



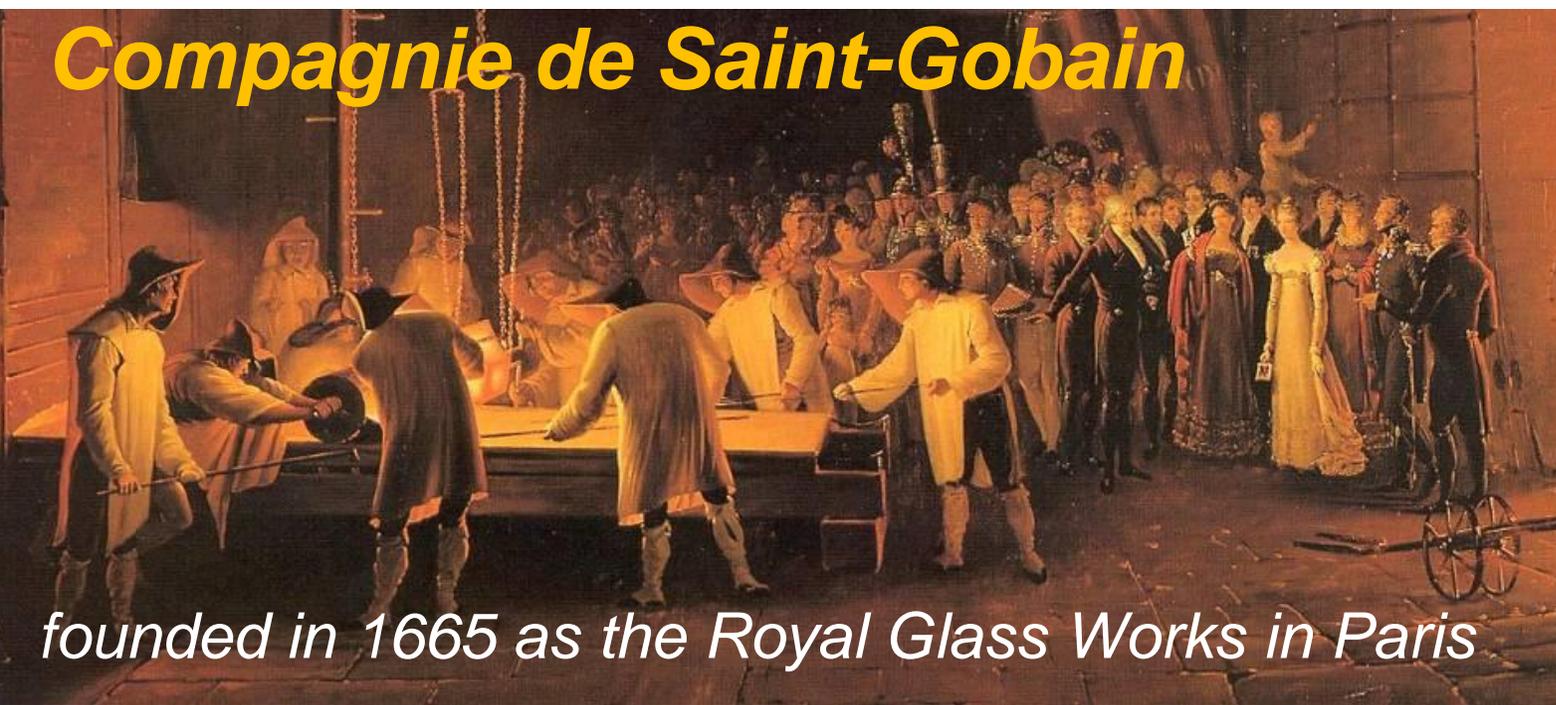
Mechanical Properties and Failure Analysis of Ceramics and Glass Materials

