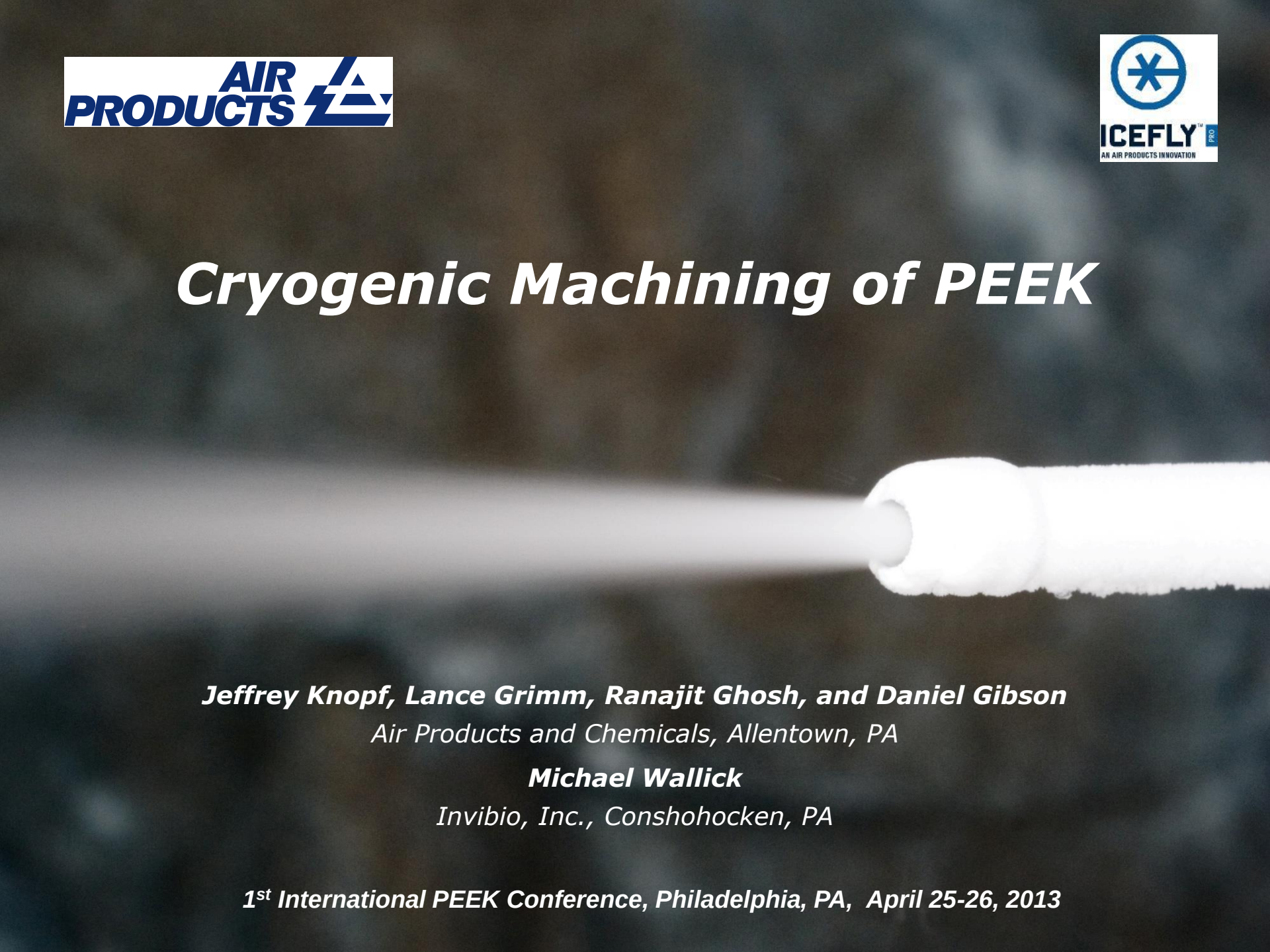


Cryogenic Machining of PEEK

Jeffrey Knopf, Lance Grimm, Ranajit Ghosh, and Daniel Gibson

Air Products and Chemicals, Allentown, PA

Michael Wallick

Invibio, Inc., Conshohocken, PA

1st International PEEK Conference, Philadelphia, PA, April 25-26, 2013

Presentation Outline

- *Cryogenic machining*
  - *Definition*
  - *Background*
- *Machining polymers*
  - *Rationale for cryogenic cooling*

- *PEEK machining demonstration*
  - *Objective(s)*
  - *Experimental setup*
  - *Conclusions*
  - *Video: Cryo machining / cryo brushing*

Cryogenic Machining

- ***Application of a low flow, controlled jet of liquid nitrogen (LIN) or cryogenic gaseous nitrogen (GAN) at a desired temperature to the cutting zone***
- ***Provides a dry, inert atmosphere for the cutting process and a residue-free product***
- ***Quickly cools the tool and work material surface***
- ***User controlled variables:***
  - ***Cryogen flow***
  - ***Nozzle distance to the work piece***
  - ***Cryogenic gas temperature***
- ***LIN / GAN are sourced from cryogenic storage vessel configured to meet nitrogen utilization***

