Emerging Trends in Grinding of Materials

K. Philip Varghese, Ph.D.

Group Leader, Advanced Application Engineering

Agenda

- Introduction (Company and Presenter)
- Emerging Materials: What and Why?
- Grinding Processes to be covered
  - Surface grinding (γ-TiAl)
  - Creep-feed grinding (γ-TiAl, IN718)
  - Large Diameter Disk Slotting (IN718)
  - Face grinding (IN718)
  - Belt polishing (IN718)
  - Gear grinding from solid (8620, 4140)
- Abrasives technology to be covered (Bonded, Super Abrasives, and Coated products)
- Summary
- Questions/Discussions

Agenda

- Introduction (Company and Presenter)

Introduction - Saint-Gobain Abrasives

A portfolio of products that offer powerful, precise and user friendly abrasive solutions for every market and for every step of the abrasive process…

61 manufacturing facilities in 27 countries

Commercially present in **79 countries**

Over **10,600 employees**

- **Bonded abrasives**
- **Coated abrasives**
- **Thin wheels**
- **Superabrasives**
- **Construction Products**

…Enabling our customers to shape and surface-finish all types of materials even in the most complex and challenging applications, from DIY home improvement to highly technical precision engineering.

Reshaping your world®

Introduction - Saint-Gobain Abrasives

United States

1. **Northboro R&D Center**
   - Polymer composites
   - Ceramic materials
   - Abrasives
   - Habitat

France

2. **Saint-Gobain Recherche**
   - Glass
   - Surfaces
   - Construction materials
   - Habitat

3. **Chantereine R&D Center**
   - Automotive glass
   - Building glass
   - Thin films
   - Acoustics and optics

4. **Centre de recherches et d'études européen** *(CREE)*
   - High temperature
   - Mineral material processing
   - Powder processing
   - Functional ceramics

Germany

5. **Herzogenrath R&D Center**
   - Flat Glass
   - Thin films
   - Complex glazing products

India

6. **Saint-Gobain Research India**
   - Abrasives and plastics
   - Building and automotive glass
   - Habitat solutions for hot-humid climates

China

7. **Saint-Gobain Research Shanghai**
   - Polymer materials
   - Abrasives
   - Powder processing
   - Optics and inspection

About 300 patents filed by the Sector each year

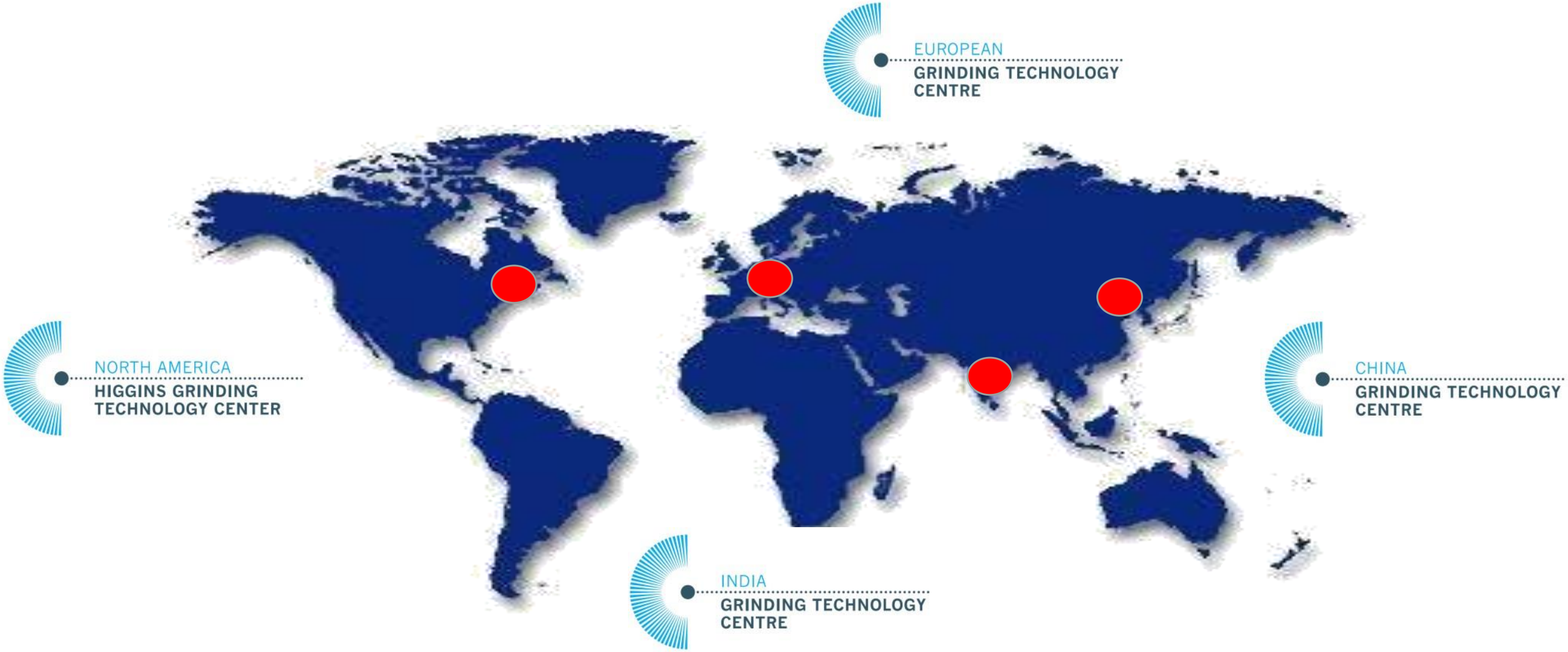
About 2/3 of the Group's R&D spending

2,100 researchers work for the Sector, with **2/3** in multi-business centers

Introduction - SGA Grinding Technology Centers (GTC)

Four Locations:

- Higgins Grinding Technology Center (HGTC) Northborough / Massachusetts/USA
- European Grinding Technology Center (EGTC) Norderstedt / Germany
- Saint Gobain Research India (SGRI) Chennai / India
- China Grinding Technology Center (CGTC) Shanghai / China



Introduction - Higgins Grinding Technology Center (HGTC)

Worcester (1993-2011)

Northborough (2011-Present)

Mission:

- To the advancement of grinding technology and abrasive products.
- To the development of grinding systems with maximum value to our customers.

Introduction – Speaker (Dr. K. Philip Varghese)

Education

2000	B.E. in Production Engineering
2003	M.S. in Mechanical Engineering
2008	Ph.D. in Mechanical Engineering

CR Foundation

2008 – 2011: Chief Scientific Officer

Saint-Gobain Abrasives/Norton

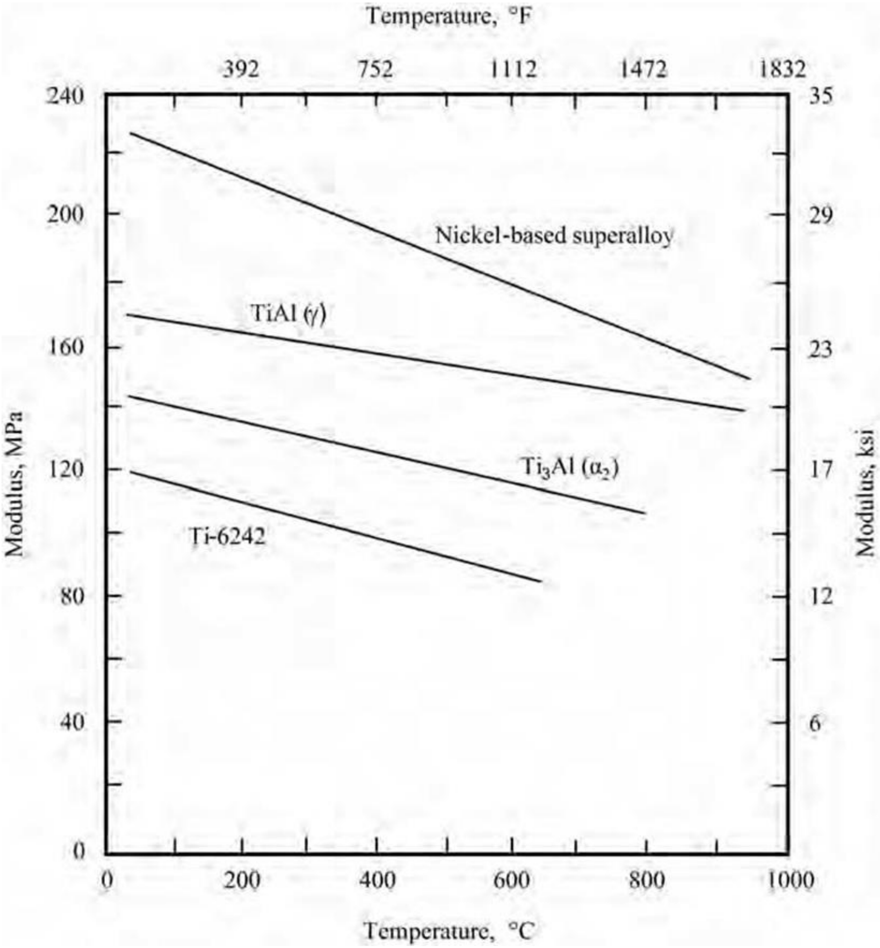
2011 – Current: Group Leader, Advanced Application Engineering

Agenda

- Introduction (Company and Presenter)
- Emerging Materials: What and Why?

Grinding Titanium Aluminides (γ-TiAl)

- Low density, titanium aluminides based on Ti_3Al and TiAl for applications in
  - advanced aerospace engine components (latter stages of the compressor or turbine sections), airframe components
  - automotive valves and turbochargers.
- The γ-TiAl phase apparently remains ordered upto its melting point of approximately 1450 °C (2640 °F).
- γ-TiAl can be processed by conventional methods, including casting, ingot metallurgy, and powder metallurgy.
- General Electric certified and implemented TiAl in the new GEnx-1B engine for the Boeing 787 Dreamliner that entered service in 2011.



Source: F.C. Campbell, Lightweight Materials – Understanding the Basics

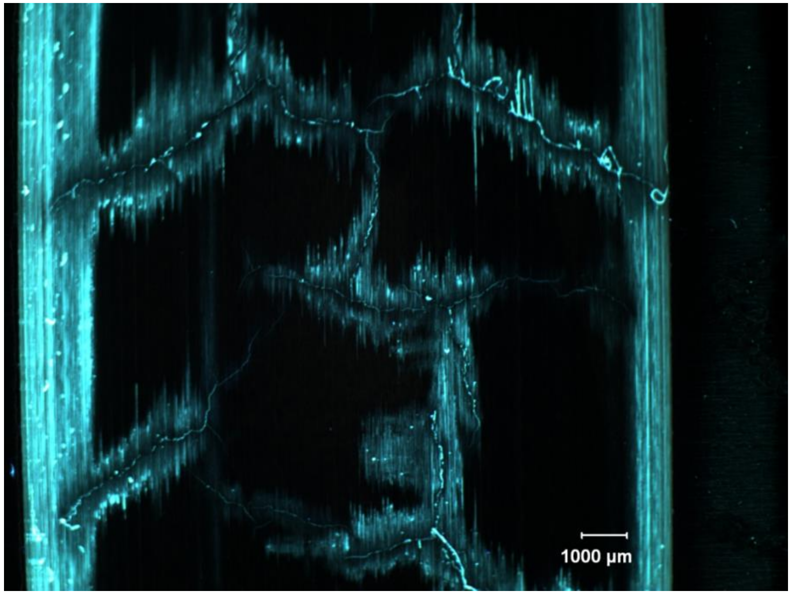
Grinding Titanium Aluminides (γ-TiAl)

Traditional Grinding Solution

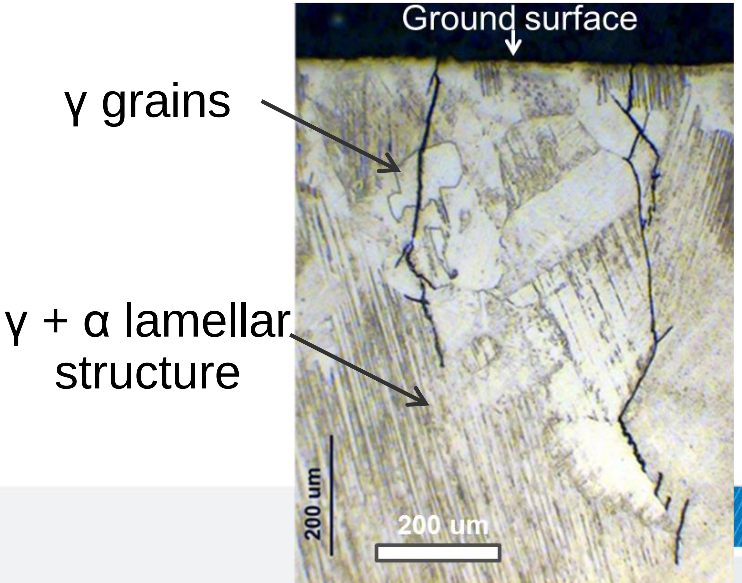
- Using Vitrified SiC wheels
  - High purity, very brittle, green silicon carbide abrasives, held using a dedicated vitrified bond
  - Lesser loading/capping than Alox wheels
  - High firability of SiC helps helps to lower threshold power/forces, allows cooler cutting (limit heat damage risk)

Challenges

- Loading of grinding wheels
- Parts susceptible to burn
- Parts susceptible to cracking



CRACKING IN A COMPONENT USING LIQUID DYE PENETRANT



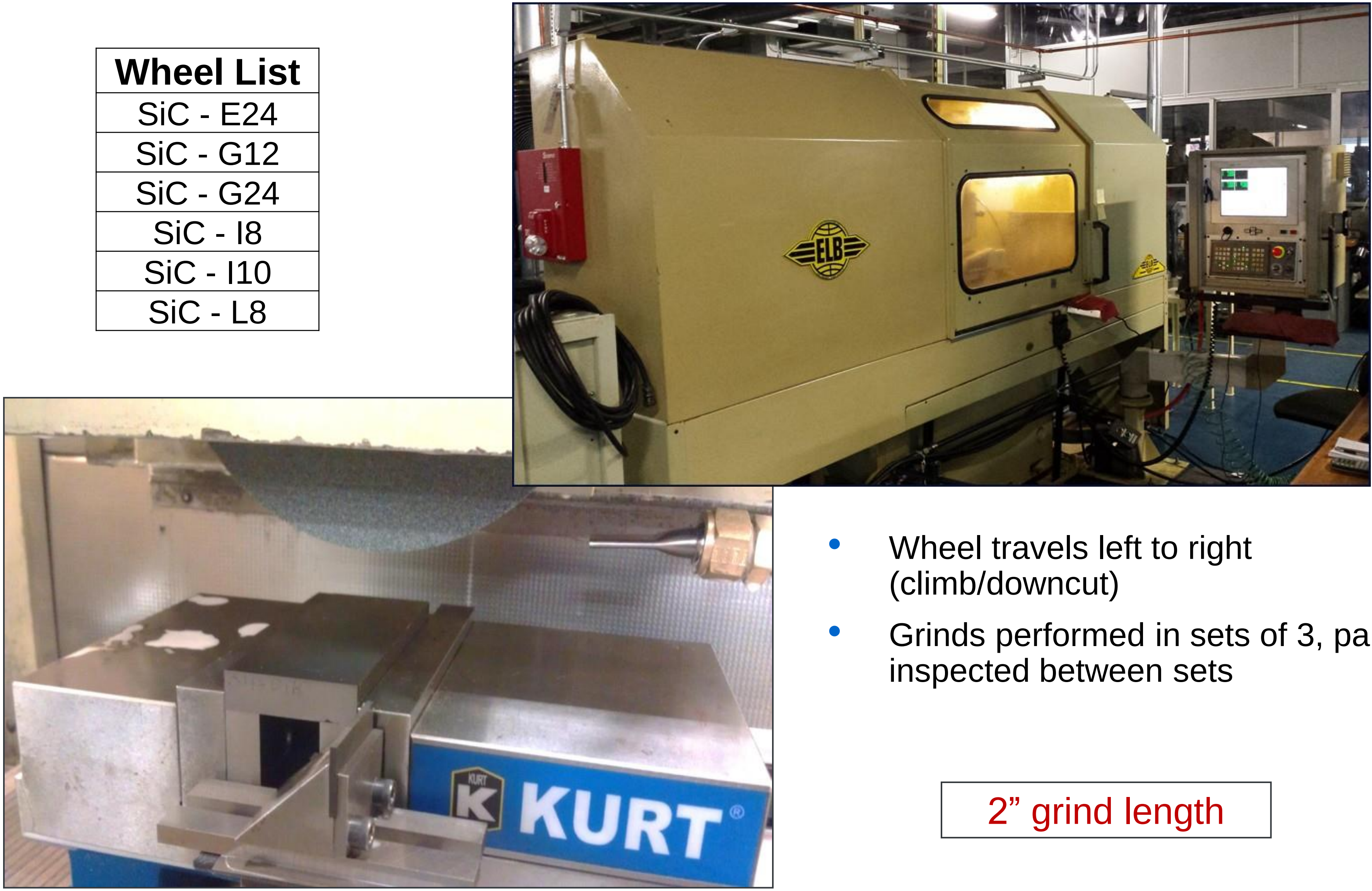
CROSS-SECTION VIEW

Agenda

- Introduction (Company and Presenter)
- Emerging Materials: What and Why?
- Grinding Processes to be covered
    - Surface grinding (γ-TiAl)

Surface Grinding γ-TiAl with SiC wheels

Wheel List
SiC - E24
SiC - G12
SiC - G24
SiC - I8
SiC - I10
SiC - L8



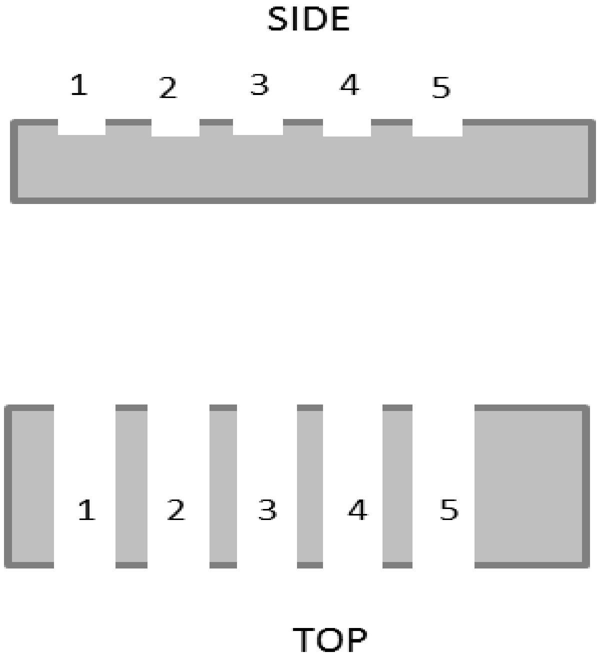
- Wheel travels left to right (climb/downcut)
- Grinds performed in sets of 3, part inspected between sets

2” grind length

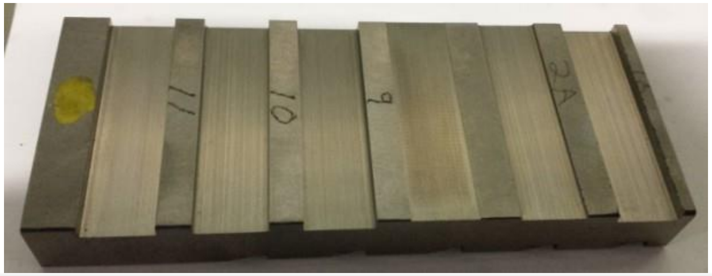
Test Conditions & Measurements

Machine	Elb Brilliant
	Mode: Slot Grinding
	Coolant: WS
Material	48-2-2 γ TiAl
Operational Parameters	DOC: 0.006, .012 , 0.018 in
	Table Speed: 50 to 200 ipm
	Vs: 30 m/s
	Grind Length: 2 in
	# passes per slot: up to 18
Outputs/ Measurement	Power, forces
	Corner radius (graphite coupons)
	Surface roughness (Ra, Rz, Wt)
Dressing Conditions	BPR Diamond Roll
	Dress Comp: 10 uin/rev
	Plunge Rate: 0.0005" DOC for 20 passes
	Speed Ratio: +0.8

Workpiece schematic



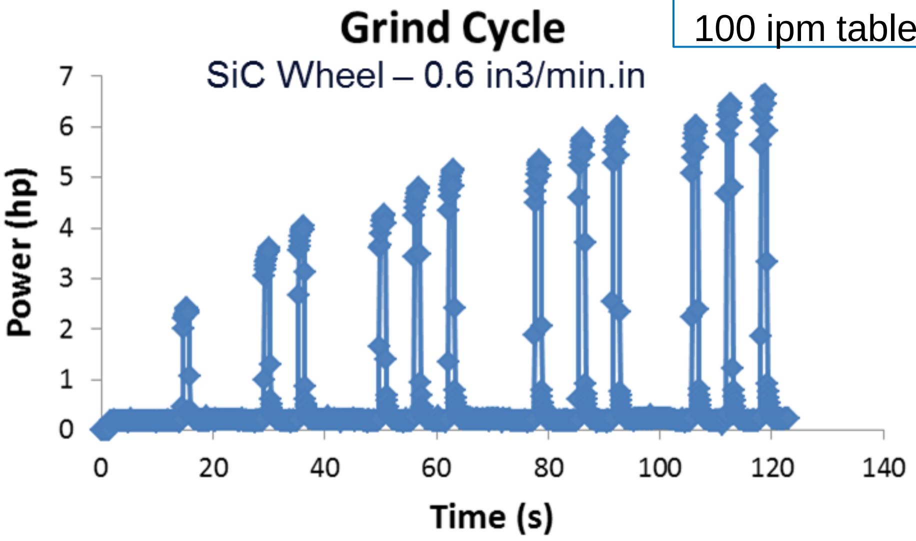
$$h_c = \left[\left(\frac{V_w}{V_s} \right) \left(\frac{DOC}{D_e} \right)^{\frac{1}{2}} \frac{1}{kC} \right]^{\frac{1}{2}}$$

