Strategic Operations Solutions, LLC®

Analysis of Fusion UV Systems, Inc. FUV Bulbs from VALEO Blois

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Agenda

- FUV Bulb Analysis
- SOS® Findings
- Known Root Causes
- FUV Recommendations
- Questions?

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FUV Bulb Analysis

- Symptoms Reported
  - Exploders predominantly in zone 1
  - Noted principally in past 2 years
  - Typically <2K hours
- Forensic Analysis Possible
  - Glass has "memory" of last condition
  - Fragments not available for fracture analysis
  - Used FUV bulbs from VALEO analyzed

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FUV Bulb Analysis

- Bulb Exploders: 2 conditions must exist
  - Flaws (induced)
    - Stress risers: mechanical, chemical
    - Lowers the glass strength
    - Mitigated by proper cooling air filtration
    - Evaluated under microscope
  - Tension (induced)
    - Compression and tension co-exist
    - Provides the force for enlarging flaws
    - Mitigated by proper air cooling
    - Evaluated under polariscope

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FUV Bulb Analysis

- Bulb Exploders: any glass (cont'd)
  - Flaws propagate in tension
    - Compression preferred on outside surface
    - Design practice <1K psi (6.8 x 10^6 pa) on surface
    - Mechanical properties available at… Click Here

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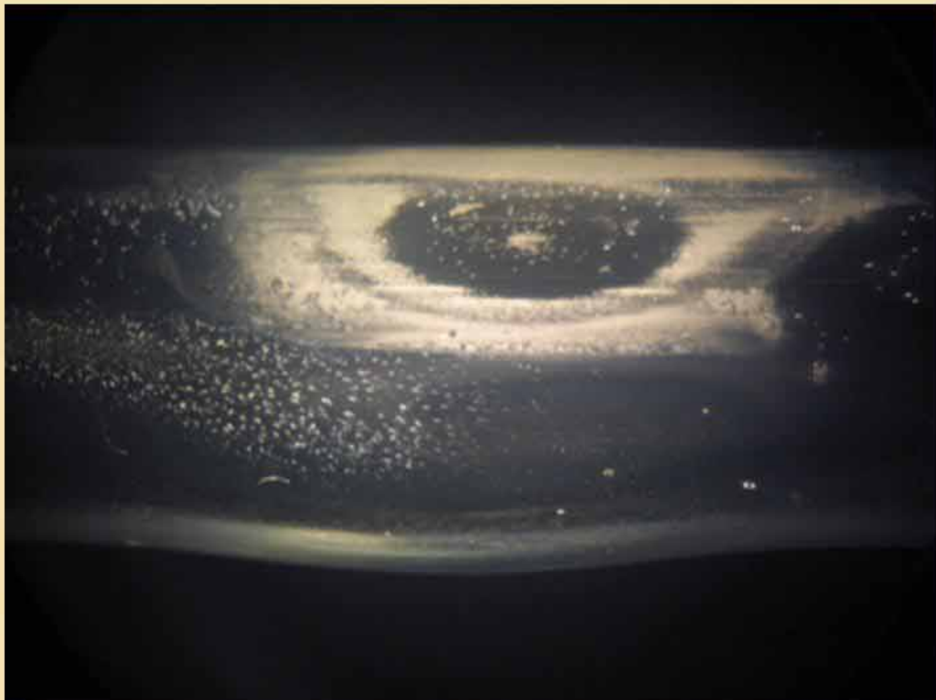
FUV Bulb Analysis

