2015 IMECE – International Mechanical Engineering Congress & Exposition
November 13-19, 2015, Houston, Texas
SAND2015-9501C

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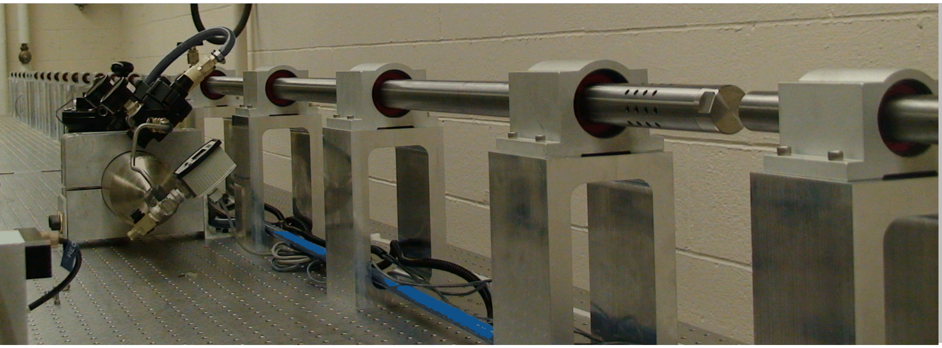
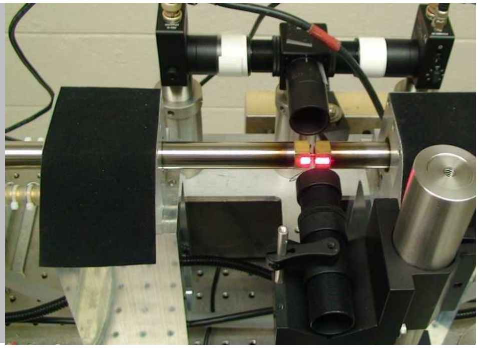
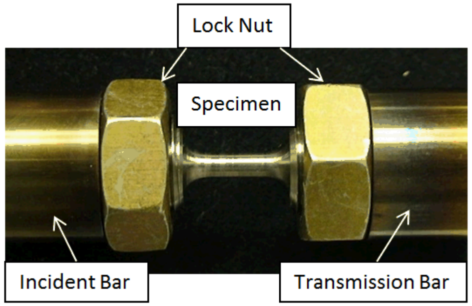

Dynamic Tensile Characterization of VascoMax® Maraging C250 and C300 Alloys

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U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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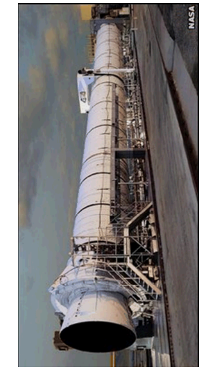
VascoMax® Maraging Alloys

- VascoMax® Maraging Alloys
  - Iron-based steels alloyed with 18% nickel
- Maraging C-Type Alloys
  - Strengthened steels with 7-12% cobalt, depending on the grade
  - C300 – 300 ksi (yield); C250 – 250 ksi (yield)
- Characteristics
  - Relatively soft in annealed condition
  - Significant hardness increase after a precipitation hardening process
    - No protective atmosphere required
    - Relatively low furnace temperatures



	C	S	Mn	Si	Cr	Mo	Co	Ti	Al	B	Zr	Cu	P	W	Ni	Fe
C250	0.005	0.0004	0.02	0.01	0.02	4.76	7.81	0.42	0.11	0.003	<0.01	<0.01	0.003	<0.01	18.55	BAL
C300	0.004	0.0005	0.03	0.02	0.03	4.85	9.27	0.63	0.09	0.003	<0.01	<0.01	0.006	0.01	18.58	BAL

Dynamic Failure/Fracture

- **Very serious problem in engineering applications**
- **Difficult to be predicted**
  - **Reliable material models with failure**
  - **Reliable experimental data**
    - **Particularly in abnormal mechanical environments, such as high-rate/impact loading**

