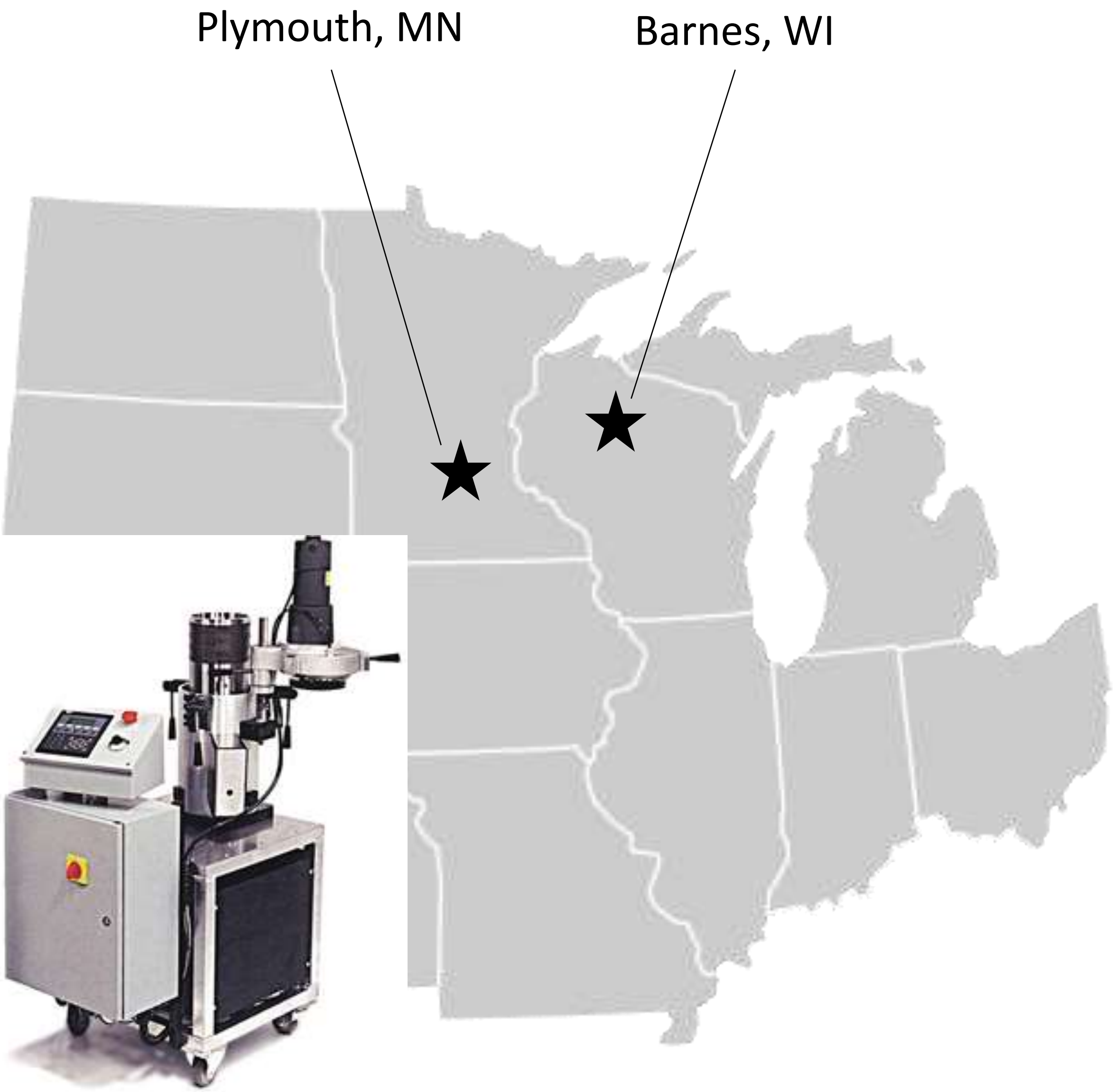
TEST QUIP

The Future of Mix Performance Testing: Fatigue/Thermal Cracking

Presented by Tom Brovolod

Testquip

- Established in 1995
- Background in servo-hydraulic test machines
- Initially produced the Brovold Gyratory Compactor
- Provided products and consulting to the asphalt industry for over 20 years with a focus on equipment used for research and testing of asphalt
- New location in Plymouth, MN
- Only manufacturer that produces a portable DCT machine



Superpave Contributions

- PG Binder grading
- Mix design using gradation and optimizing air voids for asphalt content
- Qc/Qa using the gyratory compactor
- Planned to have a Phase 3 that would be a mix performance criteria
- This started as the SST and ended as the AMPT

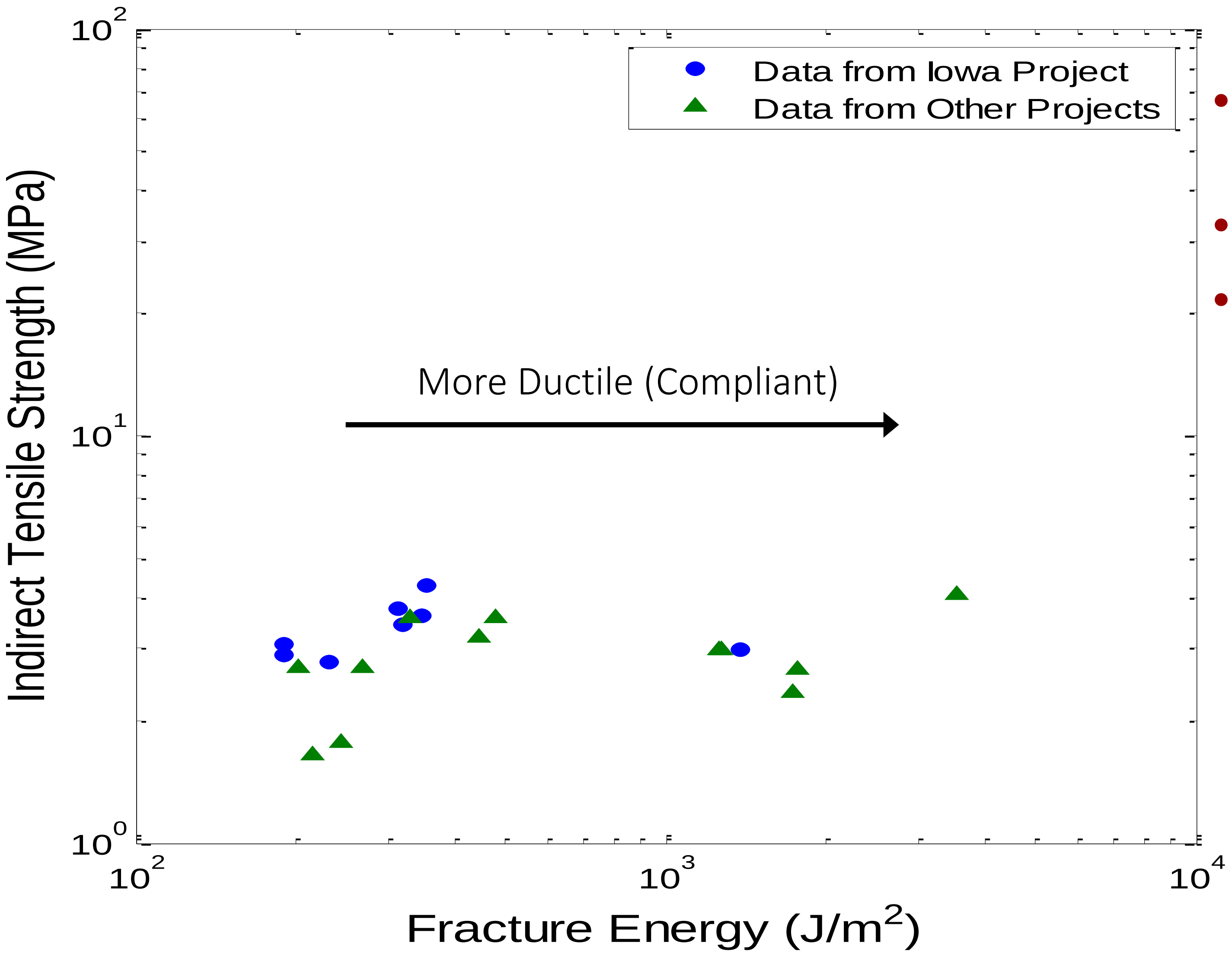
Results of Superpave

- Reduced rutting
- Reduced asphalt content
- Increased cracking

How do we know if a mix will crack?

