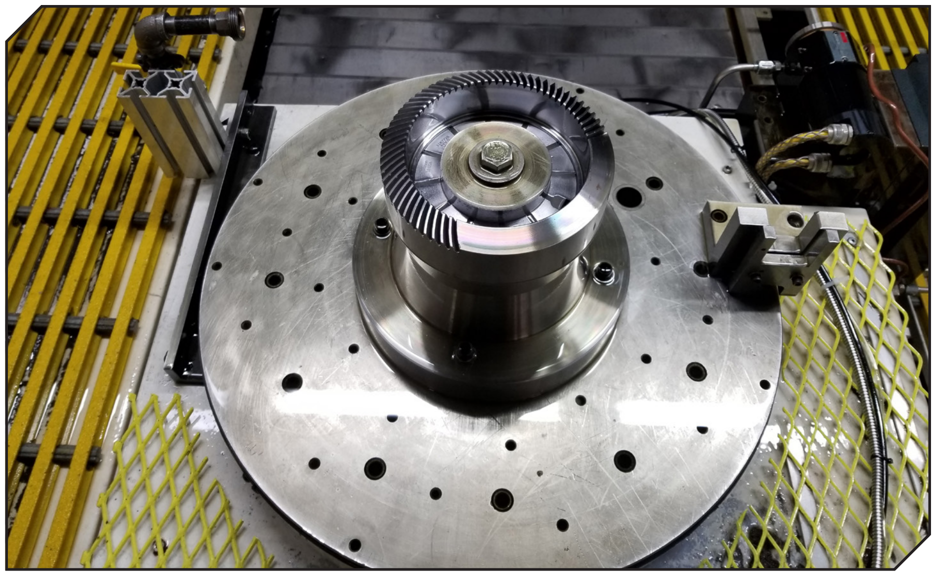
Teaming Up to Solve Bevel Gear Grinding Application Challenges

Norton|Saint-Gobain Abrasives and Gleason Works Collaborate to Achieve a High Performance Gear Grinding Solution

Mark Martin, Phil Plainte and Eric Mundt

Fine pitch grinding from solid can be particularly problematic, as the typically narrow wheel tip width required to grind these gears makes it very difficult to achieve good balance between tip wear and productivity. To achieve the most efficient fine pitch bevel grinding solution, Norton|Saint-Gobain Abrasives (Worcester, MA) and Gleason Works (Rochester NY,) teamed up to evaluate, test and implement the latest, best abrasives application. Norton|Saint-Gobain Abrasives is a one of the world's largest abrasives manufacturers. Gleason Works is a global leader in state-of-the-art manufacturing equipment for all types of bevel gears and produces bevel and cylindrical gear machines as well as tooling products.



Norton and Gleason have a longstanding working relationship and wanted to accelerate the development of new grinding wheel technology in the bevel gear market. The goal was to expedite grinding wheel product development, so that Gleason could apply the latest technology. Norton wanted to provide Gleason with a well-defined grinding product that would enhance the operation of its machines for specific bevel grinding applications.

In order to do this, Norton needed a viable screening method for testing new grinding wheels on bevel gears. This would allow Gleason to select the best products for use on their machines and their customers' specific needs, reducing Gleason process development times.

System Approach

To advance grinding technology, innovative materials research and development teams at Saint-Gobain Research North America's Higgins Grinding Technology Center (Northborough, MA) work with business and customer partners to solve problems in challenging industrial markets.

For the fine pitch bevel grinding challenge, Norton used a "system approach" methodology aimed at evaluating the variables that influence the output of the process. The diagram below (Fig 1.) shows the process as well as the importance of understanding the microscopic interactions in a grinding process.