Cryogenic Machining: Background and development highlights

- ***Development of Icefly® cryogenic machining technology initiated at Air Products in 1996***
- ***Initial focus on metal machining field:***
  - ***Use of liquid nitrogen (LIN) jet focused at cutting insert***
    - + ***Replace emulsion coolants***
    - + ***Increase productivity***
    - + ***Extend tool life***
    - + ***Improve part quality***
- ***Numerous successful applications in metal machining field***
  - ***Medical segment: cobalt chrome, titanium, porous titanium***
- ***Applications expertise broadened commencing in 2008 to include cryogenic machining of polymers***
  - ***Use cryogenic gas to cool the cutting zone***
  - ***Icefly® cryogen delivery equipment expanded to deliver LIN and temperature specified cryogenic gas***

Machining of Polymers: Variables Affecting Surface Finish

Material Variables

- *Glass Transition Temperature (Tg)*
- *Melt Temperature (Tm)*
- *Viscosity*
- *Molecular Weight*

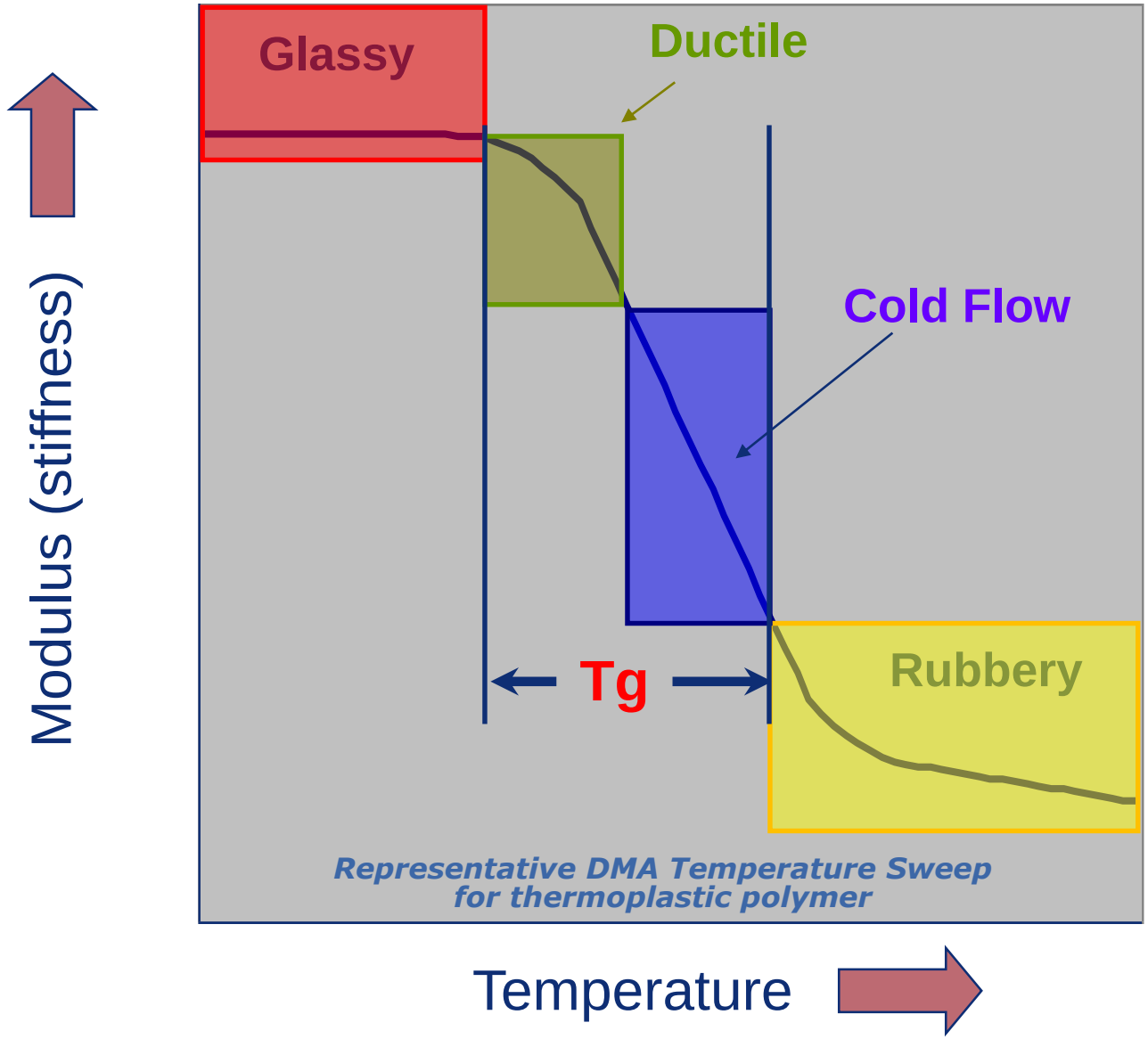
Machining Variables

- *Cutting Speed (relaxation rate)*
- *Cutting Edge Radius*
- *Tool Angles (Rake/Clearance)*
- *Feedrate*
- *Tool surface tribological properties*