- Do we just measure it’s tensile strength?
- NO! We learned a long time ago that energy causes damage and that causes cracks. Aerospace figured that out to design better aircraft structures.

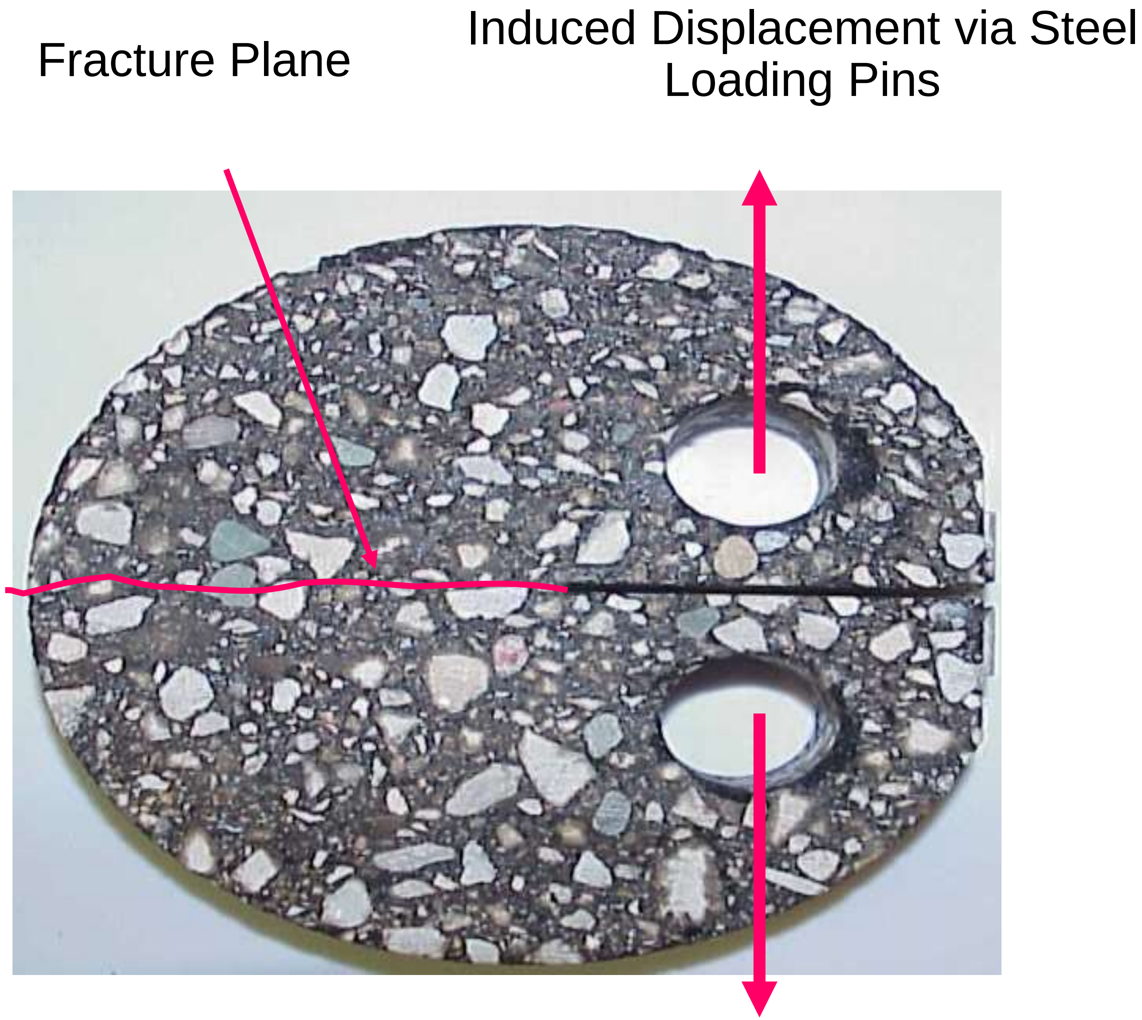
Tensile Strength-Fracture Energy Comparison



Source: Wagoner and Buttlar, 2007

- Fracture energy appears to disseminate between mixes better than IDT strength
- Especially prevalent with modified binders
- Data supported need for fracture mechanics approach

Disk-Shaped Compact Tension - DC(T)



Motivation – measure fracture energy, use cylindrical specimens, maximize repeatability, use true fracture test

Based on ASTM E399 – Geometry slightly modified to account for differences in the fracture behavior of steel and asphalt concrete

Wagoner, M. P., Buttlar, W. G., and G. H. Paulino, "Disk-Shaped Compact Tension Fracture Test: A Practical Specimen Geometry for Obtaining Asphalt Concrete Fracture Properties," *Experimental Mechanics,* Vol. 45, No. 3, pp. 270-277, 2005.

Similar Peak Load (Strength), Very Different Fracture Energy

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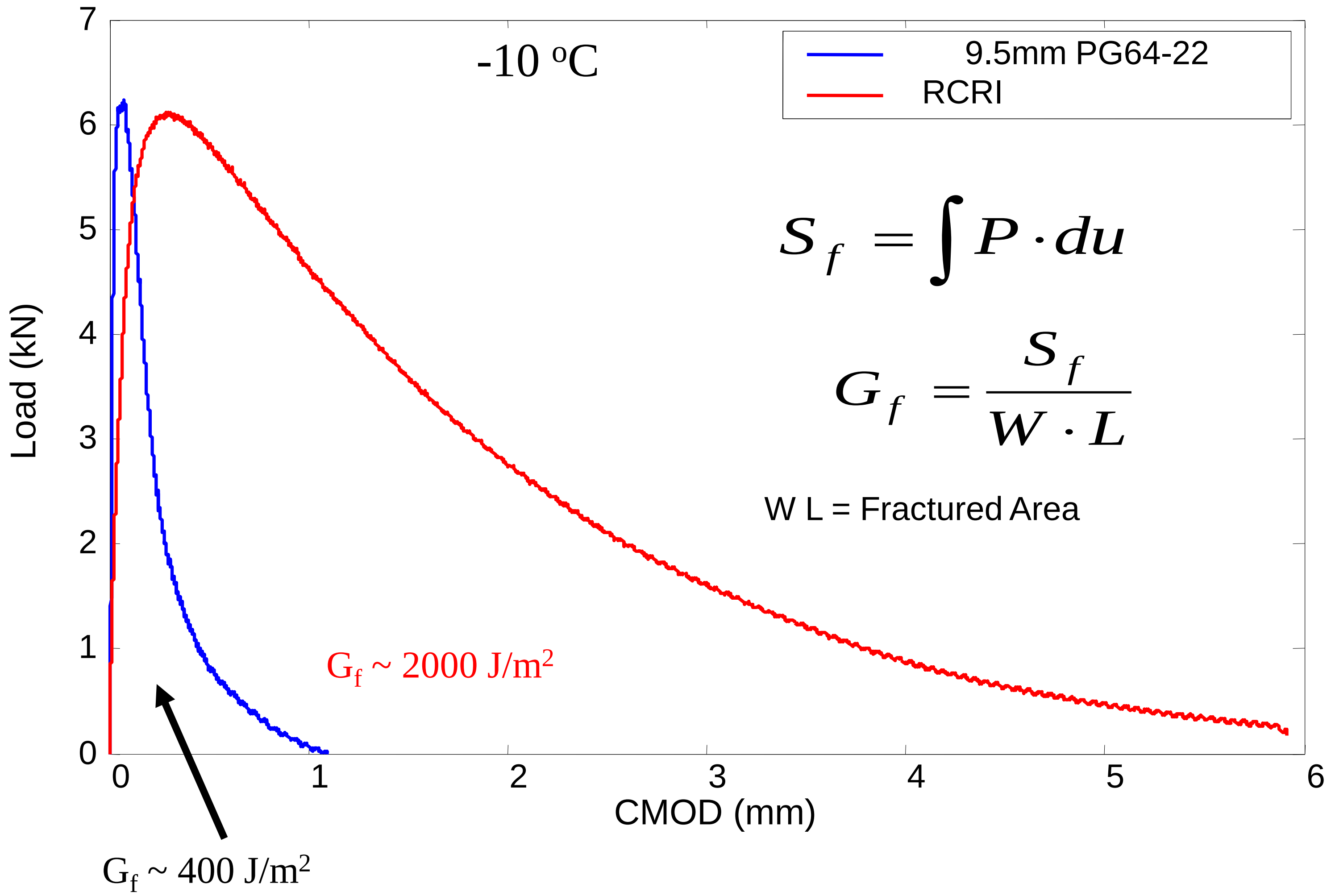


