SSM Technology
Additional Technical Issues

Fahmy M. Haggag

ADVANCED TECHNOLOGY CORPORATION

253 Midway Lane
Oak Ridge, Tennessee 37830 USA
Tel: 865-483-5756 Fax: 865-483-5860

E-mail: info@atc-ssm.com Web: www.atc-ssm.com

Presented to:

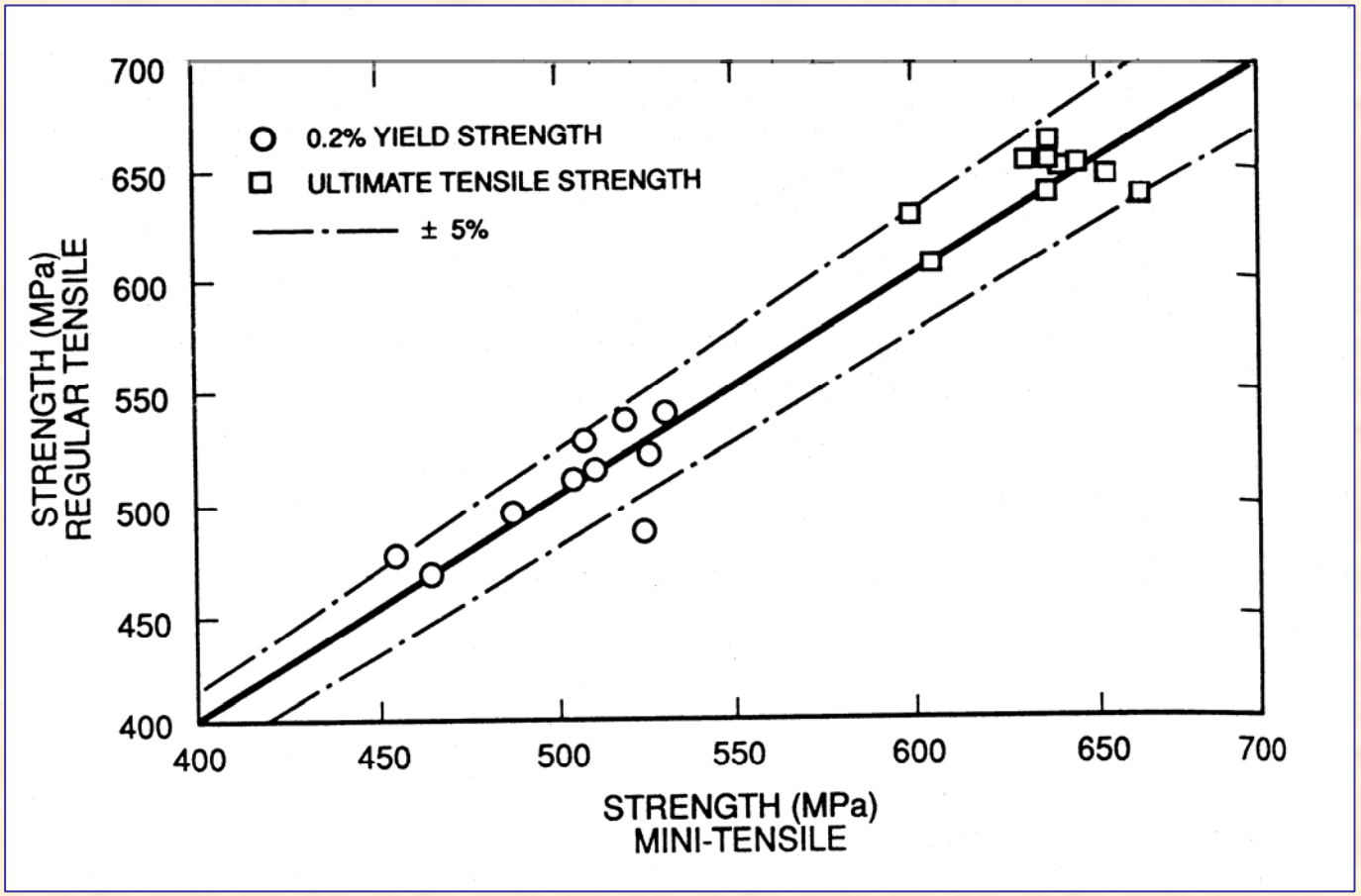
PHMSA Pipeline Safety Program

August 2008

Presentation Outline:

- Full-size versus miniature tensile specimens
- Orientation effects – Transverse versus Longitudinal
- Through-thickness gradients
- Inner and outer pipeline surface differences
- The Battelle hardness approach – technically flawed

Comparison between regular size and miniature tensile specimens of A533 grade B class 1 pressure vessel steel

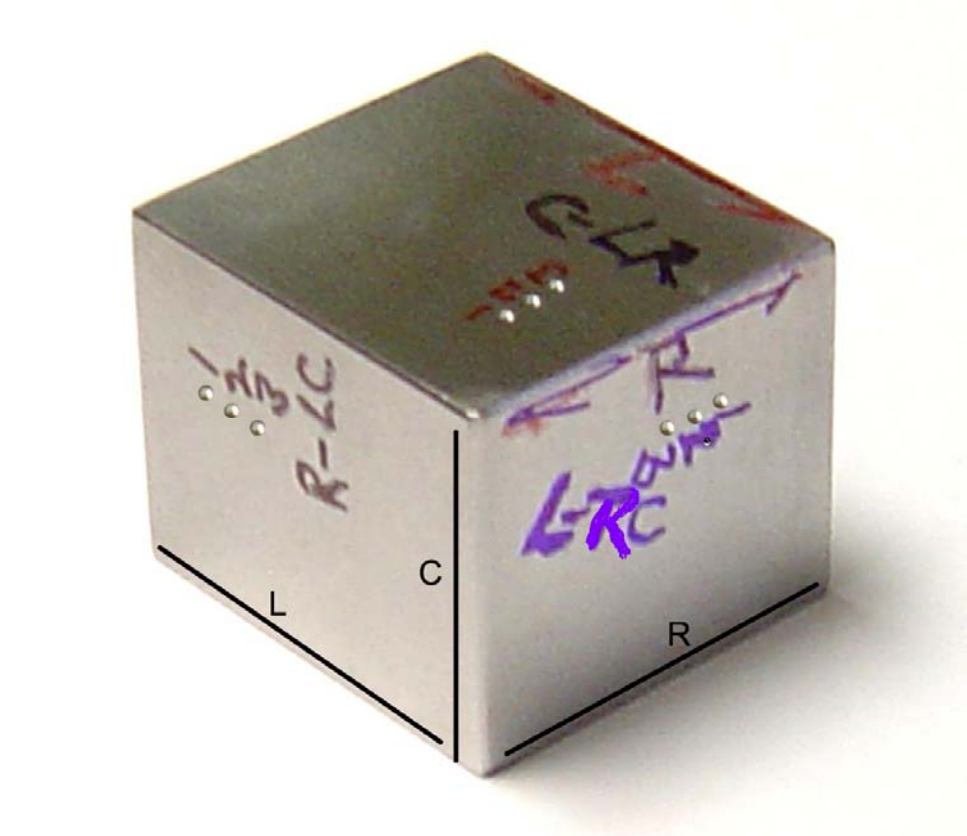


Note: The 45° line represents perfect agreement; the lines to either side represent ± 5%.

Reference: Haggag, F. M., "Effects of Irradiation Temperature on Embrittlement of Nuclear Pressure Vessel Steels," *Effects of Radiation on Materials: 16th International Symposium, ASTM STP 1175,* Arvid S. Kumar, David S. Gelles, Randy K. Nanstad, and Edward A. Little, Eds., American Society for Testing and Materials, Philadelphia, 1993, p. 182.

The ABI Test is Multi-Axis Test and Not Uni-Axial Like the Tensile Test

It Determines the Effect of Test Orientation in Three Combinations of the Three Axes (i.e., R-LC, L-RC, and C-LR)



For In-Situ/Non-destructive Testing of Steel Pipelines, the R-LC is the only orientation possible. However, on a cut sample the L-RC and the C-LR orientations can be tested.