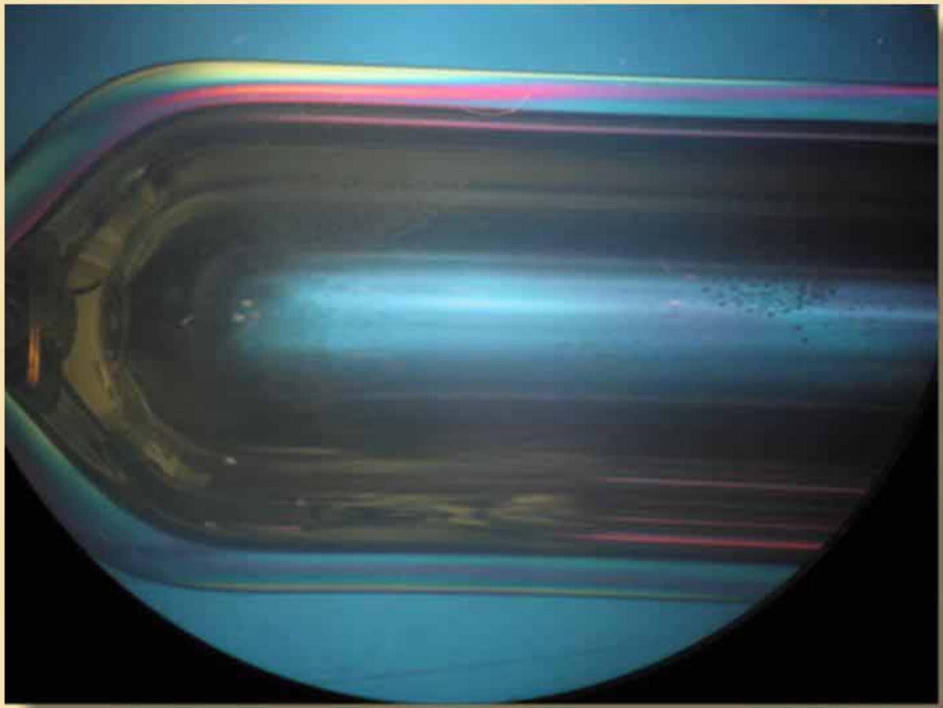


- Observed Physical Characteristics
  - VALEO 2.10 bulb
    - 769, S/N 2
    - 7015 hours
  - Deformation
  - Softening point exceeded
    - 1500°C - 1683°C
  - Click Here

FUV Bulb Analysis

- Observed Physical Characteristics
  - VALEO 2.4 bulb
    - 769, S/N 17
    - 5043 hours
  - Flaws
  - Coefficient of expansion beneficial
    - 5.5×10^{-7} mm °C
    - 20°C - 320°C
  - Click Here

FUV Bulb Analysis



- Observed Physical Characteristics
  - VALEO bulb 3.7
    - 773, S/N 4
    - 6577 hours
  - Residual stress changed
    - ~60° rotation
    - ~8K psi (5.4 x 10^7 pa)!
  - Strain point exceeded
    - 1120°C
  - Click Here

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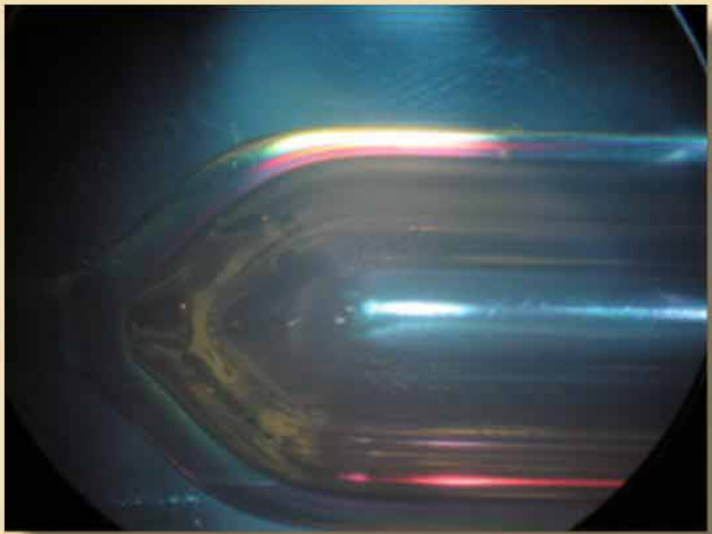
FUV Bulb Analysis



- Observed Physical Characteristics
  - FUV reference bulb
    - Stress <<1K psi or <<6.8×10^6 pa
  - Other Zones?
  - VALEO bulb 1.6
    - 773, S/N 38
    - 4282 hours
  - Residual stress changed

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FUV Bulb Analysis

- Observed Physical Characteristics
  - Other Zones?
  - VALEO bulb 2.8
    - 769, S/N 26
    - 8668 hours
  - VALEO bulb 3.2
    - 777, S/N 30
    - 3508 hours
  - Residual stress changed

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SOS® Findings

Good

- Clean surface, condensate free
- Many bulbs last >>2K hours

Not Good

- Deformation observed: subjected to 1500°C - 1683°C
- Flaws observed (multiple bulb cracks)

Catastrophic

- Residual tension stress observed: subjected to >1120°C
- ~8K psi or 5.4×10^7 pa in bulb 3.7
- Exceeds design practice by 8x!!!