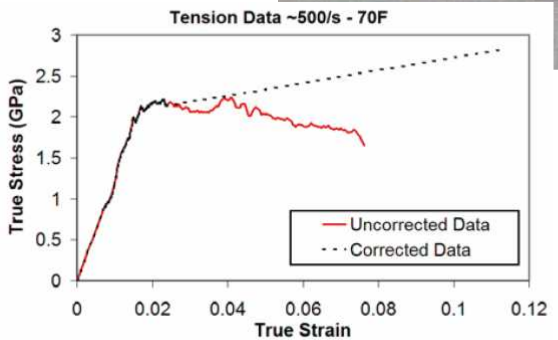
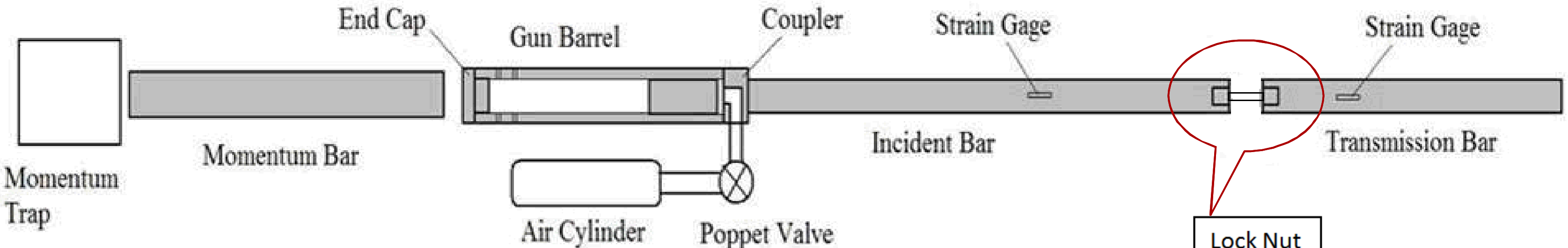
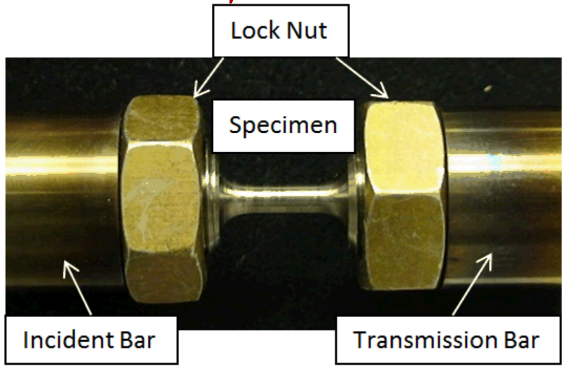


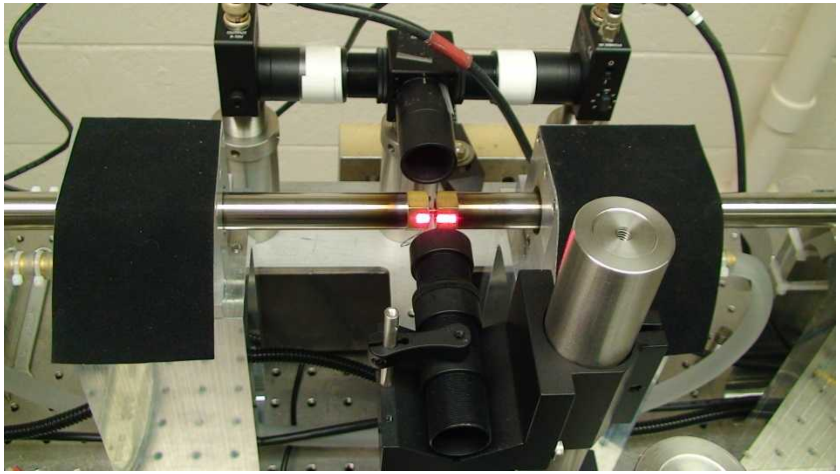
Figure 4. Typical modified VascoMax 300 curve.