Fracture Energy, G_f, Calculated as Area Under Load-CMOD Curve Divided by Fractured Area

Typical COV ~ 10%

ASTM Specification

Designation: D 7313 – 06

Standard Test Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry[1]

This standard is issued under the fixed designation D 7313; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. *Scope*

1.1 This test method covers the determination of fracture energy (G_f) of asphalt-aggregate mixtures using the disk-shaped compact tension geometry. The disk-shaped compact tension geometry is a circular specimen with a single edge notch loaded in tension. The fracture energy can be utilized as a parameter to describe the fracture resistance of asphalt concrete. The fracture energy parameter is particularly useful in the evaluation of mixtures with ductile binders, such as polymer-modified asphalt concrete, and has been shown to discriminate between these materials more broadly than the indirect tensile strength parameter (AASHTO T322, Wagoner[2]). The test is generally valid at temperatures of 10°C (50°F) and below, or for material and temperature combinations which produce valid material fracture, as outlined in 7.4.

1.2 The specimen geometry and terminology (disk-shaped compact tension, DC(T)) is modeled after Test Method E 399 for Plane-Strain Fracture Toughness of Metallic Materials, Appendix A6, with modifications to allow fracture testing of asphalt concrete.

1.3 The test method describes the testing apparatus, instrumentation, specimen fabrication, and analysis procedures required to determine fracture energy of asphalt concrete and similar quasi-brittle materials.

1.4 The standard unit of measurement for fracture energy is Joules/meter^2 (J/m^2) [inch-pound/inch^2 (in.-lbf/in.^{2})].

1.5 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

D 8 Terminology Relating to Materials for Roads and Pavements

D 6373 Specification for Performance Graded Asphalt Binder

D 6925 Test Method for Preparation and Determination of the Relative Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

E 399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials

E 1823 Terminology Relating to Fatigue and Fracture Testing

2.2 *AASHTO Standard:*

AASHTO T322 Standard Method of Test for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device[4]

3. Terminology

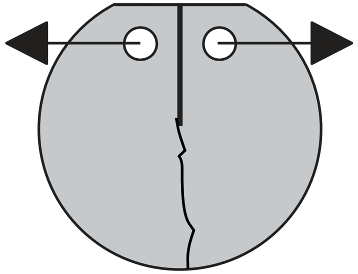
3.1 *Definitions*—Terminologies E 1823 and D 8 are applicable to this test method.

3.1.1 *crack mouth*—portion of the notch that is on the flat surface of the specimen, that is, opposite the notch tip (see Fig. 3).

ASTM D7313 **Standard Test Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry**

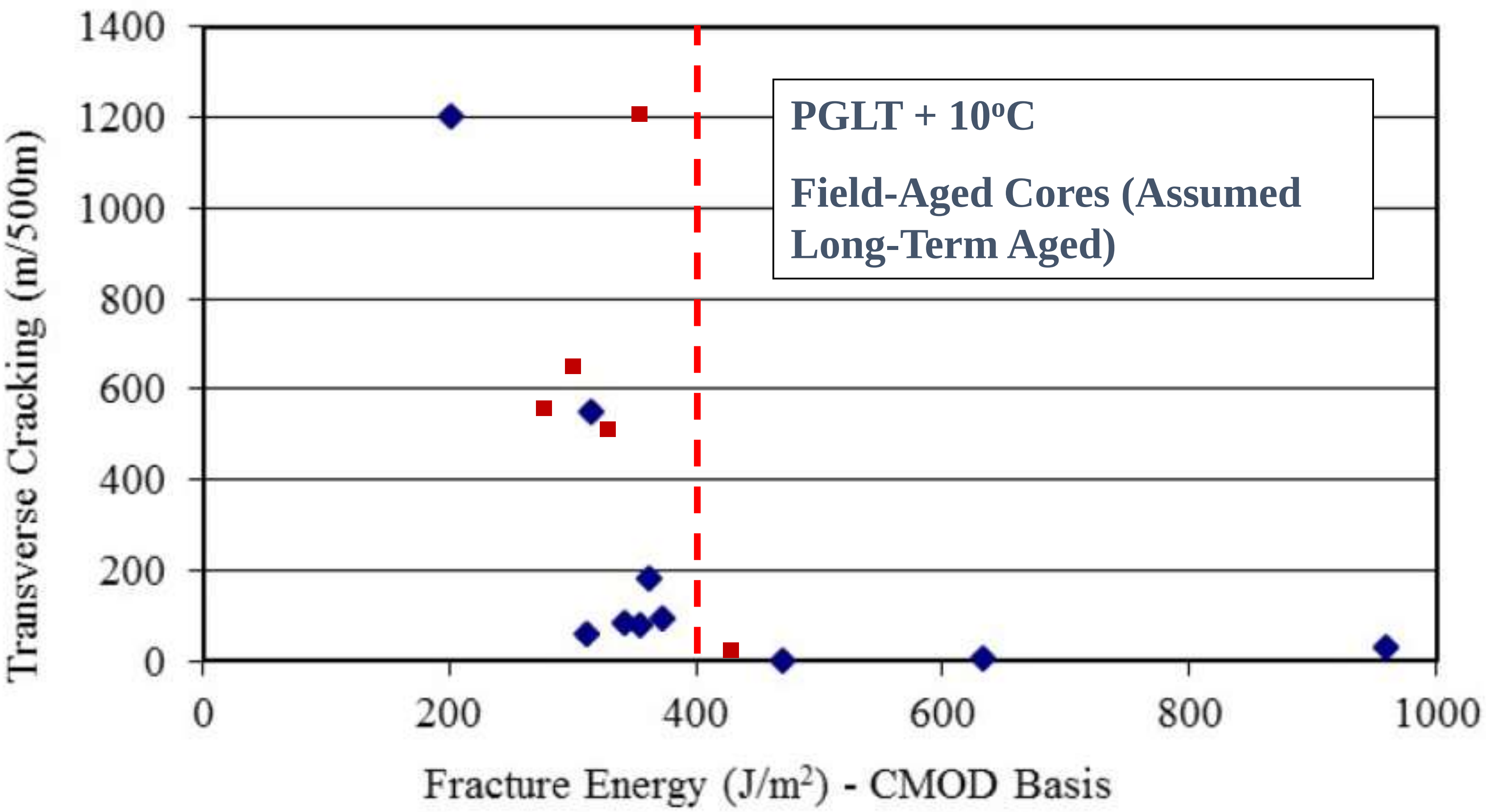
- Key Items:
  - Utilizes common specimen geometry
    - compacted from gyratory compactor or field core
    - 150mm diameter, 50mm thickness
  - Temperature typically 10°C above PG value
    - Typical test temperatures: -24°C, -18°C, -12°C
  - Tight temperature tolerance: +/-0.2°C
  - Load capabilities up 4.5klbf (20kN)
    - 0.1kN preload and 0.1kN post-peak load
  - Slow displacement (CMOD) rate: 0.017mm/sec (1mm/min)
    - 0.2” (5mm) initial gauge length, with 0.25” (6.35mm) of travel
    - Mode switch from Disp/Stroke to CMOD at preload
    - Test runs in CMOD control up to post-peak load (0.1kN)