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Known Root Causes

- Heat Transfer Inadequate
  - Cooling air source: during startup/shutdown
    - Pressure differential inadequate (maybe)
    - Air supply inadequate (maybe) or contaminated (unlikely)
    - Filter maintenance inadequate (unlikely)
  - Cooling air source: during operations
    - Air supply interrupted or diverted (?)
    - Control system timing inadequate (?)
    - Machine jogging, line stoppages (?)

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FUV Recommendations

- Maintain Proper Air Cooling
  - Pressure differential must be maintained
    - Mass air flow for heat transfer required
    - Maintain glass surface <1000 °C
    - Maintain compression stress on external surface
- Maintain Proper Cooling Air Filtration
  - Mitigate mechanical (impact) flaws
    - Includes proper filter selection and maintenance
  - Mitigate chemical (reactivity) flaws
    - Includes clean air source, free of condensation

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FUV Recommendations

- Review Cooling Air Control System
  - Adequacy of pressure and exhaust systems
    - Measure pressure differential
    - During startup, operations, shutdown
    - During machine alerts (jogging, line stoppages, etc.)
- Evaluate Pressure Differential Monitor
  - Propose piloting in Zone X (TBD)
    - At each irradiator, to prevent bulb from overheating
    - Interlock with power supply and/or control cabinet
    - Monitor to determine go/no go operating conditions
  - Evaluate for Y days (TBD)

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Questions?

- Polariscope
- Mechanical Properties
- Thermal Properties
- Reactivity

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Polariscope

- Instrument Used to Measure Stress
  - A polarizer creates polarized light, which passes through the sample
  - A 2nd polarizer (analyzer) has its polarizing axis rotated 90° to the 1st polarizer
  - The scales on the filters as set to zero when the polarizers are aligned properly at 90°
  - If there is stress in the glass part, it rotates the polarized light, passing through the analyzer
  - A full wave filter in the optical path generates colors that show tension and compression

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Polariscope

Measuring Stress

- Measurements are done by replacing the full wave filter in the light path with a ¼ wave filter
- Rotate the analyzer until the light from the stress is removed
- From the angle the analyzer is turned, the amount of stress is calculated as follows:
    - $S = [17.3 \times \theta] / [\beta \times T]$ = stress in psi ~8000 psi in bulb 3.7
        - Θ = angle of rotation on the analyzer
        - β = stress optical coefficient (Brewsters) = 3.3 for quartz
        - T = thickness of glass part (inches)
- Requires the use of immersion fluid that matches the index of refraction of the glass being analyzed

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Mechanical Properties

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Mechanical Properties

Mechanical properties of fused quartz are much the same as those of other glasses. The material is extremely strong in compression, with design compressive strength of better than 1.1×10^9 Pa (160,000 psi).

However, surface flaws can drastically reduce the inherent strength of any glass, so tensile properties are greatly influenced by these defects. The design tensile strength for fused quartz with good surface quality is in excess of 4.8×10^7 Pa (7,000 psi). Taking into consideration safety features and fatigue, the common practice is to use 6.8×10^6Pa (1000 psi).