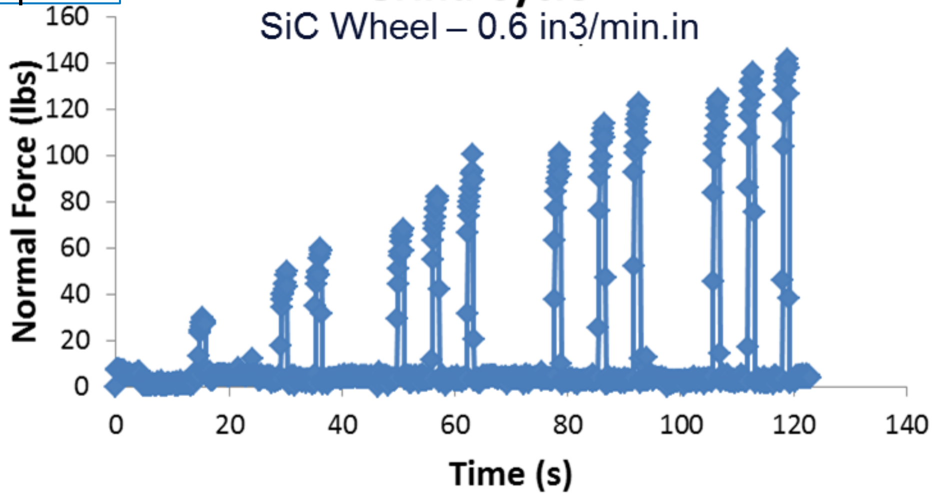


Results: Power, Force vs. Time Behavior

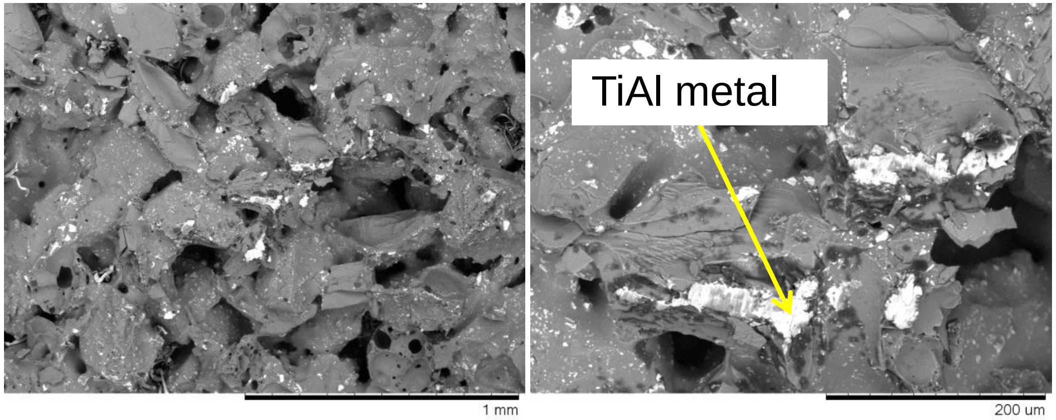
.006” DOC

100 ipm table speed

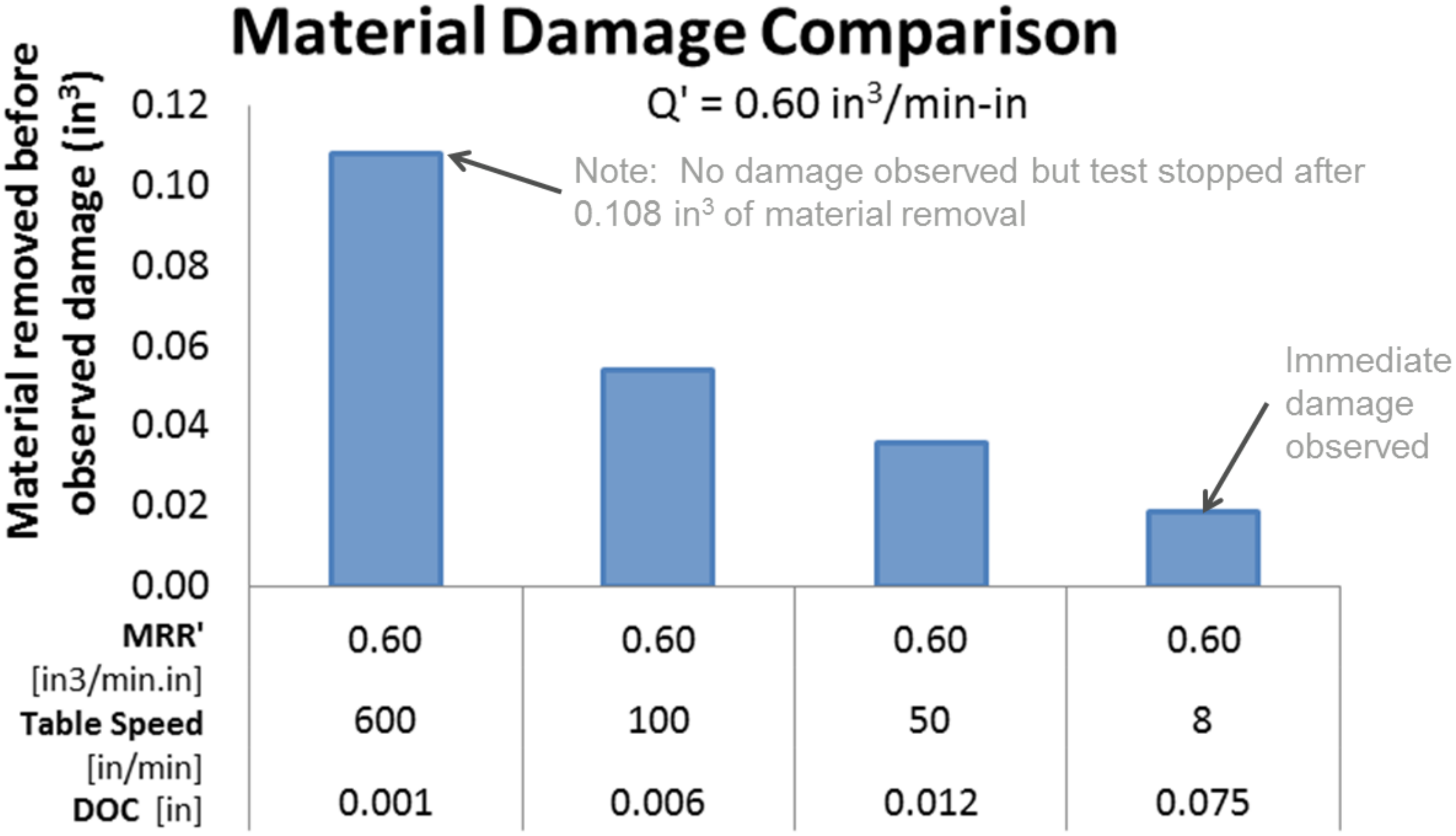




- Power & forces climb rapidly after dressing as function of pass #
- Wheel faces & bulk porosity observed to be free of significant loading
- Metal adhesion / capping observed on grain tips



Results: Effect of operational parameters on damage



Material Damage Comparison

Q' = 0.60 in^3/min-in

Note: No damage observed but test stopped after 0.108 in^3 of material removal

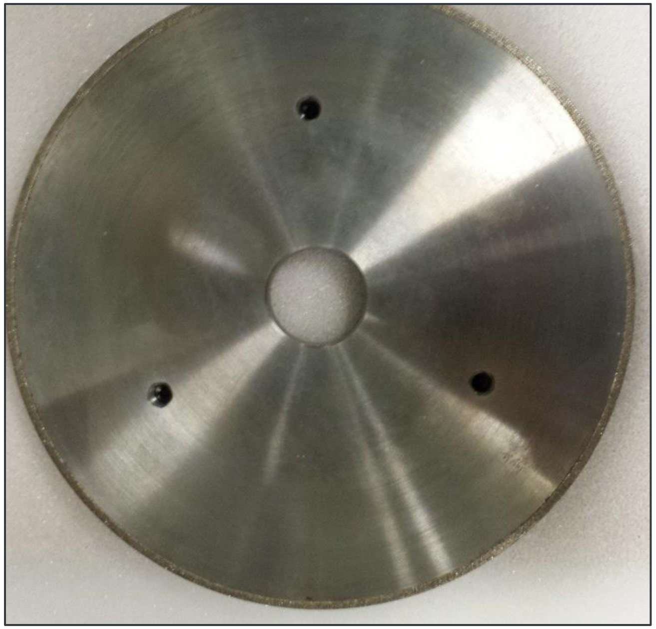
Immediate damage observed

MRR' [in3/min.in]	0.60	0.60	0.60	0.60
Table Speed [in/min]	600	100	50	8
DOC [in]	0.001	0.006	0.012	0.075

- At constant MRR’, material damage is avoided at low DOC, high table speeds

Surface Grinding γ-TiAl with Superabrasives

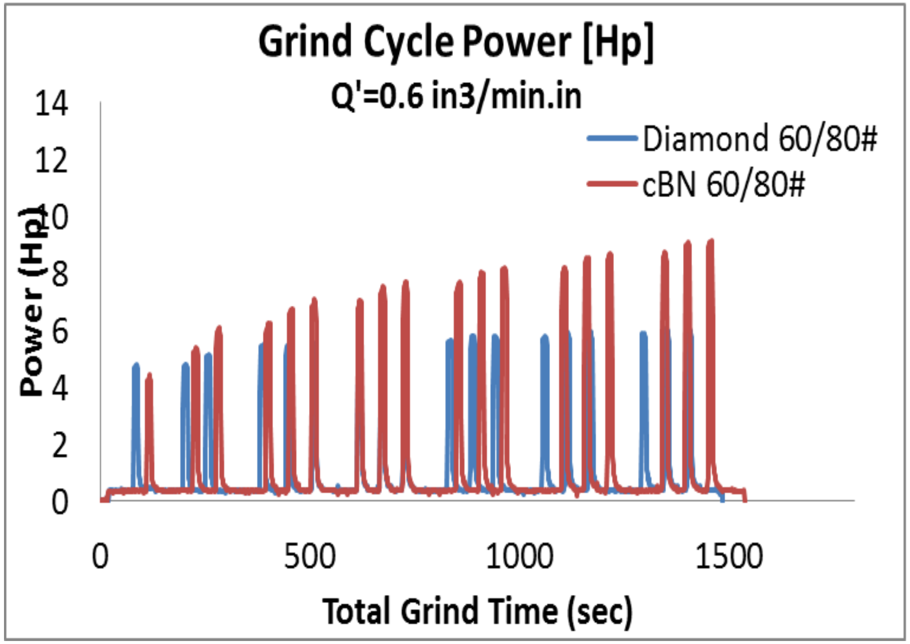
Superabrasive Wheel List
EP 60/80# Diamond
EP 100/120# Diamond
EP 60/80# cBN
EP 100/120# cBN

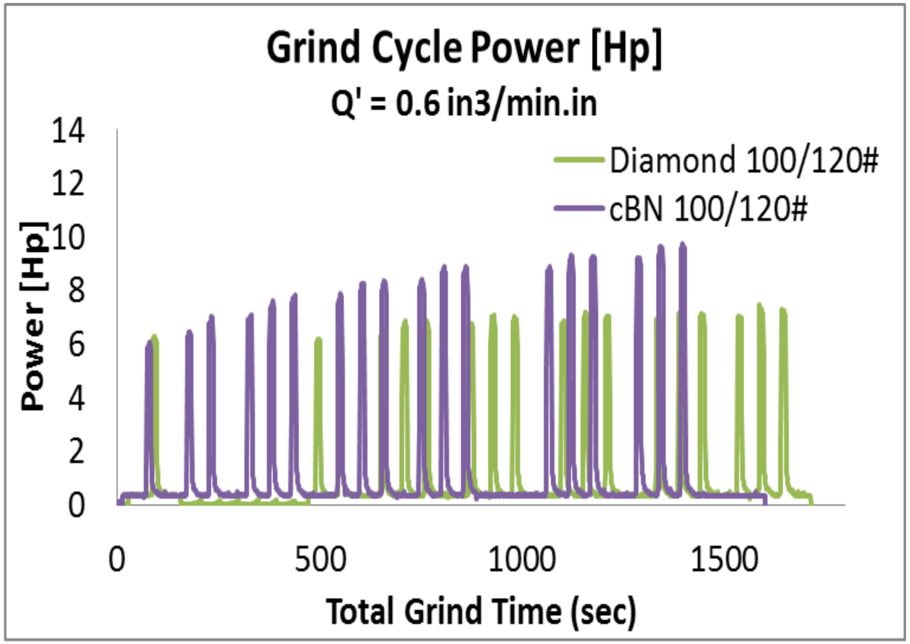


- Wheel travels left to right (climb/downcut)
- Grinds performed in sets of 1, part inspected after each grind

2” grind length

Results: Power, Force vs. Time Behavior

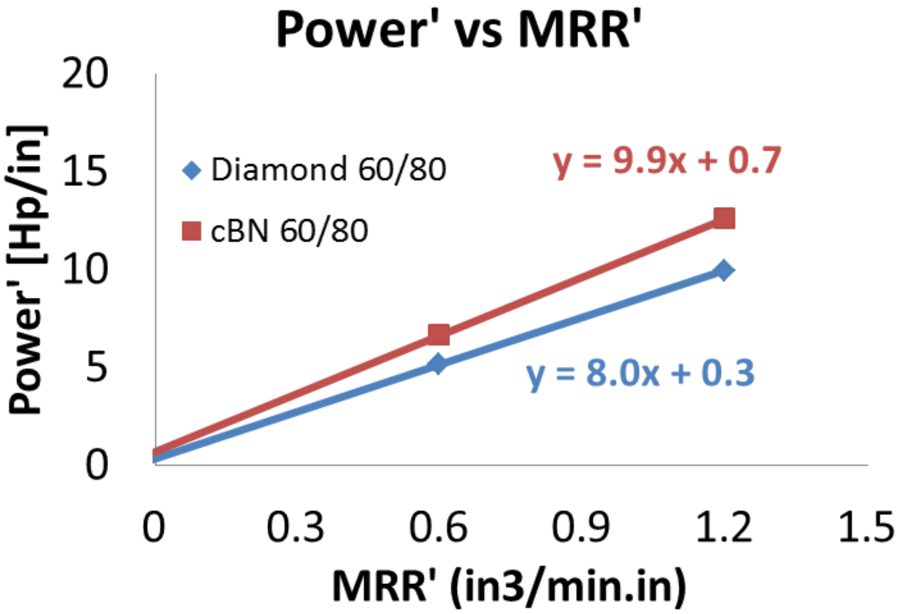


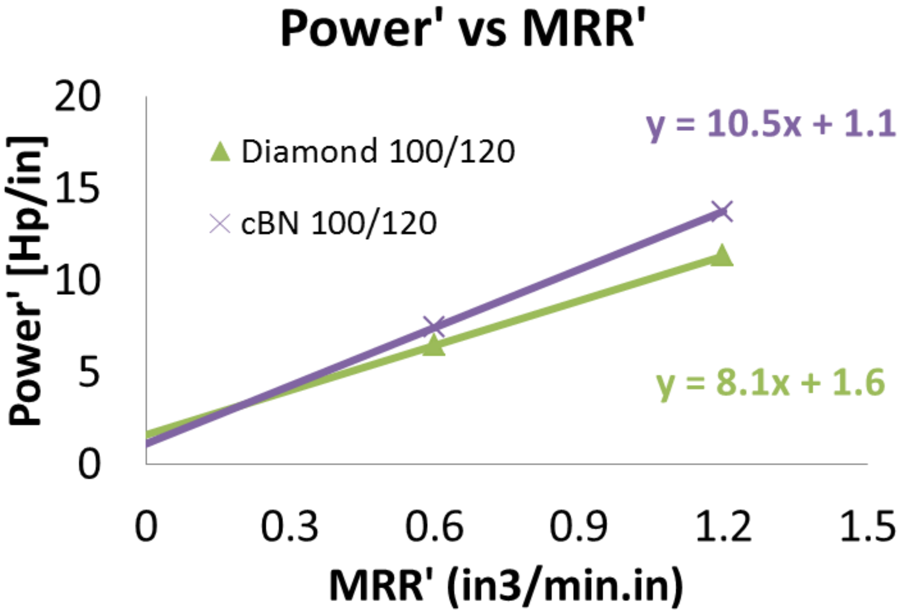


- cBN grains resulted in increasing power (and force) as a function of grind #, whereas diamond was observed to be more stable over time

- Same trend was observed at two grits sizes (60/80 & 100/120)

Results: Power, Force vs. Time Behavior

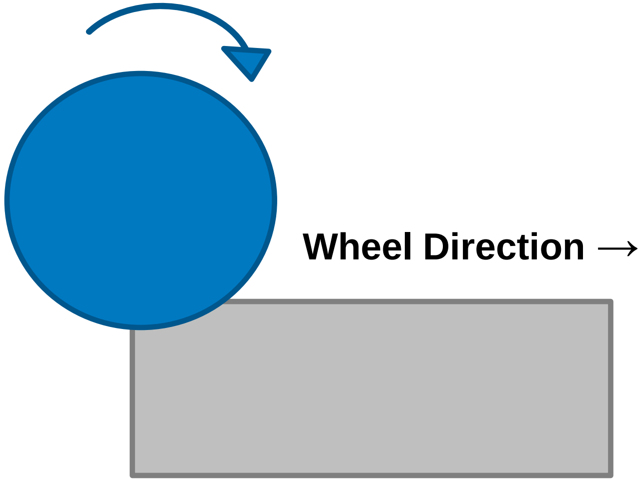




- Diamond wheels displayed lower power & specific energy compared to cBN wheels at both grit sizes (60/80 & 100/120)
- Very low threshold power observed (grit/work interaction is dominant)
  - Effect of grit size on power/threshold power also observed

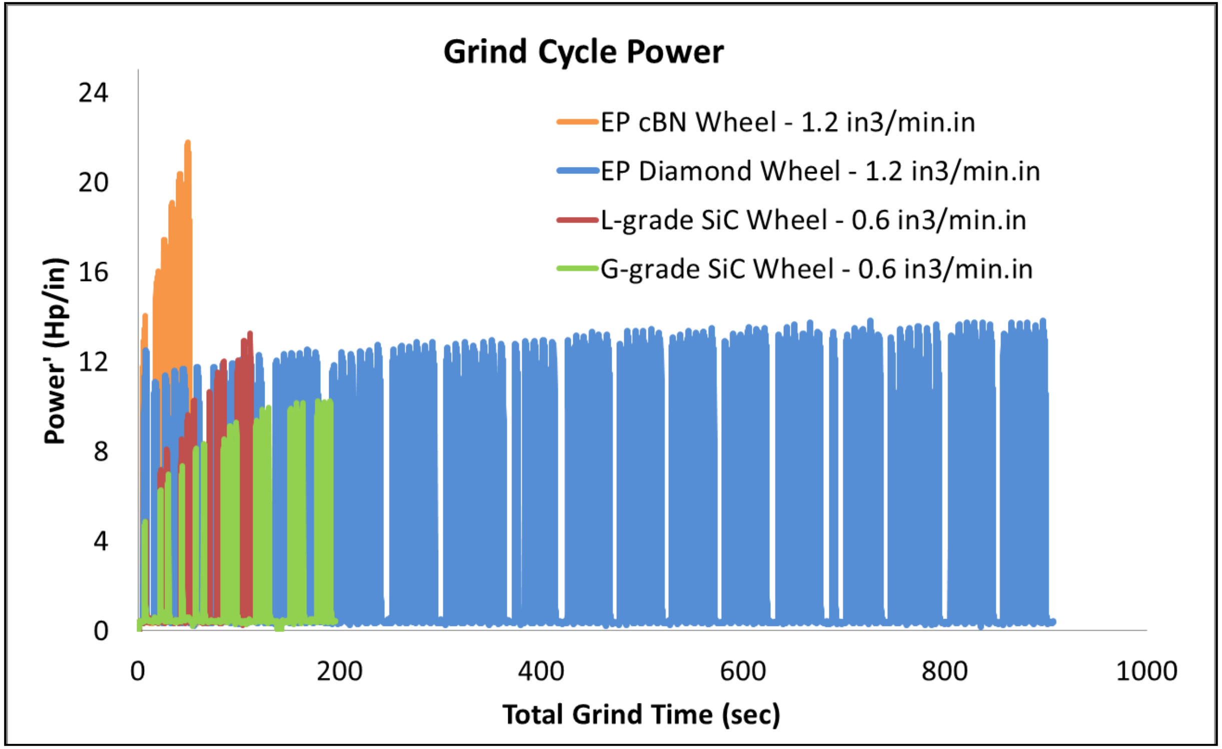
Long-duration Test Comparison (γ-TiAl)

Workpiece Schematic:
SA Wheels



Wheel Direction →

Side View



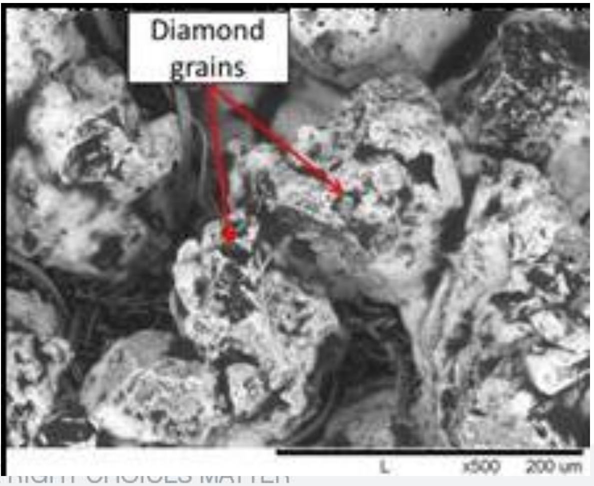
	SA	SiC
Wheel Thickness (in)	0.5	0.5
Grind Length (in)	4.85	2
DOC (in)	0.012	0.006
MRR' (in3/min.in)	1.2	0.6
Table Speed (ipm)	100	100
Wheel Speed (SFPM)	5905	5905

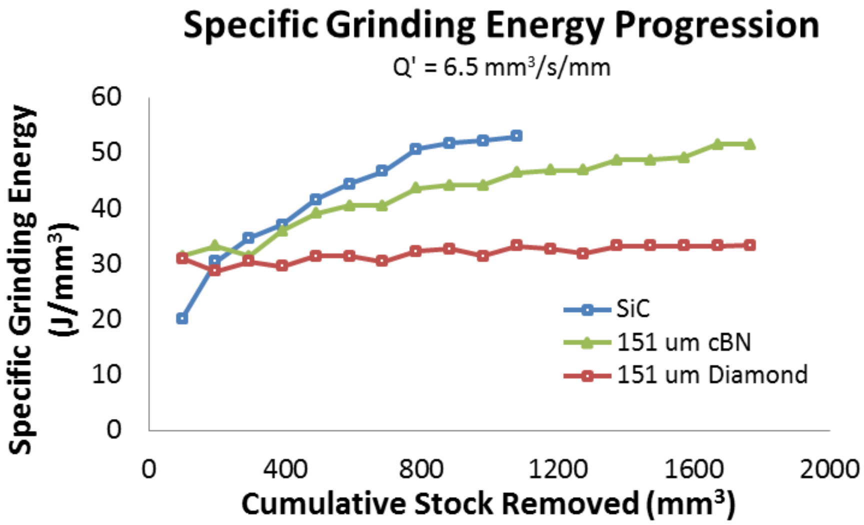
- Rapid power increase as a f(pass #) for cBN and L-grade SiC wheels
- G-grade SiC wheels resulted in high wheel wear, but no material damage was observed
- EP Diamond wheel removed significantly more material compared to the SiC and cBN wheels
- Low power increase observed in diamond wheel as a f(pass) relative to SiC and cBN wheels

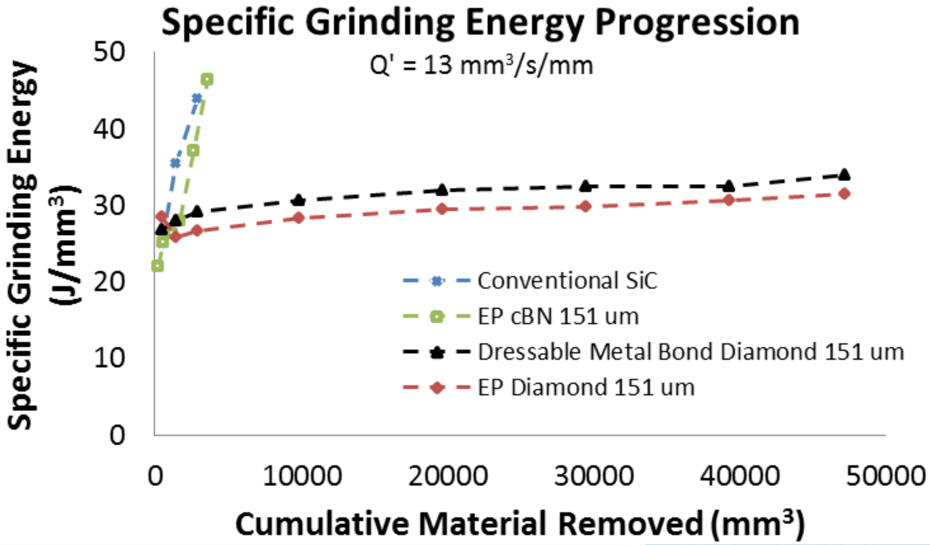
Surface grinding γ-TiAl with New Paradigm wheel