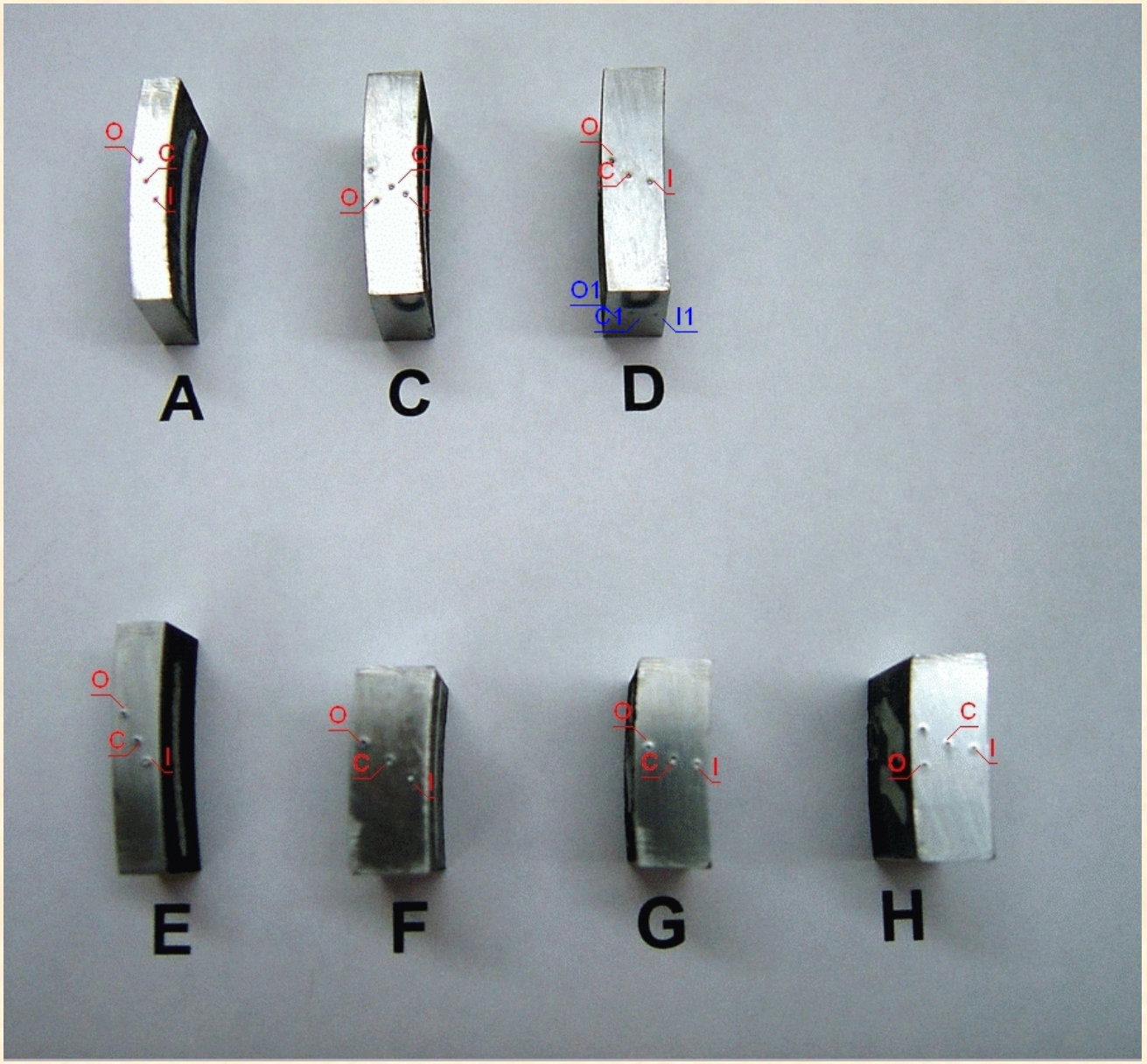
Triplicate ABI tests were conducted in three orientations (namely, C-LR, R-LC, and L-RC). **The first letter indicates the direction parallel to the indenter axis while the following two letters indicate the plane perpendicular to the indenter spherical tip.**

The ABI Test Orientation on the end tabs of both Longitudinal and Transverse tensile specimens is the same R-LC which provides an average of both orientations with agreement within 6%.

