Stress-Strain Microprobe® (SSM) Technology: Advanced NDE Techniques for Measuring Key Mechanical Properties

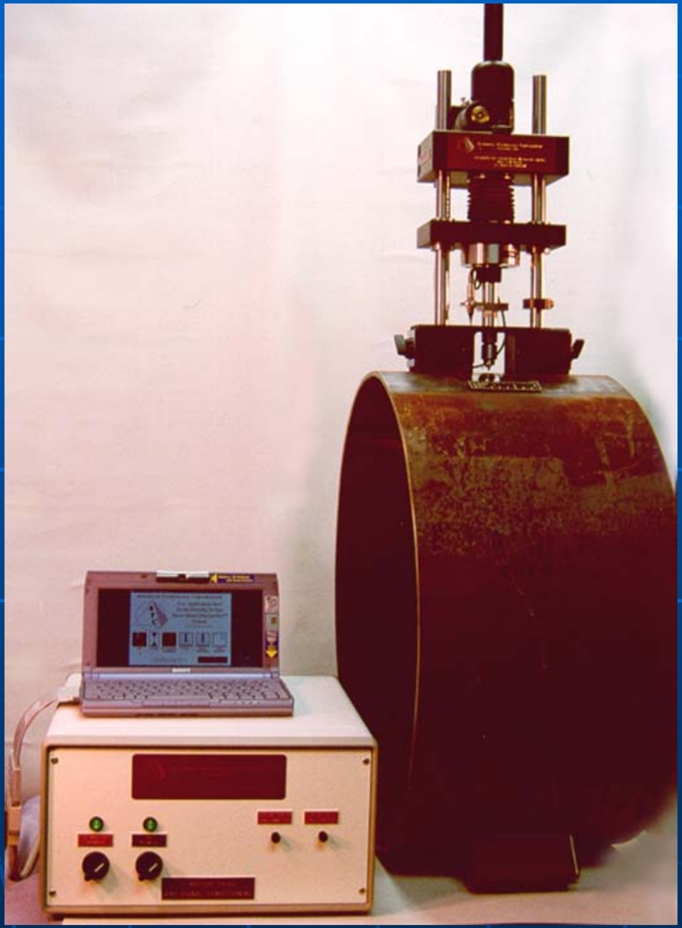
Advanced Technology Corporation
115 Clemson Drive
Oak Ridge, TN 37830
Web: www.atc-ssm.com
Contact: Fahmy M. Haggag, President

The **Stress-Strain Microprobe®** (SSM) System Performs:

- Automated Ball Indentation (ABI) tests to measure tensile and fracture toughness properties while eliminating the manufacturing of destructive specimens

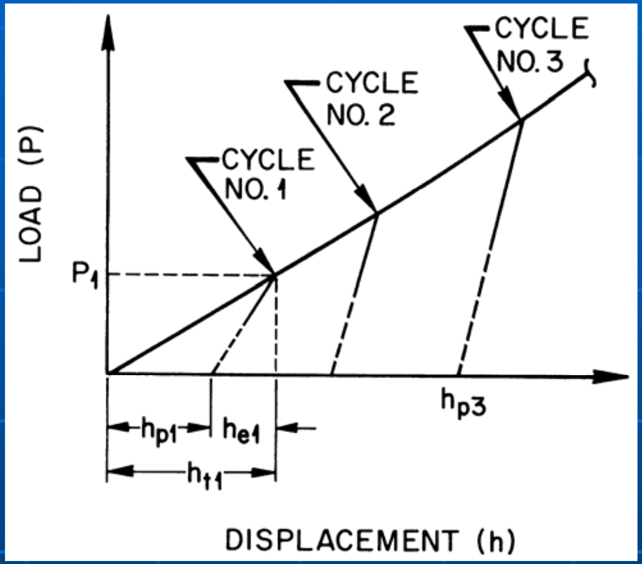
- In addition to the nondestructive ABI test, the SSM system is also a state-of-the-art Computer-Controlled Universal Testing Machine that performs all conventional destructive tests (tensile, fracture toughness, etc.)