Advantages of Norton Paradigm

- Easy to Profile
  - Can be profiled on the machine using Diamond rolls in both traverse and plunge dress modes:
- Up to 42% of natural porosity achievable creating a topography that lends itself to "free" cutting states.
- 100% Metal bond best suited for "pulling" heat fro Heat sensitive materials







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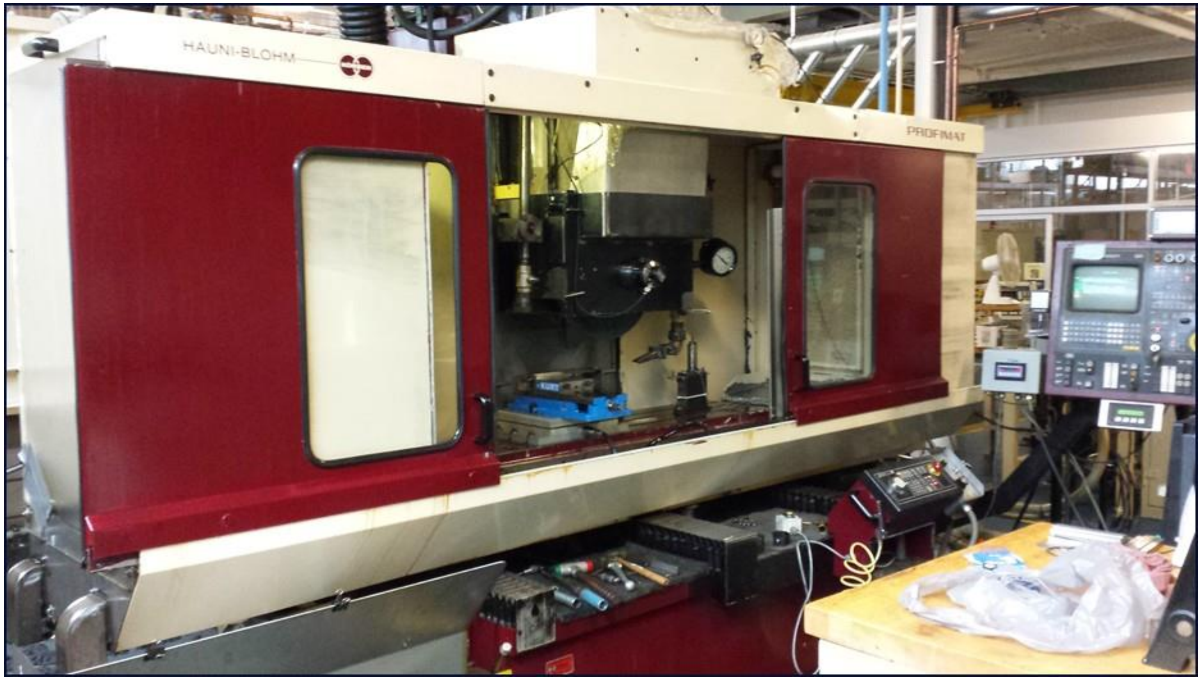
    - Surface grinding (γ-TiAl)
    - Creep-feed grinding (γ-TiAl, IN718)

Creepfeed Grinding γ-TiAl with SiC wheels

Creepfeed Wheels
SiC – G24
SiC – E24



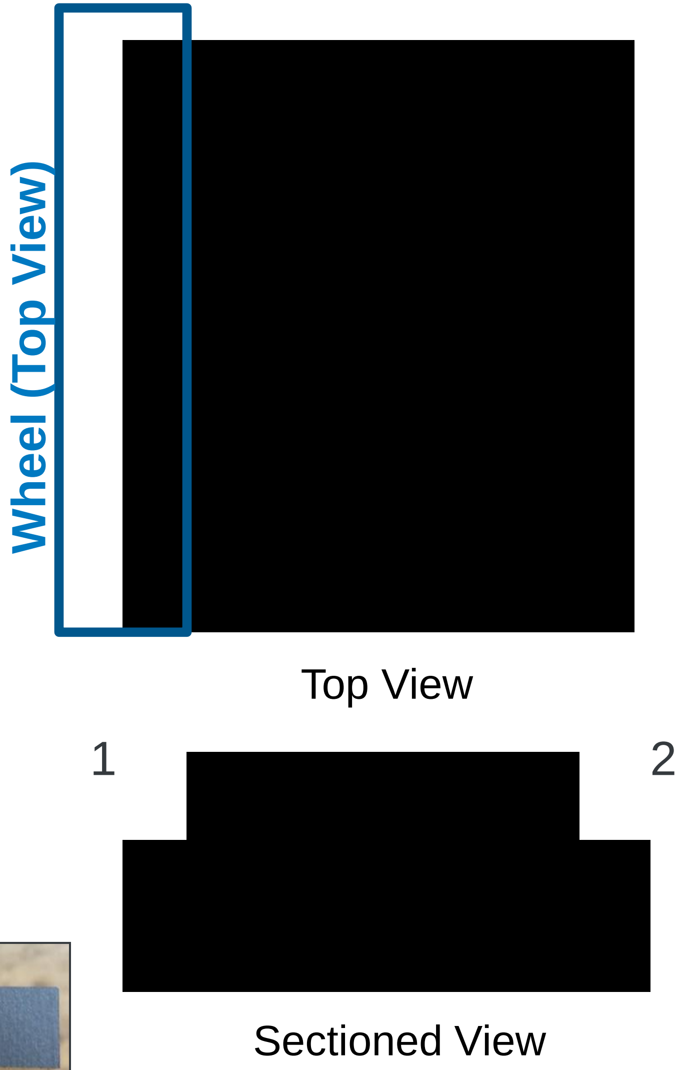
- Wheel travels left to right (climb/downcut)
- Grinds performed in sets of 1, part inspected after each grind

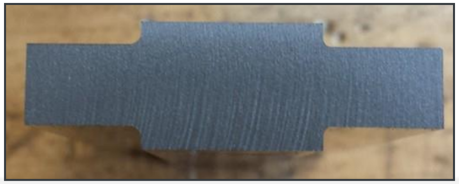
5” grind length

Test Parameters & Measurements

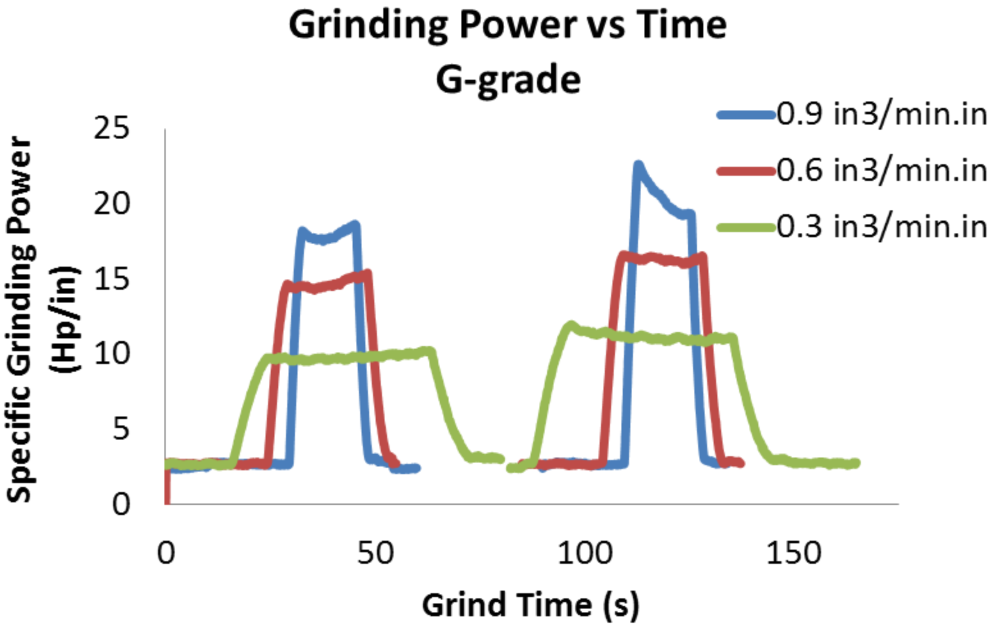
Machine	Blohm
	Mode: Creepfeed (NCD)
	Coolant: WS
Material	48-2-2 γ TiAl
Operational Parameters	DOC: 0.050 in
	Table Speed: 6 to 24ipm
	Vs: 30 m/s
	Grind Length: 5 in
	# passes per slot: up to 2
Outputs/ Measurement	Power, forces
	Corner radius (graphite coupons)
	Surface roughness (Ra, Rz, Wt)
Dressing Conditions	Diamond Roller
	Dress Comp: 80 uin/rev
	Total stock removed: 0.060 in
	Speed Ratio: +0.8

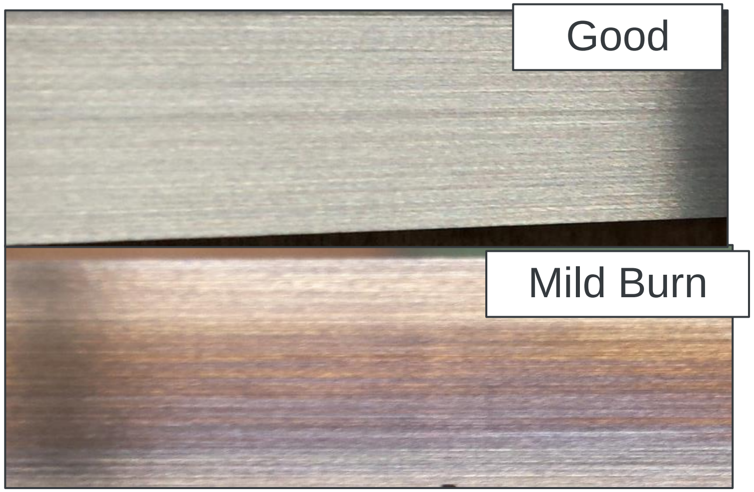
Workpiece schematic

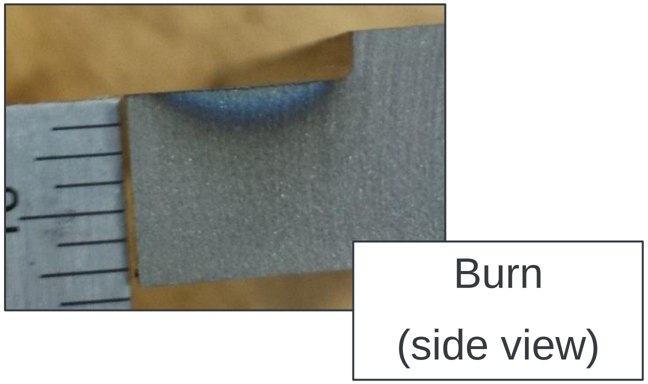




Results: NCD Creepfeed Testing

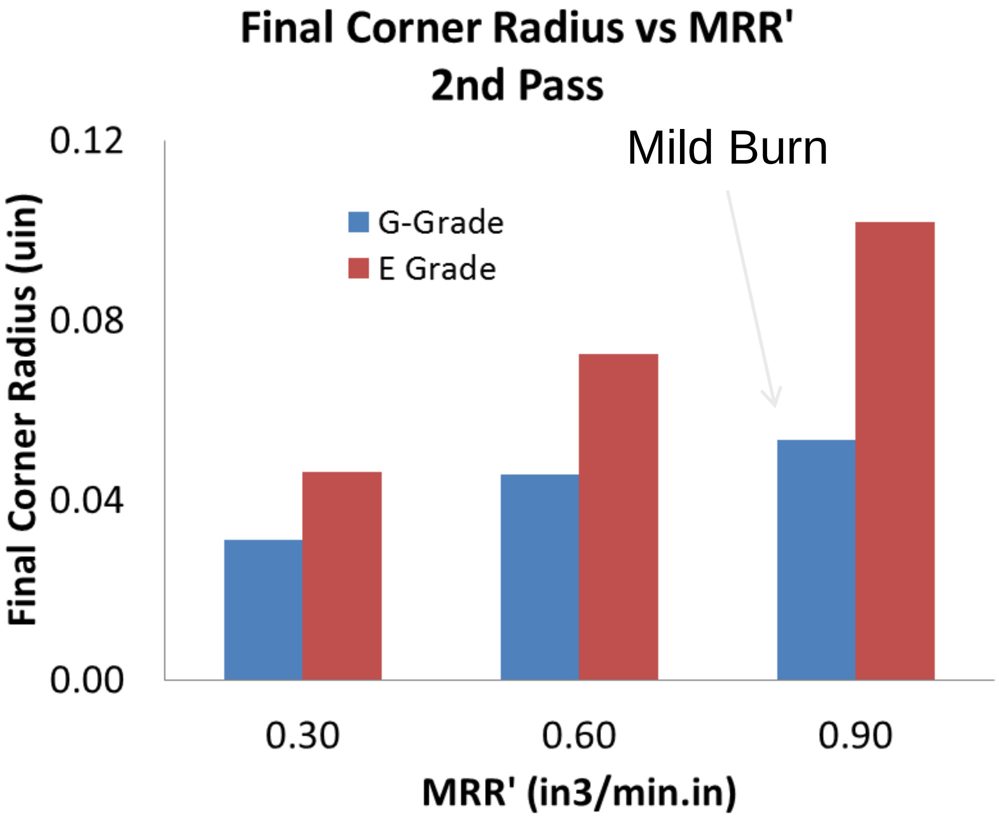






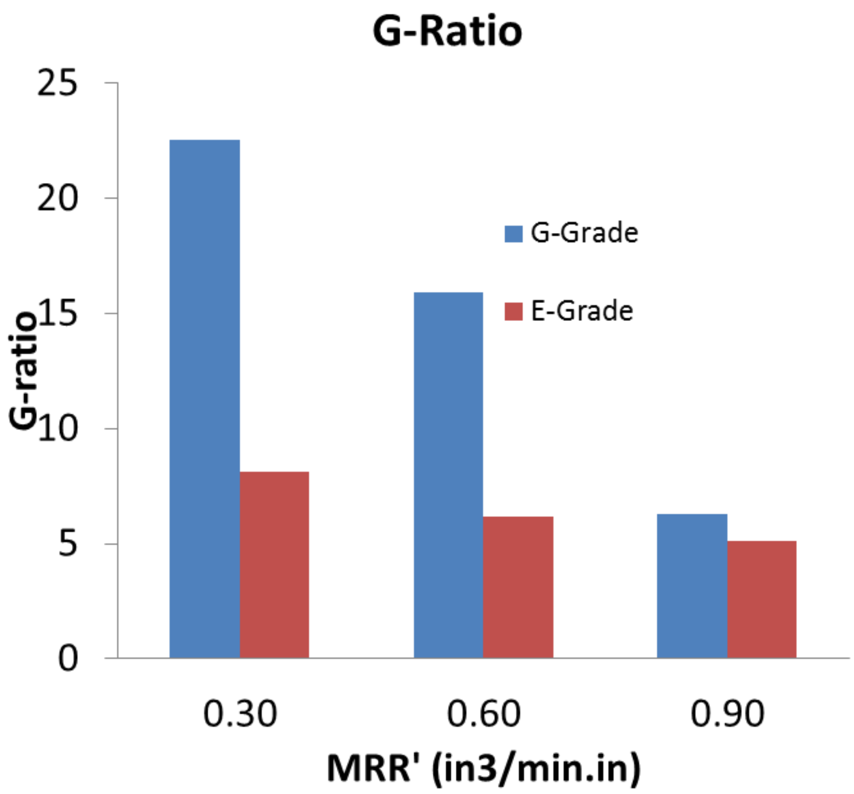
- No wheel breakdown or part damage was observed in two passes at lower MRR’s
  - Wheel breakdown observed during second pass at 0.9 in^3 / min.in
  - Correlated with mild burn in the parts

Results: NCD Creepfeed Testing



Final Corner Radius vs MRR' 2nd Pass

Mild Burn

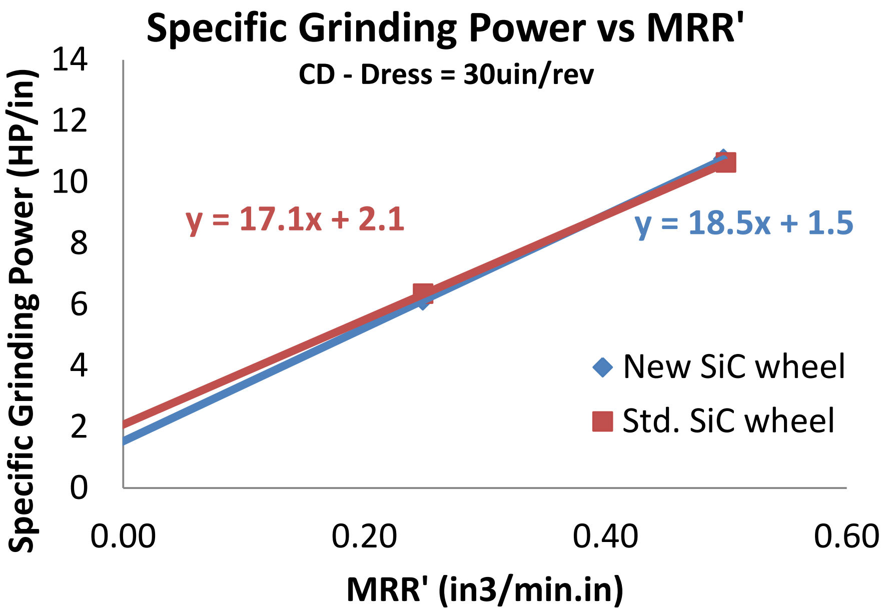


G-Ratio

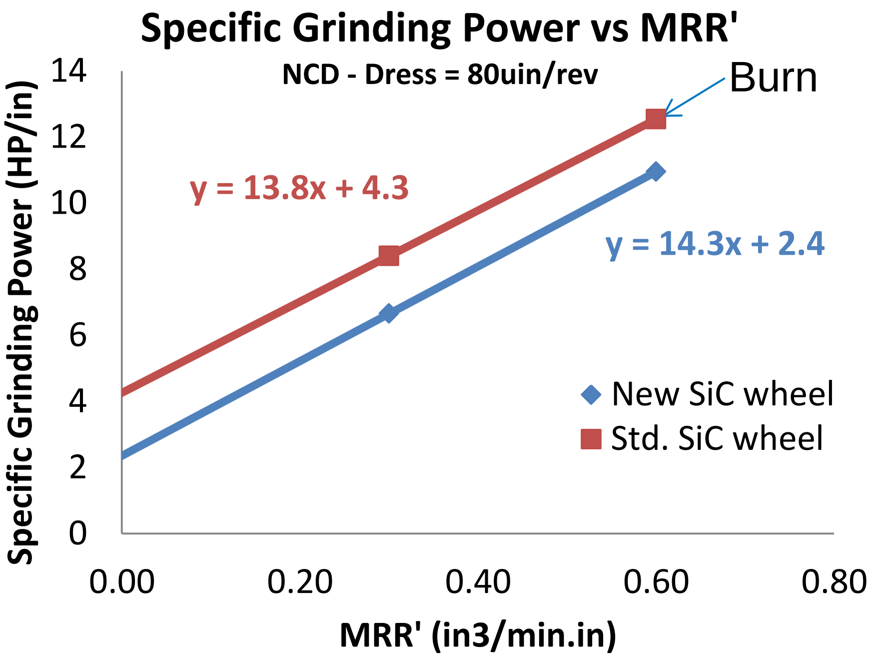
- G-grade wheel showed improved corner holding and higher G-ratio relative to E-grade wheel at same MRR’
  - Dressing implications for damage vs form

Creepfeed grinding γ-TiAl with New SiC wheel

CD Grinding



NCD Grinding



- No clear advantage or disadvantage in power compared to standard wheels

- New SiC wheels had lower power & threshold power
- New SiC wheels were able to reach higher MRR'

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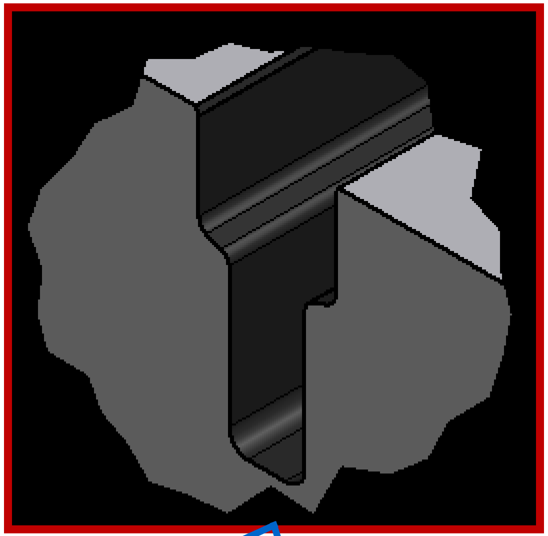
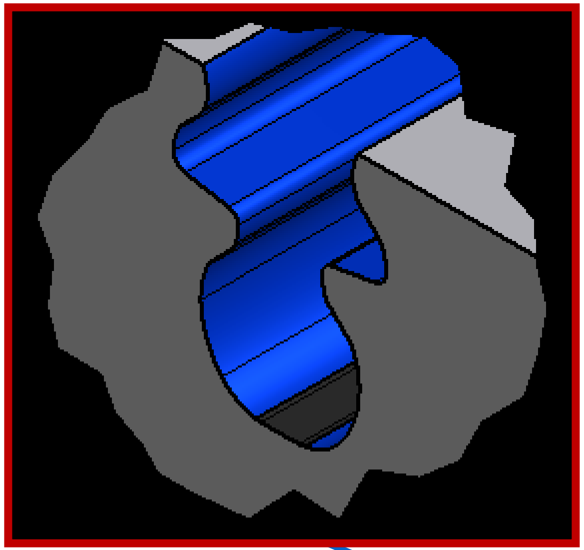
  - Large Diameter Disk Slotting (IN718)

Large Diameter Disk Slotting

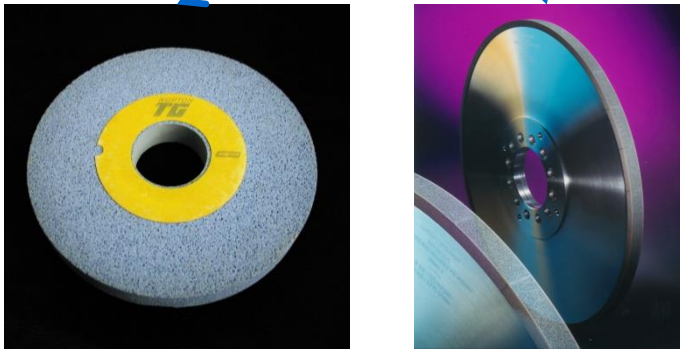
Step 1.
Slotting





Step 2.
Rough
Profiling

Step 3.
Finish
Profiling



Wheels

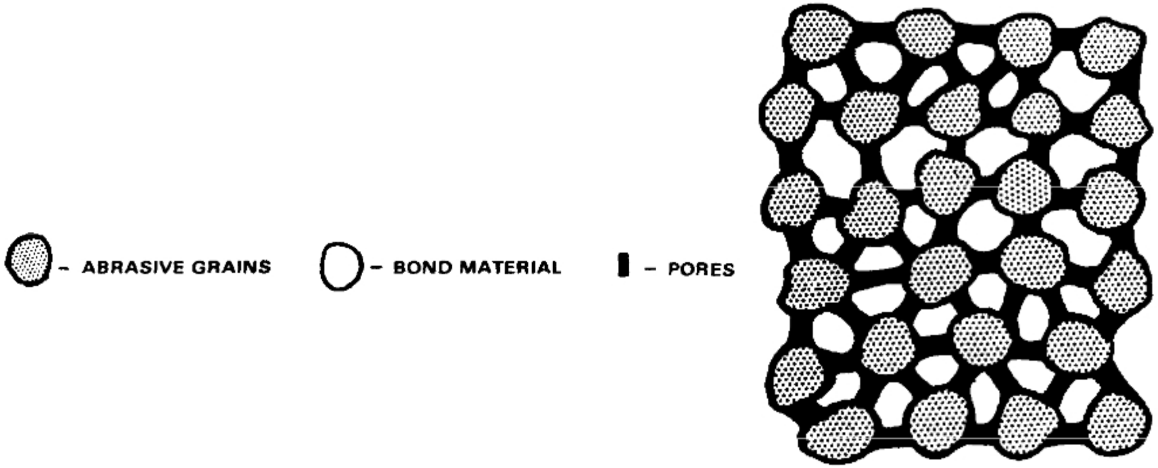
Quills

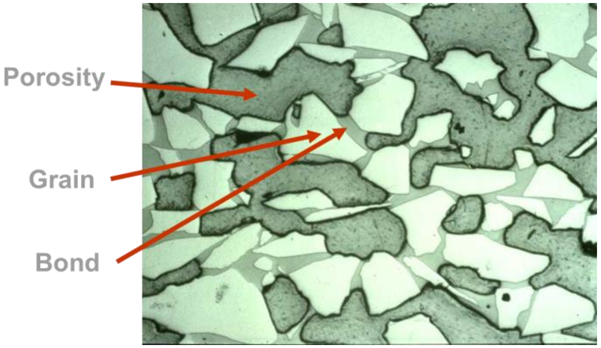
Ground
Component

Creep Feed Slotting (IN-718)