**Kristin Breder, Senior Principal Scientist,
Saint-Gobain Research North America**

Ceramics Expo May 3, 2023



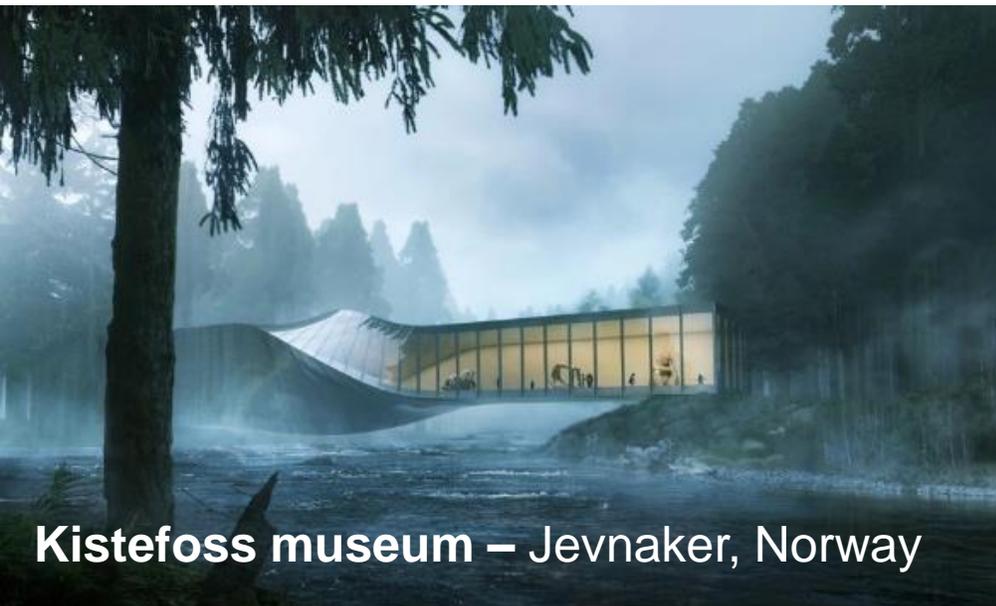
Compagnie de Saint-Gobain



founded in 1665 as the Royal Glass Works in Paris



**Saint-Gobain Tower –
Courbevoie,
France**



Kistefoss museum – Jevnaker, Norway



**Academy Museum of Motion Pictures –
Los Angeles, USA**



SEFPRO

Refractory solutions for glass furnaces.

PERFORMANCE CERAMICS AND REFRACTORIES

Engineered ceramics and refractory products for extreme operating conditions and high-temperature applications: metallurgy, automotive, energy, etc.

SPECIALTY GRAINS AND POWDERS (SGP)

Engineered ceramic grains, powders, suspensions and chemicals for a wide range of industries: abrasives, semiconductors, aerospace, automotive, energy, etc.

QUARTZ

Quartz fibers and fabrics for aerospace, 5G, railway solutions.

ZIRPRO

Ceramic beads for milling, ceramic beads and grains for blasting, zirconium oxide powders and chemicals for a wide range of industries: EV, 5G, new energies, automotive and aerospace, surface treatments etc.

NORPRO

Ceramic catalyst carriers and process ceramics for refining, petrochemical, chemical, environmental, gas and biofuel processing industries.

VALOREF

Refractories and technical ceramics waste management for a circular economy.

NEW HORIZONS TEAM

An agile and empowered team focused on partnering with key innovators to create breakthrough solutions for new markets.

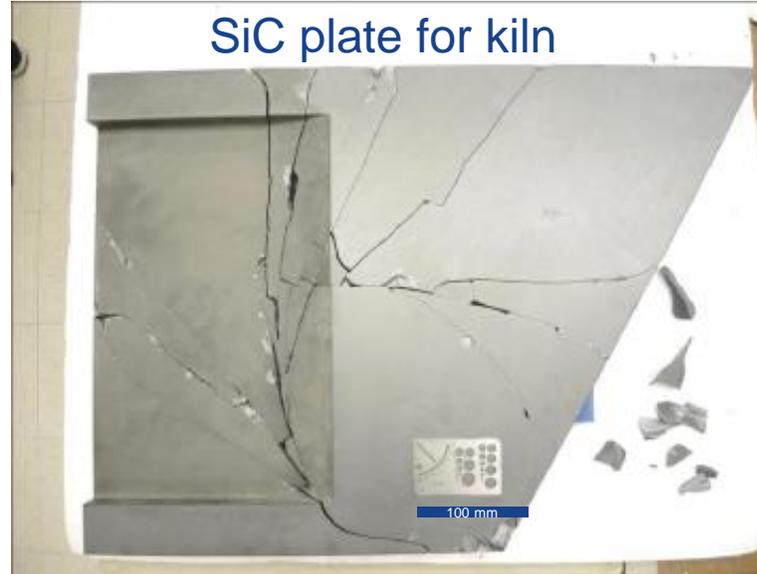


How do we predict the fracture of real components?

