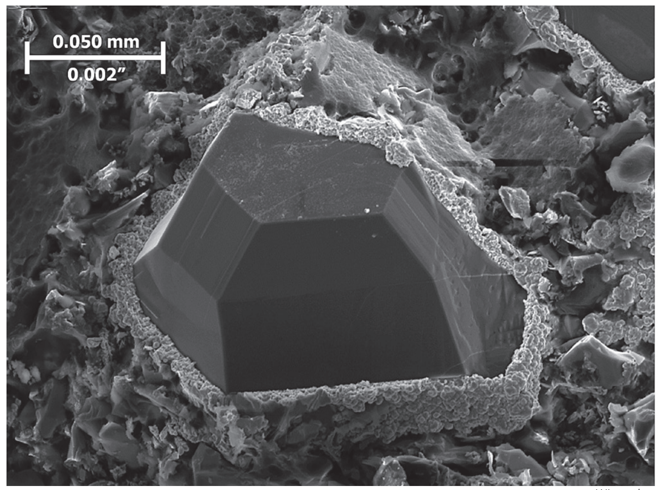
Figure 8: A worn tap (top) and a single tooth from that tap (bottom). The surface finish from thread grinding was poor, but the surface finish from flute grinding was good. There's some abrasive wear at the corner, but no fracture wear, a consequence of the good surface when flute grinding. As a result, this tap enjoyed a long life.



Niagara Cutter

Figure 1: Mouth of a spider from Reynoldsville, Pa. The spider's smaller teeth are about the size of a 60-mesh grit.



Winterthur

Figure 13: A coated superabrasive grit is held in the bond material of a grinding wheel. The coating envelopes the grit, allowing the bond material to hold it firmly in place. During grinding or "sticking," the soft coating is stripped from the top area of the grit, exposing the hard superabrasive.

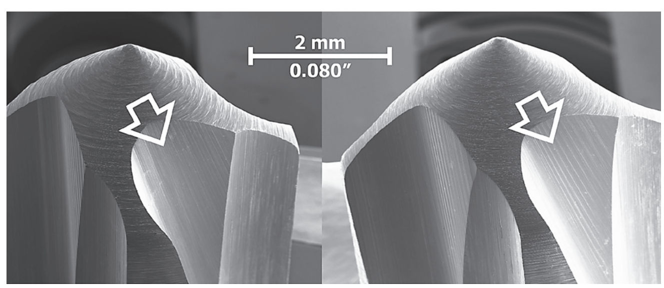


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Figure 4: A HSS cutting tap after flute and gun-nose grinding. The gun-nose surface on the left was ground with a 280-mesh aluminum-oxide grinding wheel and the one on the right with a 120-mesh Al_2O_3 wheel. There are several other ways to improve surface finish: finer dressing, lower feed rates and faster wheel speeds. All have a negative side effect, such as greater heat generation (leading to longer cycle times) and greater risk of chatter. The best approach is to use a smaller grit, which usually has only one negative side effect: increased wheel wear.

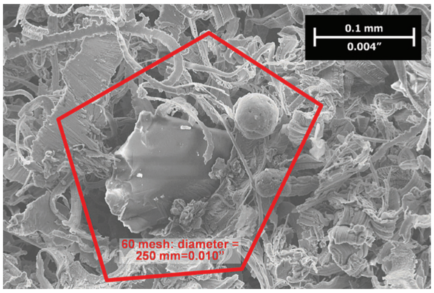

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Figure 15: Grinding swarf generated from grinding hardened steel with a 60-grit Al_2O_3 wheel. Notice the chunk of Al_2O_3 grit contained in the swarf. A 60-grit has a diameter of around 0.250mm (0.010"), shown in red. The chunk in the swarf is much smaller, meaning the grit fractured during grinding. This wheel contained white Al_2O_3, a friable grit that is more prone to fracture than tougher varieties of Al_2O_3, such as brown and pink Al_2O_3.