- **Wheels Tested**
  - TG280-F20 VTX2
  - 5NQX46-H16 VTX2
- **V_s = 8,500 sfpm**
- **Material**
  - IN-718
  - Two 1” thick plates stacked
- **Depth of cut**
  - 0.100 DOC
- **Coolant**
  - Oil
  - 200 psi
  - Scrubber nozzles 1,000psi
  - Bottom extinguishing nozzle 7 gpm

Product Technology & Terminology

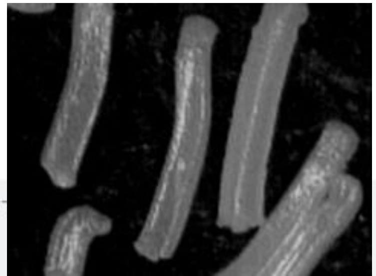




Source: US Army Handbook

TGII Extruded Grain

- Shape Long Thin Grain 8:1 Aspect ratio
  - Very low Loose Pack Density
  - High Force Necessary to Initiate Cutting
- Good Hardness and wear resistance
- Micro Fractures to Keep Grain Sharp



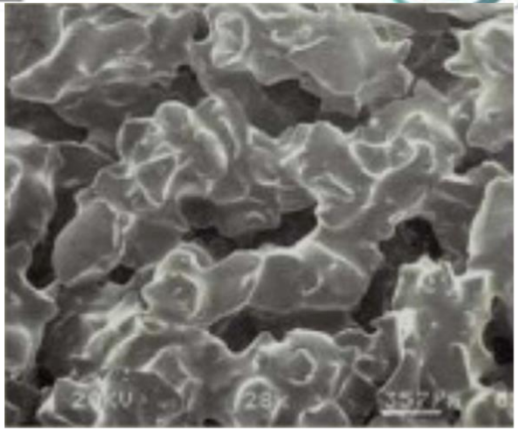
NQ Grain

- Shape Sharp Edges aspect ratio ~ 1:1
  - Average Loose Pack Density
  - Low Force Necessary to Initiate Cutting
- Good Hardness and wear resistance
- Micro Fractures to Keep Grain Sharp

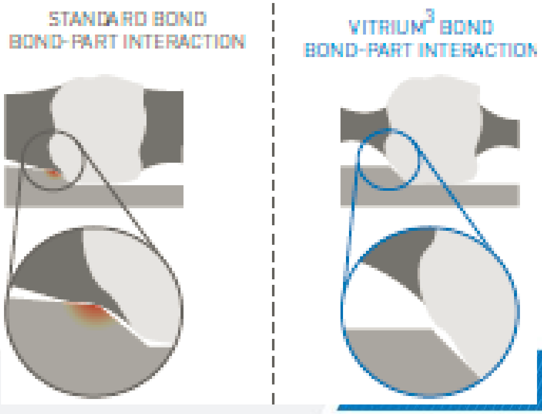
Product Technology & Terminology

- Low Loose Pack Density with Agglomerated Fused Secondary Grain – Vortex 2
- High Adhesive Strength - Vitrium
- Low Bond % Volume – Vitrium

NORTON SAINT-GOBAIN VORTEX 2 TECHNOLOGY



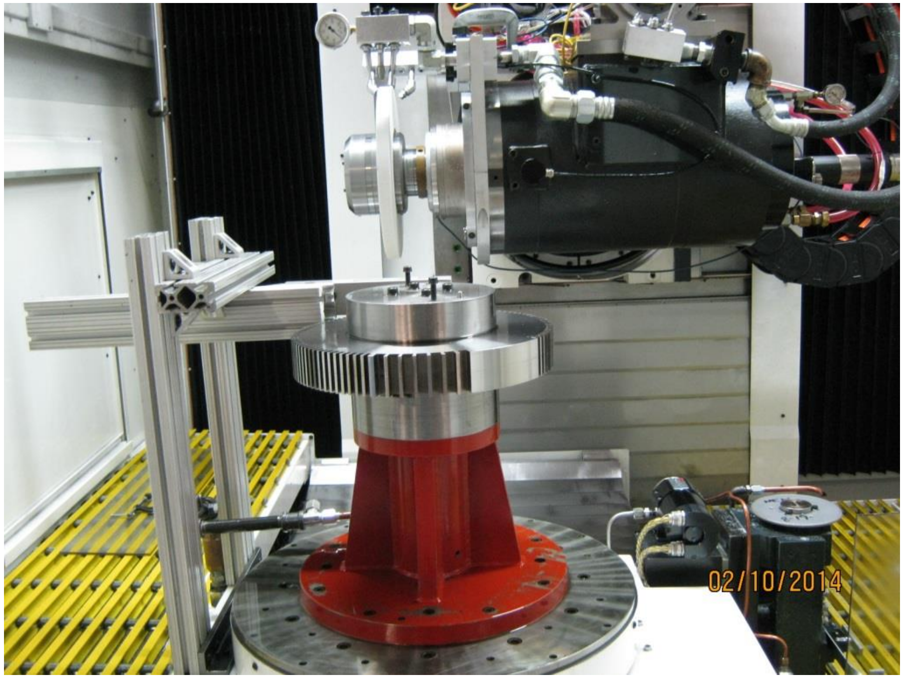
NORTON SAINT-GOBAIN VITRIUM 3



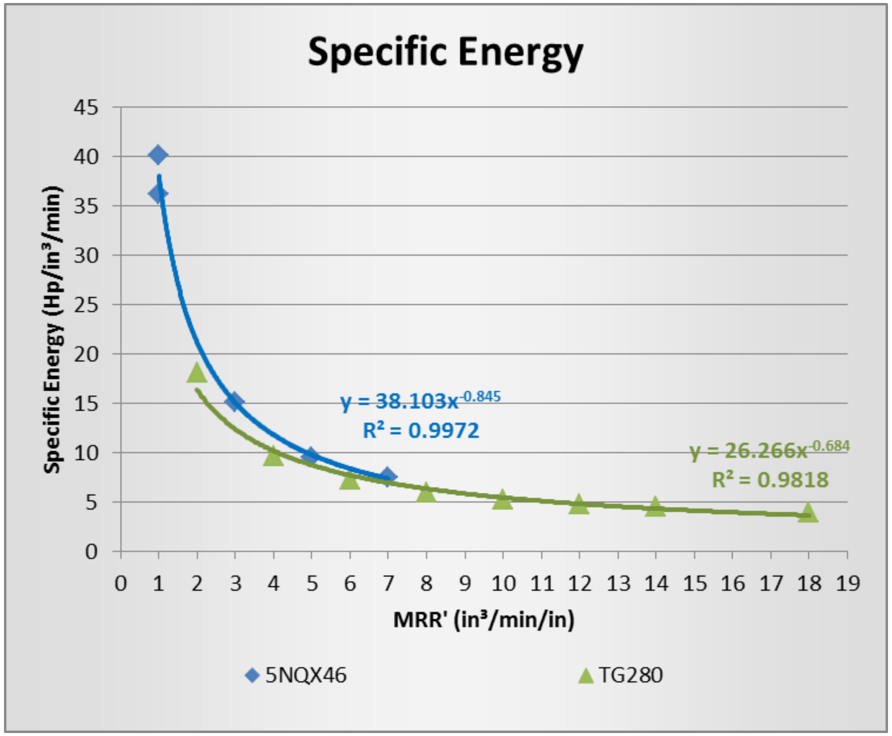
NORTON SAINT-GOBAIN QUANTUM X™

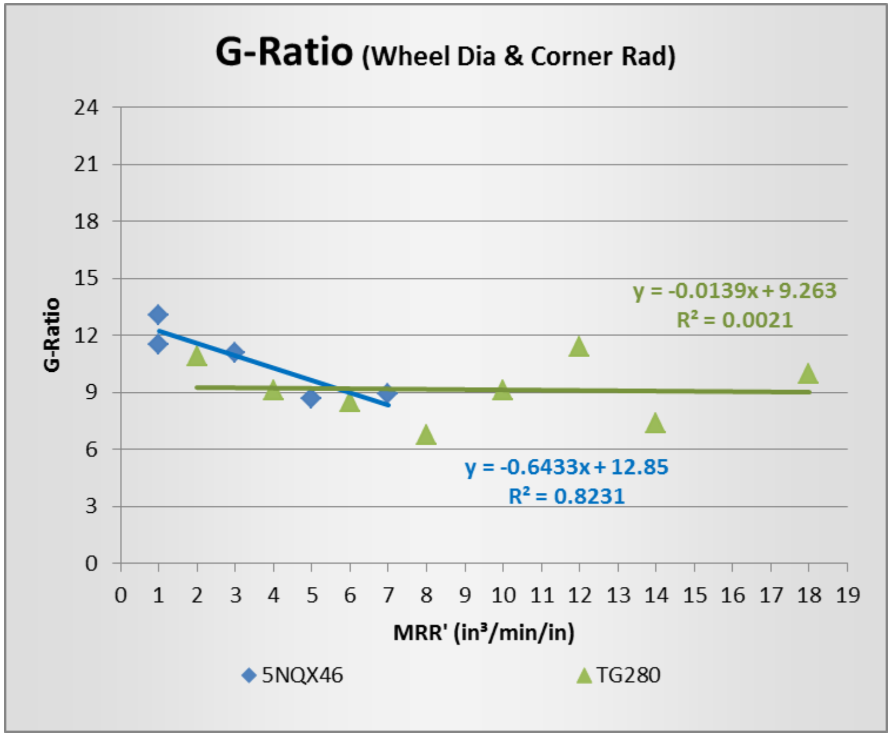
Creep Feed Slotting (IN-718)

- **Removal Rates**
  - TG280-F20 VTX2
    - 2.0 – 18.0 In³/min/in
  - 5NQX46-H16 VTX2
    - 1.0 – 7.0 In³/min/in
- Slot Depth 0.5”
- 4 Slots per Condition to get wheel wear
- 4 Slots per Dress



Creep Feed Slotting (IN-718)



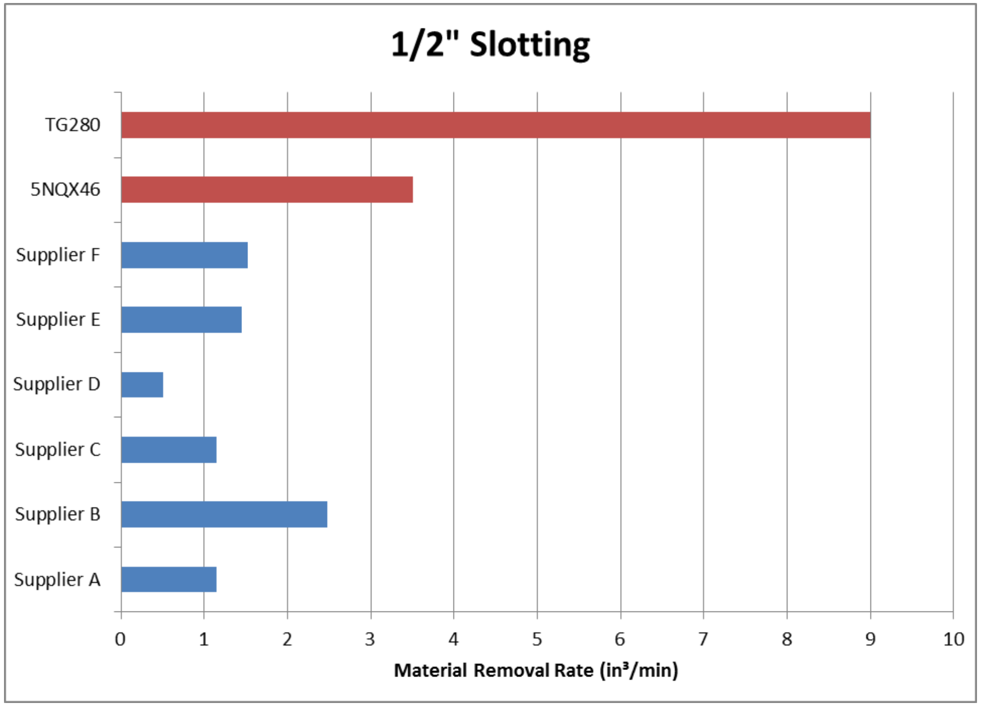


- 5NQX
  - V_w = 70 ipm
  - Q' = 7 in³/min/in
- TG280
  - V_w = 180 ipm
  - Q' = 18 in³/min/in

More Recent test in Waspaloy with TG2 wheel at 7 in³/min/in yielded a G-Ratio of ~ 19

Creep Feed Slotting (IN-718)

- Comparison with Slotting using ½” carbide end mills at recommended feeds and speeds
- Grinding with 5NQX46 and TG280 wheel



Milling — Carbide Endmill								
Tool	DOC	Dia	SFPM	rpm	IPT	Teeth	ipm	in^3/min
Supplier A	0.5	0.5	100	764	0.0015	4	4.6	1.15
Supplier B	0.5	0.5	162	1238	0.002	4	9.9	2.48
Supplier C	0.5	0.5	60	458	0.0025	4	4.6	1.15
Supplier D	0.5	0.5	67	512	0.001	4	2.0	0.51
Supplier E	0.5	0.5	105	802	0.0018	4	5.8	1.44
Supplier F	0.5	0.5	200	1528	0.001	4	6.1	1.53

Grinding								
Tool	DOC	width					ipm	in^3/min
5NQX46	0.1	0.5					70	3.50
TG280	0.1	0.5					180	9.00

Agenda

- Introduction (Company and Presenter)
- Emerging Materials: What and Why?

Grinding PM Ni Based Superalloys (Rene 95, Astroloy, IN-100, N-18 etc.)

- **Application HPT/LPT disks**
  - 200-300°C range in the bore and up to 650°C in the rim
  - Rotational speed > 10,000 rpm (Mech. Stress > 1000 MPa in the bore for take-off)
  - Oxidizing/corrosive environment.

- **PM Alloys vs. Cast Alloys**
  - Grain size is smaller (< 7 microns)
  - Contains higher alloy content
  - Uniform structure, homogeneous distribution of phases
  - Low thermal conductivity
  - Work hardening is severe
  - Adhesion to tool surface

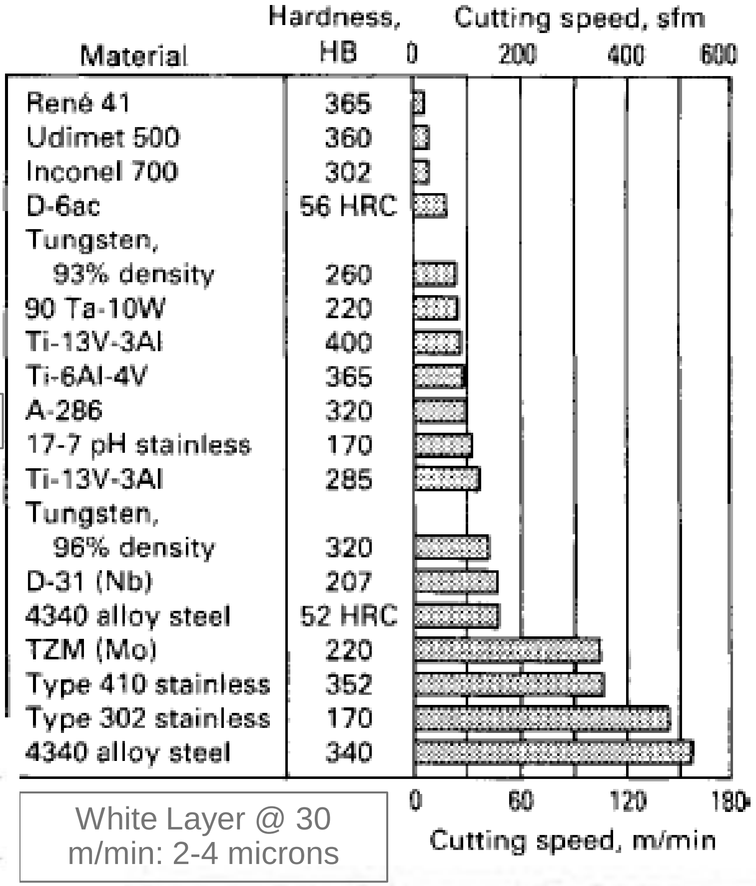
- **Advanced PM Ni-Based Super Alloys**
  - New engine development programmes pushing the use of newer advanced PM Ni based alloys
  - Drivers:
    - capability of significant grain size evolutions
    - metallurgical stability for long term exposures up to 750°C
    - higher creep and fatigue resistance
    - and a density lower than 8.35 g/cm^3.
  - Machining solutions becoming closer to being impractical
    - Up-to 30% reductions in cutting speeds from 3rd generation (40 m/min – 28 m/min)
    - Low productivity not being able to meet existing and future demands

Grinding PM Ni Based Superalloys (Rene 95, Astroloy, IN-100, N-18 etc.

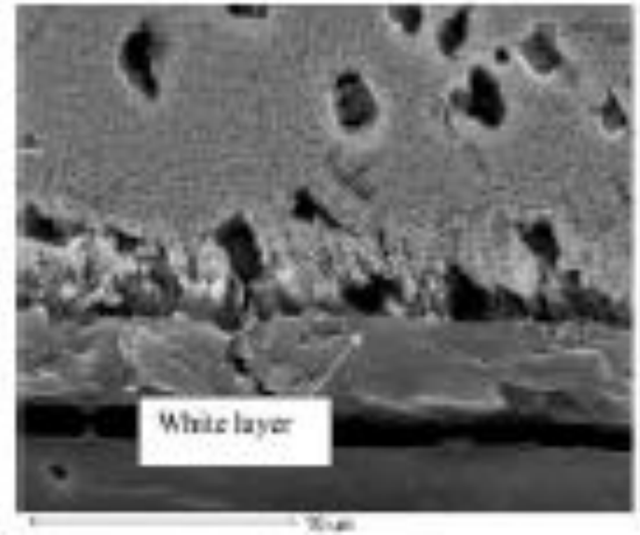
Productivity issues while machining new PM Ni Base Superalloys

- Reduction in cutting conditions
- Surface Condition effect on Fatigue Strength – White layer

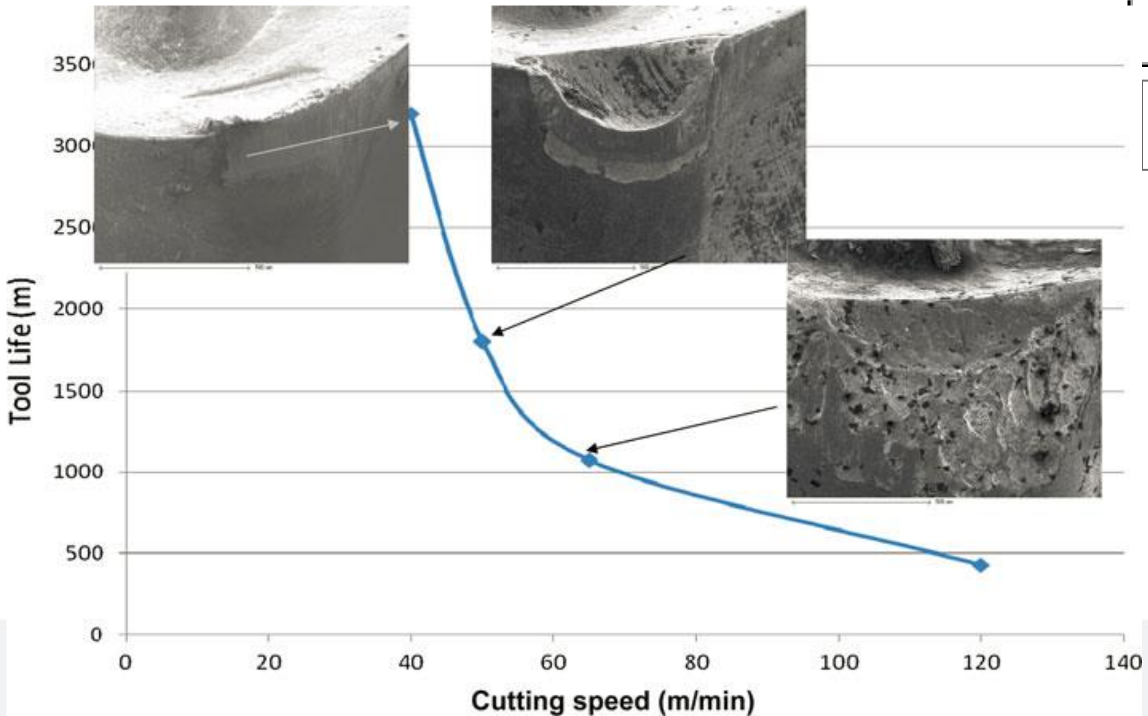
Face Milling



White Layer @ 30 m/min: 2-4 microns



Turning ME16, 30 m/min, 0.1225 mm/rev, 0.125 mm (source: Veldhius et. al., 2009)



Agenda

- Introduction (Company and Presenter)
- Emerging Materials: What and Why?
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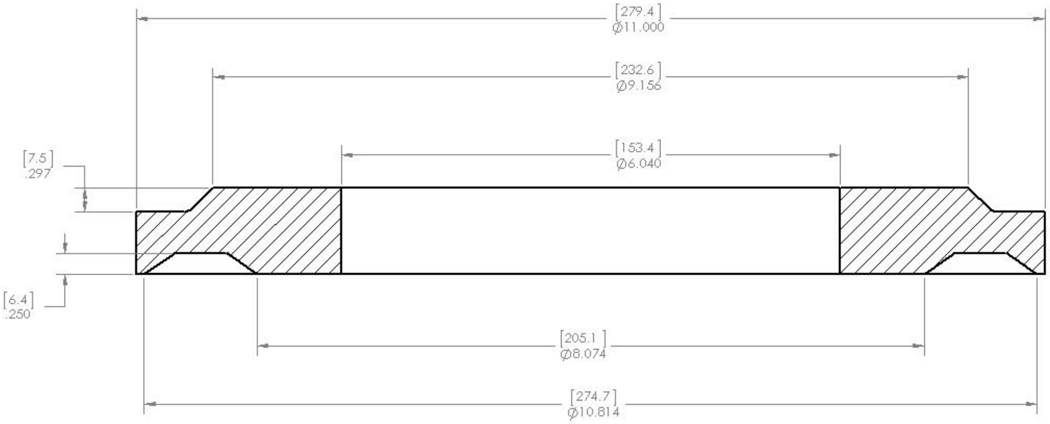
    - Surface grinding (γ-TiAl)
    - Creep-feed grinding (γ-TiAl, IN718)
    - Large Diameter Disk Slotting (IN718)
    - Face grinding (IN718) 