Face milling PEEK

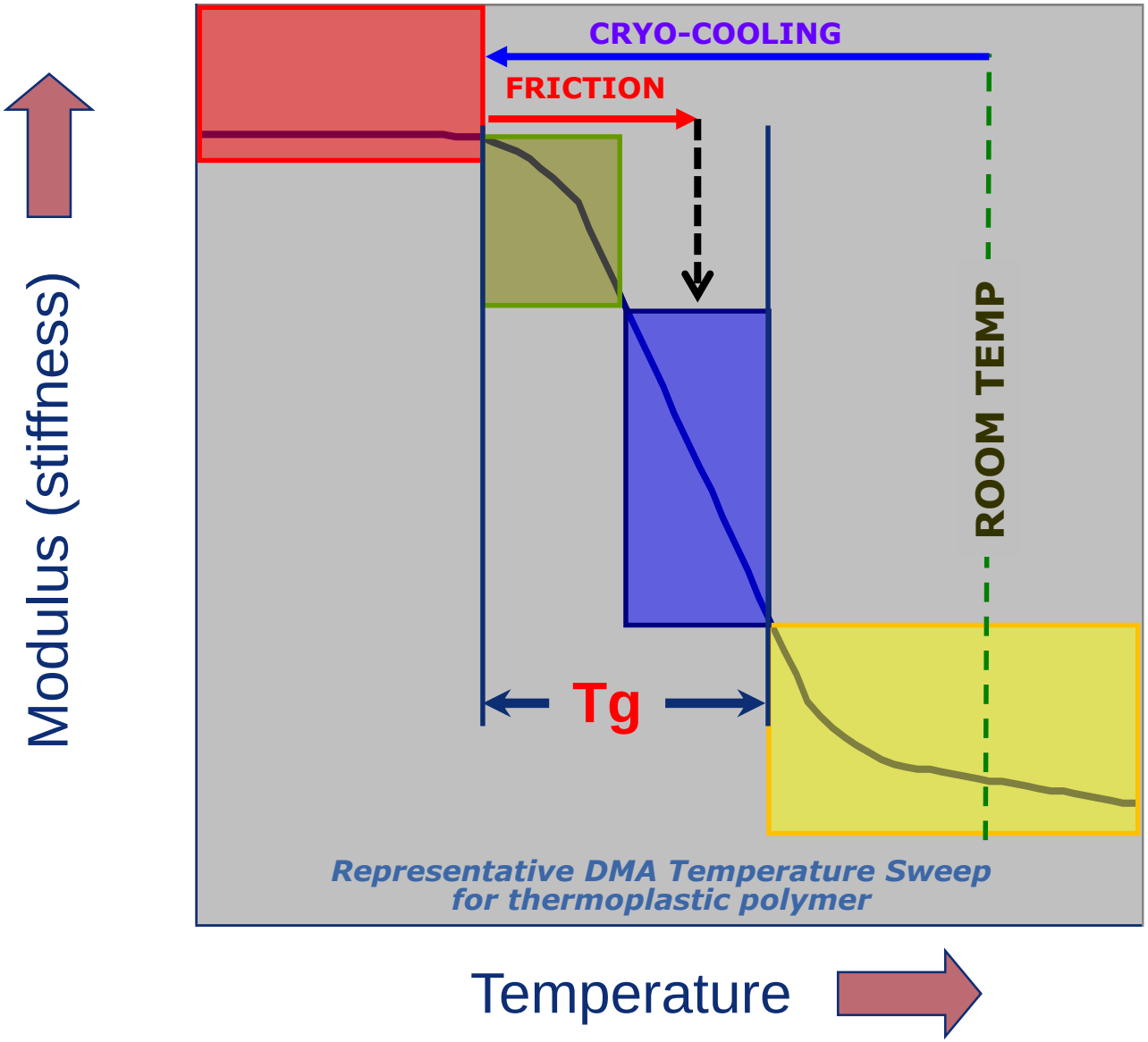
with compressed air cooling

Representative Temperature Sweep - Thermoplastic Polymers



Rationale for temperature controlled cryo machining

(Tg below room temperature)