Fracture Toughness

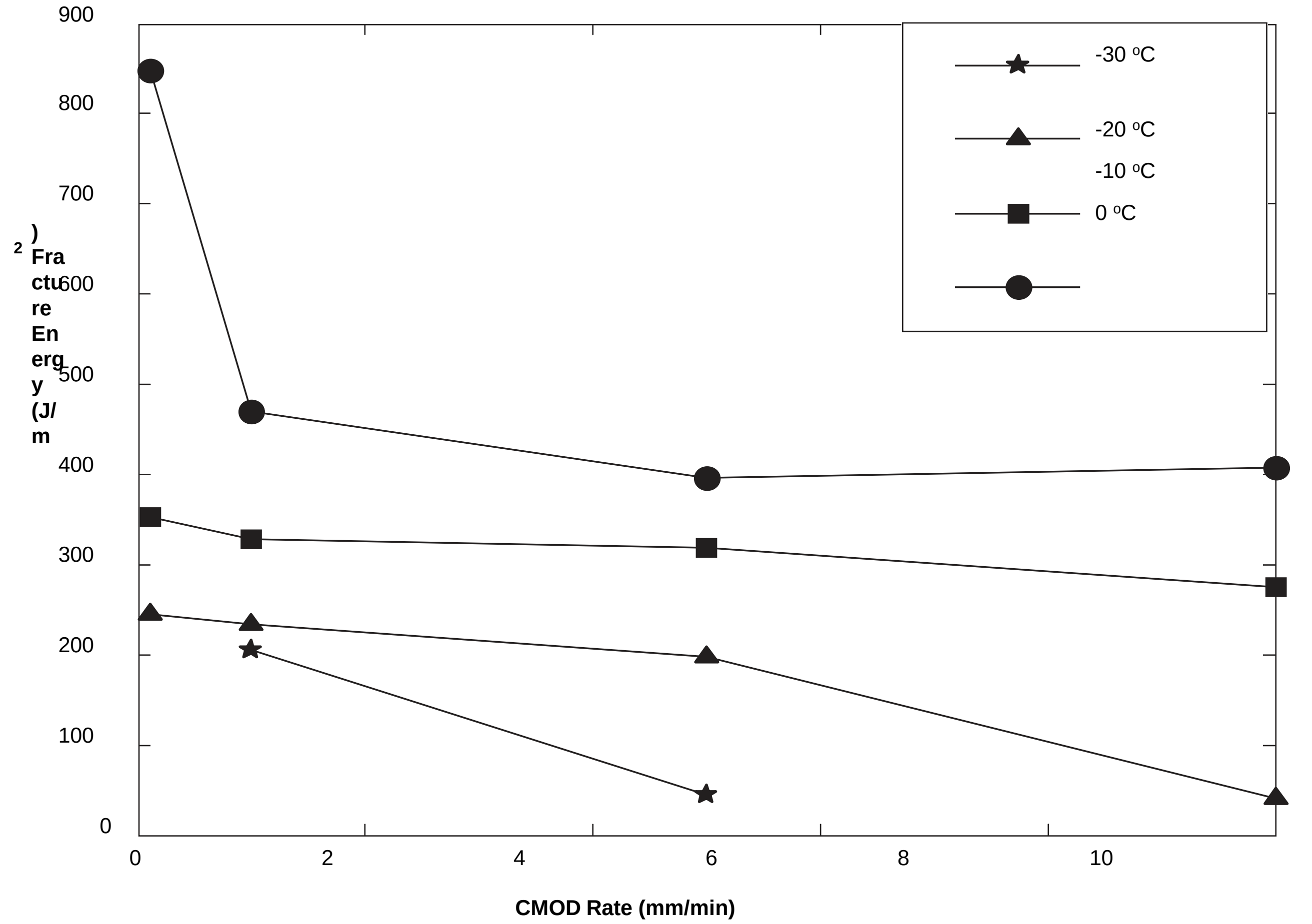


- Fracture Toughness – generic term for the material property that indicates a cracks ability to resist fracture
- Brittle materials will have lower values, while ductile materials while have higher values
- Griffith described early relationship of fracture energy to surface energy in 1920s. In the 1950s, George Irwin expanded the theory to include plastic deformation at the crack tip.
- When a material contains cracks, it’s strength becomes less than the theoretical value
- It takes energy to start a crack and energy to grow a crack.
- How much energy to start a crack?
  - Stress intensity factor (K_{IC}) at crack tip is used in metals testing (ASTM E399, E1820) which have linear elastic behavior and little ductile behavior
  - Mode I – crack is perpendicular to the load state (Mode II = shear, Mode III = tear)
- How much energy to grow a crack?
  - Fracture Energy (G_f) – energy required to create a unit surface are of crack (ASTM D7313)
  - Value calculated by DCT test includes both the crack initiation and crack extension

Results from Pooled Fund Study



Energy at different rates and temperatures



Machine Features

Portable

- Weight: 400lbs
- Dimensions: 40” x 20” x 37”
- Power: 120V, 20A

Load: 5kip

Chamber Temperature: -39.5C to 25C

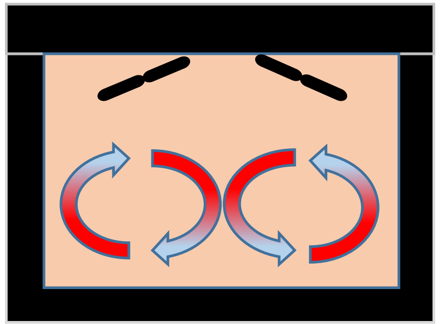
Horizontal loading

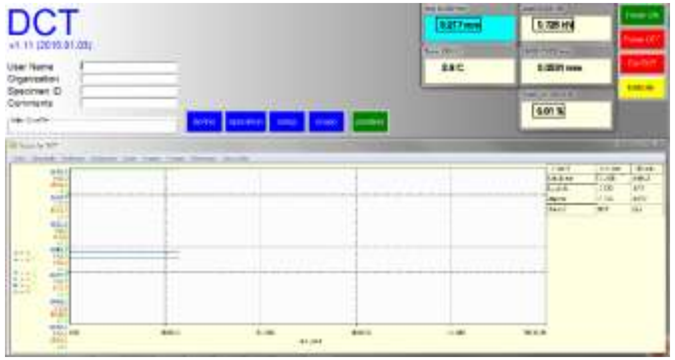
PC interface to embedded controller via Ethernet cable

Testquip’s DCT+ Machine

Components:

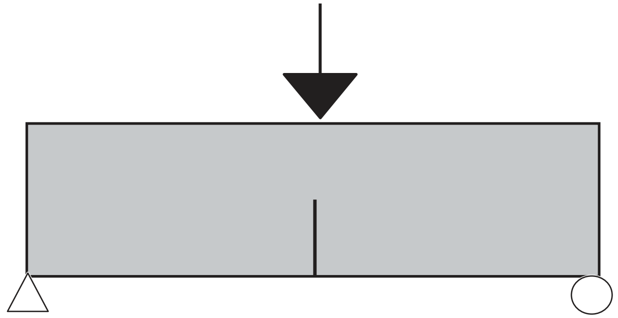
- Hydraulic
  - 1hp, 1GPM pump
  - 1” stroke actuator
- Temperature chamber
  - Chest freezer design
  - Fans promote uniform temperatures and heat exchange
  - Copper tub (good thermal mass and conductivity)
  - Insulated box enclosure
- Sensors & Conditioning
  - 5kip load cell, 0.25” CMOD, 50mm disp transducer, RTD
- Software
  - NT software runs on Windows laptop
- Controls
  - Embedded PC104 controller
- Calibration
  - Annually calibrated channels for Load, CMOD, Disp, and Temperature