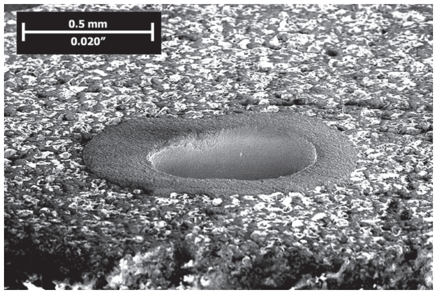

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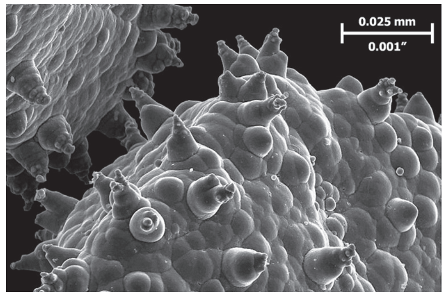
Figure 11: A pore in an induced-porosity diamond wheel for grinding tungsten carbide. The 0.5mm-dia. pore is much larger than the grits in the wheel. The idea is to improve coolant flow in an otherwise nonporous wheel. However, this porosity is noncontiguous, meaning coolant cannot flow from pore to pore. Noncontiguous porosity, especially when it comes in large pores with large spacing between pores, is not as effective as contiguous porosity.



Winterthur

Figure 12: A coated, 140-mesh CBN grit. Because resin bond does not adhere well to CBN and diamond abrasives, the abrasives are coated. The bond adheres to the coating and the coating adheres to the grit. Coatings that have more surface area are held more firmly within the bond material. Therefore, all types of unusual coatings are developed to increase the surface area.

As coatings become more sophisticated, the requirements for the substrate's surface finish below the coating are becoming more stringent.

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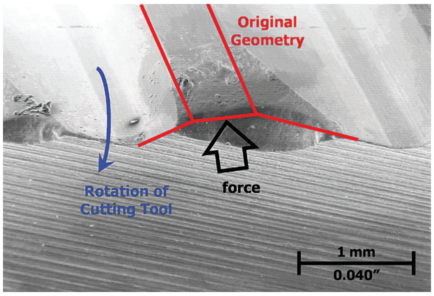

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Figure 7: This worn cutting tool fractured during use because of the large scratches from grinding. The figure shows the original, unfractured geometry, the direction of rotation and the direction of the force acting on the cutting edge during the cutting process. The forces were acting in a direction that caused the grinding scratches to "open up" during use, causing fracture.

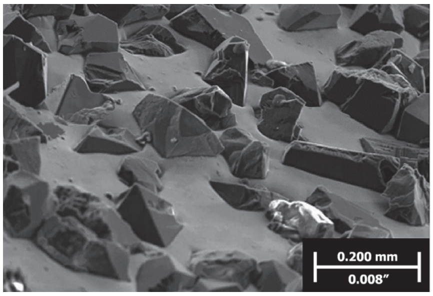

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Figure 5: A new, 120-grit electroplated CBN wheel. CBN grits impart a rougher surface than the same grit size in an Al_2O_3 wheel because they are sharper. Electroplated wheels, because they are not dressed and therefore have a lower cutting-point density, produce a rougher surface than the same grit size in a dressed wheel. Therefore, this 120-grit electroplated wheel will produce a relatively rough surface finish.

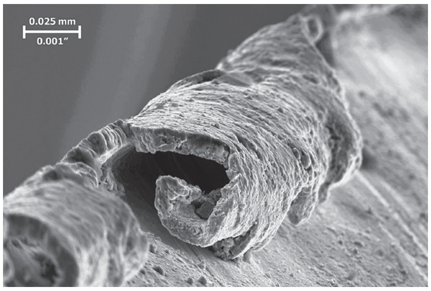

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Figure 3: As noted in Figure 2, a burr is caused by plowing material in front of the grit. Grinding operations with sharper grits, deeper grit penetration and—usually—smaller grits generate less burr formation. In ductile materials, such as aluminum, soft steel, hardened steel and nickel-base alloys, burr formation can never be "eliminated"—it can only be reduced. CTE

There are several other ways to improve surface finish: finer dressing, lower feed rates and faster wheel speeds.

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