A "choke" for mining applications



SiC plate for kiln



Fractured
abrasive grits

Precision grinding wheel
returned by a customer



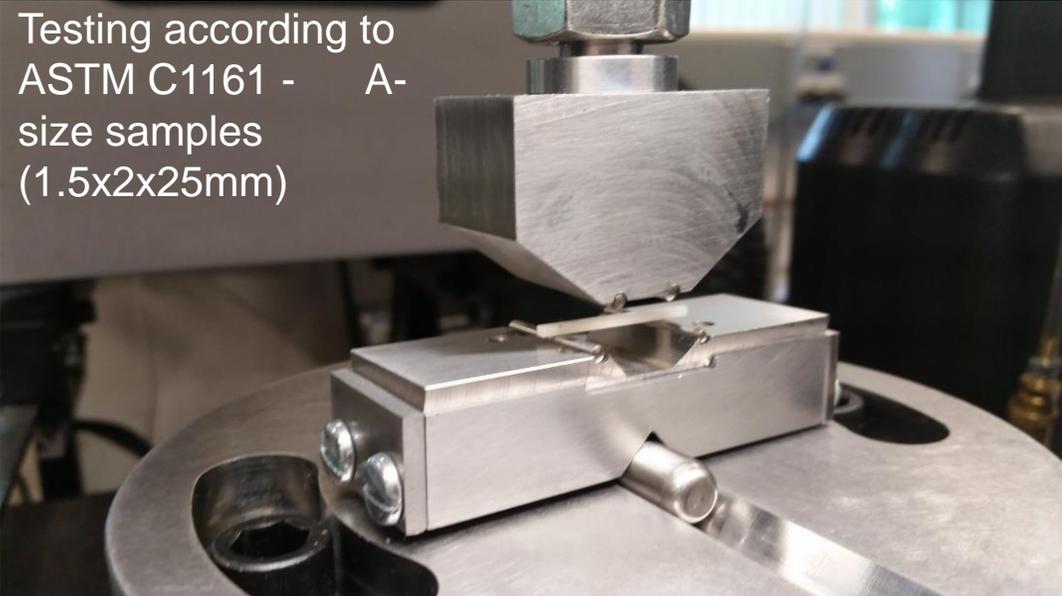
Grinding wheel fractured on a machine



Pieces of rollers used in a large kiln - new rollers are 3 m long

Standard methods for measuring strength of brittle materials

- ❑ Testing of well defined samples in carefully designed fixtures
- ❑ Stress & strength are readily calculated from fracture load
- ❑ Statistical analysis of data



Testing according to ASTM C1161 - A-size samples (1.5x2x25mm)

Committee C28 Advanced Ceramic Standards

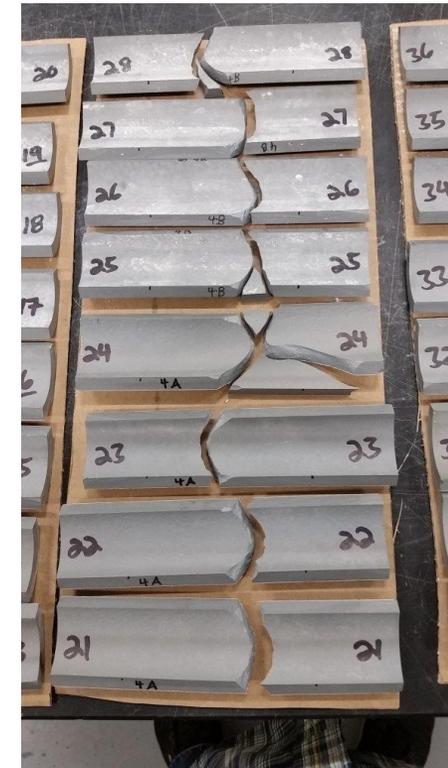
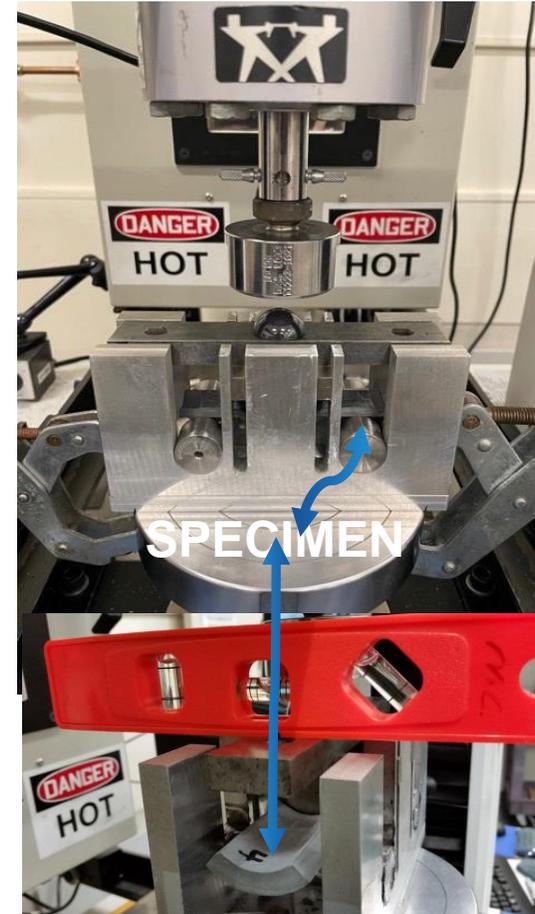
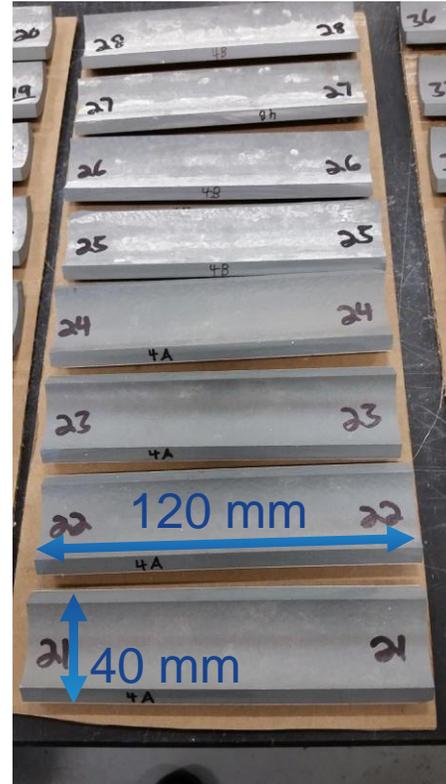
Visit the C28 website (<http://www.astm.org/COMMITTEE/C28.htm>) to purchase C28 standards or to join Committee C28.

