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New Grind

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Grinding round HSS cutting tools can be more efficient than milling them. Being able to dress new hybrid metal/polyimide-bond wheels on the grinder adds to the efficiency.

Many cutting tool manufacturers already use CBN grinding wheels to grind small, round, HSS cutting tools from hardened blanks. However, recent field trials demonstrate that the latest superabrasive hybrid metal/polyimide-bond wheels, when automatically profiled on the machine, not only outperform milling in the production of large (¾" and up) round HSS cutting tools, but also outperform other CBN wheels. An all-grinding process using hybrid wheels can reduce HSS toolmaking cycle time dramatically (Figure 1).

CBN wheels come in various bond technologies and grades and therefore have different properties. Some plated CBN wheels, such as those used in the tests described later, develop flat

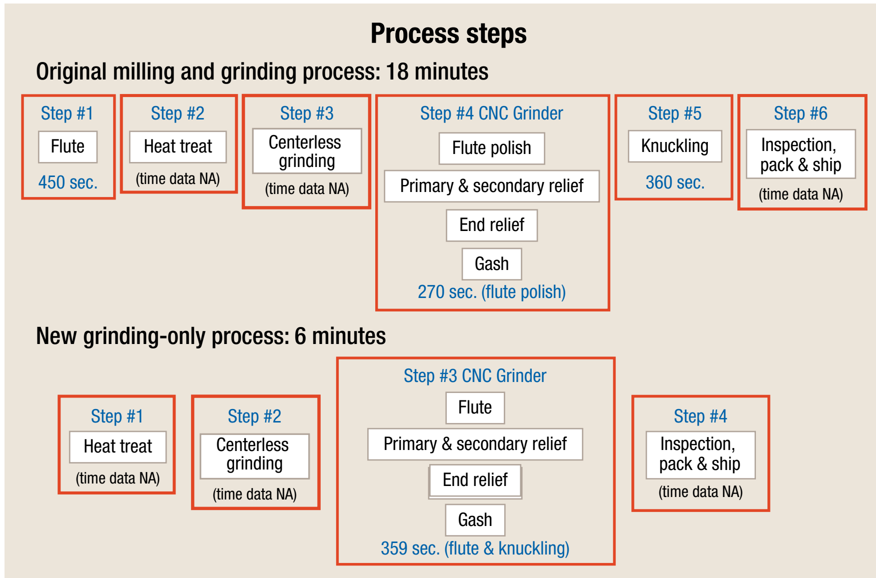


Figure 1: Parts per retrue and cycle time comparisons for CBN and hybrid metal/polyimide wheels.