Rationale for temperature controlled cryo machining

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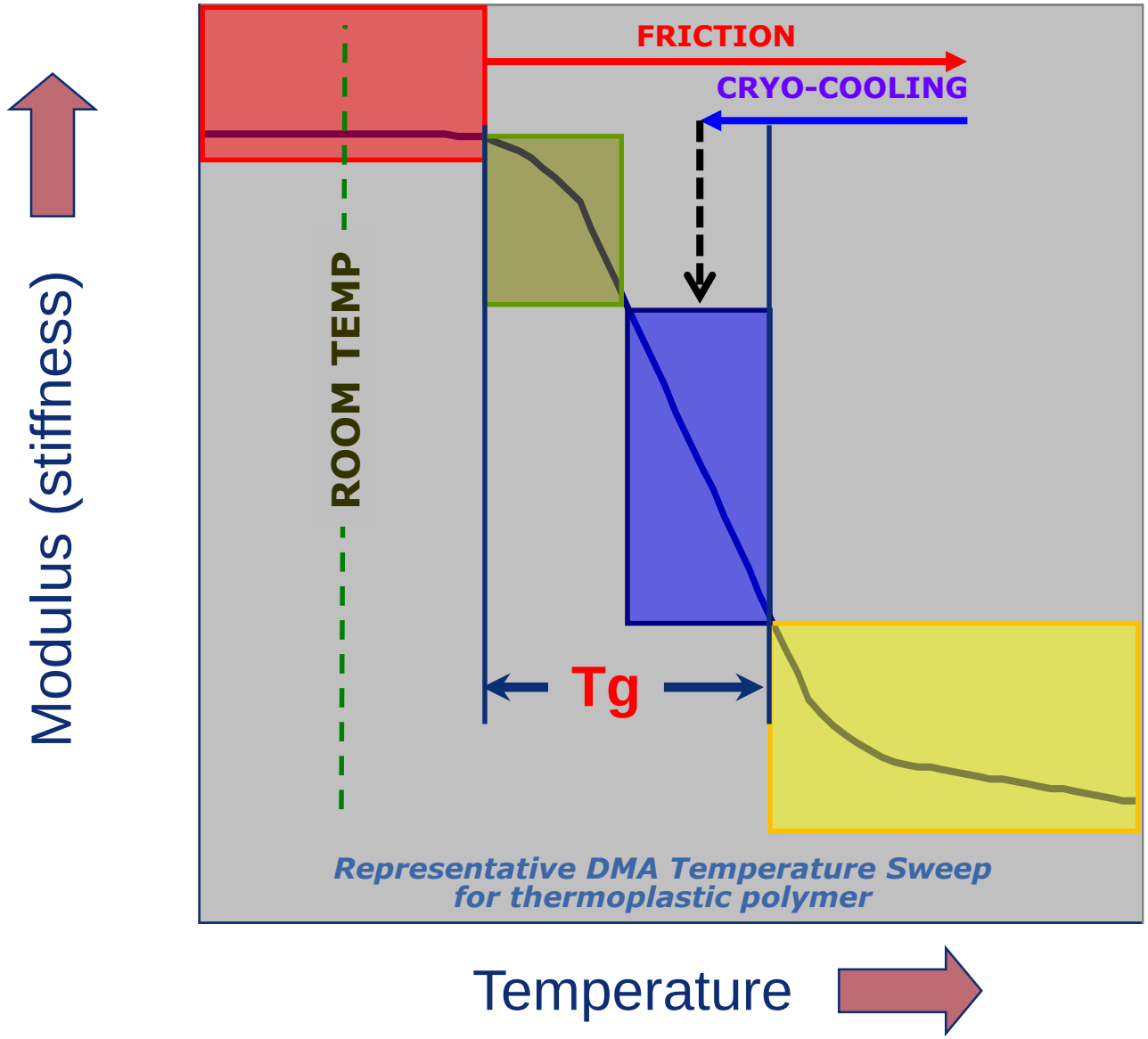
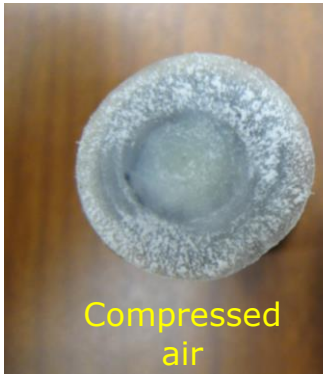
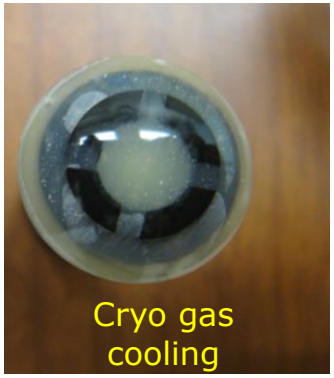


Cryo machining examples

Example 1:

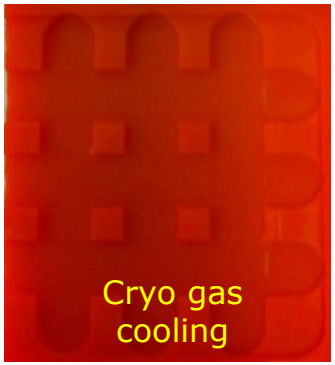
Intraocular lens polymer
Tg ~ (-20°F)





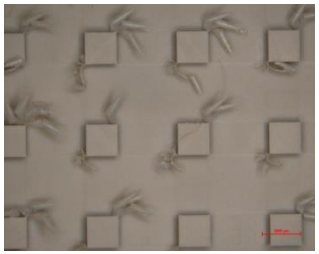
Example 2:

Industrial Polyurethane polymer
Tg ~(-40°F)

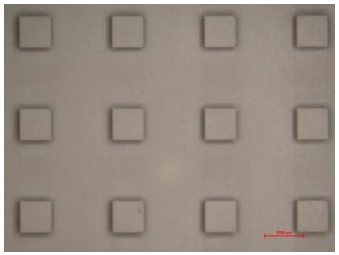


Example 3:

Unfilled PEEK
Tg (290 to 325 °F)



Compressed air



Cryo gas cooling

PEEK machining demonstration

Objective(s):

- *To investigate the impact of various cryo gas temperatures on burr formation*
- *To compare surface characteristics of hydroxyapatite filled PEEK when machined dry and cryogenically*

Materials:

- *Unfilled PEEK, hydroxyapatite filled PEEK*

Machining conditions:

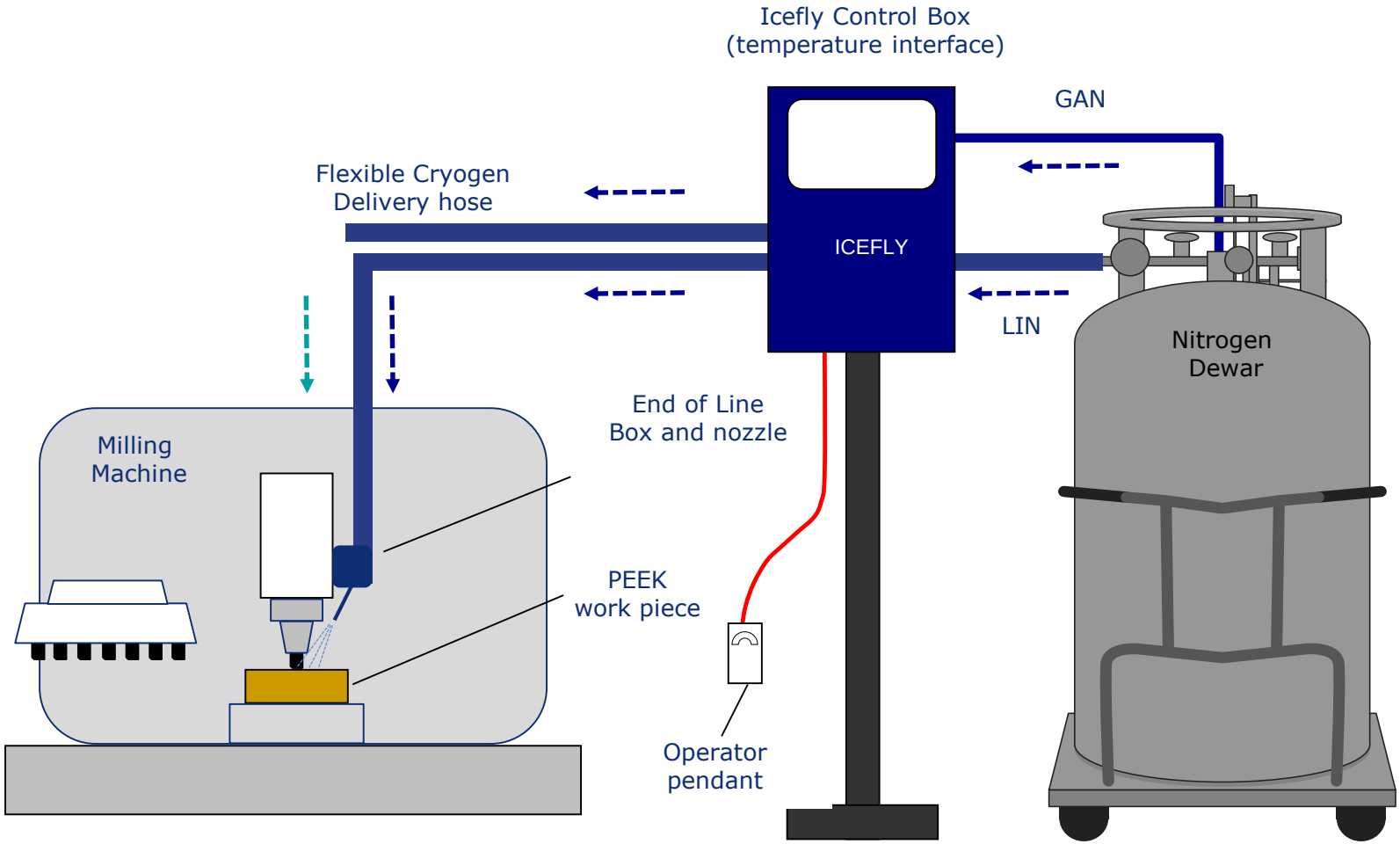
- *Tooling and machining standards per publicized guidelines (constant for dry and cryo machined samples)*
- *Cooling:*
  - *Compressed air*
  - *Various cryogenic cooling conditions:*
    - *Liquid nitrogen, Cryo gas at -250°F, -150°F, -100°F and -50°F*
    - *Cryo brushing at -250°F*