Monolithics	Composites, Coatings, Porous Ceramics
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>C 1161 Flexural Strength (RT) C 1211 Flexural Strength (HT) C 1368 Slow Crack Growth (RT, Dyn Fatigue) C 1465 Slow Crack Growth (HT, Dyn Fatigue) C 1576 Slow Crack Growth (RT, Stress Rupture) C 1684 Flexural Strength (Rods) C 1834 Slow Crack Growth (HT, Stress Rupture)</p> </div> <div style="text-align: center;"> <p>C 1424 Compression Strength (RT)</p> </div> <div style="text-align: center;"> <p>C 1322 Fractography C 1678 Fracture Mirror</p> </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <p>C 1273 Tensile Strength (RT) C 1291 Creep, Creep Rupture C 1366 Tensile Strength (HT) C 1361 Cyclic Fatigue</p> </div> <div style="text-align: center;"> <p>C 1326 Knoop Hardness C 1327 Vickers Hardness</p> </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <p>C 1499 Biaxial Strength (RT)</p> </div> <div style="text-align: center;"> <p>C 1198 Elastic Modulus - continuous C 1259 Elastic Modulus - impulse</p> </div> <div style="text-align: center;"> <p>C 1470 Thermal Guide</p> </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <p>C 1323 C-ring Strength</p> </div> <div style="text-align: center;"> <p>C 1495 Grinding</p> </div> <div style="text-align: center;"> <p>C 1525 Thermal Shock</p> </div> </div>	<div style="display: flex; justify-content: space-around; margin-bottom: 10px;"> <div style="text-align: center;"> <p>C 1275 CMC Tensile Strength (RT) C 1337 CMC Creep, Creep Rupture C 1359 CMC Tensile Strength (HT) C 1360 CMC Cyclic Fatigue C 1773 CMC Tube Axial Tensile (RT) C 1869 CMC Open Hole Tensile (RT)</p> </div> <div style="text-align: center;"> <p>C 1358 CMC Compression Strength</p> </div> <div style="text-align: center;"> <p>C 1468 CMC Tensile Strength Trans Thickness</p> </div> <div style="text-align: center;"> <p>C 1862 End Plug Adhesion</p> </div> </div> <div style="display: flex; justify-content: space-around; margin-bottom: 10px;"> <div style="text-align: center;"> <p>C 1469 CMC Joint Strength</p> </div> <div style="text-align: center;"> <p>C 1341 CMC Flexure Strength</p> </div> <div style="text-align: center;"> <p>C 1674 Honeycomb Flex Strength</p> </div> <div style="text-align: center;"> <p>C 1557 Filament Strength & Stiffness</p> </div> </div> <div style="display: flex; justify-content: space-around; margin-bottom: 10px;"> <div style="text-align: center;"> <p>C 1783 Guide for Specs C-C Composites C 1793 Guide for Specs SiC-SiC CMCs C 1835 Classification for SiC-SiC CMC C 1836 Classification for C-C Composites</p> </div> <div style="text-align: center;"> <p>C 1292 CMC Shear Strength (RT) C 1425 CMC Shear Strength (HT)</p> </div> <div style="text-align: center;"> <p>C 1819 and C1863 Hoop Tensile Strength of CMC Tubes C 1624 Coatings - Scratch Adhesion</p> </div> </div>
<h3 style="text-align: center;">Powders</h3> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <p>C 1070 Particle Size, Laser Light C 1274 Particle Size, BET C 1282 Particle Size, Centrifugal Sed C 1730 Particle Size Distribution, X-Ray Gravity Sedimentation</p> </div> <div style="text-align: center;"> <p>C 1239 Weibull C 1683 Weibull Scaling</p> </div> </div> <div style="text-align: center; margin-top: 10px;"> <p>C 1494 C, N, O in silicon nitride</p> </div>	<h3 style="text-align: center;">NDE and Design</h3> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <p>C 1212 Seeded Voids C 1336 Seeded Inclusions</p> </div> <div style="text-align: center;"> <p>C 1175 NDE Guide</p> </div> </div>
<h3 style="text-align: center;">Subcommittees</h3> <p style="font-size: x-small;">C28.01 Mech. Prop. + Reliability C28.03 Physical Prop. + NDE C28.04 Applications C28.07 Ceramic Matrix Composites C28.91 Terminology</p>	
<h3 style="text-align: center;">Terms, Workshops, Education</h3> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <p>STP 1201 Life Prediction STP 1309 Composites STP 1392 Composites STP 1409 Fracture</p> </div> <div style="text-align: center;"> <p>C 1145 Terminology</p> </div> </div>	