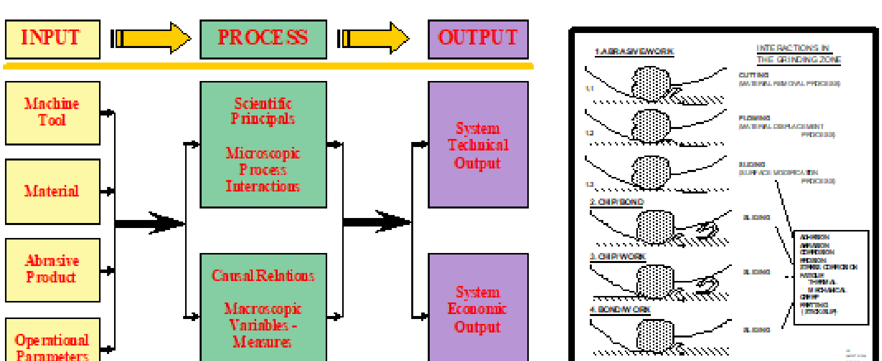


Figure 1 The "Systems Approach" methodology evaluates the variables that influence the output of the process.

Key Technical Background Details for the Systems Approach:

Grinding zone interactions

The area of contact between the wheel and workpiece is referred to as the grinding zone. The energy used during grinding is consumed by various interactions within the grinding zone. The diagram (Fig.1, box on the right) illustrates these interactions. An understanding of these interactions is needed to interpret the observations and measurements taken during testing.

Technical Approach

A bevel gear set is comprised of a pinion and ring gear. The pinion is ground using the generating method to satisfy the required tooth contact tolerances, and to ensure proper contact characteristics when the gears mesh. In the automotive world, the ring gear is generally ground using the formate process (non–generating). The formate process offers higher productivity than the generating method because the generating roll is eliminated in the former method.

A Waguri spindle used in grinding bevel gears is essentially a spindle within a spindle. The inner spindle drives the grinding wheel. The inner spindle axis is radially offset from the outer (Waguri) spindle axis so that it moves in an orbital fashion about the outer spindle axis. The orbital motion prevents the grinding wheel from being in full contact across the entire tooth length at any instant, but the frequency is high enough that the ground tooth surface is smooth and continuous. For this test, Gleason engineers used their CAM system to generate a tool path to plunge a wheel directly into the tooth space, as well as a tool path for dressing a required shape onto the wheel. The modified wheel shape is designed so that both tooth surfaces are finished at the same time and to the proper geometry without the eccentric action of a Waguri spindle.

Gleason's CAM system was used to develop software & programing that allowed Norton's 5 axis grinder to model form grinding of bevel gears to a point where data could be collected and used to screen the Norton product for Gleason's bevel gear applications.

A Multi-Phase Project

- Gleason developed software and assisted with part fixtures designed to enable the Norton 5-axis machine to simulate bevel gear grinding.
- Gleason provided parts to be ground.
- Norton provided new grinding wheel technology for testing on the parts.
- Norton conducted testing, compiled the resulting data, mapped the new grinding wheel in a format that was useful for Gleason to apply on their specific application projects.

Test Objectives

The purpose of the screening test was to reduce the number of tests needed at Gleason's location to qualify wheels for grinding bevel gears. This test ranked wheel performance for fine pitch bevel gears with a major focus on root radius wear.

1. Tested multiple Norton bevel gear wheels for grinding fine pitch bevel gears from solid in order to identify new technology that could outperform popular older technology.
2. Ranked products for their ability to hold a 0.127 – 0.178 mm root radius.
3. Identified the highest metal removal rate that each product can reasonably achieve while maintaining the 0.13 – 0.18 mm root radius.
4. Screened the influence of wheel speed on root holding capability for each product.

Test Setup

The 184 mm gear blanks, supplied by Gleason, were made of 4140 carbon steel at 90 HRB hardness. The gear blanks were mounted in the machine using a fixture supplied by Gleason.

Test method

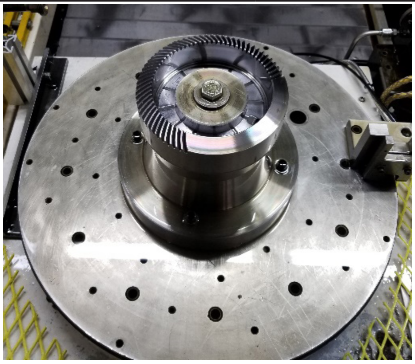
Dressing

Using a diamond roll dresser, a ~0.127 mm tip radius was dressed into each wheel specification (Table 2) using the dress parameters in Table 1. A graphite coupon was ground and the radius was measured using an optical comparator at 50X.