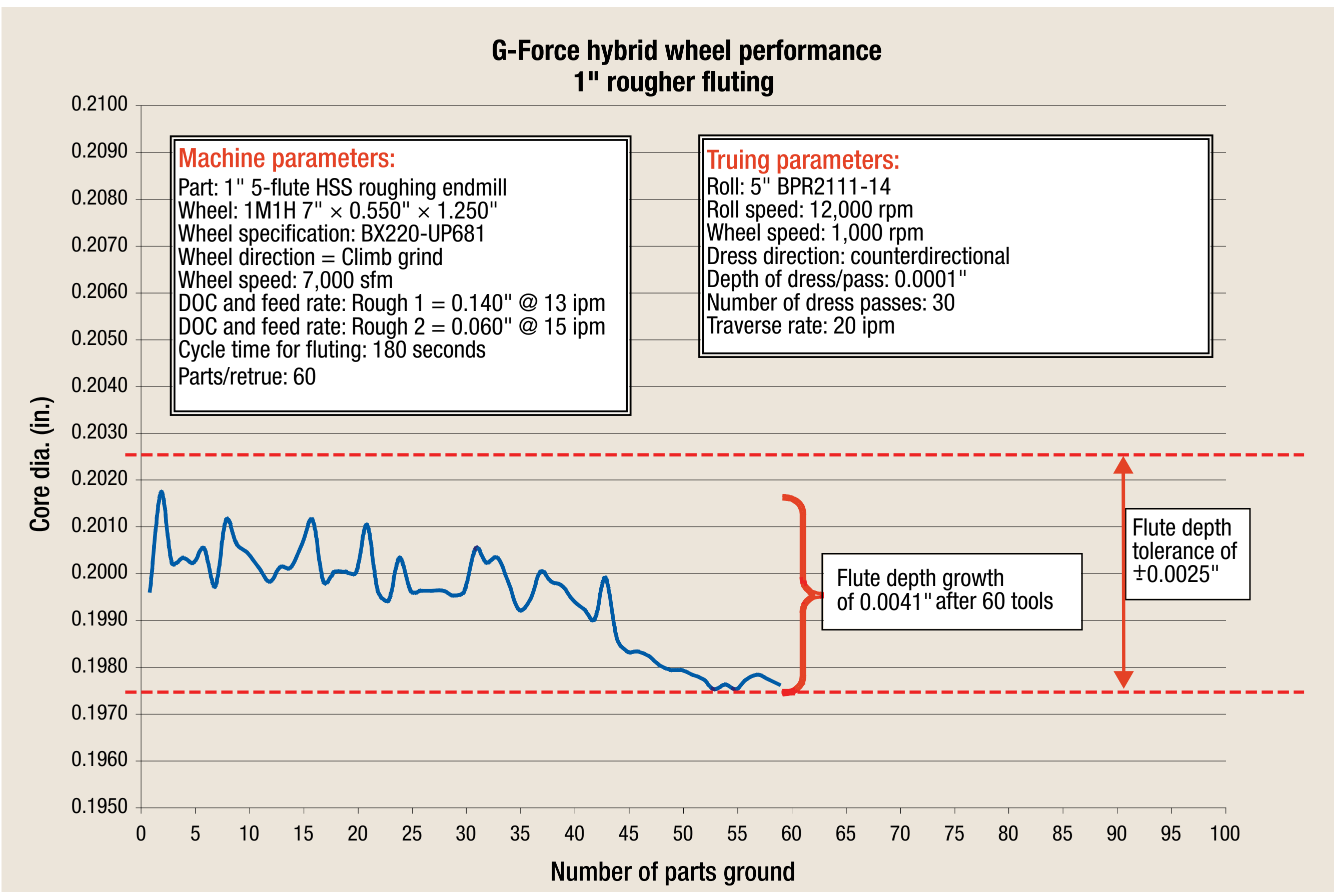


Figure 2: Summary of hybrid wheel performance in fluting a 1" roughing endmill.

spots on their individual crystals, making the wheels dull; when this happens, they must be stripped and replated. The wheels are not self-cleaning or self-sharpening but hold their form and require no dressing.

CBN vitrified-bond wheels vary in their capabilities, depending on the CBN's toughness and the bonding medium's strength. These wheels can be dressed on the machine and do not require stick dressing to open the space between grains. Because of their long life and because they can be dressed on the machine, CBN vitrified wheels were preferred in many applications, particularly in lights-out machining, prior to the advent of hybrid metal/polyimide wheels.

The new hybrid wheels have a self-sharpening bond structure that allows them to maintain a consistently sharp surface. Like CBN vitrified-bond wheels, hybrid wheel profiles can be regenerated on a grinding machine using an automated truing system. Hybrid wheels can grind faster and hold form longer than CBN wheels, which increases the number of parts produced per truing. For example, in a manufacturing process for a ¾" HSS endmill, a Saint-Gobain BX220-UP681 wheel operating at a feed rate of 12 ipm had a cycle time of 69 seconds per tool and produced 60 tools per retruing. In the same application, a Saint-Gobain Vitrified CBN 2 wheel operating at a 9.75-ipm feed rate had a cycle time of 158 seconds and produced only 15 tools per retruing.

It is important to note that hybrid wheels sometimes require stick dressing to open the wheel structure, especially if the on-machine dressing system is not optimally adjusted.

For companies currently milling flutes in soft blanks before heat treatment, this improvement in grinding efficiency makes the move from milling to grinding a more attractive option. Those toolmakers can switch to hybrid wheels to grind an entire tool from prehardened solid blanks, on one machine in one setup (Figure 1).

