



Mechanical Properties and Failure Analysis of Ceramics and Glass Materials

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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



Saint-Gobain Ceramics

INNOVATIVE SOLUTIONS FOR TODAY'S AND TOMORROW'S MARKETS



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

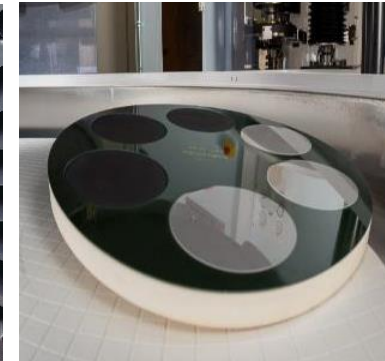
Ceramic catalyst carriers and process ceramics for refining, petrochemical, chemical, environmental, gas and biofuel processing industries.

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

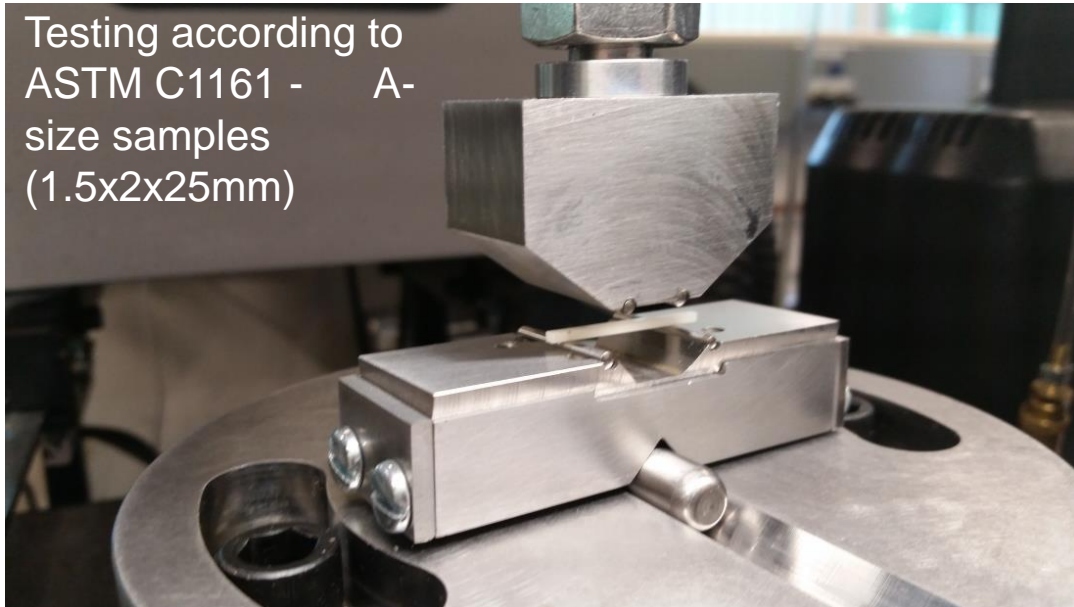



Pieces of rollers used in a large kiln - new rollers are 3 m long

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

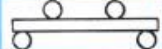


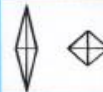
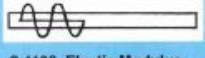


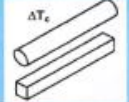

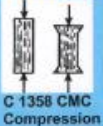





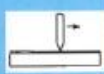

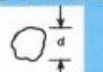

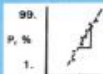
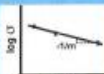



Testing according to ASTM C1161 - A-size samples (1.5x2x25mm)