Phase 1

Seven teeth were ground at the parameters in Table 3 using a wheel speed of 23 ms^{-1} and a graphite coupon was cut after tooth number 1, 4 and 7. If a 0.25 mm radius was reached, grinding was stopped before seven teeth were completed. Power was also recorded for each grind.

Table 1 Dress Parameters



Dress Conditions	
Wheel Speed (rpm)	2480
Dress Roll Speed (rpm)	2458
Dress Speed Ratio	0.65
Lead (mm/rev)	0.051
Compensation (mm)	0.013

Table 2 Wheel Specifications

120 Grit Ceramic New Product
150 Grit Ceramic New Product
180 Grit Ceramic Standard Product
220 Grit Ceramic Standard Product

Table 3 Grind Parameters

Material	4140 @ 90 HRB
Full Wheel Dimensions (in)	178 × 127 × 89
Wheel Speed (m/sec)	~ 23 & ~ 28
MRR' ((mm³/sec)/mm)	2.7, 5.4, 8.1
Main Coolant Pressure (bar)	8.6
Main Coolant Flow (lpm)	182
Scrubber Pressure (bar)	34.5

Results Phase 1

The coupon radius measurements indicated what radius each specification could sustain after grinding. When tested at 23 ms^{-1}, only the 180 Grit Standard Product wheel could hold ~0.013 mm radius at 2.7 ((mm³/sec)/mm). None of the wheels run at 23 ms^{-1} could hold ~0.013 mm radius at an MRR' of 5.4 ((mm³/sec)/mm). However, some held much better at 28 ms^{-1}. Figure 2 shows the radius size for each tooth ground.

Results Phase 2

After testing at 23 ms^{-1}, the wheels were tested at 28 ms^{-1} using the same parameters in Table 3 at 5.4 and 8.1 ((mm³/sec)/mm).

Radius

The 180 Grit Standard Product wheel and the 150 Grit New Technology wheel both held ~0.013 mm radius at 5.4 ((mm³/sec)/mm) when run at 28 ms^{-1}. The 150 Grit New Product

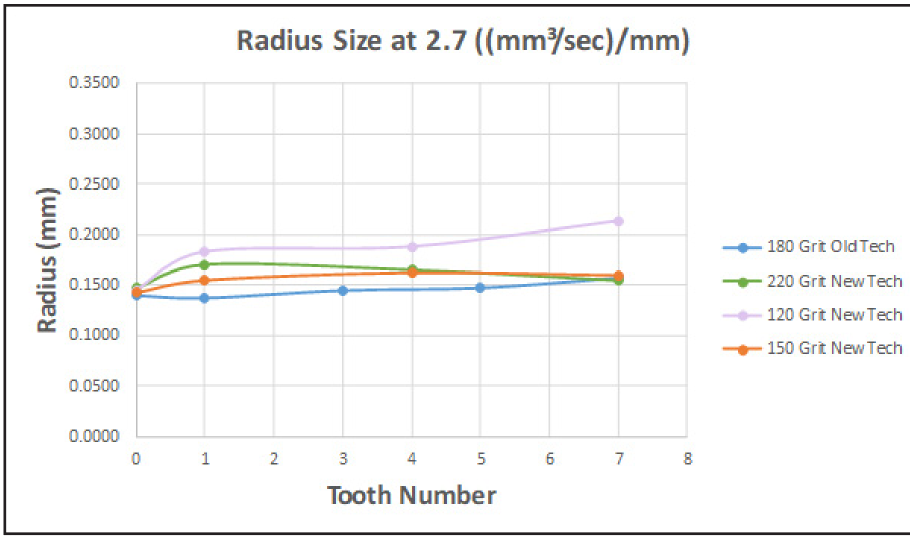


Figure 2 Radius Size at 23 ms^{-1}.