The new wheels have a grain-locking mechanism using new bonding agents and a self-dressing, wear-resistant bond, which typically eliminates the need for stick dressing or dressing with a diamond roll after being profiled.

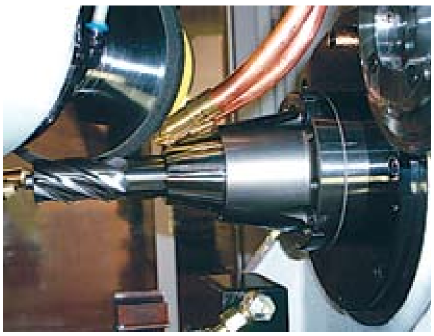
Machining to Grinding

Manufacturers of round cutting tools up to 1¼" in diameter that switched to grinding tools using new hybrid wheels realized significant productivity gains. A typical process used to manufacture a large-diameter HSS tool often begins with centerless grinding of the OD and then milling the flutes into unhardened blanks. Next, the tool is hardened through heat treating. Then it moves to a 5-axis CNC grinder for flute polishing, producing other features, such as end teeth and primary and secondary diameters, and finally gashing. If required, knuckling is done on a different machine.

By using hybrid wheels, large round tools can be ground completely in a hardened state with preliminary centerless grinding, then performing fluting, primary and secondary relieving, knuckling, end relief and gashing on a CNC grinder in a single setup, eliminating at least two handlings and increasing overall process efficiency. (Figure 1 compares the original process, requiring 18 minutes, with the new process, requiring 6 minutes.) Not only are there benefits from eliminating steps, but stock removal is much faster using grinding.

An investment is required to make the transition to hybrid wheels. For example, adding a dressing spindle to an existing grinder requires the purchase of both the spindle and the software required to do the dressing automatically. However, the improved process efficiency should quickly offset those costs.

The benefits of moving from milling to grinding HSS round tools were demonstrated at the facilities of a toolmaker that manufactures HSS, cobalt-HSS and P/M endmills, as well as carbide endmills. One of the company's specialties is providing high-performance endmills to aerospace customers.



All Images: Saint-Gobain Abrasives

A Saint-Gobain G-Force hybrid metal/polyimide-bond wheel grinding a cutting tool.

Working with the toolmaker, Saint-Gobain tested the new hybrid metal/polyimide superabrasive wheels against vitrified CBN wheels for several tools. In one test that involved grinding ¾" HSS endmills, despite the increased cost of the new wheels—1.5 times the cost of the vitrified CBN wheels—total cost per tool was $10.79 with the CBN wheels vs. $5.89 with the initial installation of the hybrid wheels, a productivity improvement of 45.4 percent (based on reduced cycle time and lower abrasives cost). Due to poor coolant conditions, grinding had to be done in an upcutting mode. When the coolant was improved, the grinding was changed to the more efficient down-cutting mode, and total cost per tool was reduced to $5.11, for a productivity improvement of 52.6 percent.

In a production test on a 1" HSS endmill, a B150-2-G5 vitrified CBN wheel produced six parts per retrue while a hybrid BX220-UP241 wheel produced 40 parts and a hybrid BX220-UP681 wheel produced 60. The vitrified CBN wheel had a maximum mrr of 0.360 in.^{3}/min. and a cycle time of 374 seconds while the BX220-UP241 wheel had a maximum mrr of 0.525 in.^{3}/min. and a cycle time of 206 seconds. The BX220-UP681 wheel was the best performer, achieving a maximum metal-removal rate of 0.569 in.^{3}/min. and a cycle time of 180 seconds.

A production test on a ¾" HSS endmill produced similar results. A B150-2-G5 vitrified CBN wheel produced six parts per retrue while a hybrid BX220-UP681 wheel produced 60 parts. The vitrified CBN wheel had a maximum mrr of 0.49 in.^{3}/min. and a cycle time of 160 seconds, while the BX220-UP681 wheel had a maximum mrr of 0.62 in.^{3}/min. and a cycle time of 69 seconds.