Large-diameter Disk Grinding **(IN718)**

- Machine: Campbell 930
  - 3 linear axes and two rotary axes
  - B axis Positioning only
  - spindle mounted on the B-axis
  - 40 Hp Spindle

- Material: IN 718
  - ~ 15” Diameter
  - ~ 0.3” stock removal

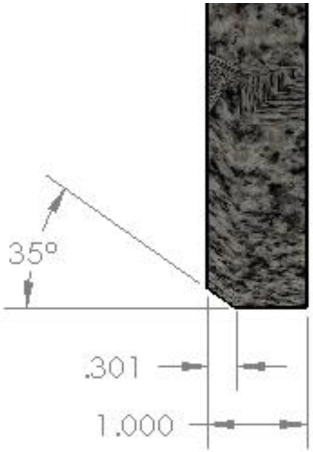


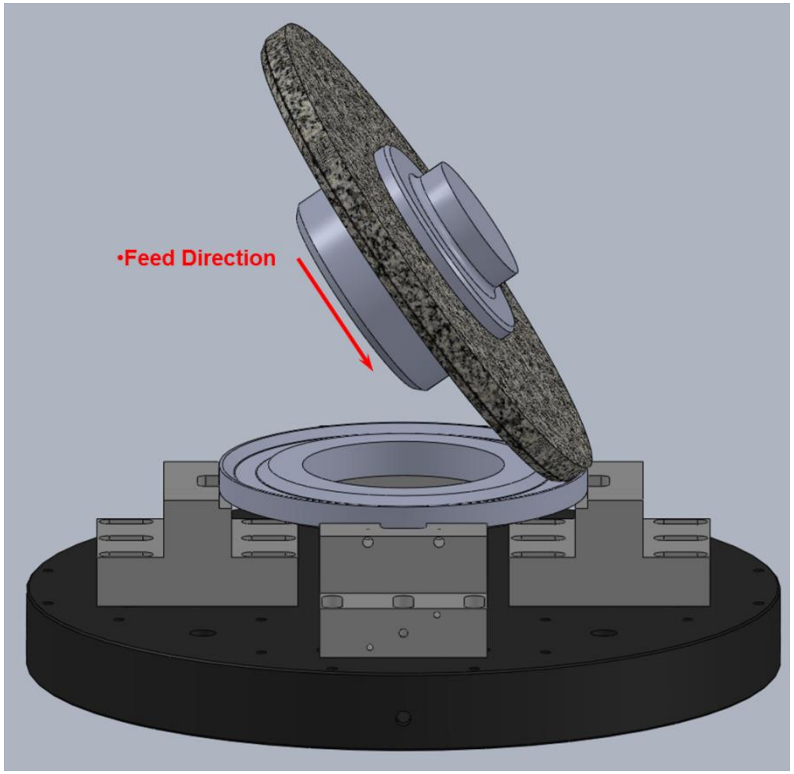
Large-diameter Disk Grinding **(IN718)**

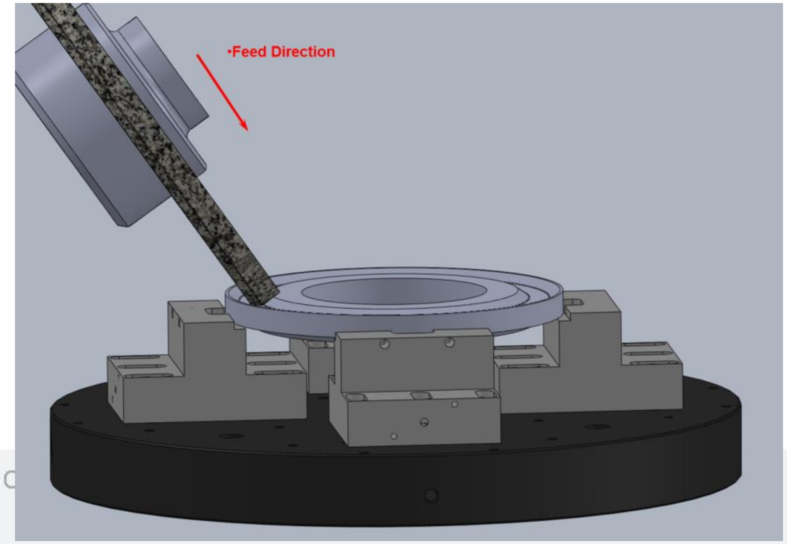
Side 1 — First Plunge outside 35° Surface, Second Plunge Inside 35° Surface

Wheel = TGX

- Q’ = 3.97 in^3/min/in
- Oil Coolant
- Specific Energy = 4.8 Hp/in^3/min



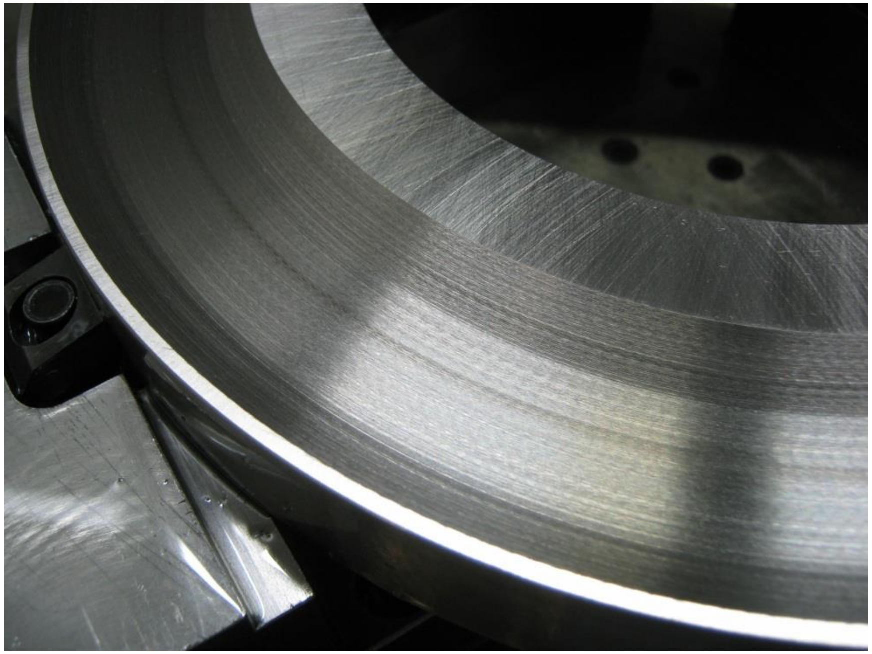


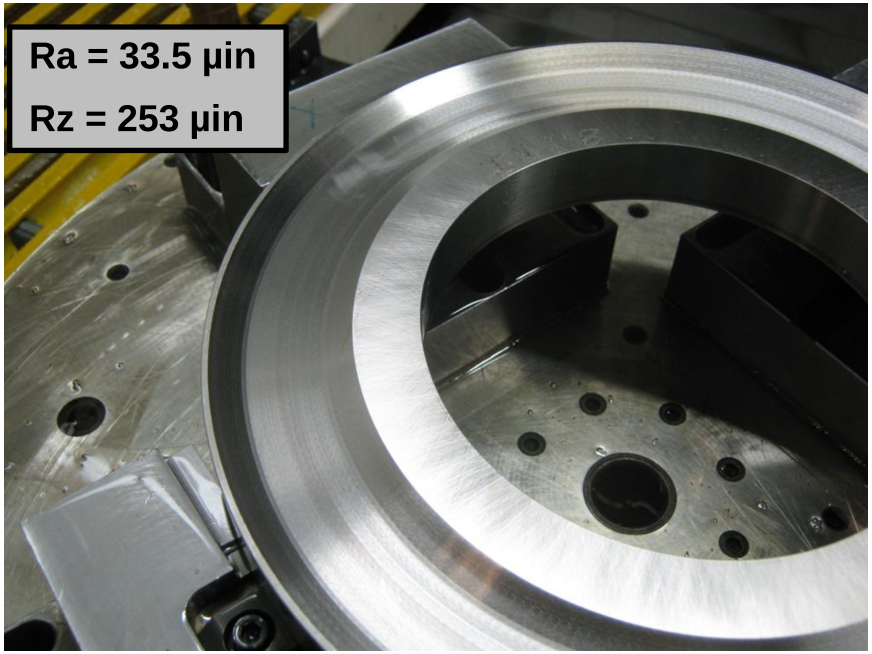


Large-diameter Disk Grinding (IN718)

Inside, Outside 35° & Bottom Surfaces Roughed

Inside, Outside 35° & Bottom Surfaces Finished





Ra = 33.5 µin

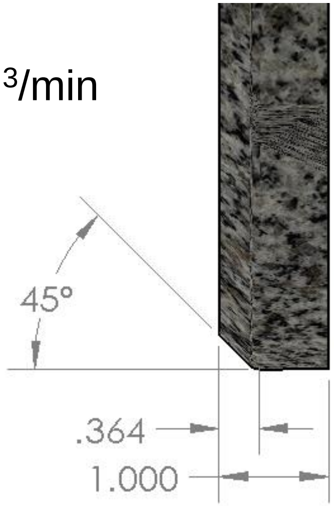
Rz = 253 µin

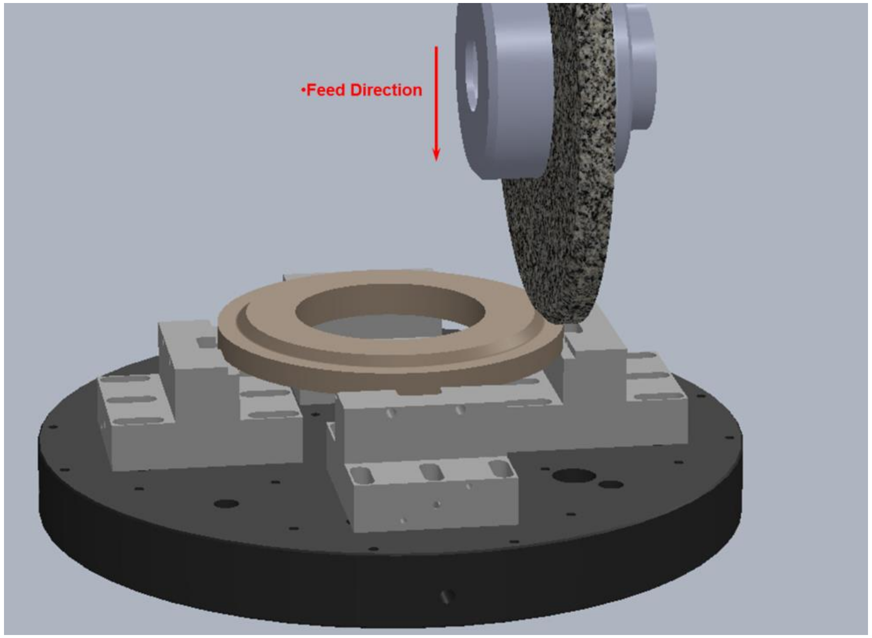
Large-diameter Disk Grinding (IN718)

Side 2 — OD Step & 45° Surface

Wheel = TGX

- Q’ = 3.97 in^3/min/in
- Oil Coolant
- Specific Energy = 4.8 Hp/in^3/min

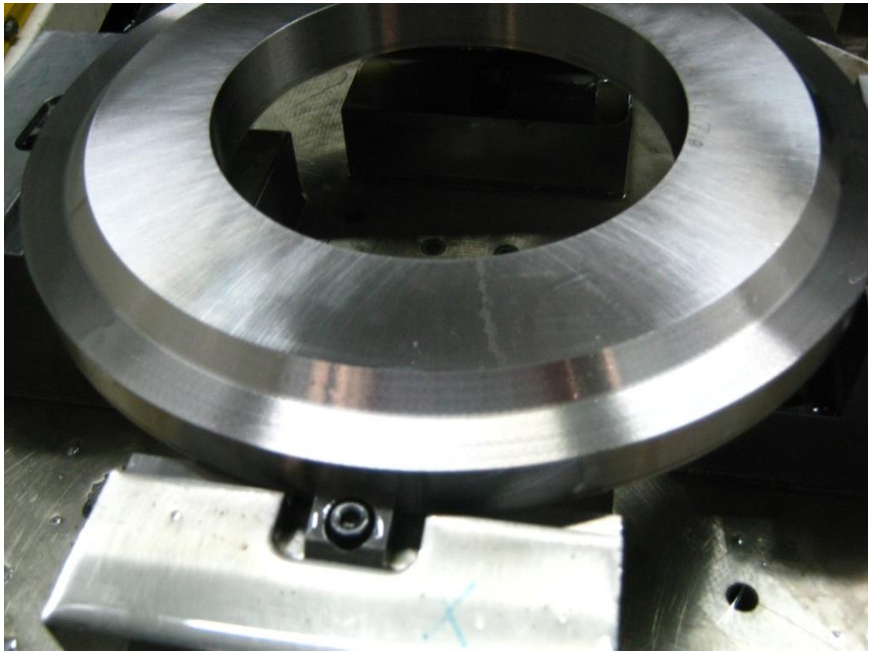


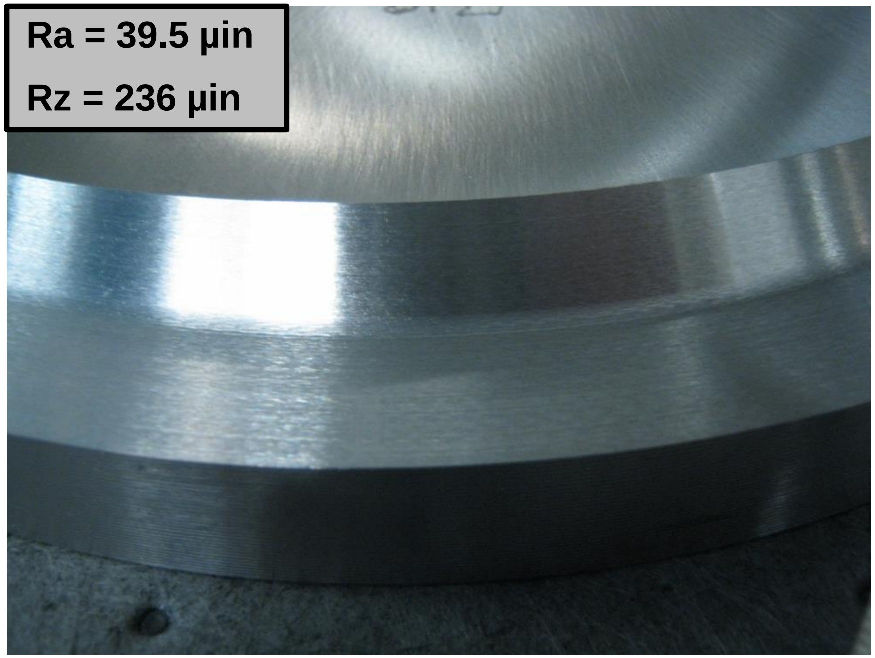


Large-diameter Disk Grinding (IN718)

Outside & 45° Surfaces Roughed

Outside & 45° Surfaces Finished





Ra = 39.5 µin

Rz = 236 µin

Agenda

- Introduction (Company and Presenter)
- Emerging Materials: What and Why?
- Grinding Processes to be covered
    - Surface grinding (γ-TiAl)
    - Creep-feed grinding (γ-TiAl, IN718)
    - Large Diameter Disk Slotting (IN718)
    - Face grinding (IN718)
    - Belt polishing (IN718)

Robotic Abrasive Applications

Abrasive media:

- Coated abrasives, such as belts, discs, flap wheels, and specialty shapes
- Nonwoven abrasives, such as wheels, belts and discs
- Abrasive brushes, such as radial wheels and cup wheels

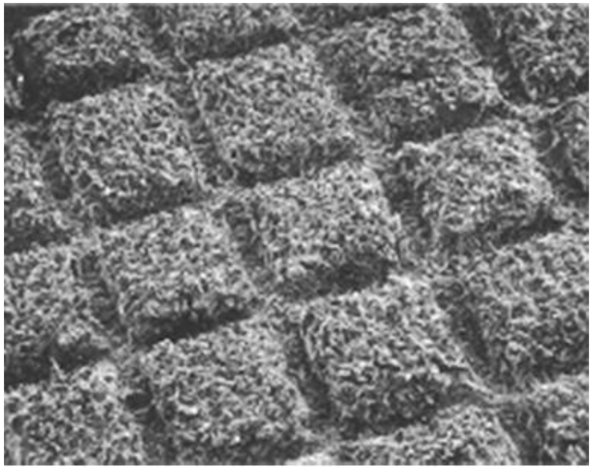
Source: R. McNamee, The Fabricator, 2014

Robotic Abrasive Applications

Essentials for Robotic deburring/polishing

- Controlled pattern of the engineered structure allows for a consistent cut rate as well as surface finish.
- Compliant fixturing or tooling refers to the ability to control the amount of force between the workpiece and the tool
- Conformability refers to the ability of the abrasive to match, or reach, the various contours and intricacies of the workpiece.

Conventional Belt

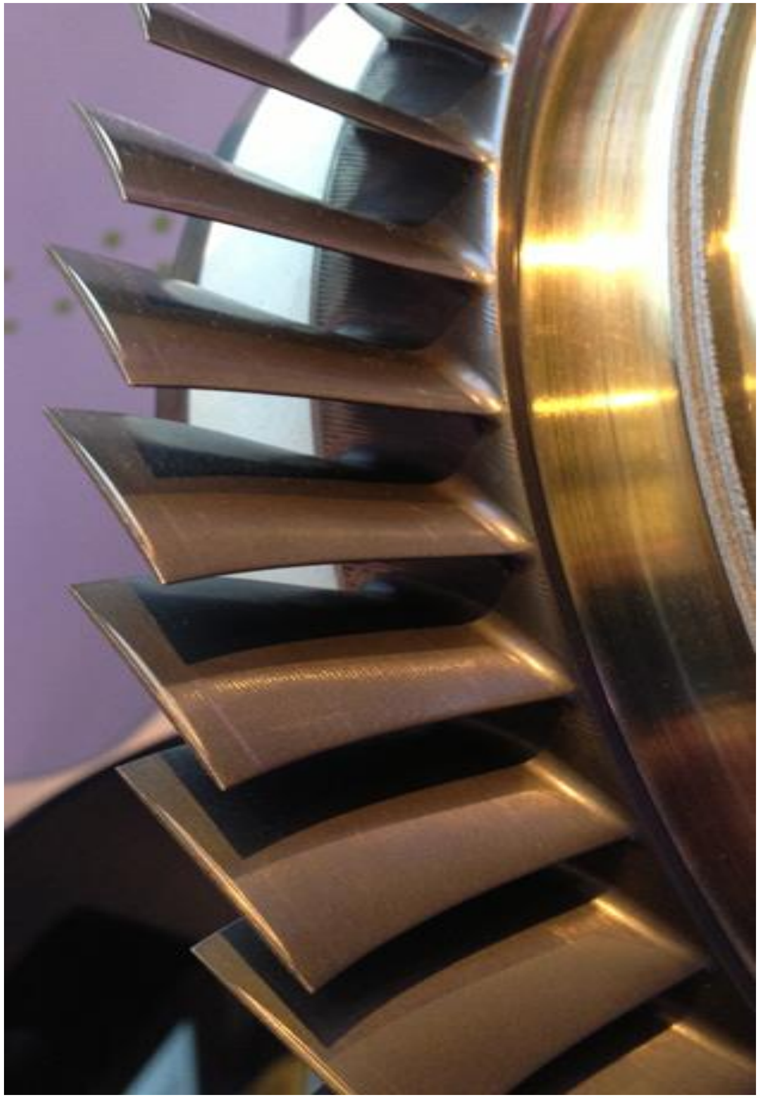


Belt with Engineered Structure

Target Application

Polishing the airfoil surfaces of turbine engine blades or blisks

- The blades and the rotor are machined/ground from solid piece of Ni-based superalloy or titanium
- Various stages have different sized blades with some less than 1”
- Finish requirement = 5-10 µ-in
- Challenges
  - Tooling geometric constraints
  - Life of tooling due to size restrictions
  - Tight tolerances
  - Long process time

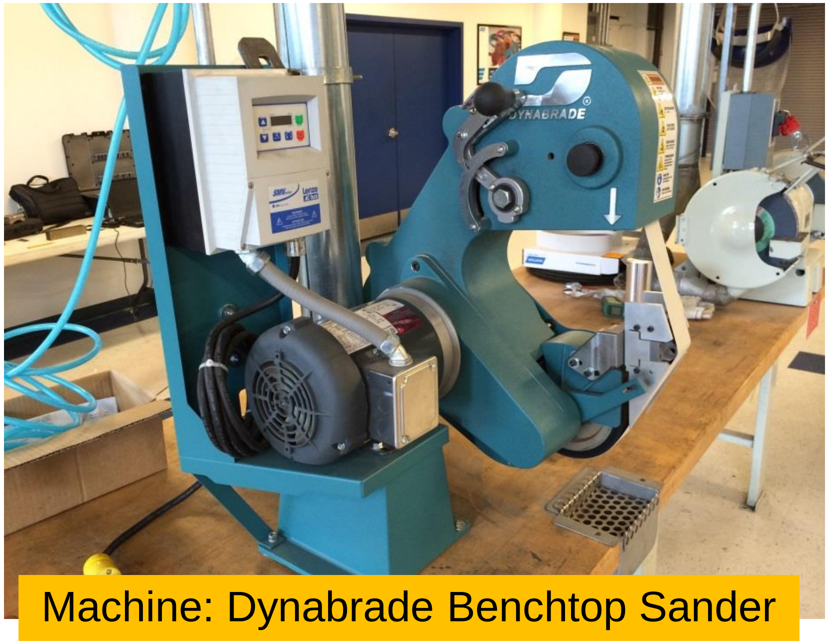


Source: J. Tirpak, Air Force Magazine, 2014

Fixed Abrasive Polishing

- Twin Challenges
  - part geometry and precise robotic programming to ensure maneuverability and access to all areas of interest on the part becomes critical
  - to avoid over-cutting or excess stock removal than what is desired to achieve the finish and cosmetic specifications on a component

Test Methodology



Machine: Dynabrade Benchtop Sander

Work Material: IN 718 (20 µ-in Ra)