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
 <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>  <p>C 1424 Compression Strength (RT)</p>  <p>C 1322 Fractography C 1678 Fracture Mirror</p>  <p>C 1326 Knoop Hardness C 1327 Vickers Hardness</p>  <p>C 1499 Biaxial Strength (RT)</p>  <p>C 1198 Elastic Modulus - continuous C 1259 Elastic Modulus - impulse</p>  <p>C 1323 C-ring Strength</p>  <p>C 1495 Grinding</p>  <p>C 1525 Thermal Shock</p>	 <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>  <p>C 1358 CMC Compression Strength</p>  <p>C 1469 CMC Joint Strength</p>  <p>C 1341 CMC Flexure Strength C 1674 Honeycomb Flex Strength</p>  <p>C 1292 CMC Shear Strength (RT) C 1425 CMC Shear Strength (HT)</p>  <p>C 1468 CMC Tensile Strength Trans Thickness C 1862 End Plug Adhesion</p>  <p>C 1819 and C1863 Hoop Tensile Strength of CMC Tubes</p>  <p>C 1557 Filament Strength & Stiffness</p>  <p>C 1624 Coatings - Scratch Adhesion</p>
<h3 style="text-align: center; margin: 0;">Powders</h3>  <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>  <p>C 1494 C, N, O in silicon nitride</p>	<h3 style="text-align: center; margin: 0;">NDE and Design</h3>  <p>C 1212 Seeded Voids C 1336 Seeded Inclusions</p>  <p>C 1239 Weibull C 1683 Weibull Scaling</p>  <p>C 1175 NDE Guide</p>
<h3 style="text-align: center; margin: 0;">Terms, Workshops, Education</h3>  <p>STP 1201 Life Prediction STP 1309 Composites STP 1392 Composites STP 1409 Fracture</p>  <p>C 1145 Terminology</p>	

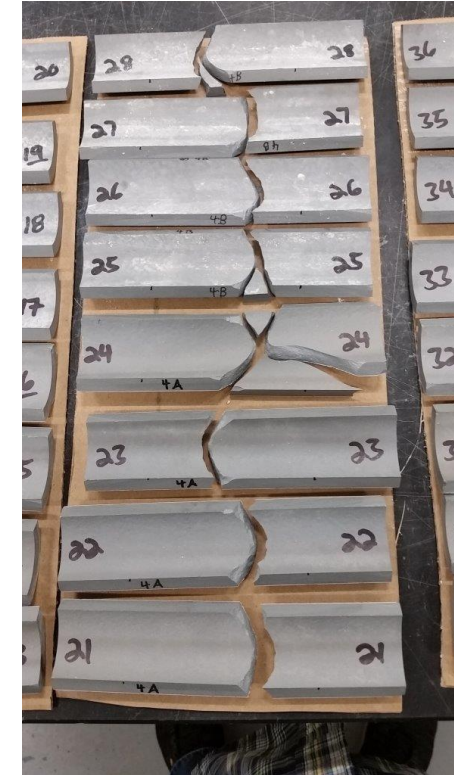
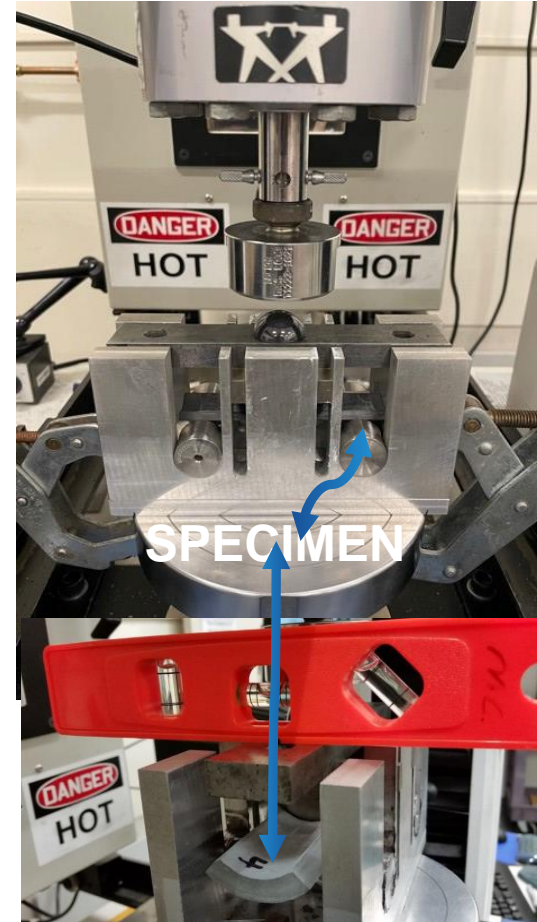
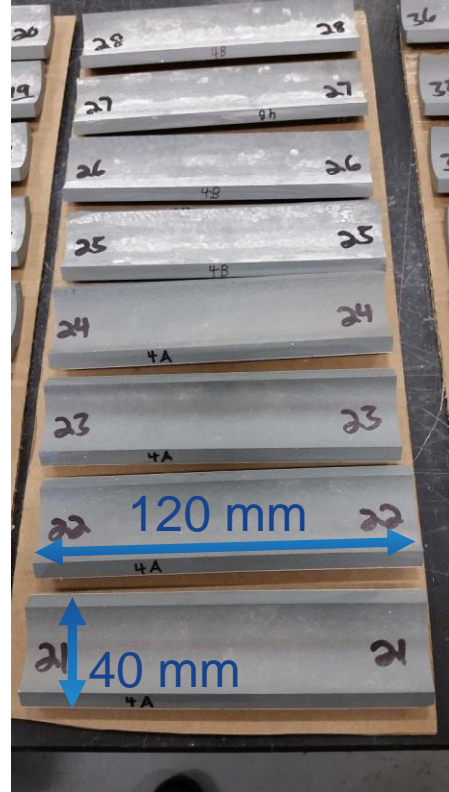
Subcommittees
C28.01 Mech. Prop. + Reliability
C28.03 Physical Prop. + NDE
C28.04 Applications
C28.07 Ceramic Matrix Composites
C28.91 Terminology