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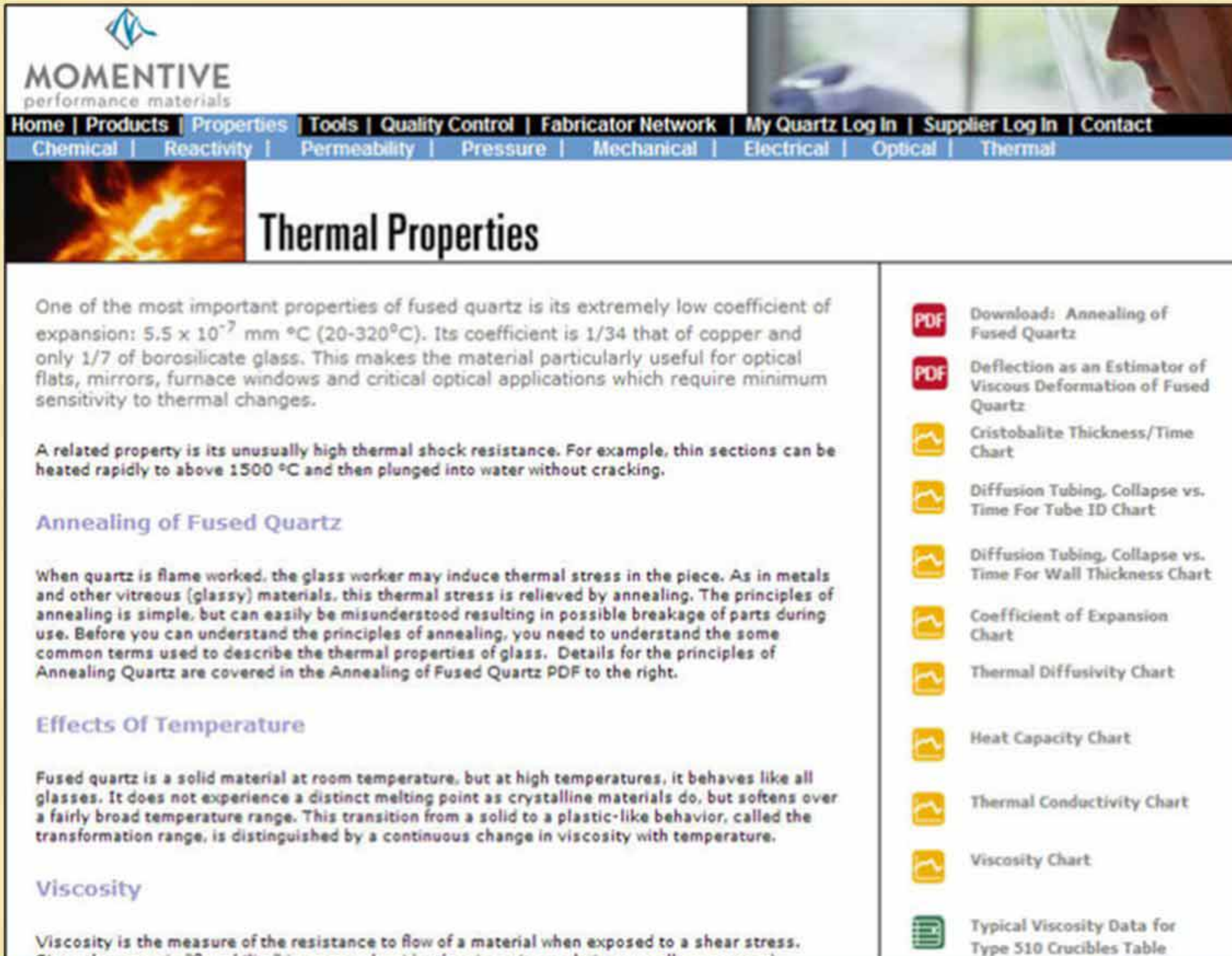
- Shear Modulus Chart
- Internal Friction Chart
- Young's Modulus Chart
- Internal Damping Chart
- Poisson's Ratio Chart
- Modulus of Rupture Chart
- Hardness Chart

Click Here

Thermal Properties



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Thermal Properties

One of the most important properties of fused quartz is its extremely low coefficient of expansion: 5.5 x 10^{-7} mm °C (20-320°C). Its coefficient is 1/34 that of copper and only 1/7 of borosilicate glass. This makes the material particularly useful for optical flats, mirrors, furnace windows and critical optical applications which require minimum sensitivity to thermal changes.

A related property is its unusually high thermal shock resistance. For example, thin sections can be heated rapidly to above 1500 °C and then plunged into water without cracking.

Annealing of Fused Quartz

When quartz is flame worked, the glass worker may induce thermal stress in the piece. As in metals and other vitreous (glassy) materials, this thermal stress is relieved by annealing. The principles of annealing is simple, but can easily be misunderstood resulting in possible breakage of parts during use. Before you can understand the principles of annealing, you need to understand the some common terms used to describe the thermal properties of glass. Details for the principles of Annealing Quartz are covered in the Annealing of Fused Quartz PDF to the right.

Effects Of Temperature

Fused quartz is a solid material at room temperature, but at high temperatures, it behaves like all glasses. It does not experience a distinct melting point as crystalline materials do, but softens over a fairly broad temperature range. This transition from a solid to a plastic-like behavior, called the transformation range, is distinguished by a continuous change in viscosity with temperature.