ASTM C28 standards are found in Vol. 15.01 of the Annual Book of ASTM Standards 01-2020

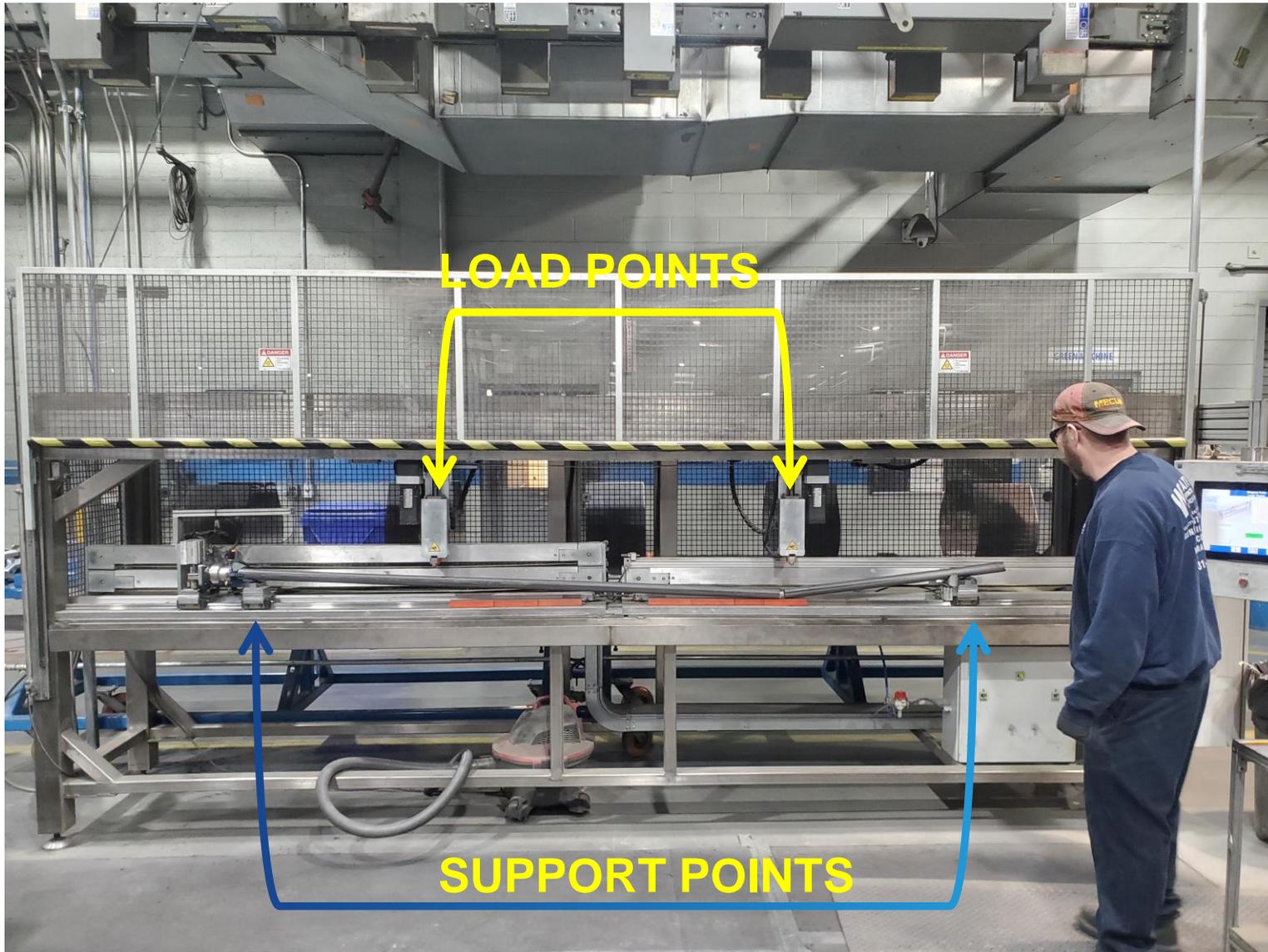
Testing of materials from an application