Analytical information:

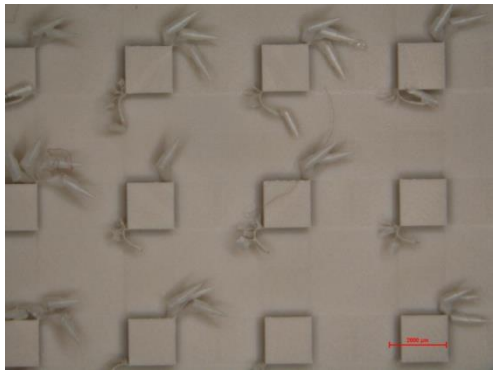
- *Light microscopy, SEM, EDS analysis*

Note: Cryo gas temperature measured at End-of-Line (EOL) box prior to nozzle

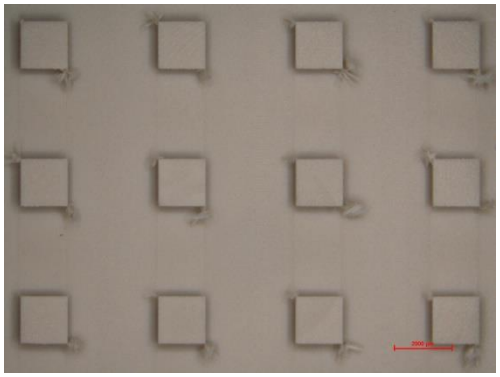
Icefly® cryogen delivery system



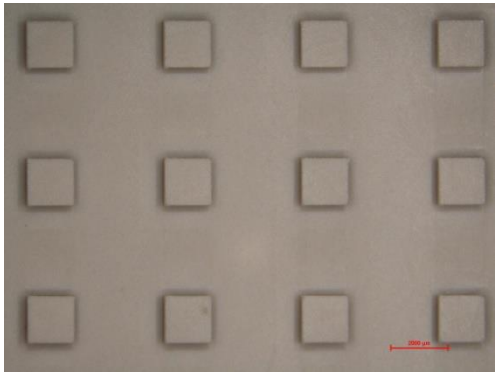
Dry machining vs. cryo machining results



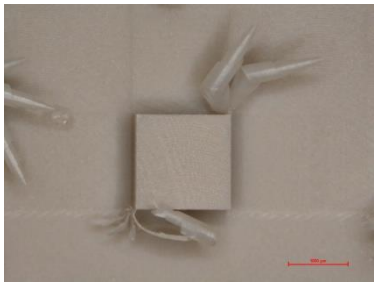
Dry machining
+ compressed air



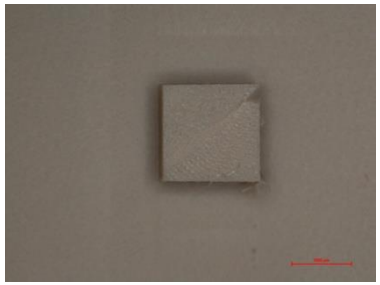
Cryo machining
(-250°F cryo gas)



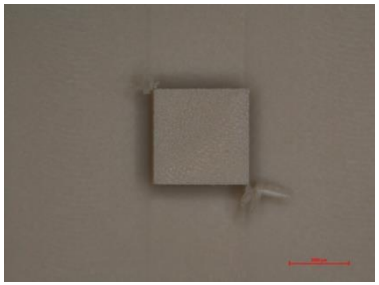
Cryo machining + Cryo brushing
(-250°F cryo gas)



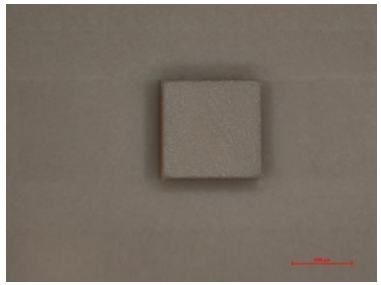
Dry machining
+ compressed air



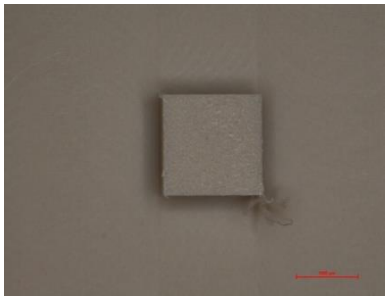
Cryo machining
Liquid Nitrogen



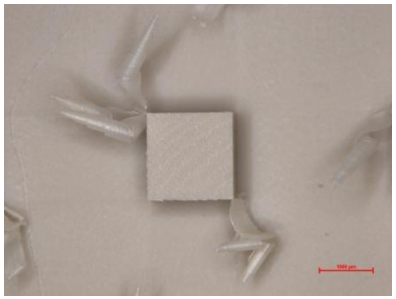
Cryo machining
(-250°F cryo gas)