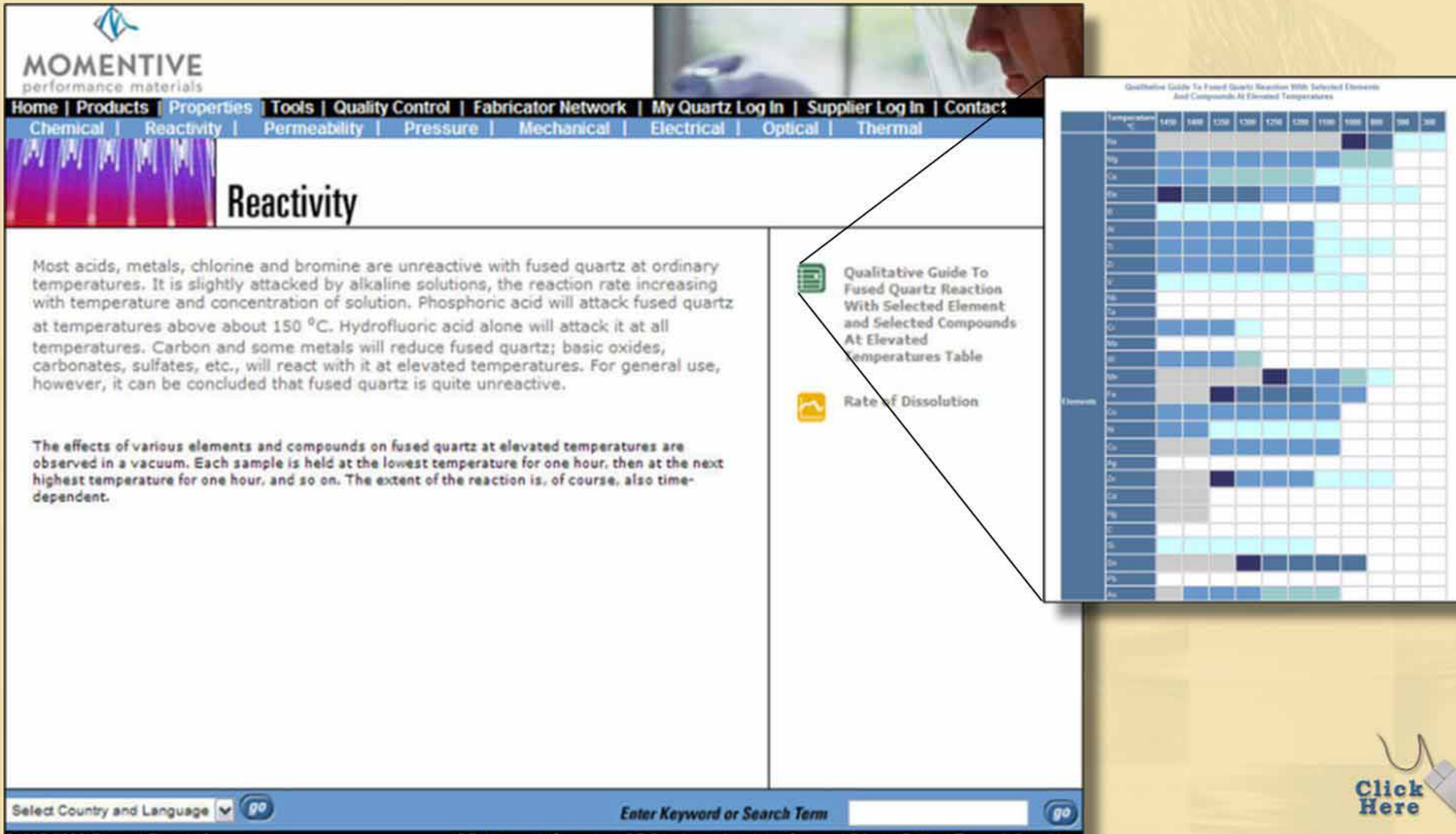
Viscosity

Viscosity is the measure of the resistance to flow of a material when exposed to a shear stress.