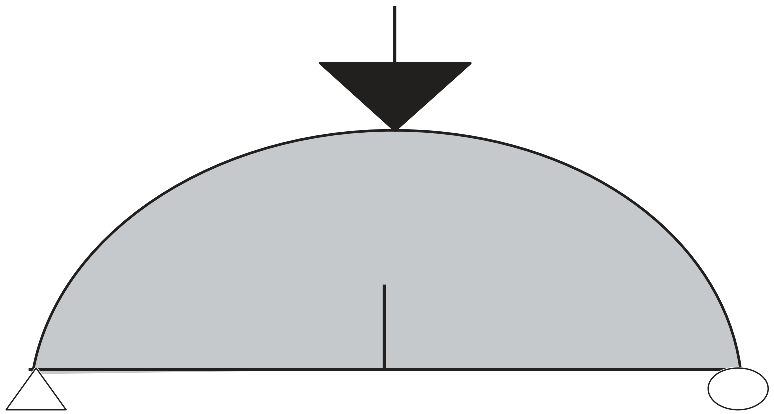


3 Common fracture tests

- Single edged notched beam



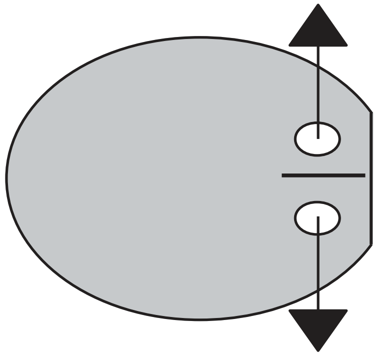
Semi circular beam



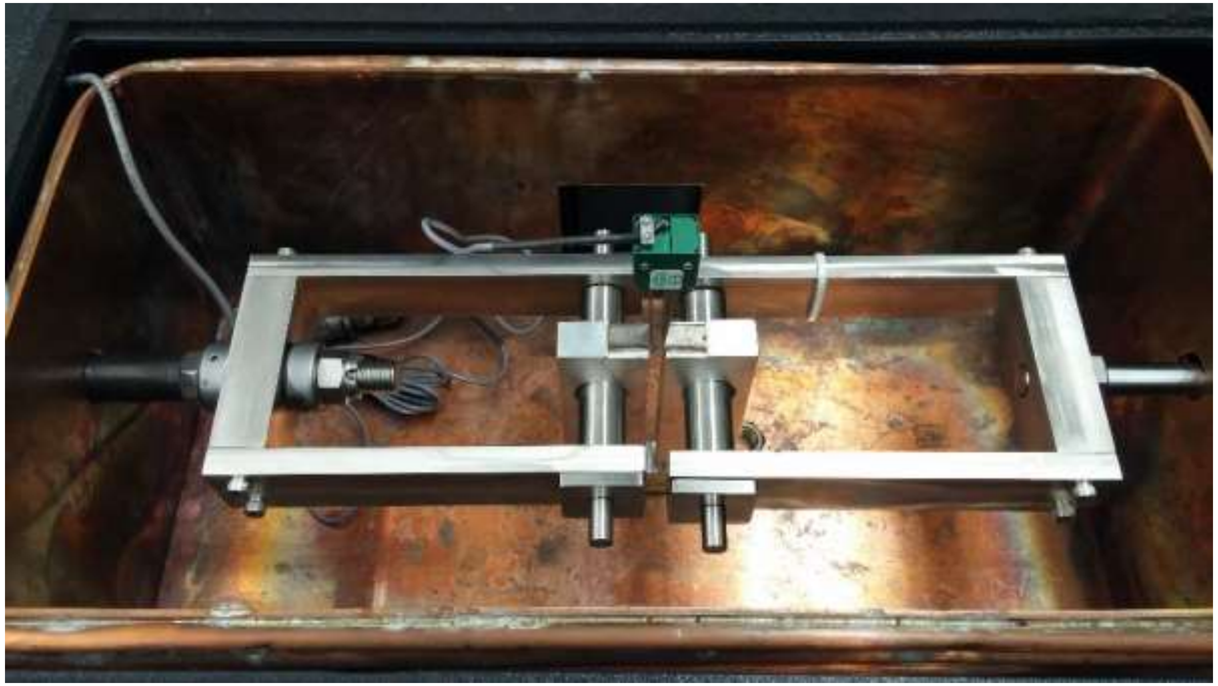
Threests SCB T

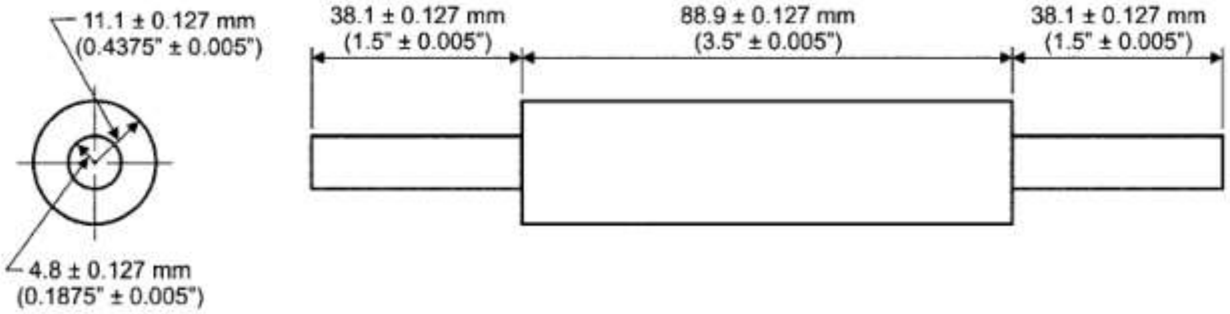
- ASTM T 105
- LTRC
- Illinois Modiied T106