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

01-2020

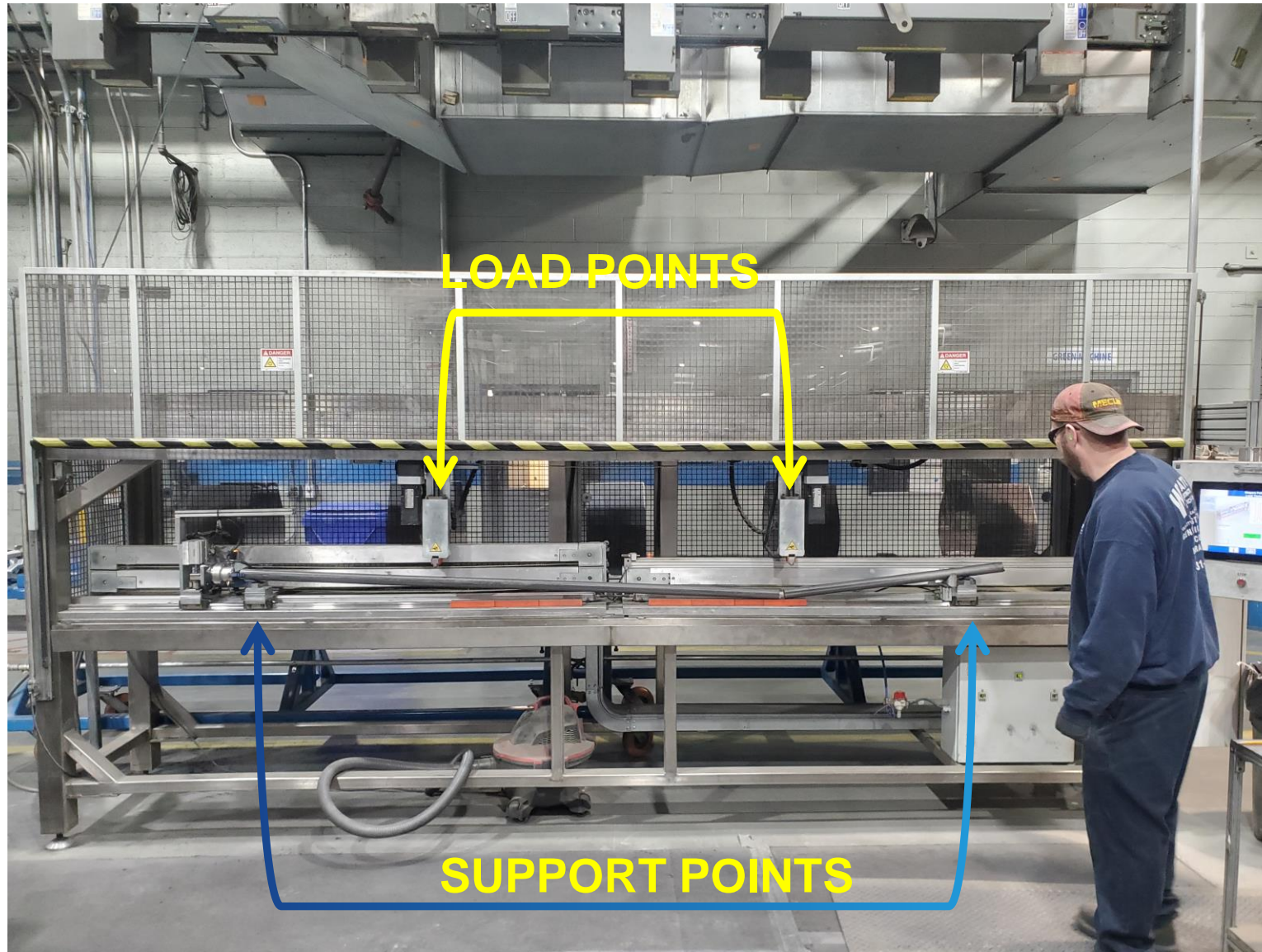
Testing of materials from an application

- ❑ 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)