- PDF Download: Annealing of Fused Quartz
- PDF Deflection as an Estimator of Viscous Deformation of Fused Quartz
- Cristobalite Thickness/Time Chart
- Diffusion Tubing, Collapse vs. Time For Tube ID Chart
- Diffusion Tubing, Collapse vs. Time For Wall Thickness Chart
- Coefficient of Expansion Chart
- Thermal Diffusivity Chart
- Heat Capacity Chart
- Thermal Conductivity Chart
- Viscosity Chart
- Typical Viscosity Data for Type 510 Crucibles Table

Click Here

Reactivity



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Reactivity

Qualitative Guide To Fused Quartz Reaction With Selected Elements And Compounds At Elevated Temperatures

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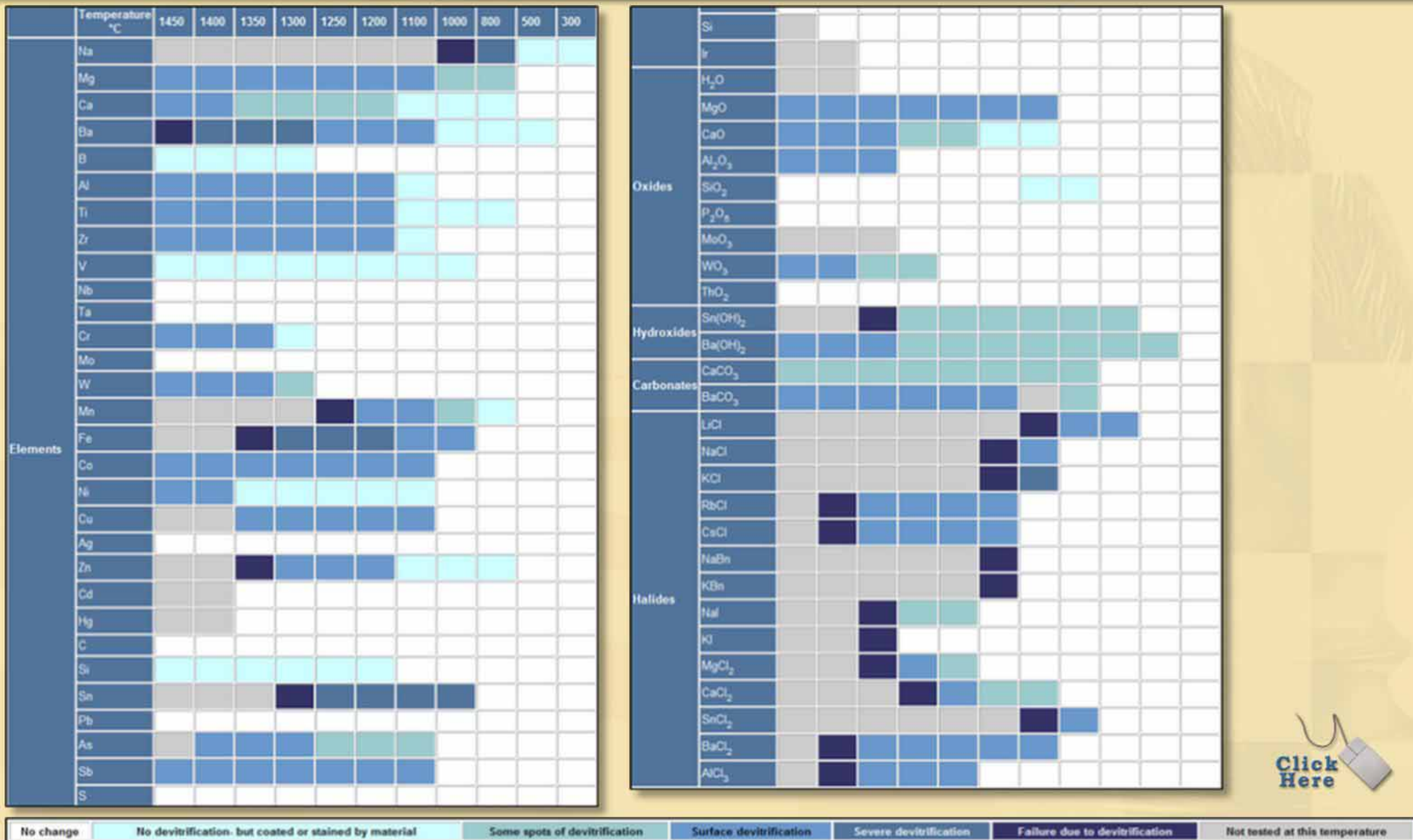

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