DCT Disk shaped compact tension

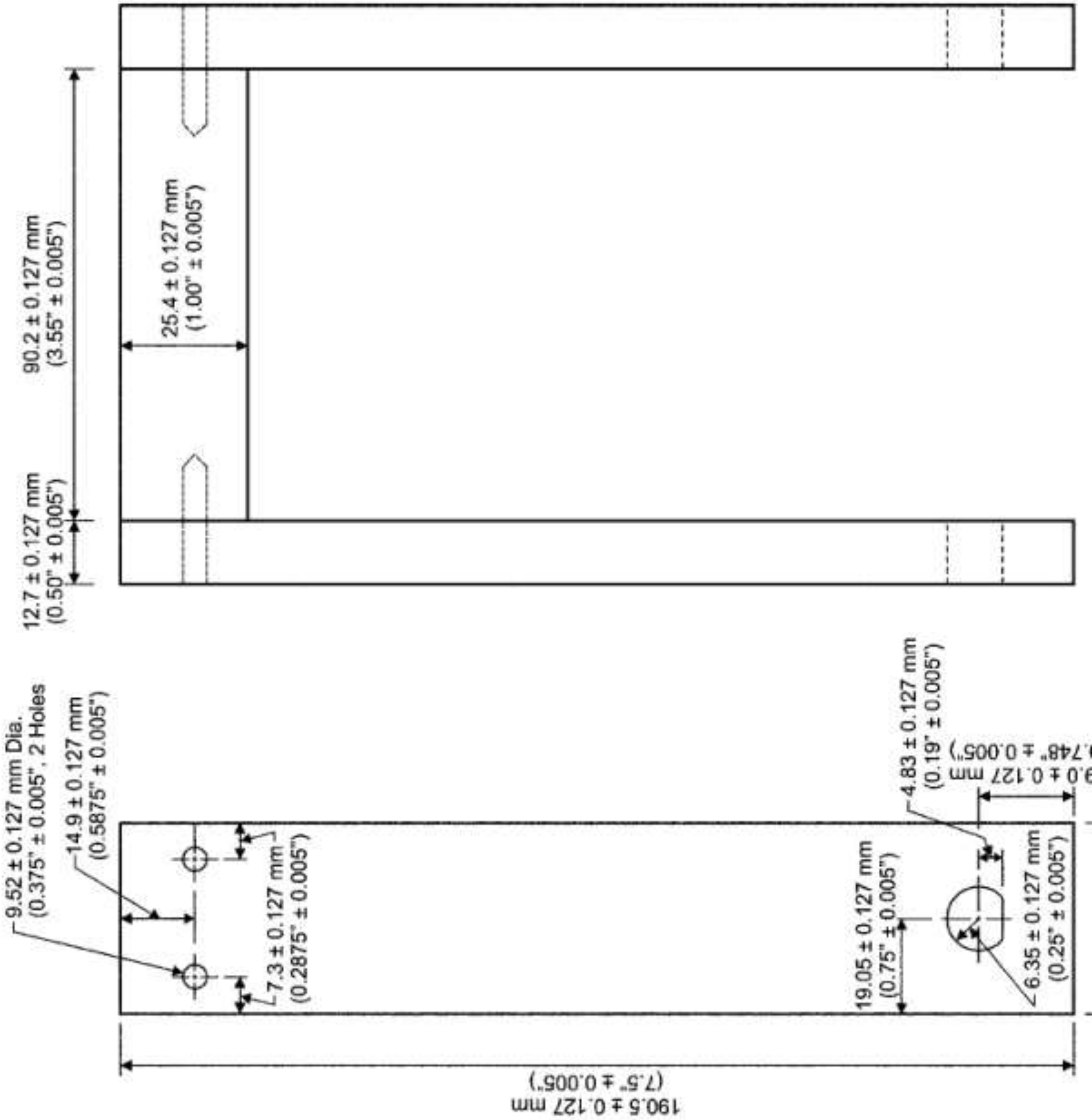


Fixturing





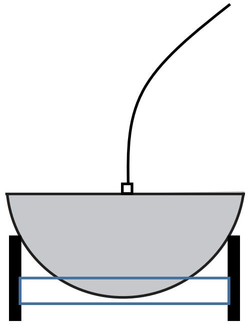
11.1 ± 0.127 mm
(0.4375" ± 0.005")
4.8 ± 0.127 mm
(0.1875" ± 0.005")
38.1 ± 0.127 mm
(1.5" ± 0.005")
88.9 ± 0.127 mm
(3.5" ± 0.005")
38.1 ± 0.127 mm
(1.5" ± 0.005")



90.2 ± 0.127 mm
(3.55" ± 0.005")
25.4 ± 0.127 mm
(1.00" ± 0.005")
12.7 ± 0.127 mm
(0.50" ± 0.005")
9.52 ± 0.127 mm Dia.
(0.375" ± 0.005", 2 Holes
14.9 ± 0.127 mm
(0.5875" ± 0.005")
7.3 ± 0.127 mm
(0.2875" ± 0.005")
19.05 ± 0.127 mm
(0.75" ± 0.005")
4.83 ± 0.127 mm
(0.19" ± 0.005")
6.35 ± 0.127 mm
(0.25" ± 0.005")
190.5 ± 0.127 mm
(7.5" ± 0.005")

Temperature Monitoring

- RTD used to monitor chamber air temperature
- Specimen dummy can be placed in cradle inside chamber to represent specimen temperature
  - Shape is approximately half gyro specimen
  - Similar mass as DCT specimen

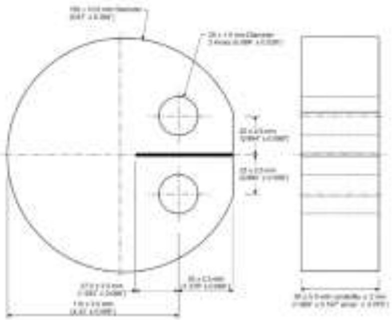


- Precision (0.025°C uncertainty) external probes can optionally be logged by software
  - Used to ensure specimen and dummy are in close agreement to provide confidence in temperature measurement

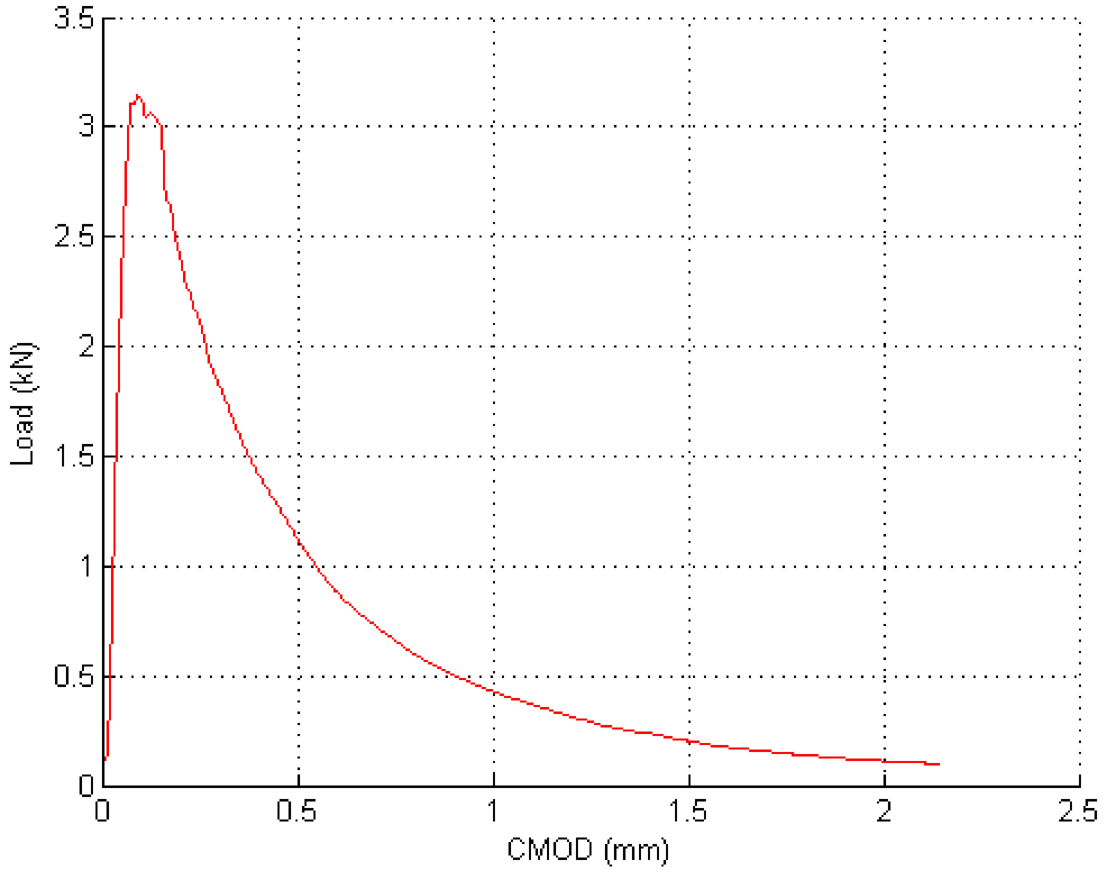
Specimen Fabrication

- Masonry saw for cutting thickness and flat
  - Diamond Products CC500M or CC800M
- Coring rig for drilling loading holes
  - Diamond Products M1AA-15
  - 1” diameter coring bit
- Bandsaw for cutting notch
  - Diamond Tech DL7000

- MnDOT youtube video provides overview on sample fabrication and example fixturing
  - Search “DCT Sample Preparation”