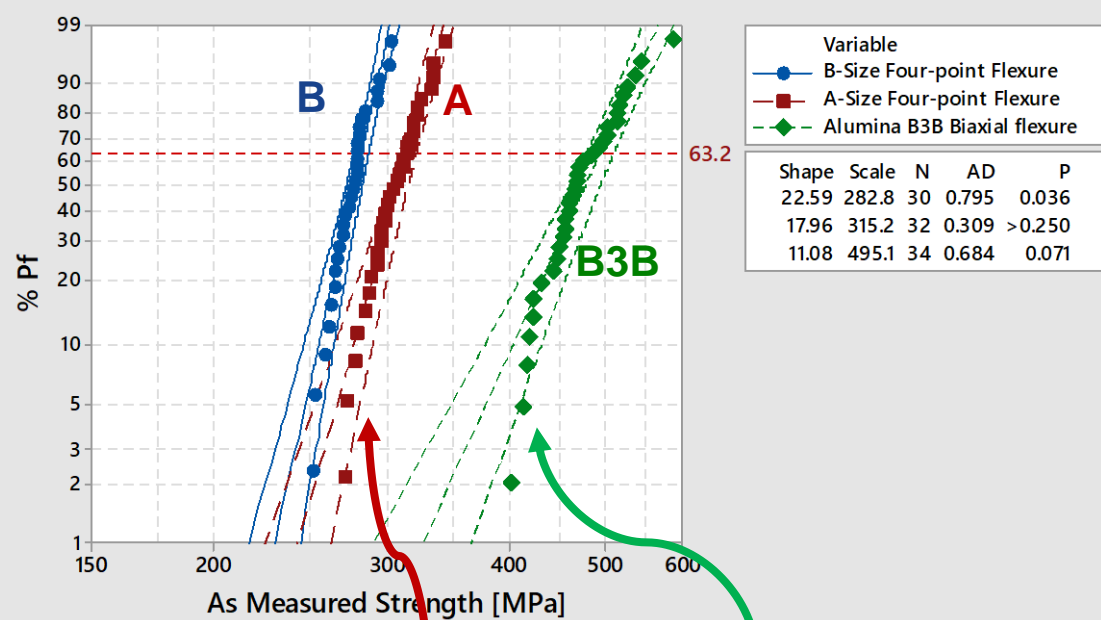


- ❑ A true test of the as-made strength of the real part!
- ❑ Valuable for proof testing
- ❑ Too expensive for practical use as a strength test