In-Situ **Stress-Strain Microprobe®** (SSM) System, Model SSM-M1000

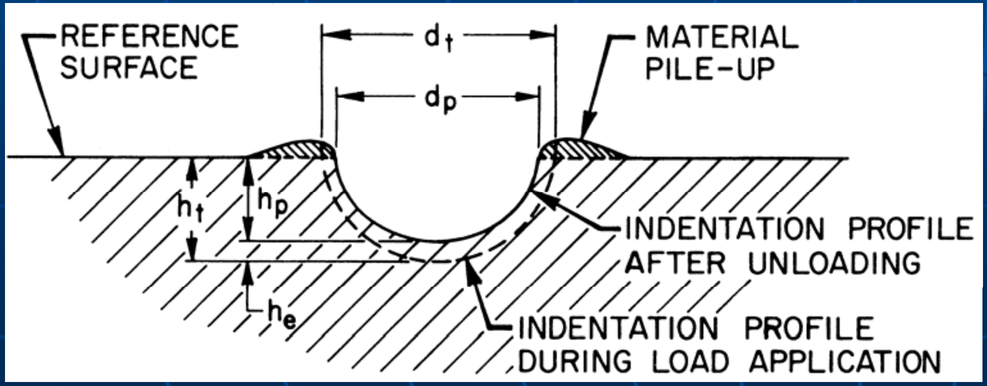


The testing head of the SSM system is mounted with manual magnets on a 24-inch diameter X52 pipeline.

Cyclic Loading and Unloading of Ball Indenter into Material



(a) Schematic of Applied Load versus Penetration Depth



(b) Indentation Geometry During Load Application and After Load Removal

Calculation of Stress-Strain Curves

Tensile Test

- **Two Data Parameters:**
  (1) Tensile Load,
  (2) Sample Extension

Stress = Load / Cross-Sectional Area

Strain = ΔL / L_o

ABI Test

- **Two Data Parameters:**
  (1) Compressive Load,
  (2) Progressive Indentation Depth

Stress = Load / Effective Indentation Size

Strain = Constant x (Progressive indentation diameter / Indenter diameter)

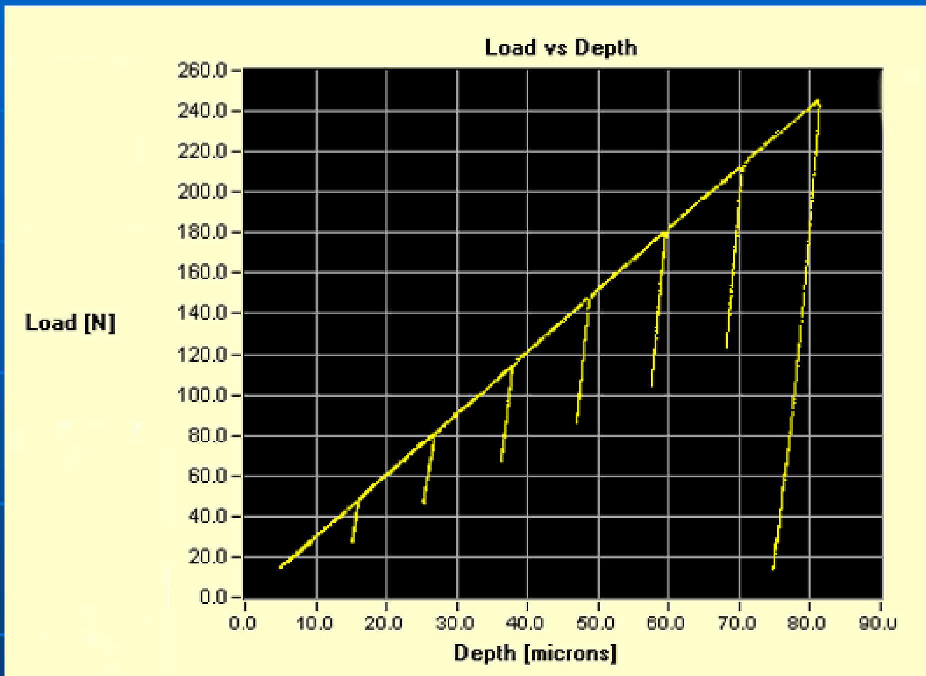
Equations for Calculating the Yield Strength and Stress-Strain Properties from ABI Tests