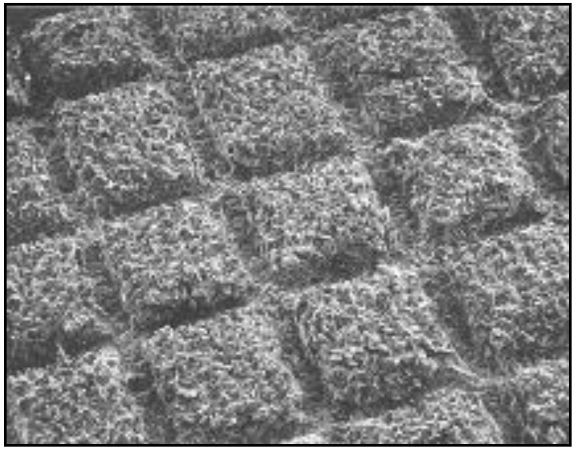
Concave Surface Polishing

Convex Surface Polishing

Product Technology : Norax Engineered Abrasives

Features

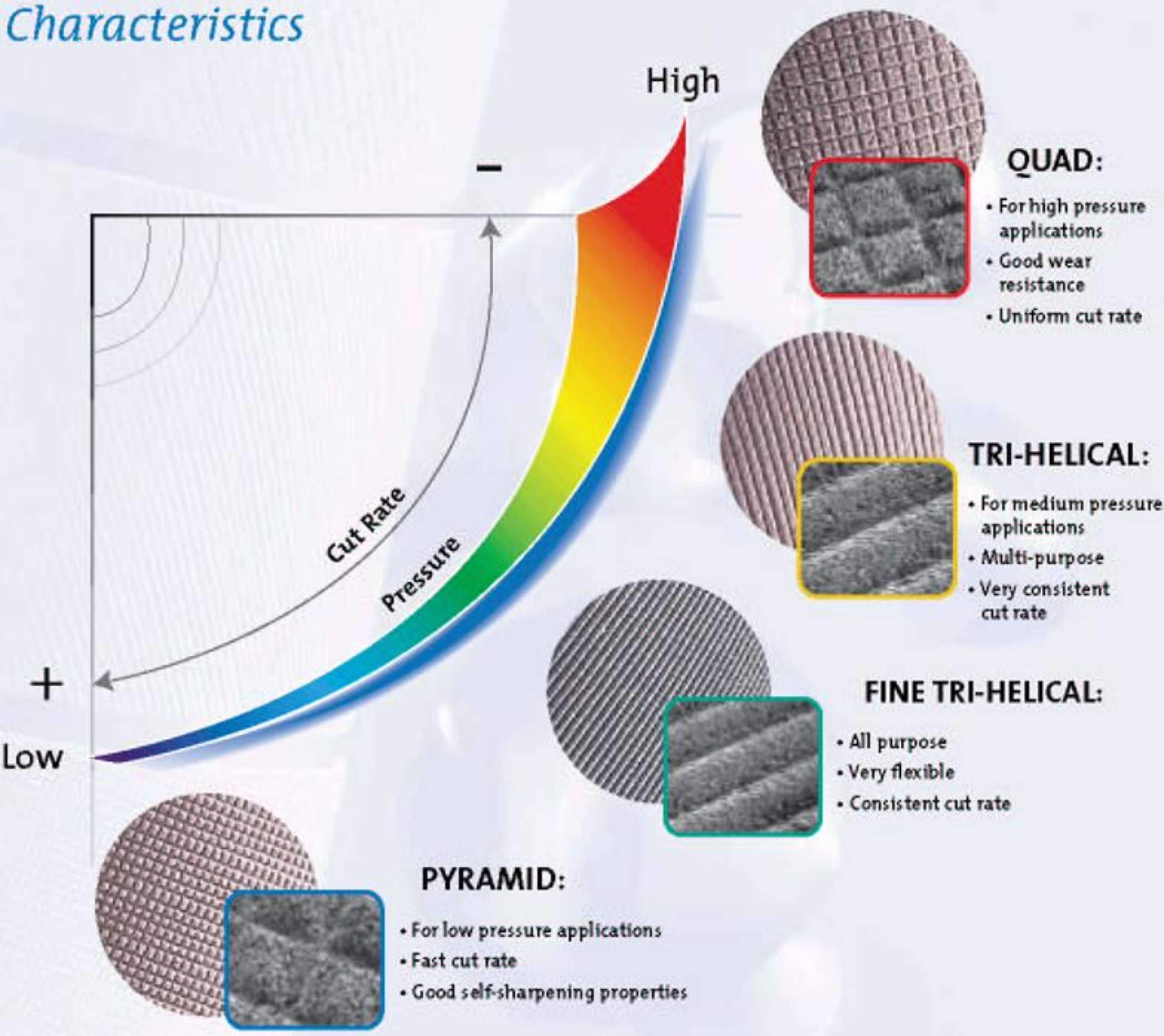
- Multi-layer of erodeable structured abrasive grain
- As the belt wears, dull abrasive particles are lifted out of the belt and a new layer of sharp abrasive is exposed to the work surface
- The continuous replacement of dulled abrasive particles can result in longer belt life, higher cut rates, and a more consistent surface finish.
- A surface powder grinding aid is incorporated into this line of belts to increase initial belt aggressiveness and decrease grinding temperature.



NORaX Engineered Abrasive

Product Technology : Norax Engineered Abrasives

- Patterns and performance differences



QUAD:
- For high pressure applications
- Good wear resistance
- Uniform cut rate

TRI-HELICAL:
- For medium pressure applications
- Multi-purpose
- Very consistent cut rate

FINE TRI-HELICAL:
- All purpose
- Very flexible
- Consistent cut rate

PYRAMID:
- For low pressure applications
- Fast cut rate
- Good self-sharpening properties

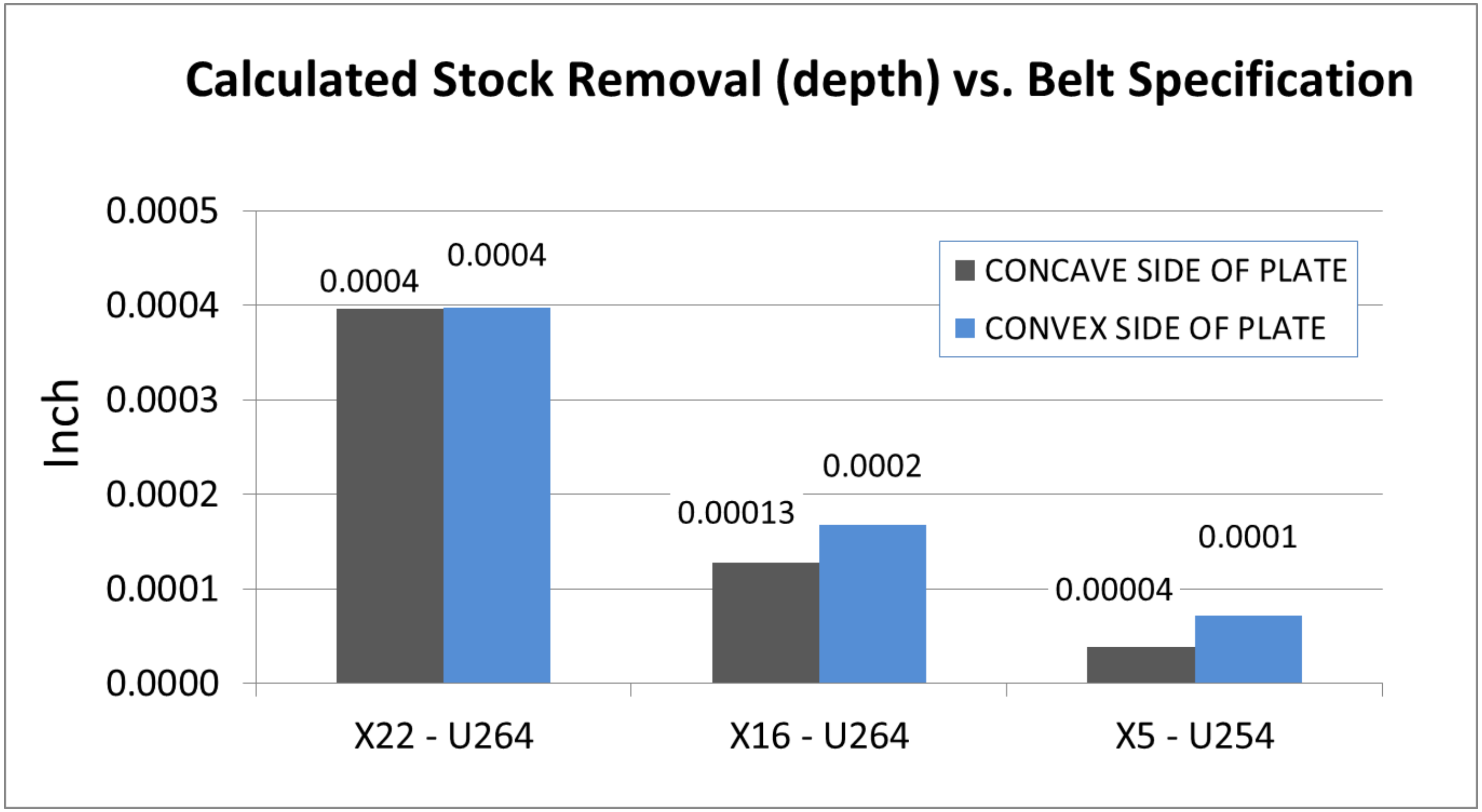
Test Details

- The work pieces were weighed before and after each grind
- The contact time recorded, allowed for the stock removal rates to be calculated.
- Knowing the amount of material removed allowed for an approximate depth of cut calculation, using the contact area and the material density.
- The surface finishes were recorded before and after polishing using a profilometer and a profile scan.

Grinding Sequence for 10 piece run:

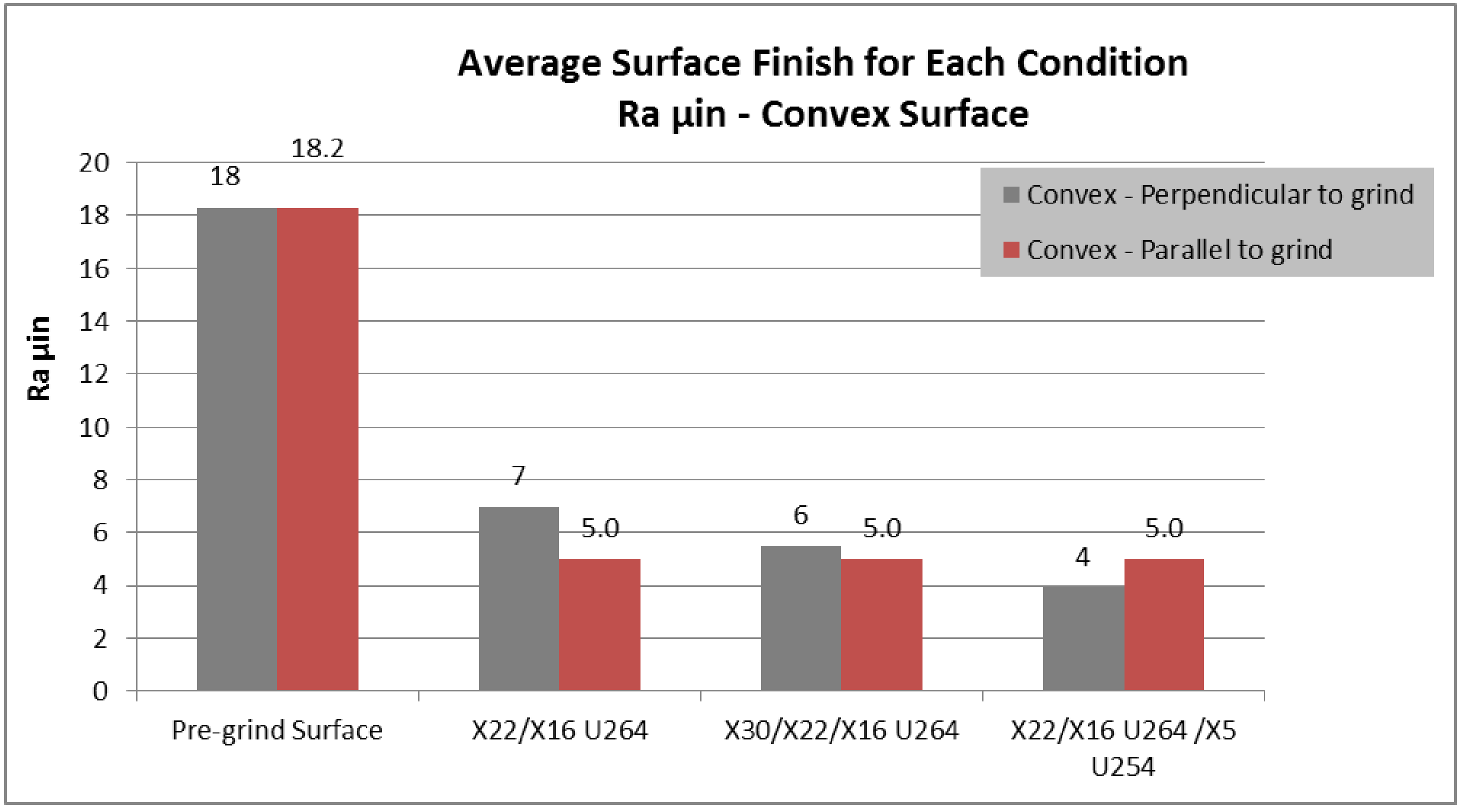
- X22 U264
- X16 U264
- X5 U254

Estimated Stock Removal (depth)

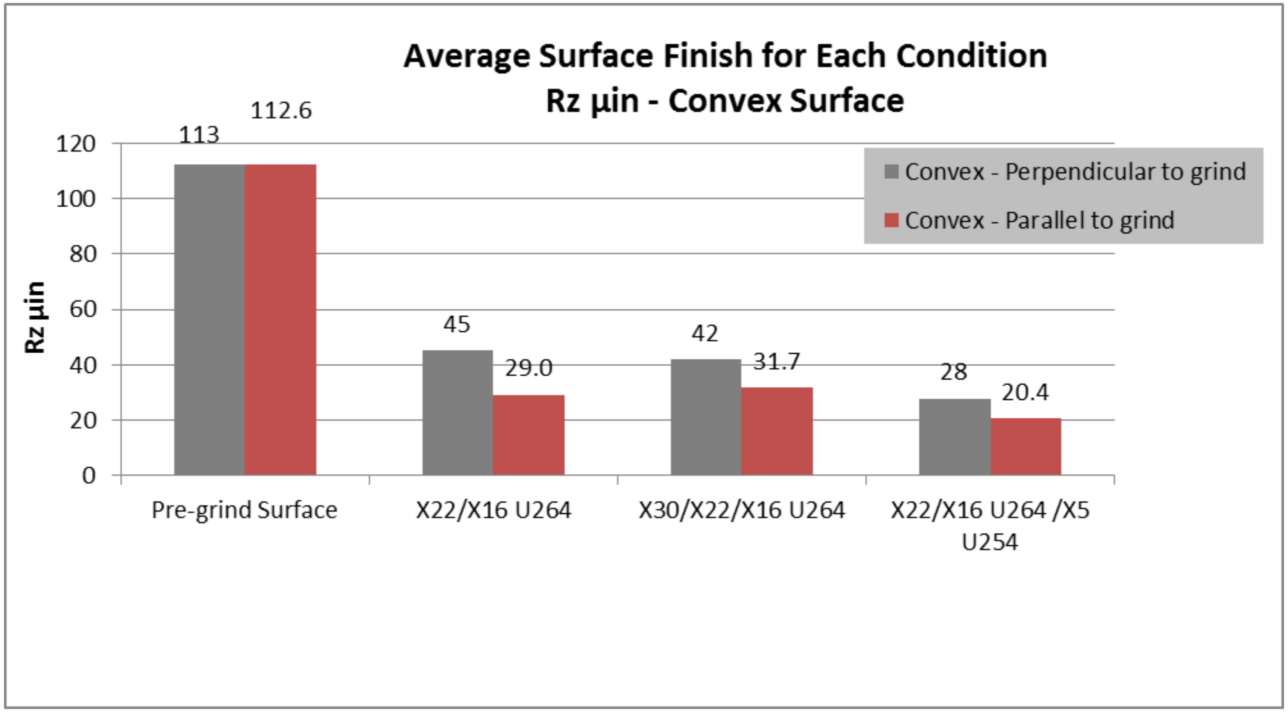


10 piece Grinding Test Data

Surface Finish Ra



Surface Finish Rz



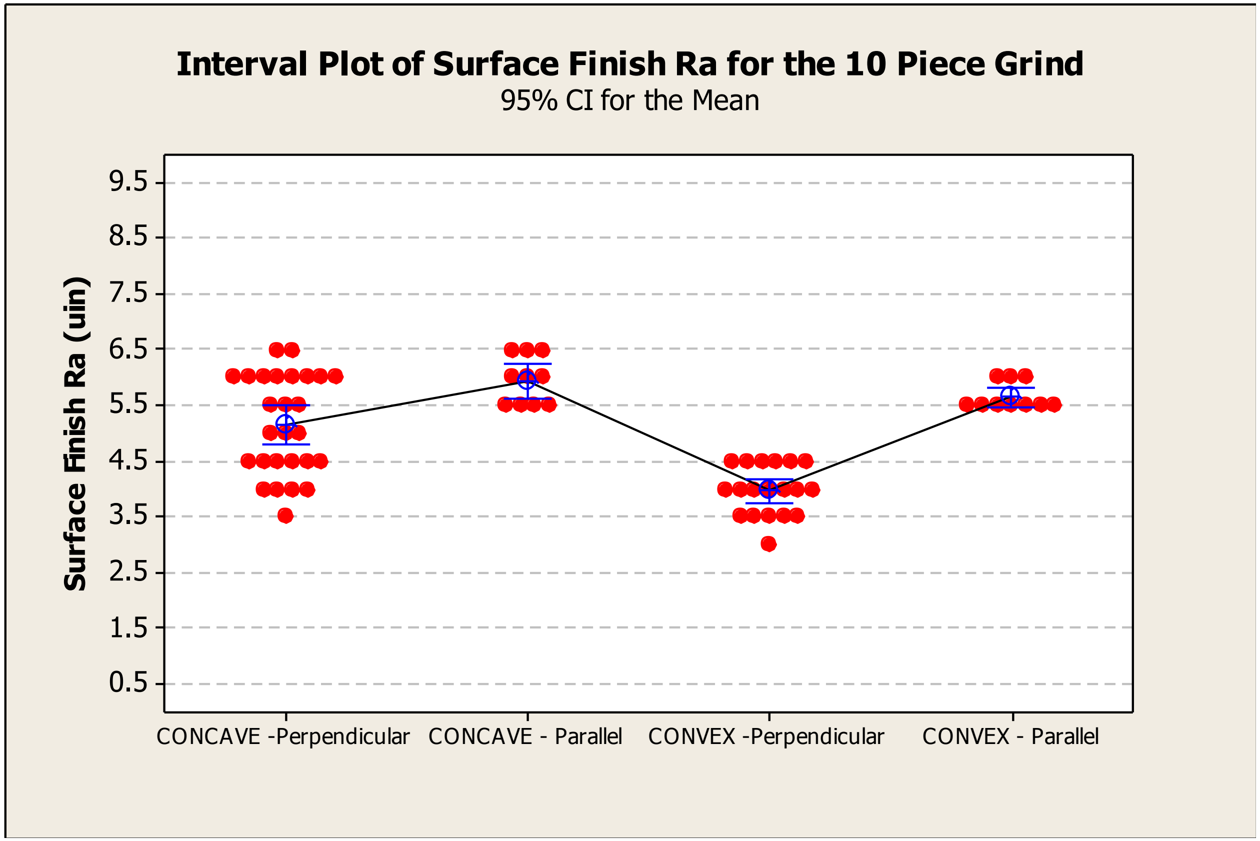
Surface Finish Ra

Grinding Sequence:

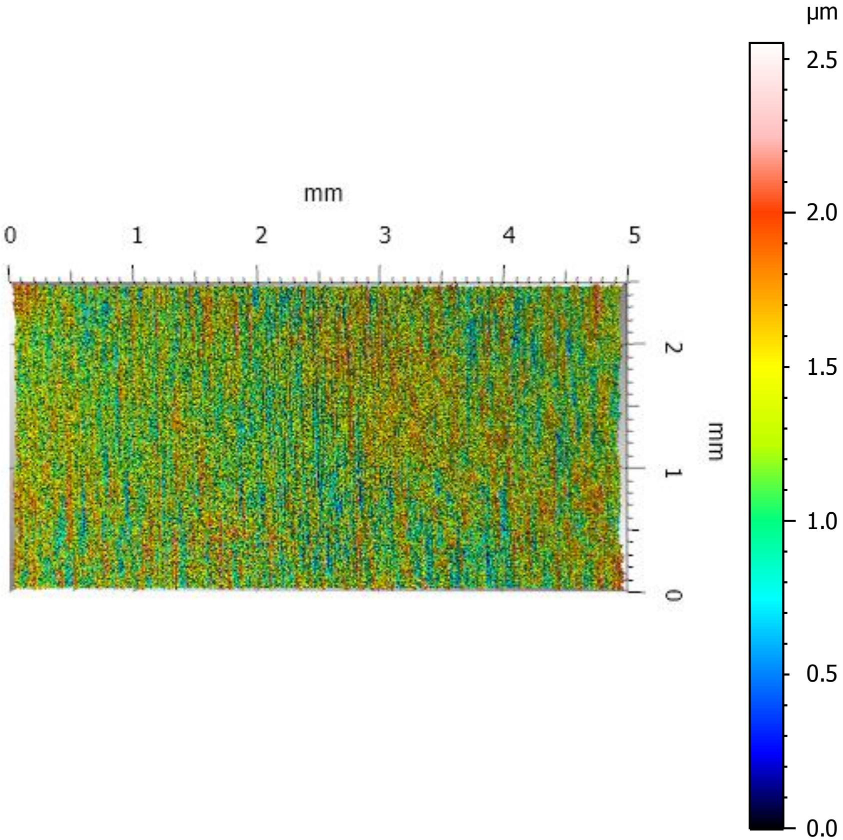
X22 U264

X16 U264

X5 U254



- Each red dot is a Ra measurement taken from the workpieces ground in the 10 piece run
- 3 measurement taken for each piece in the perpendicular direction
- 1 measurement taken from each piece in the parallel direction



Extracted 2D Profile Parameters

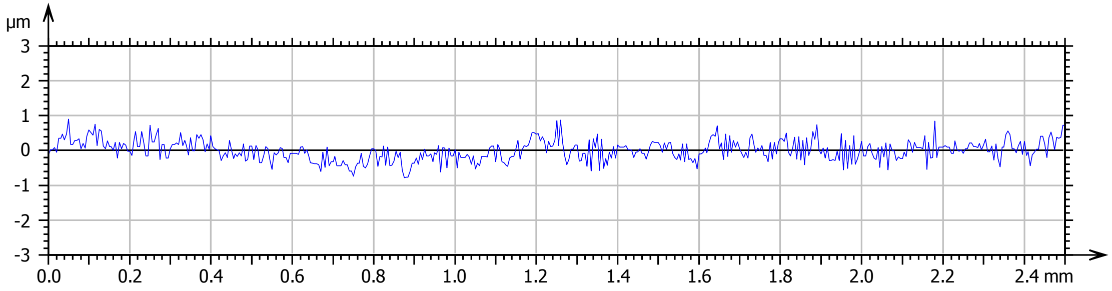
		Mean	Std dev	Min	Max
Amplitude parameters - Roughness profile					
Rp	µm	0.40	0.05	0.29	0.55
Rv	µm	0.37	0.05	0.28	0.49
Rz	µm	0.77	0.09	0.60	1.01
Ra	µm	0.13	0.02	0.10	0.18
Rq	µm	0.17	0.02	0.13	0.22
Amplitude parameters - Waviness profile					
Wp	µm	0.49	0.15	0.20	0.97
Wv	µm	0.45	0.12	0.19	0.76
Wz	µm	0.93	0.23	0.39	1.49
Wa	µm	0.19	0.06	0.08	0.34
Wq	µm	0.23	0.06	0.10	0.38

Part #	Measured Surface	Ra (uin) high	Ra (uin) low	Ra (uin) mean
35	Convex polished	7.1	3.9	5.1