The above and other tests revealed key factors that will help ensure success in a company's move from machining to grinding of HSS tools:

- Use a 5-axis CNC machine with at least 35 hp.
- Make sure the workpiece is rigidly held by ensuring that deflection in the workholder and the machine itself are minimal.
- Ensure that the coolant and its delivery system are adequate to the operation.
- Provide truing capabilities on the grinding machine.
- Ensure the dress ratio is optimal.

Case Histories

One of the tests documented the parameters for optimizing the toolmaker's transition from milling to grinding of 1"-dia., 5-flute, 30° helix HSS roughing endmills. By using hybrid metal/polyimide wheels (G-Force wheels from Saint-Gobain Abrasives) and switching to grinding from solid blanks, the toolmaker reduced cycle time by approximately 55 percent, driving the cost per component from $12.10 to $7.22, a savings of 40.3 percent. The cycle time does not include the time to harden the soft-milled workpiece before flute polishing or the time a workpiece spent in queue at each step. The hardening time and time-in-queue were shorter in the grind-only operations than they were in the milling operations. If those times are included, then the productivity improvement for the grind-only operations is even greater.

The benefits of moving from milling to grinding were demonstrated at the facilities of a toolmaker that manufactures HSS, cobalt-HSS and P/M endmills, as well as carbide endmills.

There are benefits not only from eliminating steps, but stock removal is faster using grinding. It took 7.5 minutes to mill the flutes in the soft blank but only 6 minutes to grind them into the hardened blank using the hybrid metal/polyimide wheel. If a manufacturer of round HSS cutting tools is not already grinding instead of milling, it will benefit from considering this process change even if only for making large tools with flute depths of 0.160" or more. The performance of the G-Force wheel in this test is summarized in Figure 2 on page 62.

Tweaking the Process

The 1" endmill test demonstrated the

The change from milling to grinding at a glance

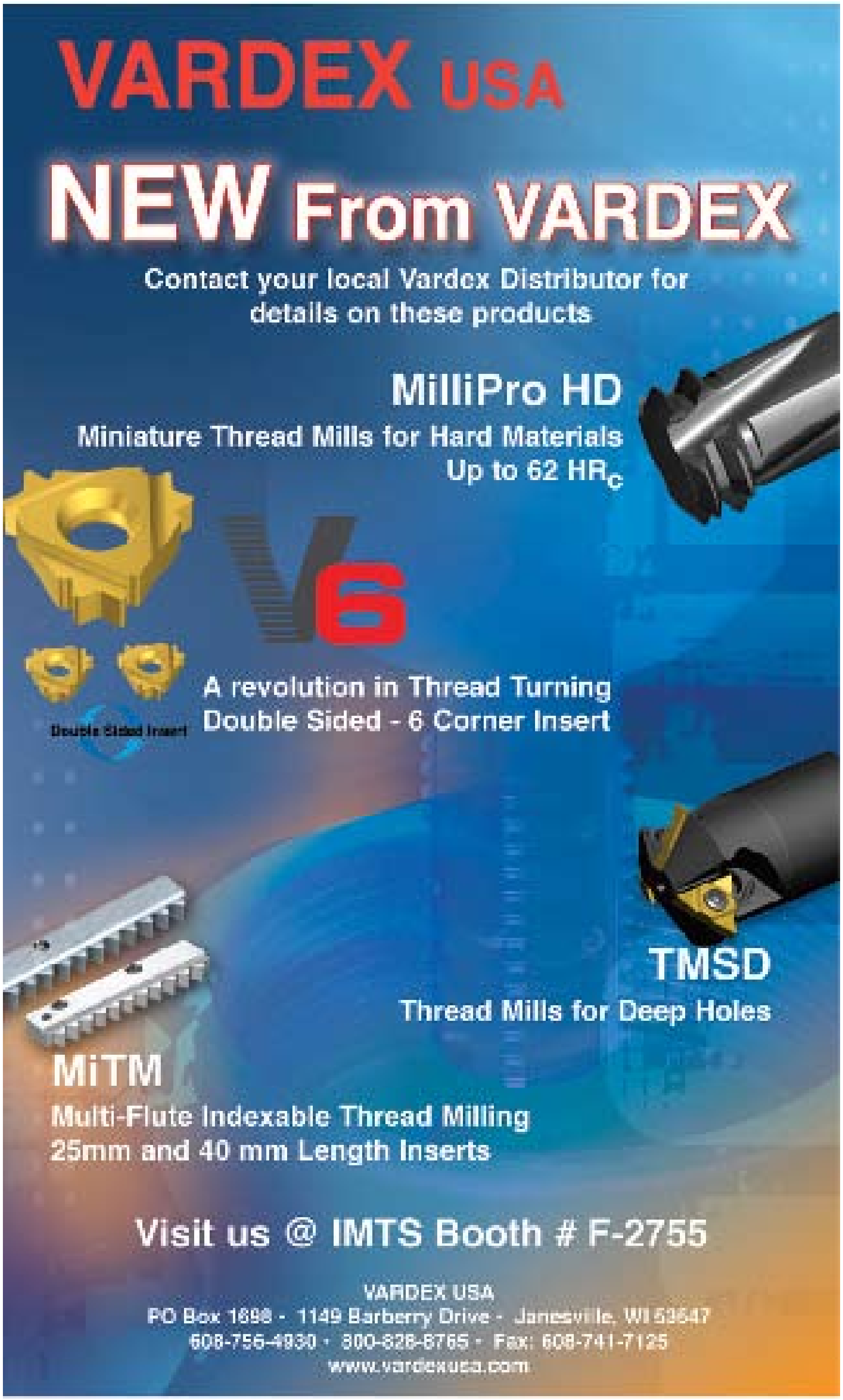
FOLLOWING ARE BRIEF, comparative descriptions of the steps involved in milling vs. grinding a ¾"-dia., 4-flute HSS roughing endmill:

Typical large round tool manufacturing process (milling)

- Centerless-grind OD of a round, unhardened blank
- Machine the flutes
- Heat treat
- Polish the flutes
- Primary and secondary relieving
- Produce end teeth and perform gashing

Proposed large tool manufacturing process (grinding)

- Heat treat a round, unhardened blank
- Centerless-grind OD of the hardened blank
- Grind the flutes
- Primary and secondary relieving
- Produce end teeth and perform gashing



feasibility of grinding instead of milling HSS tools. Additional tests at the same toolmaker refined the grinding process. For example, in another test using a 5-hp Walter Helitronic CNC machine, the baseline was established using a standard plated CBN wheel to grind four 2"-long flutes on ¾"-dia. endmills. That wheel was then replaced with a hybrid wheel capable of being profiled on-machine so it could continue grinding without operator intervention. The plated wheel developed wear flats and required replacing, while the hybrid wheel continued grinding in a lights-out operation.

In this test, the same surface speed was used for both the CBN and hybrid wheels (11,000 rpm), but the feed rate for the metal/polyimide wheel (60 ipm) was double that of the CBN wheel (30 ipm). The plated wheel finished 250 parts without being trued or dressed. In contrast, the hybrid wheel finished 125 parts per dress, but on-machine profiling was done and each hybrid wheel produced 3,000 parts.

The hybrid wheel's initial cost in this test was nearly four times that of the plated wheel, but abrasive cost per tool declined from $0.57 for the CBN wheel to $0.18 for the hybrid one, and the total $1.92 cost per tool with the hybrid wheel was just under half the $3.57 cost per tool for the CBN wheel, a 46.2 percent improvement. This cost improvement is, in part, the result of a reduction in cycle time from 3 minutes to 1.7 minutes. In addition, the hybrid wheel produced a visually sharper and finer finish on the tool's cutting edge.

In the next test, a baseline was established using a standard CBN vitrified wheel to grind four 2"-long flutes in ¾"-dia. endmills on a 35-hp Walter Vision machine. Then, two other tests were performed, the first with a premium CBN vitrified wheel and the second with the hybrid wheel. The intermediate test was performed because the toolmaker wanted to see how the hybrid wheel compared to a premium CBN vitrified wheel. The initial cost of the premium CBN vitrified product is about the same as the cost of the hybrid wheel, and that CBN vitrified wheel provided a 1.7 percent savings compared with the baseline (the incumbent standard CBN vitrified wheel)—$4.61 vs. $4.69 cost per part.