Test Name	ABI Yield Strength [ksi]	ABI UTS [ksi]	Tensile Yield Strength [ksi]	Tensile UTS [ksi]
X-42 Transverse				
ABI-X42-C1-1	59.0	74.4	56.2	71.2
ABI-PRCI-X42-SC2-3	64.2	77.0	60.6	72.6
ABI-PRCI-X42-C3-1	65.8	80.3	62.2	74.8
ABI-PRCI-X42-C4-1	59.3	74.1	56.7	72.1
Average	**62.1**	**76.5**	**58.9**	**72.7**
Standard Deviation	**3.4**	**2.9**	**2.9**	**1.5**
X42 Longitudinal				
ABI-PRCI-X42-A5-1	58.8	74.4	59.4	71.4
ABI-PRCI-X42-A6-1	65.3	79.7	63.4	74.4
Average	**62.1**	**77.1**	**61.4**	**72.9**
Standard Deviation	**4.6**	**3.7**	**2.8**	**2.1**
X52 Transverse				
ABI-X52-C2-1	68.0	84.4	75.1	83.8
ABI-X52-C3-2	76.3	90.0	76.4	86.5
ABI-X52-C4-2	77.1	92.3	75.6	85.2
Average	**73.8**	**88.9**	**75.7**	**85.2**
Standard Deviation	**5.0**	**4.1**	**0.7**	**1.4**
X52 Longitudinal				
ABI-PRCI-X52-A5-1	73.5	90.4	74.7	87.0
ABI-X52-A6-2	78.1	93.4	78.7	85.8
ABI-PRCI-X52-A7-1	77.9	90.2	82.6	87.0
ABI-PRCI-X52-A8-1	73.6	87.6	79.2	83.1
Average	**75.8**	**90.4**	**78.8**	**85.7**
Standard Deviation	**2.6**	**2.4**	**3.2**	**1.8**

Test Name	ABI Yield Strength [ksi]	ABI UTS [ksi]	Tensile Yield Strength [ksi]	Tensile UTS [ksi]
X65 Transverse				
ABI-PRCI-X65-C1-1	80.8	90.4	83.0	89.8
ABI-PRCI-X65-C2-1	79.1	94.1	77.2	88.8
ABI-PRCI-X65-C3-1	85.6	99.1	82.6	89.6
ABI-X65-C4-1	76.9	87.6	76.6	87.0
Average	**80.6**	**92.8**	**79.9**	**88.8**
Standard Deviation	**3.7**	**5.0**	**3.4**	**1.3**
X65 Longitudinal				
ABI-PRCI-X65-A5-1	81.1	95.5	77.9	87.4
ABI-PRCI-X65-A6-1	83.3	97.3	85.0	91.0
ABI-PRCI-X65-A7-1	83.3	98.1	85.8	90.5
ABI-X65-A8-2	81.2	91.1	79.9	87.8
Average	**82.2**	**95.5**	**82.2**	**89.2**
Standard Deviation	**1.2**	**3.1**	**3.9**	**1.8**

A total of 24 ABI tests were conducted on 7 Pipeline Steels to verify that Variations in Tensile Properties at Through-Thickness Locations and ABI Test Orientation Effects are Negligible.



Triplicate ABI Tests Conducted on 7 Pipeline Steels at Near Outer Surface (O), Mid-Thickness (C), and Near Inner Surface (I) in the L-CR Orientation Show Negligible Effects on ABI-Measured Tensile Properties. Similarly, triplicate ABI tests on Sample D in the C-LR orientation show negligible effects as compared with results from the L-CR orientation.