Area Parameters

Sa	0.29	µm
Sq	0.37	µm
Sz	2.52	µm
Sp	1.36	µm
Sv	1.19	µm
St	2.55	µm

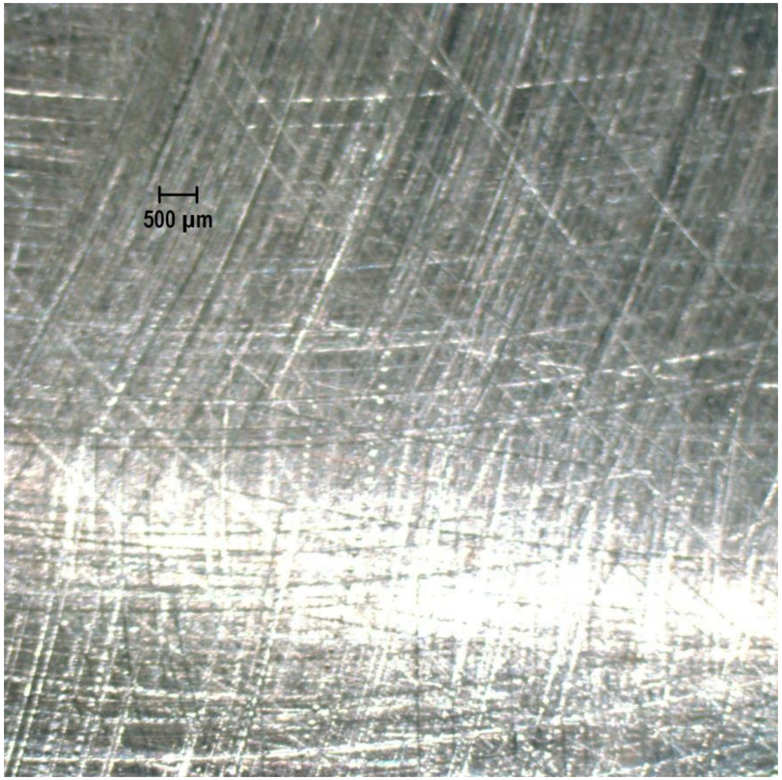
Representative 2D Profile



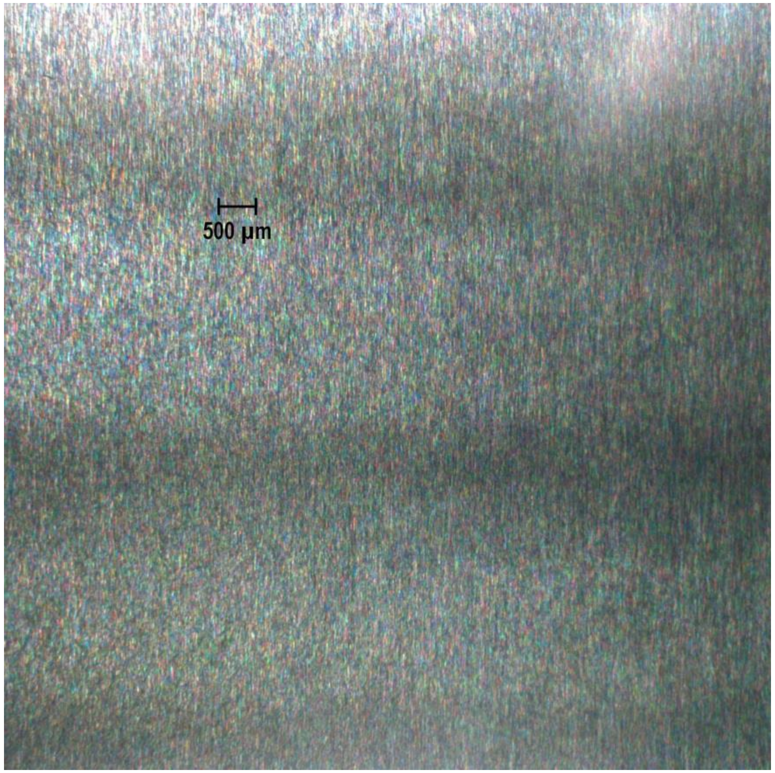
#35 Convex Polished

Part Before and After Grind

Rough Finish

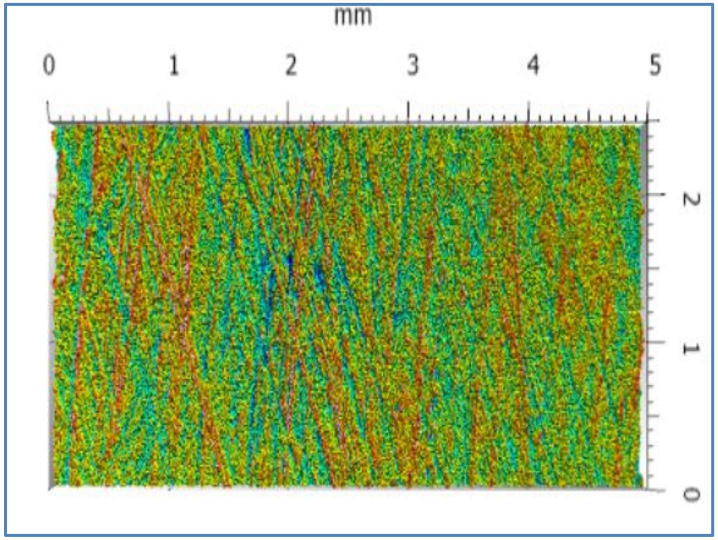


X5 U254 (Part #41)

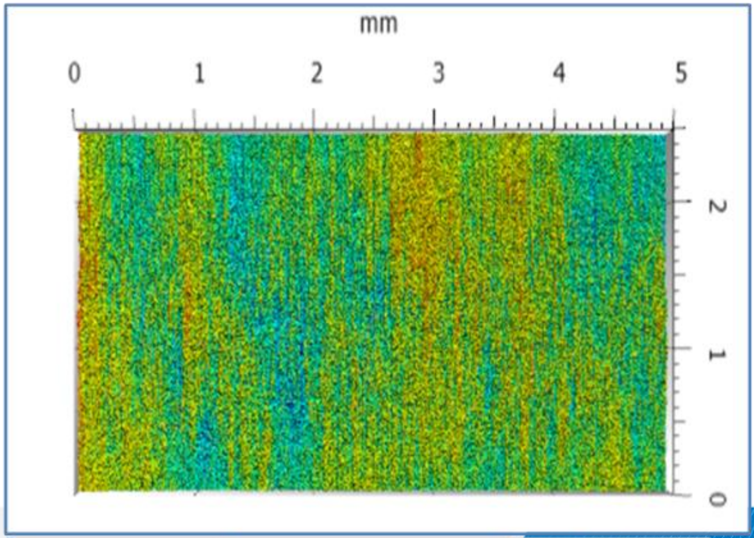


Lay Direction On Ground Parts

- In loose abrasive applications, *such as chemical vibratory polishing or extrude hone*, the surface finish is typically the same irrespective of the measuring direction.
- When utilizing the coarser belts the grind-lines were evident and the surface measurements in the perpendicular direction were indeed greater than measured in the parallel direction.
- The grind-lines were greatly reduced when following a sequential process with a series of belts.
- Parallel and perpendicular surface finish measures were the same showing a non-directional lay on Inconel 718 material, very similar to a loose abrasive process.

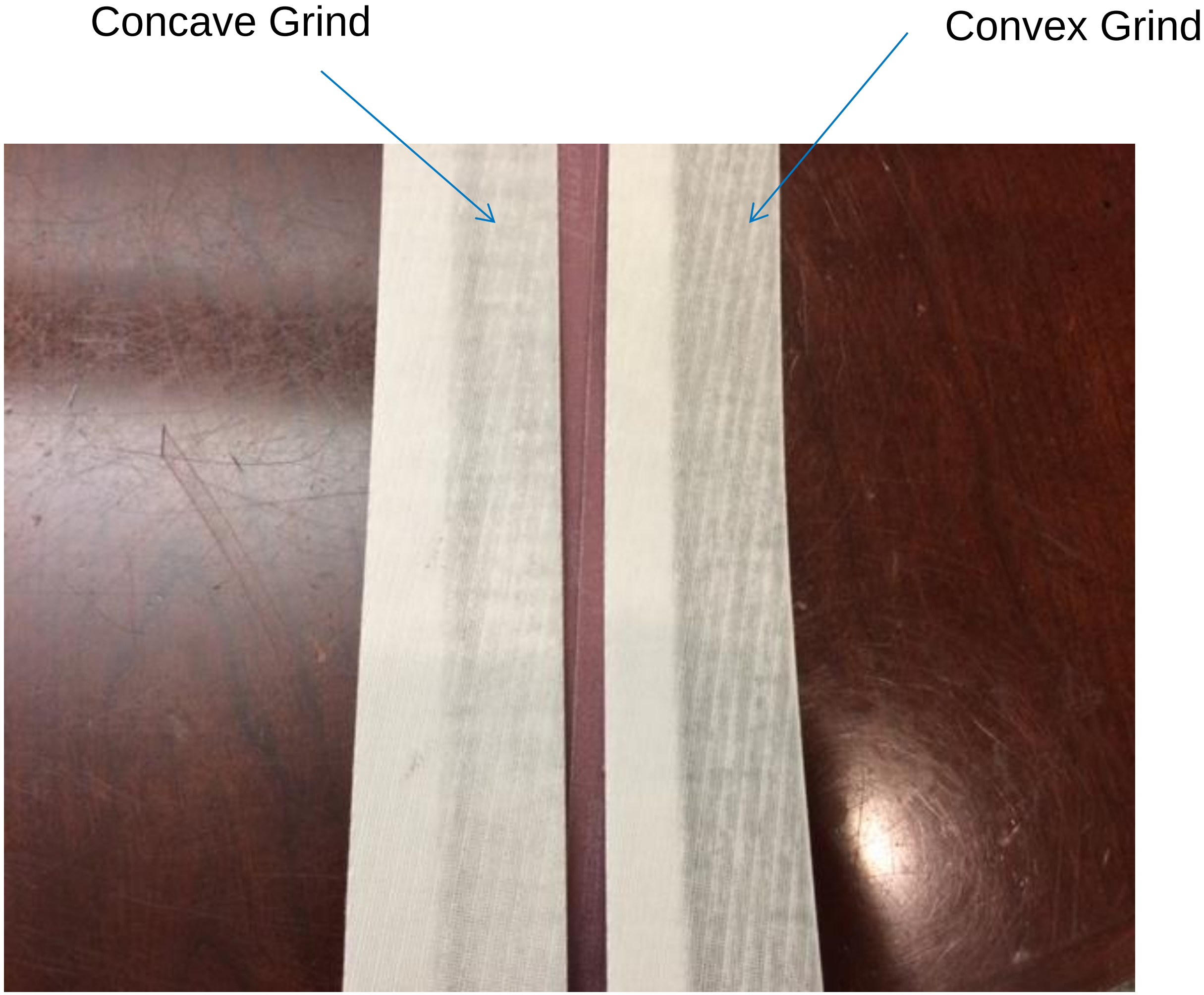


3D Surface Texture Image of coarse finish



3D Surface Texture Image of fine finish

X5 U254 Belt After Grinds

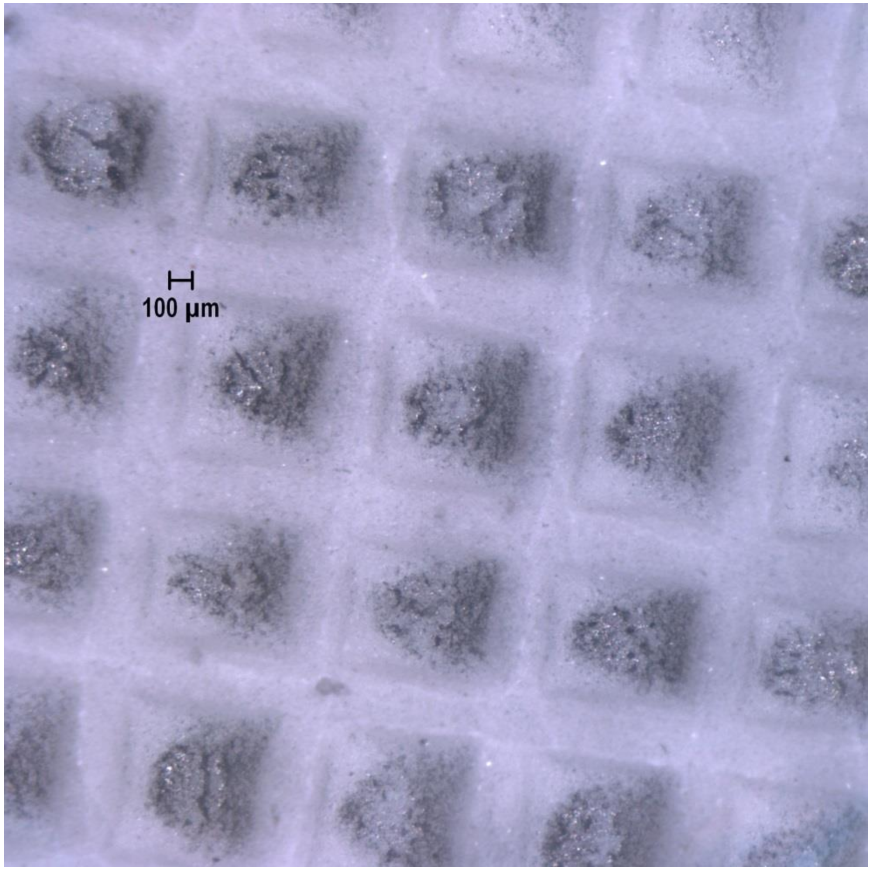


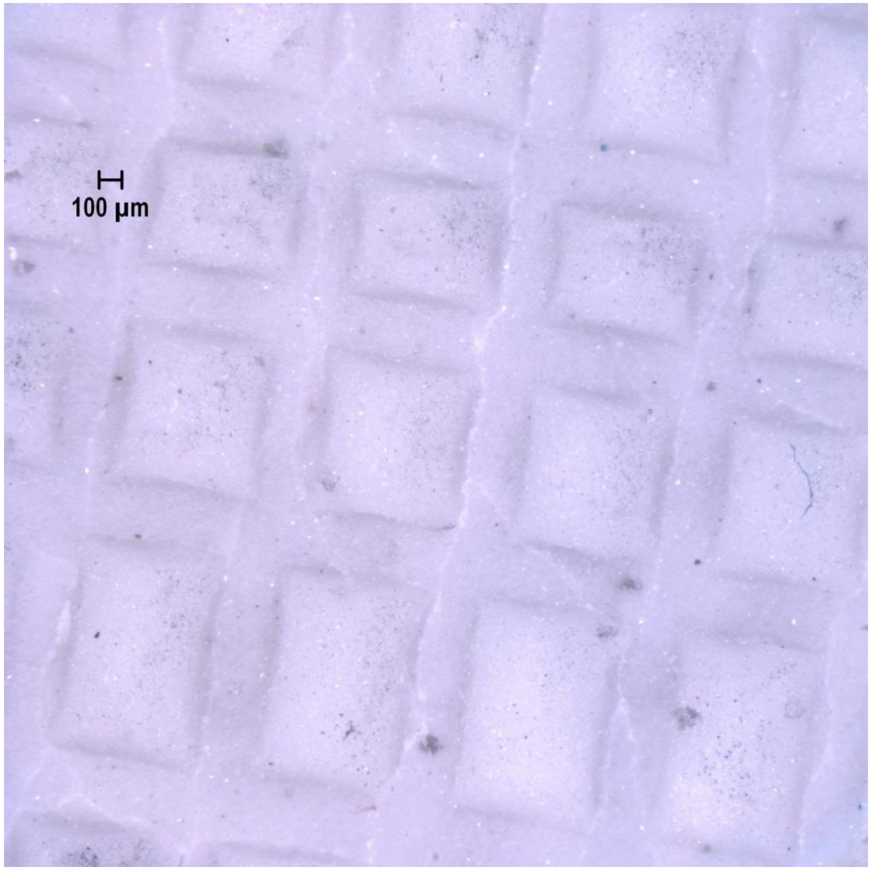
10 piece Grind

Convex X5 U254 (Concave was very similar)

Used on Concave Side

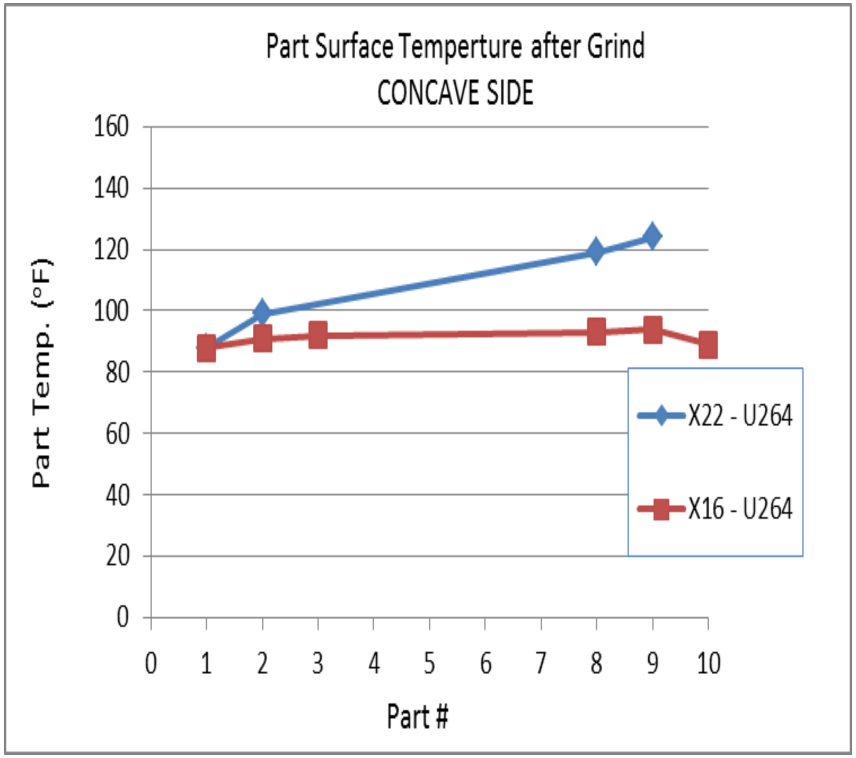
Unused

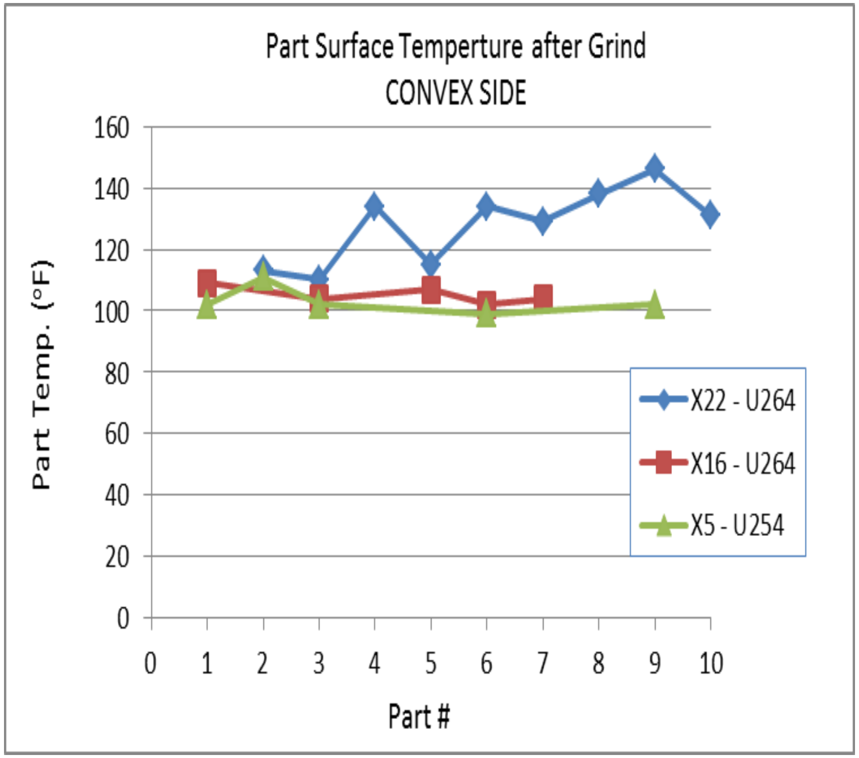




10 piece Grind

Workpiece Surface Temperature after Grind





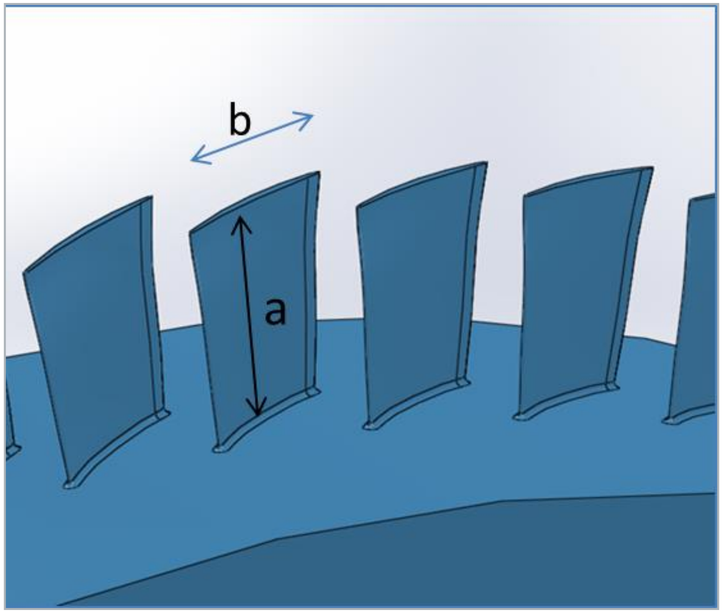
Estimated Cycletimes

INPUTS

	Blade Design 1	Blade Design 2
Number of Blades	36	36
Blade depth (a)	1.2	2.2
Blade Width (b)	1.1	1.1
Concave side Number of passes across blade	4	8
Convex side Number of passes across blade	4	8
Concave side Number of steps to blade depth	1	2
Convex side Number of steps to blade depth	1	2
Estimated None contact time per blade (seconds)	5	5
Belt Change Time (seconds)	60	60
Number of belts: X30/X22/X16/X5	4	4

OUTPUTS

	Blade Design 1	Blade Design 2
Concave Time per pass (seconds)	0.55	0.55
Convex Time per pass (seconds)	0.8	0.8
Concave Side Total time per blade (seconds)	2.2	8.8
Convex Side Total time per blade (seconds)	3.2	12.8
TOTAL TIME PER BLADE (seconds)	**17.1**	**33.3**
TOTAL TIME PER BLISK PER BELT GRIT SIZE (minutes)	**10.2**	**20.0**
TOTAL TIME PER BLISK (minutes)	**41**	**80**



Estimated Stock Removal

X30 - U264	0.001	in
X22 - U264	0.0004	in
X16 - U264	0.00012	in
X5 - U254	0.00004	in

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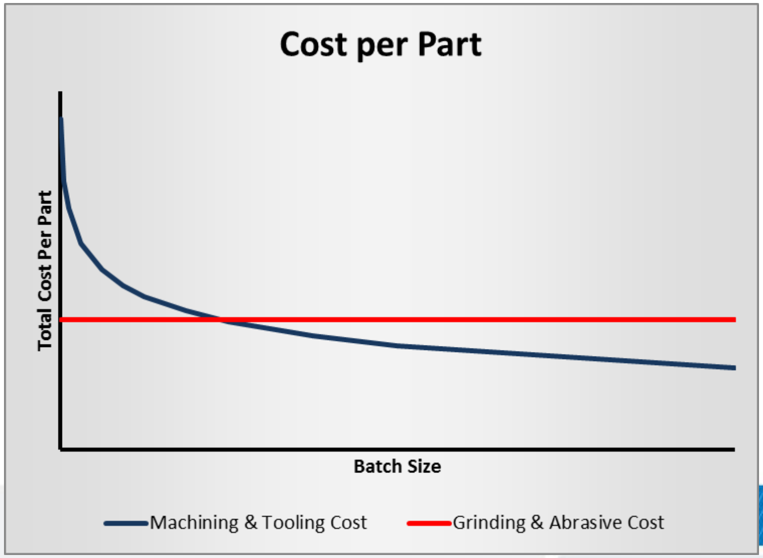
  - Large Diameter Disk Slotting (IN718)
  - Face grinding (IN718)
  - Belt polishing (IN718)
  - Gear grinding from solid (8620, 4140) ☜