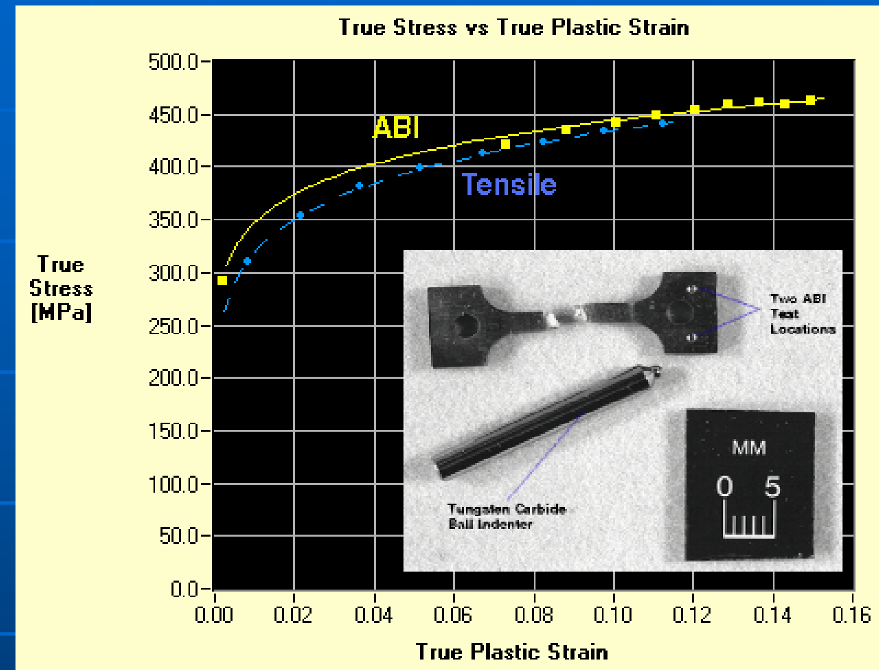
(1) True Plastic Strain: $\epsilon_t = 0.2\dfrac{d_p}{D}$	Strain range: 0-0.2 or 0% to 20% Empirical (Tabor's 1940's), Analytical (Prof. McClintock, 1960's)
(2) True Stress: $\sigma_t = P_m \dfrac{1}{\psi(\phi)} = \dfrac{P}{(\pi d_p^2/4)} \dfrac{1}{\psi(\phi)}$ Constraint factor: $\psi = \begin{cases} 1.12 & \phi \le 1 \\ 1.12 + \tau \ln\phi & 1 < \phi \le 27 \\ \psi_{max} & \phi > 27 \end{cases}$	ϕ = indentation variable: $\phi = \dfrac{\epsilon_p E_2}{0.43\sigma_\tau}$ $\psi_{max} = 2.87\alpha_m$ $\tau = (\psi_{max} - 1.12) / \ln(27)$ α_m = constrain factor index
(3) Meyer's Law (1908): $\dfrac{P}{d_t^2} = A\left(\dfrac{d_t}{D}\right)^{m-2}$	P = load d_t = total diameter of the indentation m = Meyer's index D = indenter diameter A = yield parameter (P/d_t^2 at $d_t/D = 1$)
(4) Indentation plastic diameter: $d_p = \left\{\dfrac{C(D/2)[h_p^2 + (d_p/2)^2]}{[h_p^2 + (d_p/2)^2 - h_p D]}\right\}^{\frac{1}{3}}$	$C = 5.47\, P(1/E_1 + 1/E_2)$ E_1, E_2 = Young's moduli for indenter and test material h_p, d_p = Plastic indentation depth, plastic chordal diameter
(5) Yield Stress: $\sigma_y = \beta_m A + b_m$	β_m = Material yield slope, b_m = material yield constant

True Stress = Engineering Stress (1 + Engineering Strain)

True Plastic Strain = *ln* (1 + Engineering Strain)

Comparison of Stress-Strain Curves from ABI and Tensile Tests on X42 ferritic steel





(a) Indentation versus depth in an ABI test using a 0.51-mm (0.02-inch) diameter tungsten carbide indenter on X42 ferritic steel material.

(b) True-Stress versus True-Plastic-Strain curves from ABI and tensile tests on X42 pipeline steel. A miniature tensile specimen is shown with two indentations made with a 1.57-mm (0.062-inch) indenter.

Calculation of Fracture Toughness from ABI Data

Using Critical Fracture Stress Criterion for Ferritic Steels in the Transition Temperature Region

1. $$W_T = IEF = \int_0^{h_f} P_m(h)\,dh$$

2. $$P_m = \frac{4P}{\pi d^2}$$

3. $$d = 2\sqrt{Dh - h^2}$$

4. $$\sigma_f = \sigma_y[1 + \ln(1 + 2360\left(\frac{K_{Ic}}{\sigma_y}\right)^2)] = 1.1P_m$$

5. $$(K_{Jc})^{ABI} = 30 + \sqrt{2EW_T}$$

6. $$K_{Jc}(med) = 30 + 70e^{0.019(T - T_0)},\ MPa\sqrt{m}$$

SSM-M1000™ testing in-service Kerosene pipelines in Alexandria, Egypt

Comparison between nondestructively ABI-measured $(K_{Jc})^{ABI}$ and destructive 1T CT fracture toughness test results of 73W Weld of ORNL