Vitrified wheels can be dressed or trued on-machine without the need for stick dressing. By contrast, when the optimal dressing-roll-to-wheel-speed ratio (dress speed) cannot be achieved, perhaps due to machine limitations, the hybrid wheel will often require stick dressing. In this test, for example, the correct dress ratio was not achieved, so a light stick dress was required. (Stick dressing was subsequently eliminated by achieving the correct dress ratio of 10:1.)

After about eight parts for the standard wheel and 15 parts for the premium wheel, both wheels began to burn the workpieces. However, the hybrid wheel fluted 60 tools at a 23 percent higher feed rate (12 ipm compared with 9.75 ipm) with no grinding burn.

Even with light stick dressing, the hybrid wheel appears to offer the best of both worlds. Users get a wheel that can be dressed on-machine and grinds faster while lasting longer than a premium CBN vitrified product. Grinding the ¾"-dia., 4-flute endmills with the hybrid wheel reduced the cost per part 18.9 percent compared with the standard CBN vitrified wheel and by 17.6 percent compared with the premium CBN vitrified wheel. Based on these results, the toolmaker converted this fluting operation to the hybrid metal/polyimide wheels.

In the toolmaker's final test, application engineers reprogrammed the dresser spindle to go from 8,000 rpm to a range from 10,000 rpm to 12,000 rpm during dressing. The higher speed optimized the profiling process, eliminating the need for stick dressing and a finishing dress pass. Increasing the spindle speed and eliminating the dresses reduced cost per part from $3.80 to $2.03. The hybrid wheel, when used with the less-than-optimal dressing conditions, yielded a cost reduction of 20 percent compared with the original process. Once dressing was improved, using the hybrid wheel reduced cost per part by nearly 58 percent.

The above tests with the toolmaker demonstrated that hybrid metal/polyimide wheels can grind at higher mrr than conventional CBN wheels. This increased capability is critical for toolmakers that move from milling flutes to grinding them. To achieve the hybrid wheels' full benefit, dressing conditions must be optimized.

Improving Productivity Again

Tests with a different toolmaker also demonstrated the productivity increases of manufacturing HSS round tools using an optimized grinding operation rather than milling. As with the first toolmaker, ¾"-dia., 4-flute roughing endmills were milled into a finished product at the second toolmaker. Then, operational and economic factors for the machining process were compared with the same parameters for the same tools produced by grinding.

The processes performed and the order in which they were performed appear in Figure 1. The original process began with fluting followed by heat treating and centerless grinding of the OD. Next, the workpiece moved to a CNC grinding machine where it received flute polishing, relief grinding (primary, secondary and end relief) and gashing. Then, knuckling was performed prior to inspection, packing and shipping. These procedures are fairly typical for machining round HSS cutting tools except that, in some cases, centerless grinding and fluting occur before heat treating.

The test process that exclusively ground the ¾" endmills started with hardened, round blanks. After a centerless grinding step, each workpiece went to a CNC grinder for fluting, primary

Saint-Gobain G-Force hybrid wheels.

and secondary relief grinding, knuckling, end relief grinding and gashing on a 35-hp, 5-axis Walter Power unit equipped with a programmable dressing system for truing. Oil-based coolant was used.

In the milling vs. grinding test, the cycle time per part for grinding represents an 85 percent improvement compared with milling: 69 seconds per part for grinding vs. 450 seconds per part for milling. Total cost per part for milling the endmills was $12.10, compared to $3.99 for grinding, an improvement of 67 percent.

The hybrid metal/polyimide wheels discussed in this test were custom engineered for specific applications, materials and machines.

As with most process changes, the transition from milling to grinding round tools with hybrid wheels requires an investment in time for trials and, in some cases, equipment. Manufacturers can optimize their grinding by working with abrasives suppliers that use a systems approach to grinding. **CTE**

About the Author: *Kenneth Saucier is a corporate applications engineer at Saint-Gobain Abrasives Inc., Worcester, Mass. For more information on the products and processes described in this article, visit www.nortonabrasives.com.*