Grinding Gears from Solid

- **Why?**
  - Quick response to Customer needs
  - Elimination of tooling lead time
  - Reduced tooling cost
  - Reduced tooling inventory
  - Competitive cycle time
  - Capital Equipment Cost Avoidance

- **Who?**
  - Job Shops
  - Producers of Large Gears
  - Maintenance and Repair Facilities
  - Gear Box Rebuilders
  - Producers of Specialty Gears

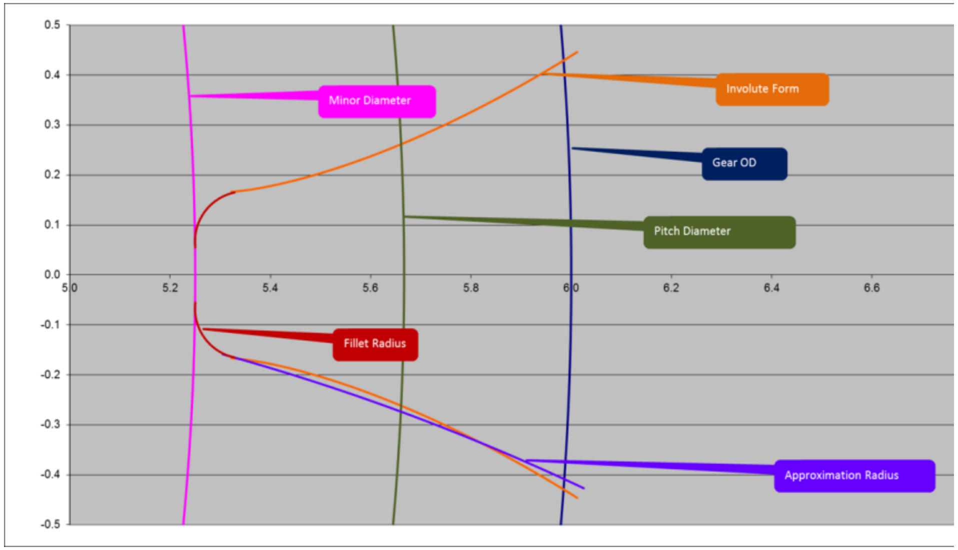
- **When?**
  - Short Lead Time
  - Special Form
  - Small to Medium Lot Size



Grinding Gears from Solid

Test Material: 8620

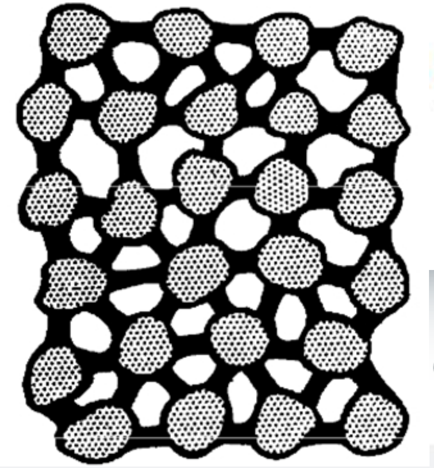
  - Prior to Heat Treatment
- 3 Diametral Pitch
  - Form Depth 0.750”
- Involute Approximation
- Thickness 3”
  - Two 1.5” parts Stacked



Test Process

- Creep Feed Form Grind
  - Up and Down Grind
- Non Continuous Dress
- Castrol Variocut B27 (straight oil)
- Coolant Velocity Matches Wheel Velocity
- High Pressure Cleaning Nozzles
- Coolant Flow Guide

Key Technology Drivers



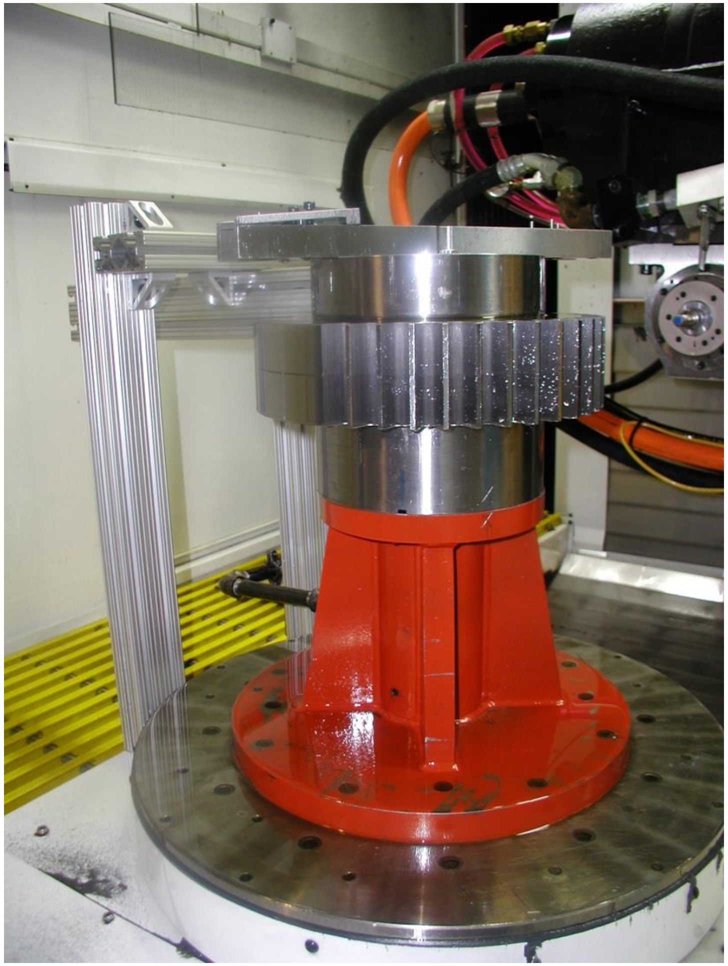
NORTON SAINT-GOBAIN VORTEX2 TECHNOLOGY

NORTON SAINT-GOBAIN VITRIUM3

NORTON SAINT-GOBAIN QUANTUM X™

Grinding Gears from Solid

- **Machine Tool**
  - 40 HP Spindle
  - 4 + 1 Axis
  - 45 gpm Coolant
  - Straight Oil
- **Abrasive Technology**
  - TGII Vitrium Bond Wheel
  - 5NQ Agglomerated Vitrium Bond Wheel



Grinding Gears from Solid

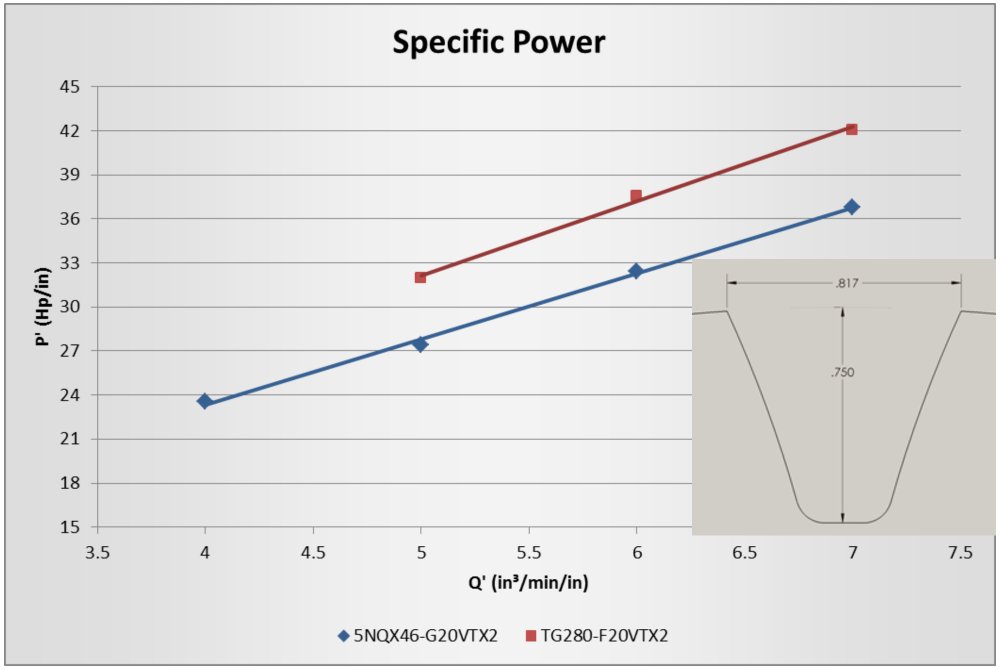
Productivity @ 7.0 Q’

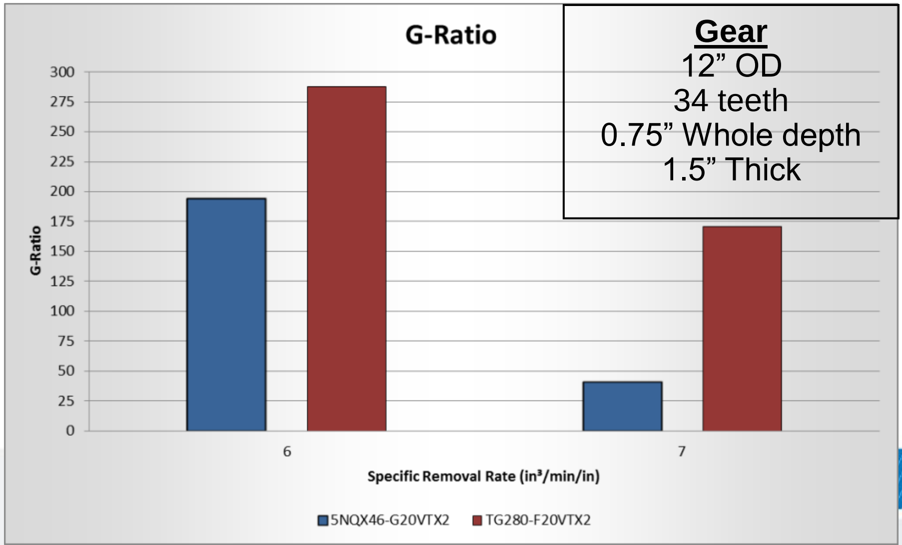
- Time per Gap ~ 52 Seconds
- Grind Time ~ 30 minutes

~ 35 Minutes @ 6.0 Q’
(15 & 17.5 Min per 1.5” thick Gear)

Wheel Life

- 575 Gears per Wheel — TG2
  @ Q’ = 6.0
- 445 Gears per Wheel — NQ
  @ Q’ = 6.0
- 394 Gears per Wheel — TG2
  @ Q’ = 7.0

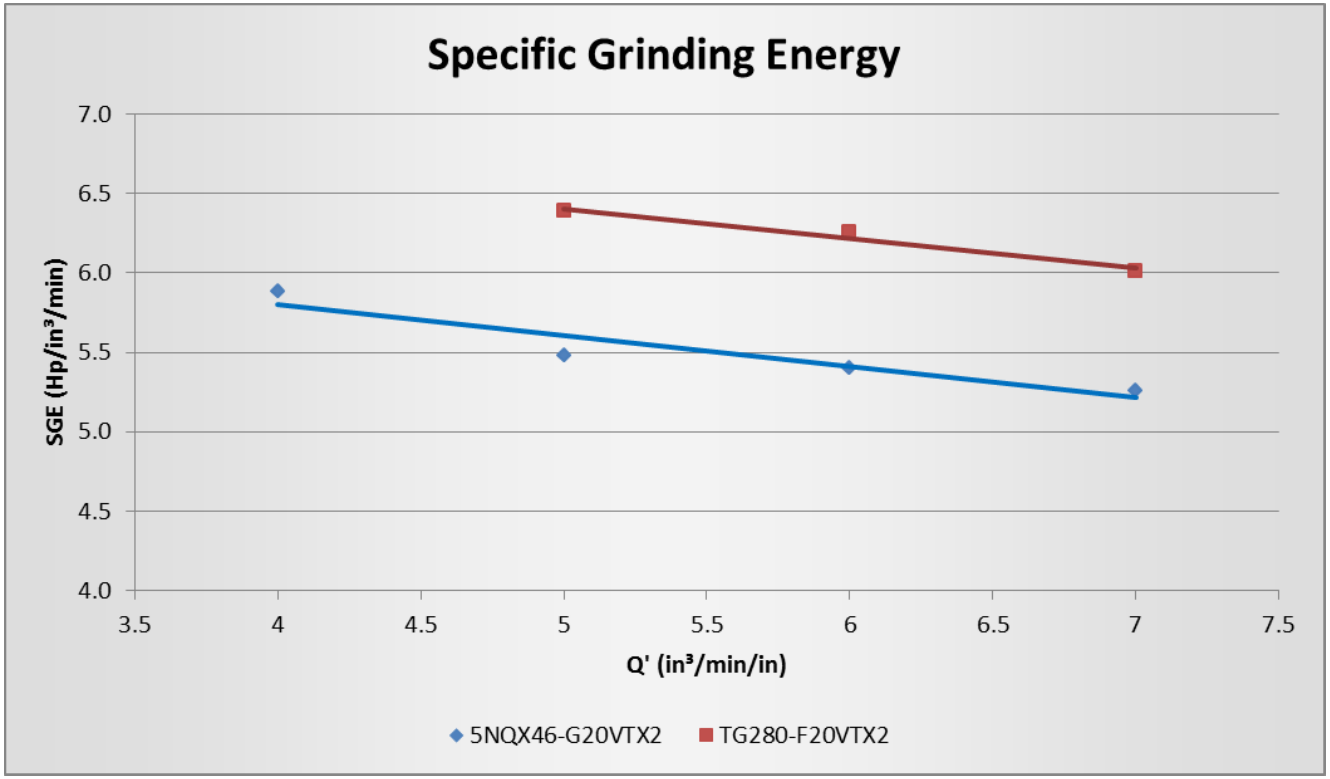




Gear
12” OD
34 teeth
0.75” Whole depth
1.5” Thick

Grinding Gears from Solid

Specific Grinding Energy



- Specific Grinding energy is an indication of the efficiency of a removal process.
- Traditional grinding processes typically have grinding energies 2 to 3 or more times those seen in this process

Rough Grind from Solid & Grind to Finish

Material: 4140 Through hardened to Rc 53-57

Abrasive: 5NQX60-G20VTX2

Wheel Speed: 6,400 sfpm

Depth of Cut per pass: 0.050”

Feed rate: 100 ipm

Q’: 5in^3/min/in

Power: 20.5 Hp/in

Whole depth: 0.640”

Face Width: 11”

G-ratio: ~100 — (less than 0.004” diametric wear/tooth with 14” wheel)

Grind time per Tooth: 115 seconds

Material: 4140 Through hardened to Rc 53-57

Abrasives: 5NQX60-G20VTX2 and TG280-G20-VTX2

Wheel Speed: 6,200 sfpm

Depth of Cut per pass: 0.003” & 0.006”

Feed rate: 300 ipm

Q’: 0.9in^3/min/in & 1.8in^3/min/in

Power (Hp/in): <10 @ 0.003 DOC and <17 @ 0.006 DOC

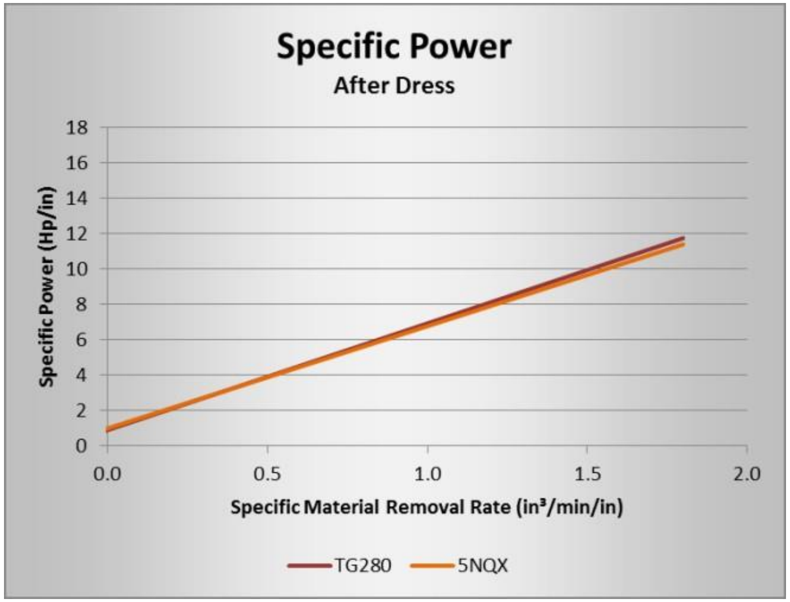
Whole depth: 0.640”

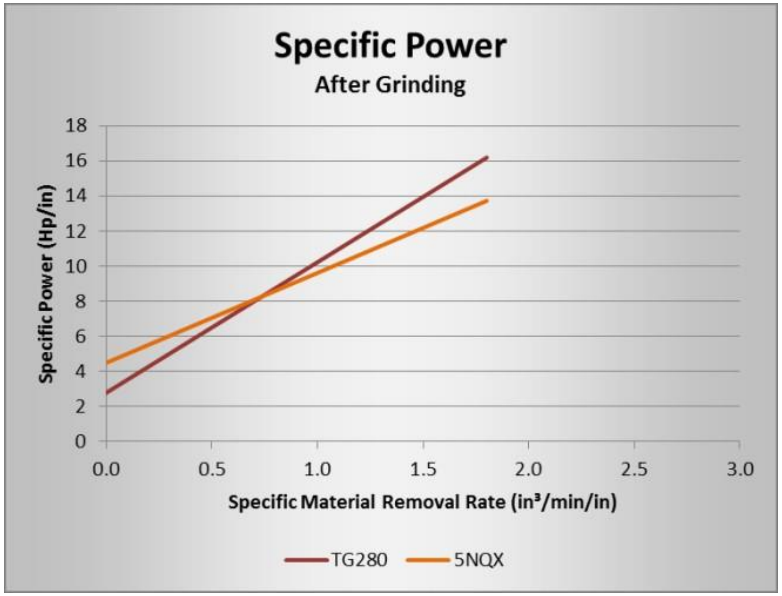
Face Width: 11”

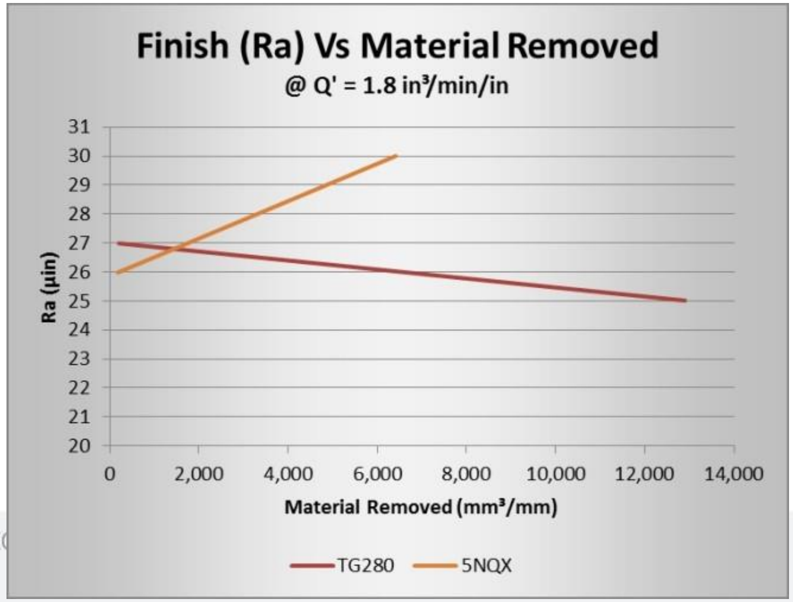
G-ratio:

- **At 0.003” DOC**
  - **5NQX: ~1,250**
  - **TG2: >3,000**
- **At 0.006” DOC**
  - **5NQX: ~100**
  - **TG2: >3,000**

Grind to Finish Data







New Grain Coming Soon!!

TQ grain

- Lower Threshold forces than TG2
- Cooler Cutting Action

Grinding Gears from Solid

Hobbing Parameters

- Coated HSS 2 start Hob
- Rough Axial advance Per Part Rev: 0.032”
- Number of Rough Passes: 5
- Finish Axial advance Per Part Rev: 0.020”
- Time per Rough Pass: 230 min
- Time for Finish Pass: 323 min
- Total cutting time: 24.5 hours

Grinding Parameters

- Wheel — 5NQX Vitrium Bond
- Wheel Speed 6,000 sfpm
- Roughing Passes at 2.5 $in^3/min/in$
- Finish Passes at 1.0 $in^3/min/in$
- Time per Tooth Rough Passes: 1.6 min
- Time per Tooth Finish Passes: 1.1 min
- Total Dress Amount per Gear: 0.58 in
- Total Dress Time per Gear: 175 min
- Total Grind & Dress Time per Gear: 10.9 hours

Material: 8620

- Hardness: 28-32 Rc
- Tooth Depth: 0.470”
- Tooth Length: 7”
- Number of Teeth: 175

Grinding Gears from Solid

Hobbing Parameters

- Carbide 2 start Hob
- Rough Axial advance Per Part Rev: 0.030
- Number of Rough Passes: 5
- Finish Axial advance Per Part Rev: 0.020
- Time per Rough Pass: 74 min
- Time for Finish Pass: 110min
- Total cutting time: 8.0 hours

Grinding Parameters

- Wheel — TG
- Wheel Speed 6,000 sfpm
- Roughing Passes at 1.1 & 2.2 in^3/min/in
- Finish Passes at 0.25 in^3/min/in
- Time per Tooth Rough Passes: 1.8 min
- Time per Tooth Finish Passes: 0.3 min
- Total Dress Time per Gear: 41.6 min
- Total Grind & Dress Time per Gear: 4.0 hours

Material: 4140

- Hardness: 28-32 Rc
- Tooth Depth: 0.438”
- Tooth Length: 7.25”
- Number of Teeth: 80

Summary

We are using the best abrasive technology to break traditional barriers (SGE, surface finish) and expand grinding technology and applications!!

Aerospace Materials

Milling vs. Grinding

for Rapid Stock Removal

An argument, with test data, for the grinding alternative.

Machine set up for test run at the Higgins Grinding Technology Center.

MARCH 2015

CHARTING NEW DIRECTIONS IN THE MANUFACTURE OF GEARS

GEAR PRODUCTION

Grinding Big Gears from Blanks

A Supplement to: Modern Machine Shop

AUTOMOTIVE DESIGN

Complex Form Grinding Technology for Advanced Abrasive Technology

The attraction of dressable CBN wheels over single layer CBN wheels, for gear grinding especially, is the ability to make profile corrections.

By Michael Hitchiner

thefabricator.com

http://www.thefabricator.com/article/finishing/automating-an-abrasive-process

Automating an abrasive process

By Robert J. McNamee

Quantifying the feel of the deburring, edge finishing process

THE FABRICATOR® APRIL 2014

April 3, 2014

Automating a manual operation can pose several unique difficulties, based on the incoming workpiece and its finish and geometric requirements, but the benefits of reduced costs and increased safety for operators may be worth it.

Manufacturing automation is becoming an integral part in maintaining revenues in an increasingly competitive market. Six-axis robots are a popular option for tasks such as material handling, painting, and spot welding.

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NEW GRINDING TECHNOLOGY IS BEING RESEARCHED ON THIS INTERMETALLIC TO HELP LOWER THE COSTS OF MANUFACTURING AEROSPACE ENGINE COMPONENTS, DEVELOP GRINDING EXPERTISE, AND DESIGN CUSTOM-BONDED ABRASIVE AND SUPERABRASIVE GRINDING SOLUTIONS THAT ARE IDEAL FOR EFFICIENT AND DAMAGE-FREE GRINDING OF COMPONENTS MADE OF TITANIUM ALUMINIDES.

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