Results

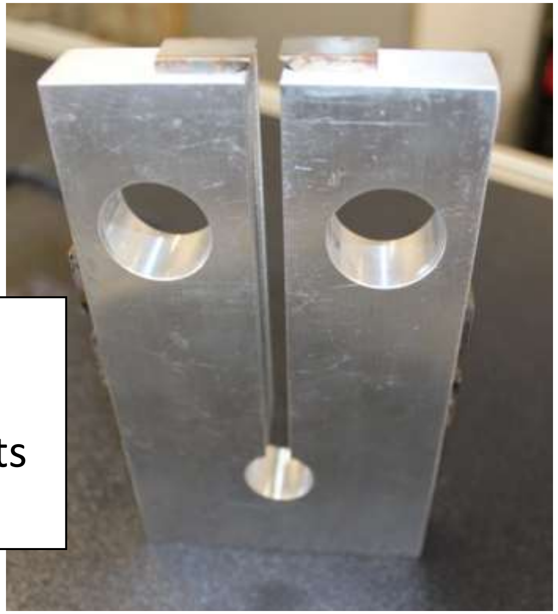


DCT-Temperature Control (TC) v1.11.3

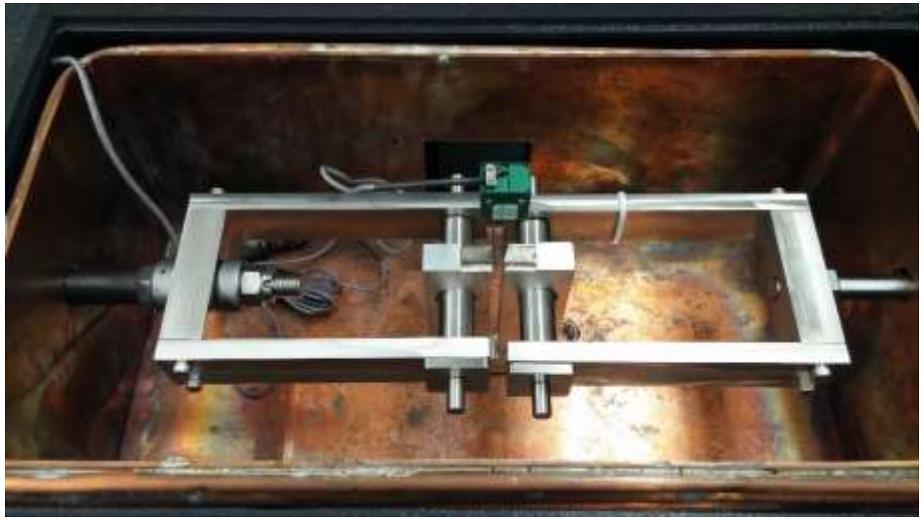
Created	: 1/15/2015 12:31:15 PM
User Name	: Shawn
Organization	: Testquip
Specimen ID	: Sample 2
Comments	: Example Test
Desired Temperature	: -24 C
Dummy Tolerance	: 0.1 C
Stabilization Time	: 15 minutes
Diameter	: 150.00 mm
Thickness	: 50.63 mm
Ligament	: 84.95 mm
Cumulative Area	: 1569.44 Nmm
Max Load	: 3.142 kN
Time at Max Load	: 5.44 seconds
Slope	: 0.0170 mm/second
Energy	: 364.9 J/m²
Avgerage Temperature	: -24.007 C
Test Time	: 125.84 seconds

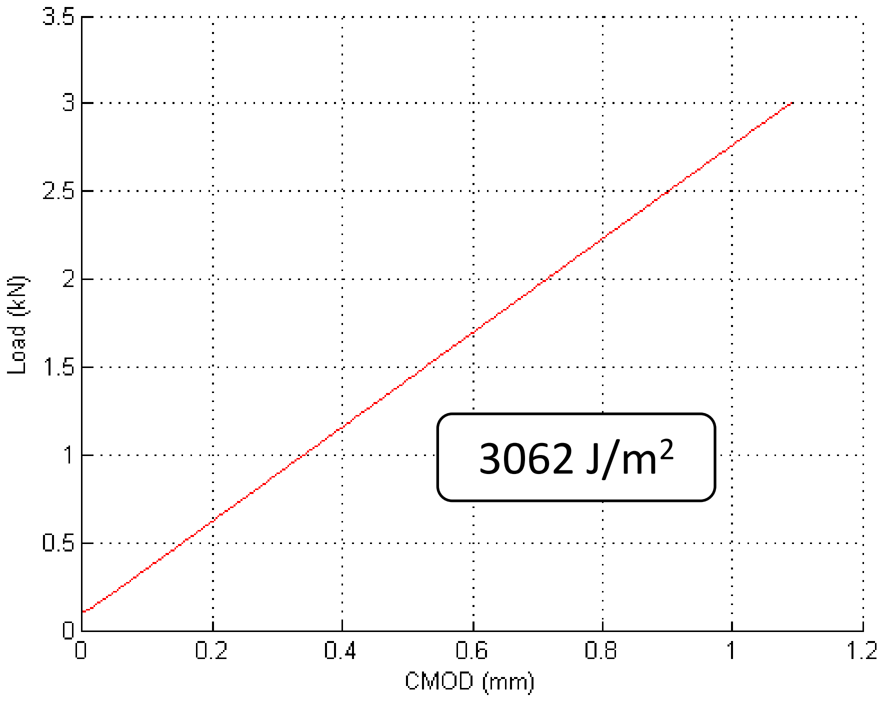
DCT Verification Device

- DCT "Validator"
  - U.S. Patent 8,825,423 B1
- Provides confidence in calibration and machine operation
- Runs to 3kN and approximately 1.1mm