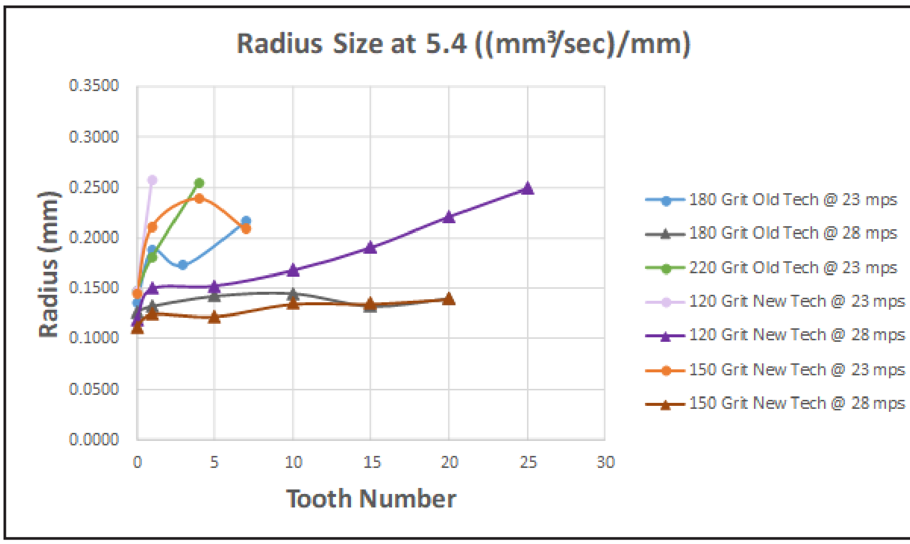


Figure 3 Radius Size 23 ms^{-1} vs 28 ms^{-1}.

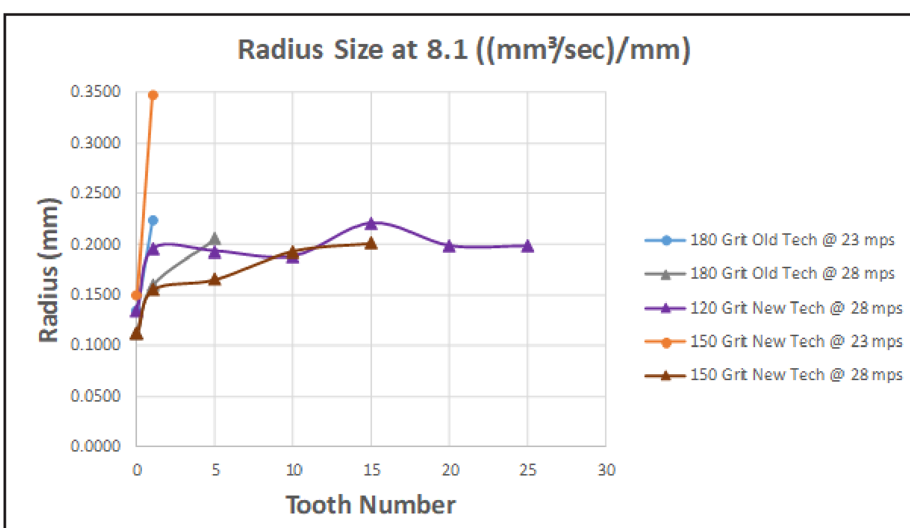


Figure 4 Radius Size 23 ms^{-1} vs 28 ms^{-1}.