- ❑ Strength of actual material with as-manufactured or corroded surfaces
- ❑ Strength calculation and statistical analysis are more complex



Our understanding of the fundamental principals behind Weibull analysis allows us to analyze any test we can perform and use those results to predict probability of failure in real applications.

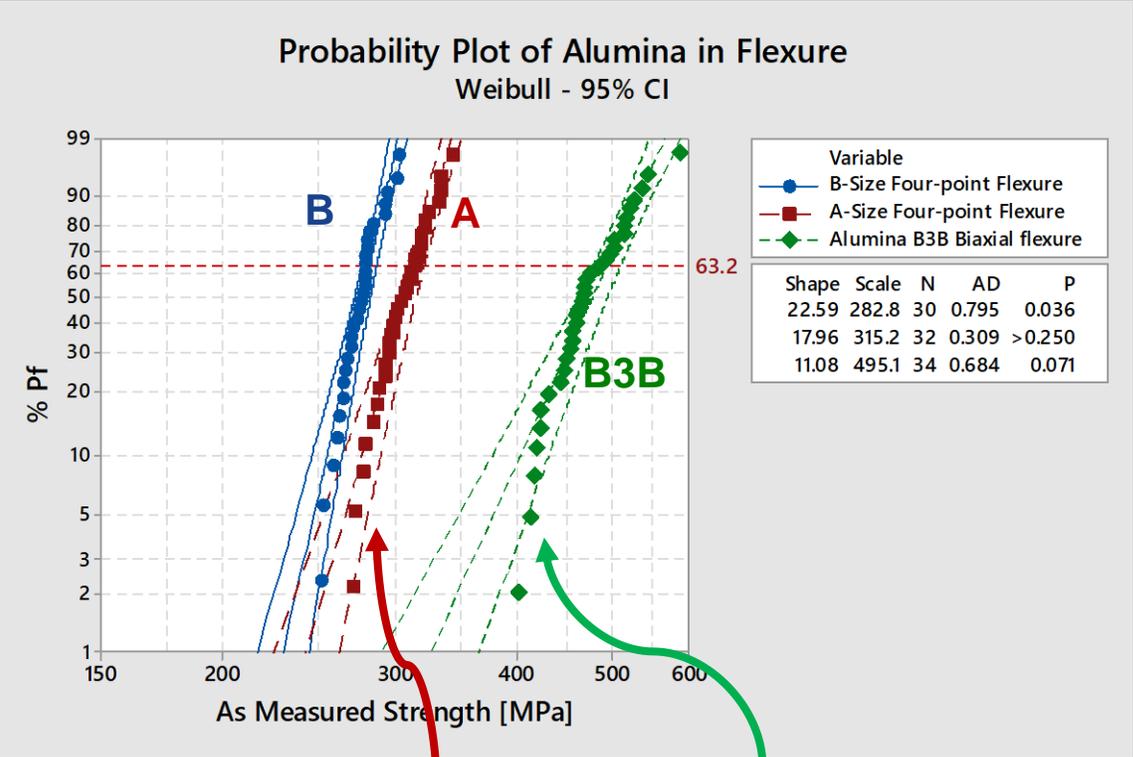
Testing of the full-size component (a 3 meter long Hexoloy tube)