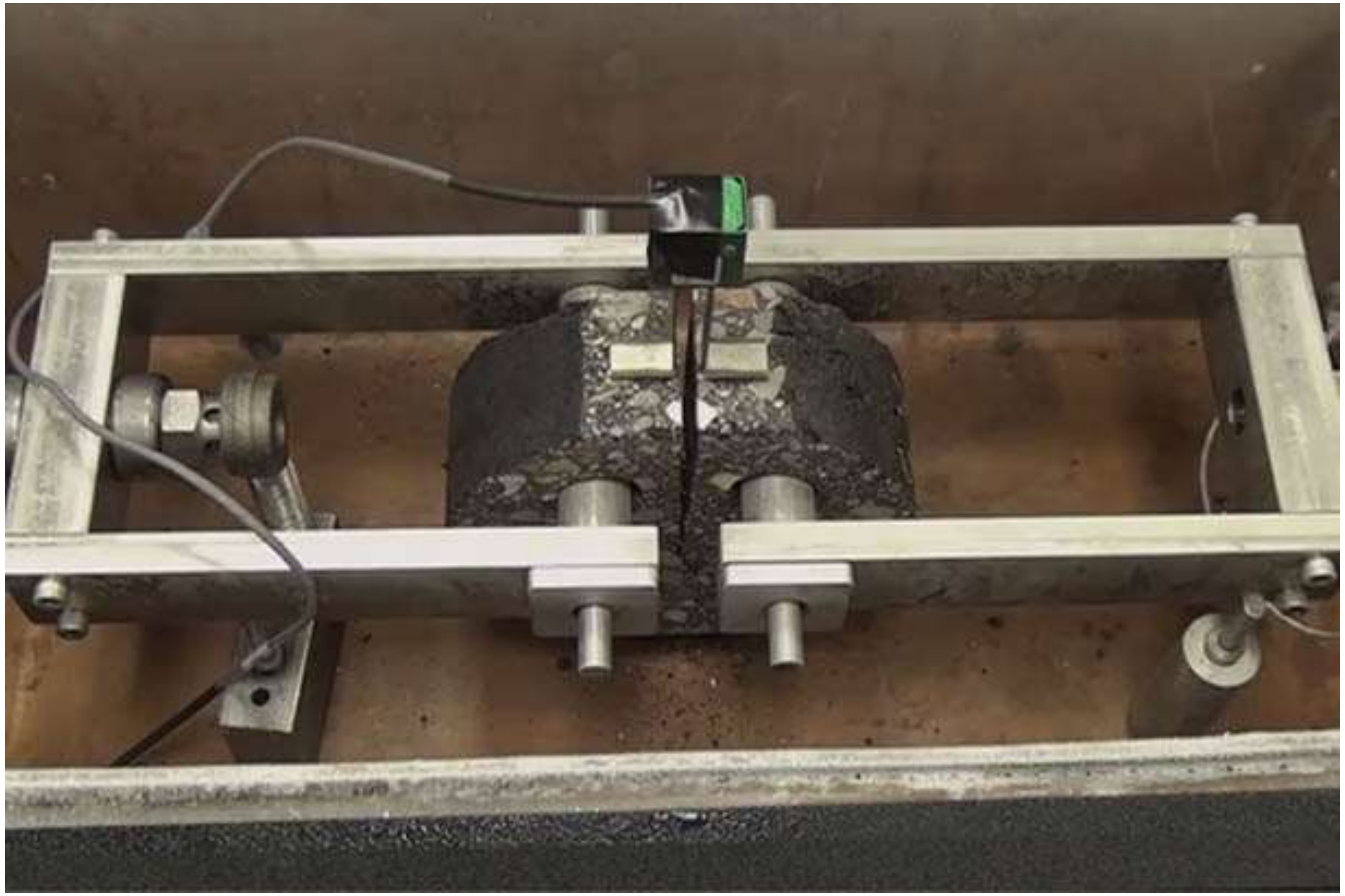


SN107 - energy value established using deadweights = 3061 J/m²





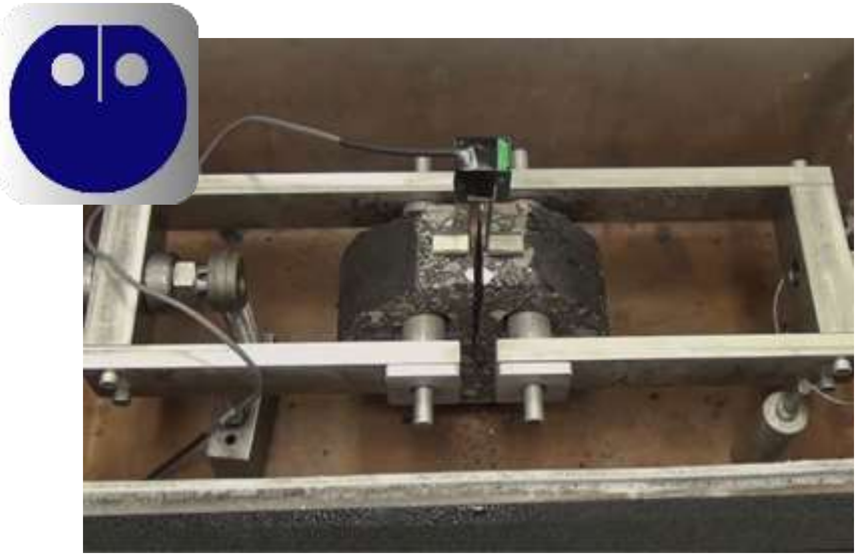
Demonstration

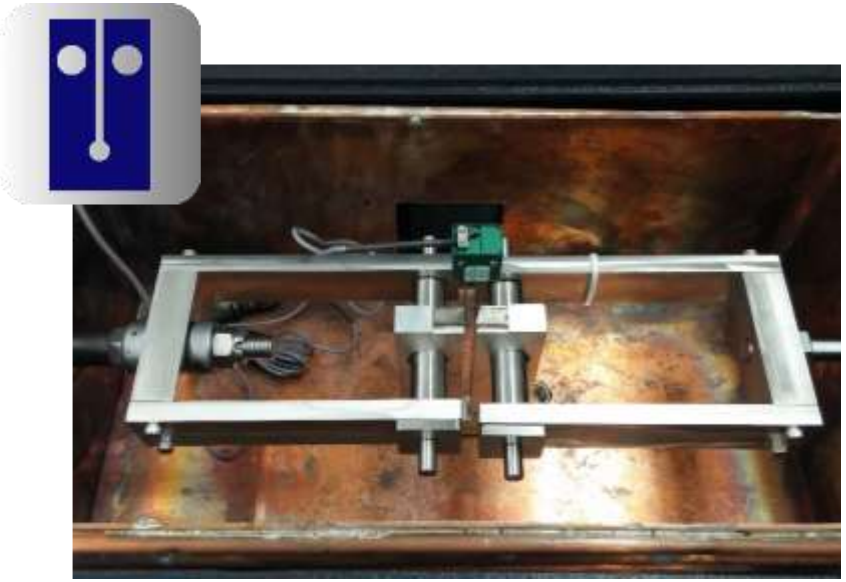


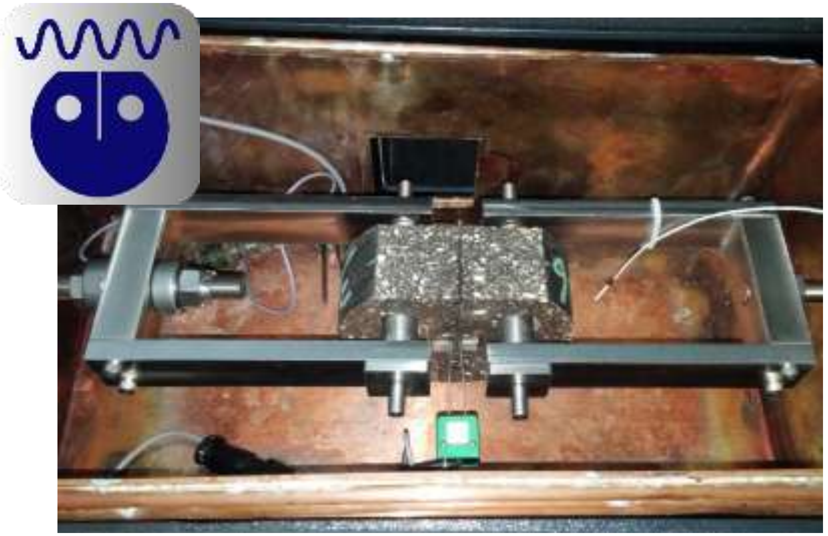
Customization

- Windows installed in front and back of chamber for video analysis

All the Tests





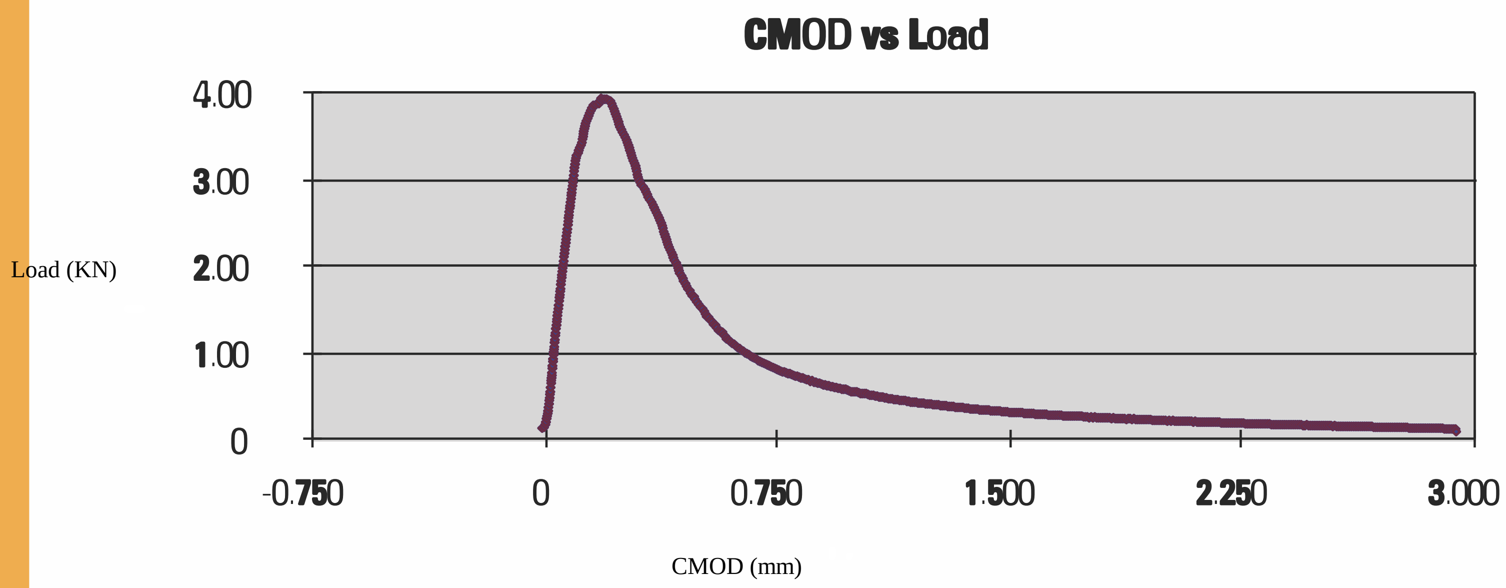


Modular Software and Controls

Fracture Energy per ASTM D7313

Test Results

The energy is calculated from the area under this curve and reported in J/M^2 units. It is the energy to tear the ligament down to 0.1KN.



Immediate results

The user gets an immediate view of the data when the test completes.

User's DC Test Results

Created	:	9/3/2013 3:43 PM
User name	:	User
Specimen ID	:	BM13-37 TH10-ER_ F
Comments	:	
Diameter	:	150.000 mm
Thickness	:	50.470 mm
Ligament	:	82.270 mm
Cumulative Area	:	2311.8424 Nmm
Max Load	:	3.95 kN at 11.24 seconds
Slope	:	0.0171 mm/second
Energy	:	556.78 J/m^2

Questions

Contact

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