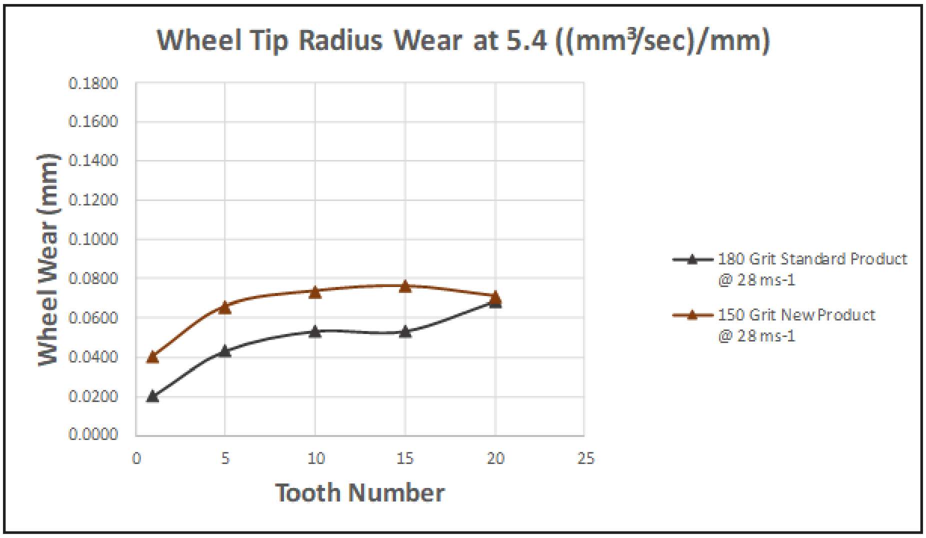


Figure 5 **Wheel Tip Radius Wear for 5.4 MRR′ at 28 ms^{-1}.**

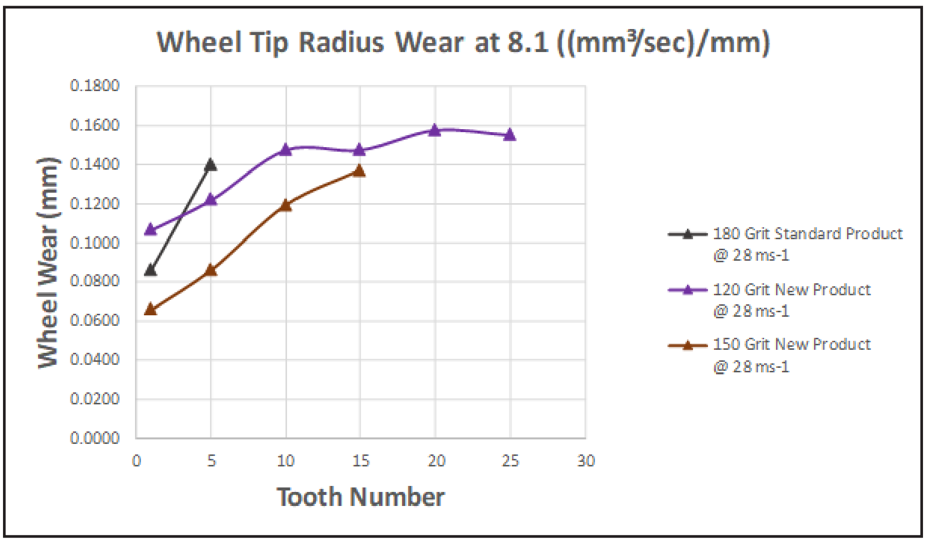


Figure 6 **Wheel Tip Radius Wear for 8.1 MMR′ at 28 ms^{-1}.**

wheel held the radius better than the 180 Grit Standard Product wheel at both 5.4 ((mm^3/sec)/mm) and 8.1 ((mm^3/sec)/mm). Figures 3 and 4 show the radius size for each tooth at 5.4 and 8.1 MRR' respectively.

Wheel Wear

Wheel tip radius wear was measured for wheels tested at 28 ms^{-1} using the graphite coupons measured on an optical comparator at 50×.

Figures 5 and 6 show wheel tip radius wear for each tooth at 5.4 and 8.1 MRR' respectively. Though the 180 Grit Standard Product had less wheel wear at 5.4 MRR' than the 150 Grit, New Product Figure 6 shows that as the products are pushed into higher MRRs the new technology outperformed the old technology.

Summary

The new product showed improvements in radius holding when using higher metal removal rates, indicating a reduction in cycle time for the end user.

The collaboration of Norton | Saint-Gobain Abrasives and Gleason Works has benefited both companies and their customers. The ability of both companies to work together has also improved the knowledge of the individuals involved in the projects, mutually providing new solutions to further the development of grinding wheels and machining technology for gear grinding.

For more information:

Gleason Corporation
www.gleason.com

Norton | Saint-Gobain
www.nortonabrasives.com

Mark Martin is an application engineer at Norton | Saint-Gobain Abrasives.

Phil Plainte is an application engineer at Norton | Saint-Gobain Abrasives.

Eric Mundt is chief research and development engineer at The Gleason Works.