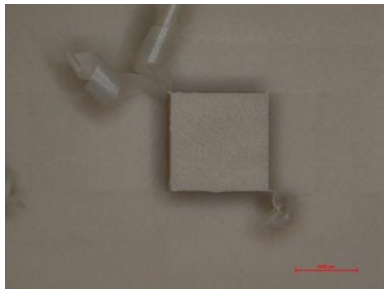
Cryo machining
+ Cryo brushing
(-250°F cryo gas)



Cryo machining
(-150°F cryo gas)



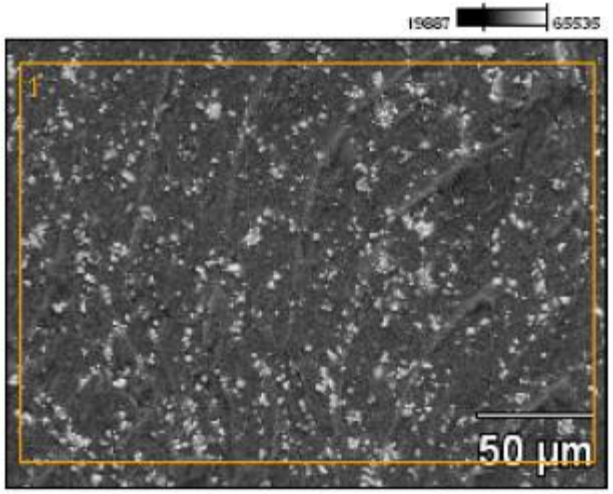
Cryo machining
(-100°F cryo gas)



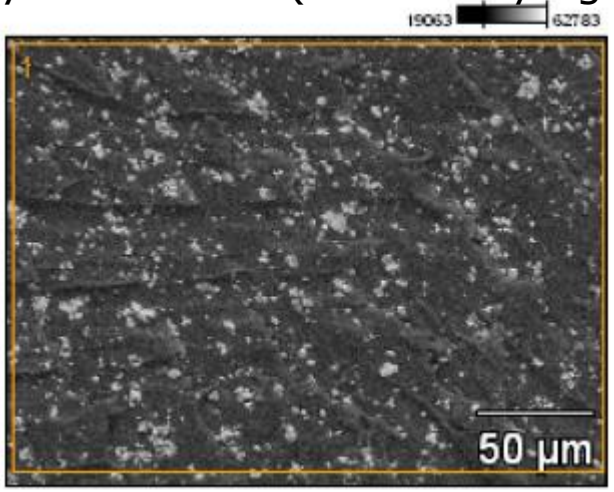
Cryo machining
(-50°F cryo gas)

Surface analysis of dry and cryo machined PEEK

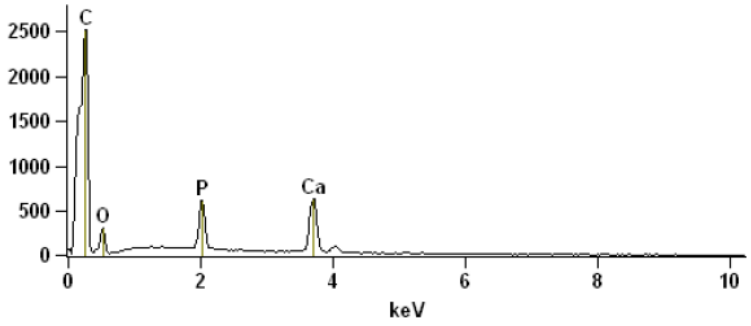
SEM image - Dry machined



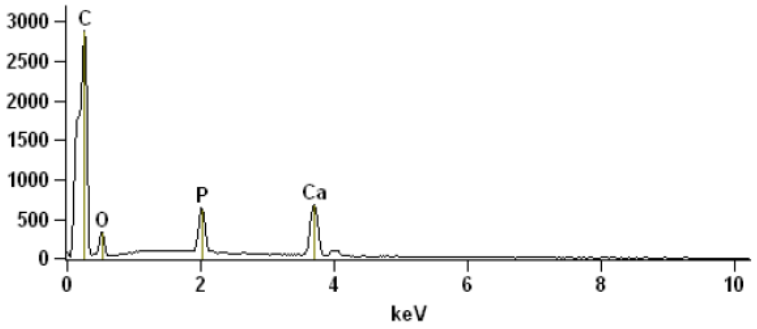
SEM image
Cryo machined (-250°F cryo gas)



EDS spectra - Dry machined



EDS spectra – Cryo machined
(-250°F cryo gas)



Conclusions from PEEK machining demonstration

- ***The use of cryogenic nitrogen gas enables residue free temperature management of polymer machining***

- ***Burr formation can be reduced by introducing cryogenic gas to the cutting zone***