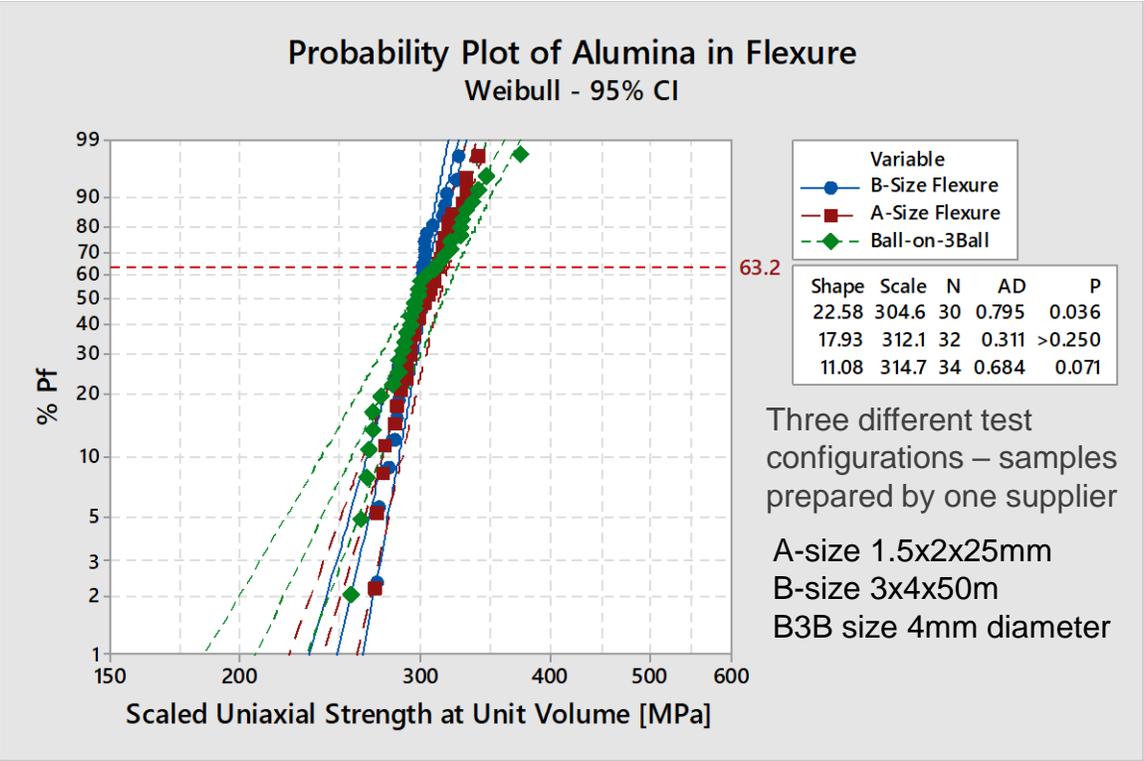
- ❑ A true test of the as-made strength of the real part!
- ❑ Valuable for proof testing
- ❑ Too expensive for practical use as a strength test

We use results of more practical tests (e.g. sector test) in combination with FEA and Weibull analysis to predict the strength of real parts in application conditions.

Combine standard and non-standard tests and perform Weibull scaling

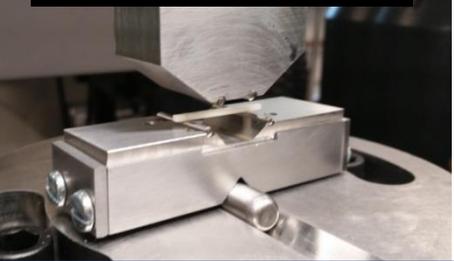


- Data scaled to unit volume using Weibull scaling analysis
- The scaling works well for similar stressed volumes with similar strength limiting flaws