Test Name	**Yield**	Strength	Strain	**Estimated**	Calculated	Ratio	ABI	Fracture
	Strength	Coefficient	Hardening	**Engineering**	Uniform	Yield	Hardness	Toughness
		(K)	Exponent	**UTS**	Ductility	to		
	[ksi]	[ksi]	(n)	**[ksi]**	[%]	UTS		(ksi*in^0.5)
A, Orientation: L-CR								
A-O-1	**62.7**	103.7	0.1	**77.9**	9.4	0.80	183 (030G)	191
A-C-1	**65.8**	109.9	0.1	**82.5**	9.4	0.80	192 (030G)	197
A-I-1	**65.9**	108.6	0.1	**81.9**	9.1	0.80	191 (030G)	194
C, Orientation: L-CR								
C-O-2	**66.1**	111.2	0.1	**83.2**	9.6	0.79	194 (030G)	197
C-C-1	**65.9**	107.1	0.1	**81.1**	7.9	0.81	191 (030G)	195
C-I-1	**68.5**	110.6	0.1	**83.9**	7.6	0.82	197 (030G)	196
D, Orientation: L-CR								
D-O-1	**67.3**	113.2	0.1	**84.7**	9.6	0.79	197 (030G)	197
D-C-1	**70.5**	108.3	0.1	**83.8**	6.7	0.84	199 (030G)	196
D-I-1	**73.1**	112.4	0.1	**86.9**	6.7	0.84	204 (030G)	199
D, Orientation: C-LR								
D-C-LR-O-1	**71.9**	109.1	0.1	**84.9**	6.5	0.85	202 (030G)	197
D-C-LR-C-1	**72.4**	108.6	0.1	**84.8**	6.4	0.85	203 (030G)	200
D-C-LR-I-1	**74.3**	113.1	0.1	**87.9**	6.6	0.85	207 (030G)	202
E, Orientation: L-CR								
E-O-1	**74.4**	113.9	0.1	**88.3**	6.6	0.84	207 (030G)	199
E-C-1	**77.6**	113.2	0.1	**89.5**	6.1	0.87	212 (030G)	201
E-I-1	**79.1**	118.9	0.1	**92.9**	6.4	0.85	218 (030G)	204
F, Orientation: L-CR								
F-O-1	**48.8**	89.2	0.1	**64.4**	10.6	0.76	156 (030G)	176
F-C-1	**50.1**	88.8	0.1	**64.8**	10.4	0.77	158 (030G)	177
F-I-1	**48.7**	91.2	0.1	**65.3**	10.7	0.75	158 (030G)	179
G, Orientation: L-CR								
G-O-1	**56.4**	98.9	0.1	**72.7**	10.2	0.78	173 (030G)	186
G-C-1	**52.7**	94.0	0.1	**68.5**	10.3	0.77	164 (030G)	180
G-I-1	**56.6**	104.4	0.1	**75.4**	10.5	0.75	175 (030G)	189
H, Orientation: L-CR								
H-O-2	**58.1**	101.6	0.1	**74.7**	10.1	0.78	177 (030G)	189
H-C-1	**66.3**	103.4	0.1	**79.4**	6.9	0.84	189 (030G)	192
H-I-1	**62.3**	103.3	0.1	**77.5**	9.4	0.80	183 (030G)	191

The average yield and UTS from tests on outer surface (R-LC) are within 4% of the average from through-thickness tests (L-RC).

The ABI tests on the inner pipe surface are slightly higher than the outer surface because the inner surface is in compression while the outer surface is in tensile (ABI test is mostly a compressive test).

Test Name	**Yield Streng.** [ksi]	Streng. Coeff., (K) [ksi]	Strain Hard. Exp. (n)	**Est. Eng. UTS [ksi]**	Calc. Eng. UTS [ksi]	Calc. Unif. Duct. [%]
ABI Tests on Outer Pipe Surface, R-LC Orientation						
Columbia Gas-OD-1	81.7	119.2	0.062	94.3	94.4	6.1
Columbia Gas-OD-2	80.7	124.6	0.070	96.4	96.4	6.7
Average	**81.2**			**95.4**		
Standard Deviation	0.7			1.5		
ABI Tests at Through-Thickness Locations, L-RC Orientation						
Columbia Gas-NOD-1	79.2	117.7	0.065	92.4	92.4	6.3
Columbia Gas-CT-1	80.9	111.2	0.054	90.1	90.2	5.6
Columbia Gas-NID-1	82.6	116.9	0.057	93.7	93.7	5.8
Average	**80.9**			**92.1**		
Standard Deviation	1.7			1.8		
ABI Tests on Inner Pipe Surface, R-LC Orientation						
Columbia Gas-ID-1	83.4	111.8	0.050	91.6	91.7	5.3
Columbia Gas-ID-2	85.0	112.0	0.047	92.5	92.5	5.1
Average	**84.2**			**92.1**		
Standard Deviation	1.1			0.6		