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

Probability Plot of Alumina in Flexure
Weibull - 95% CI



A-size Flexure

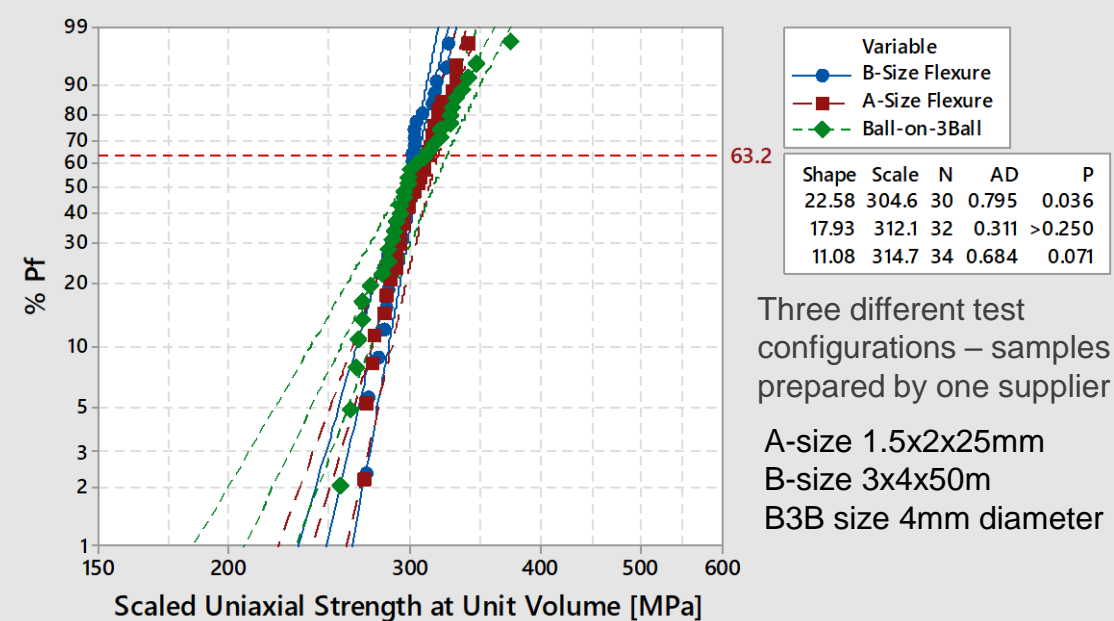


Ball-On-3-Ball



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

Probability Plot of Alumina in Flexure
Weibull - 95% CI

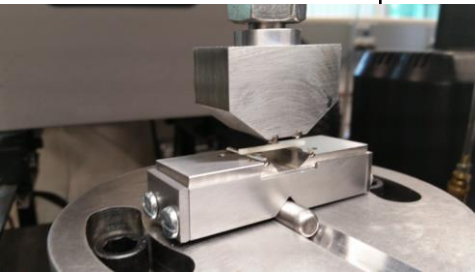