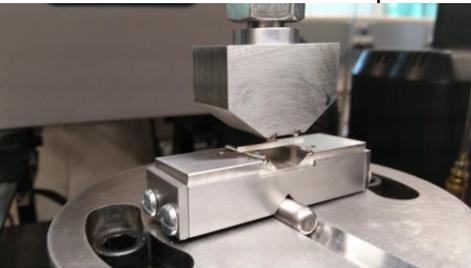
A-size Flexure

Ball-On-3-Ball



Samples with smaller stressed volume appear to be stronger

Extrapolation from tests to real applications

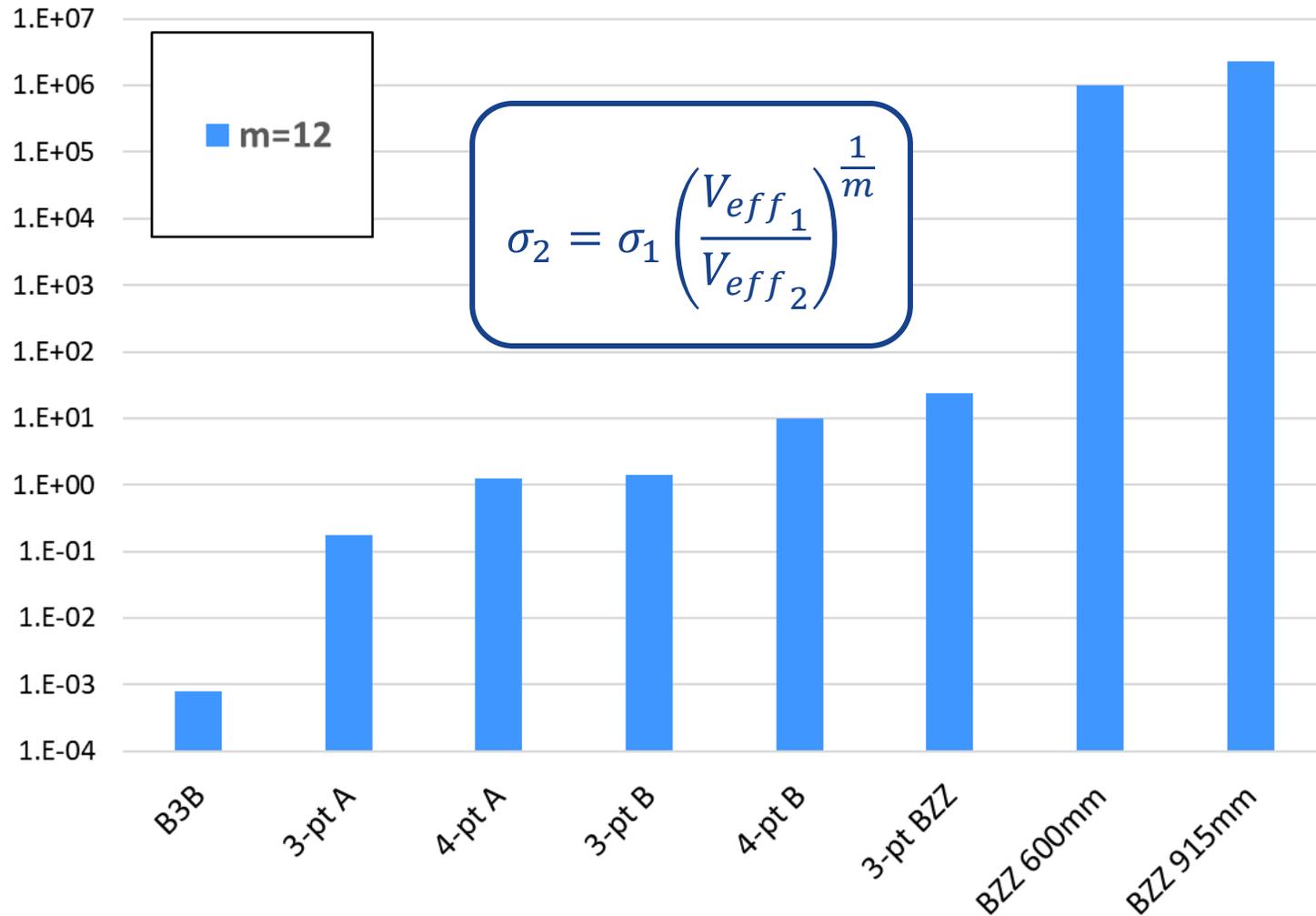


~ 4 mm



Effective Volume [mm³]

Effective Volume as a Function of Size & Loading



~ 1 m

10⁴ to 10⁵ times
difference in V_{eff} from
tests to application –
a bridge too far!

Thanks to Saint-Gobain Colleagues and collaborators:
Eric Buchovecky, Senior Principal Scientist,
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