X65 Pipeline Steel Sample from Columbia Gas Company

REPORT

Final Report

Determining the Yield Stress of In-Service Transmission Pipelines

To

Gas Pipeline Safety

Research Committee

Center for Research and

Technology Development

American Society of Mechanical

Engineers International

Washington, D.C. 20036-5104

July 15, 1999

Battelle
. . . Putting Technology To Work

ATC

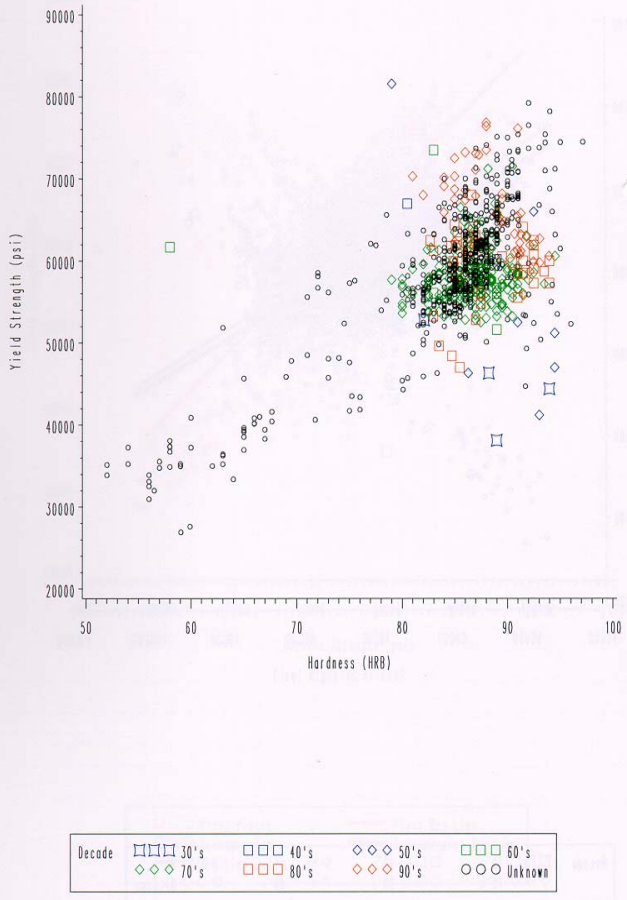
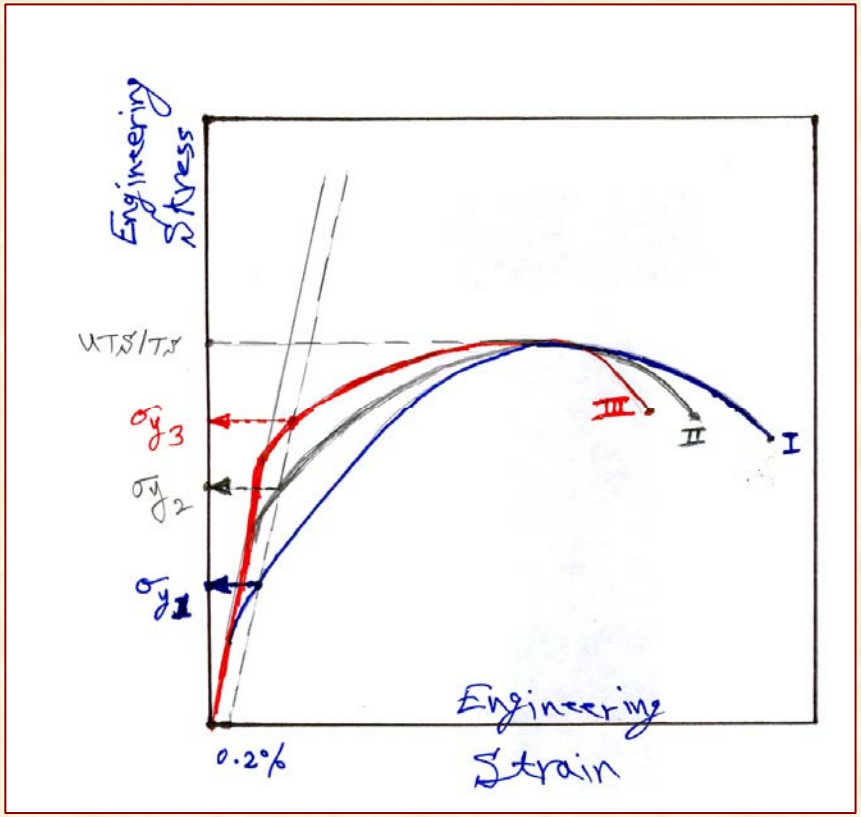


Figure 3.14. Yield strength versus Rockwell B hardness by decade of manufacture (distinguished by unique symbol types) — collected data with tensile and hardness property measures



Three steel materials might have the same UTS/TS but have three different values of yield strength because of the shape of their stress-strain curves.