Three different test configurations – samples prepared by one supplier

A-size 1.5x2x25mm
B-size 3x4x50mm
B3B size 4mm diameter

Samples with smaller stressed volume appear to be stronger

Extrapolation from tests to real applications

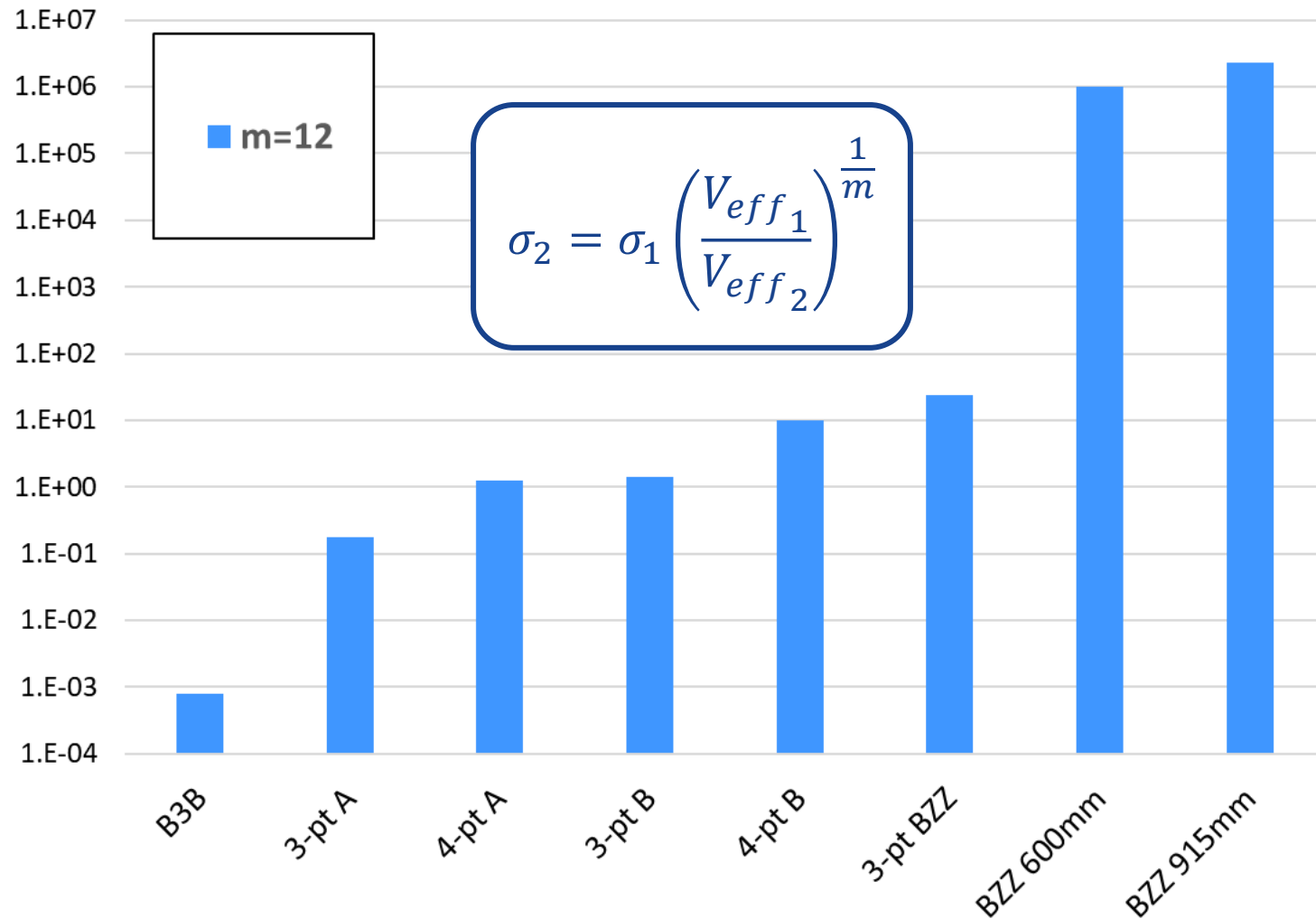


~ 4 mm



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,
Adam Stevenson, R&D Director Saint-Gobain Grains and Powders