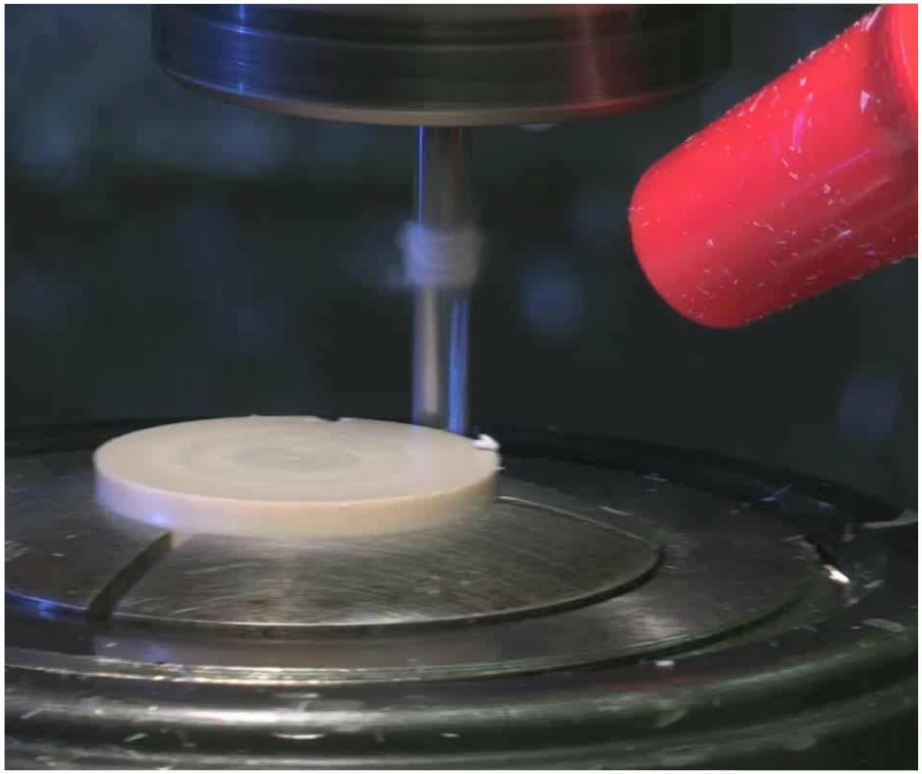
  + ***Optimal nozzle gas temperature of -150°F to -250°F resulted in minimal burr formation***

  + ***Burrs resulting from cryo machining are easily removed in a subsequent cryo brushing step resulting in a burr free surface***

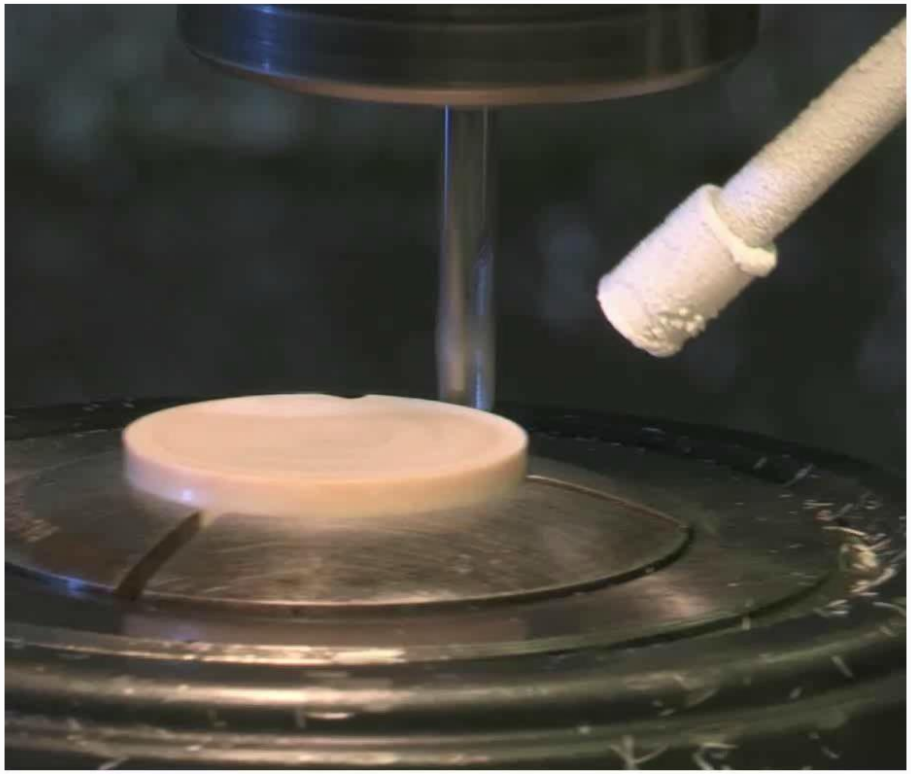
- ***Cryogenic machining does not adversely impact the surface content of hydroxyapatite when compared with dry machining***

Icefly® Control Box

Side-by-side PEEK machining comparison: Dry vs cryo machining PEEK



Dry machining + compressed air



Cryo machining (-250°F cryo gas)

Cryo brushing PEEK sample machined at -250 °F