Data from Battelle's report demonstrate that there is no useful correlation between Yield Strength and Hardness Values. There is no physical basis for correlating a hardness value near UTS (at a high strain of 8-10%) to a yield strength at a low strain value (0.2 or 0.5%) while the shape of the stress-strain curve varies with the pipeline grade and thermo-mechanical condition.

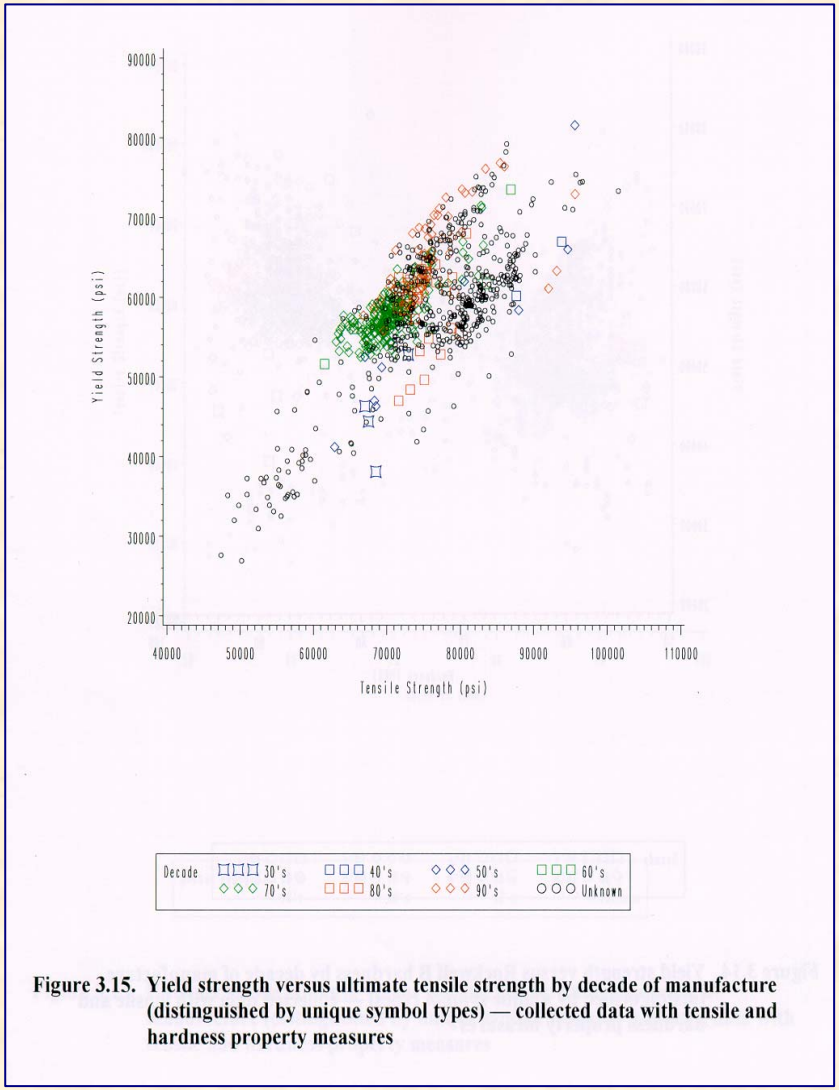


Figure 3.15. Yield strength versus ultimate tensile strength by decade of manufacture (distinguished by unique symbol types) — collected data with tensile and hardness property measures

Data from Battelle's report demonstrate that there is no useful correlation between Yield Strength and Ultimate Strength. Again, there is no basis for any correlation to exist because all steel materials do not have one shape for their engineering stress-strain curves. Pipeline grades have different ductility values and work-hardening behaviors.