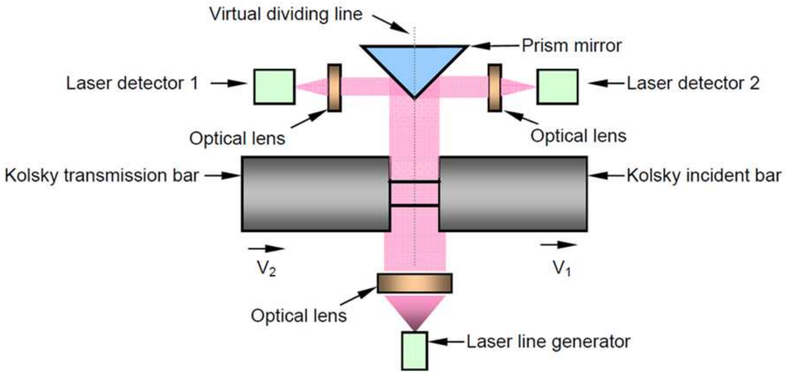
Cinnamon et al. 2005

Kolsky Tension Bar Technique



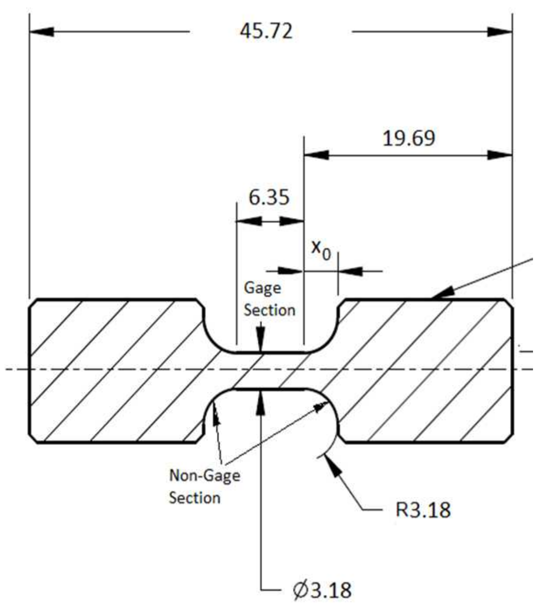




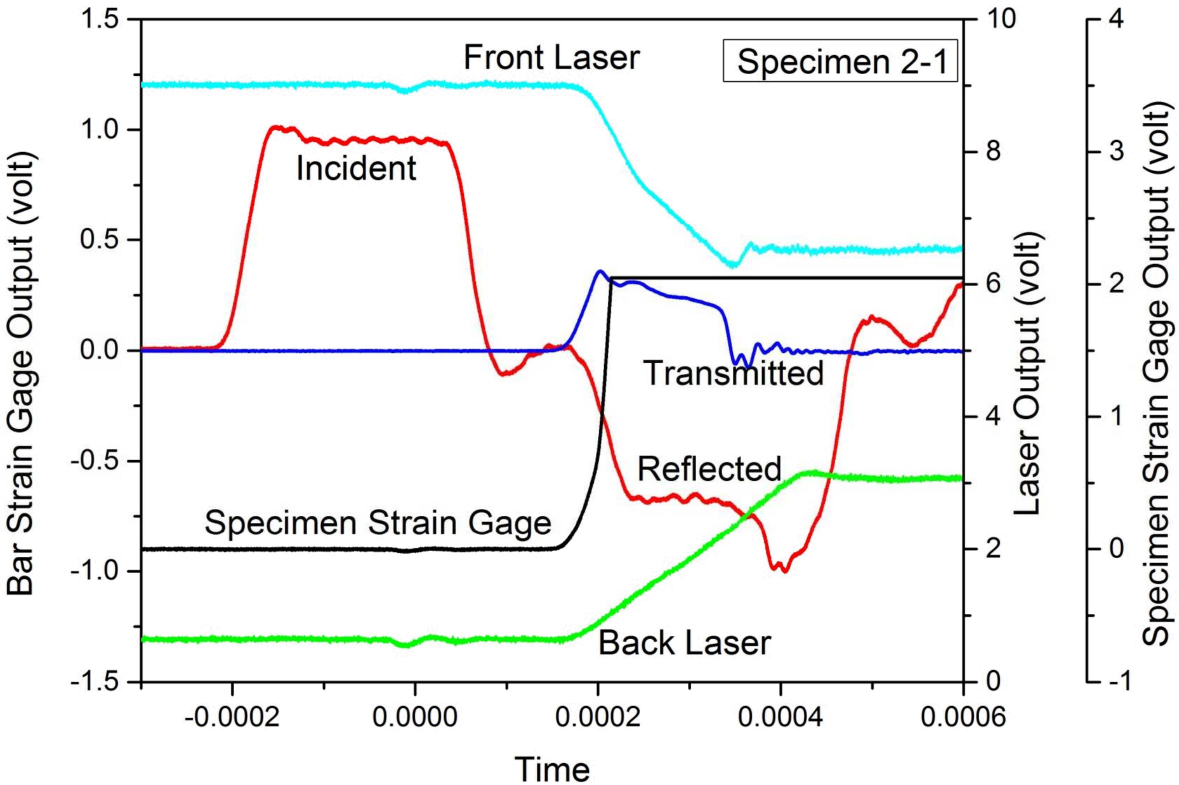


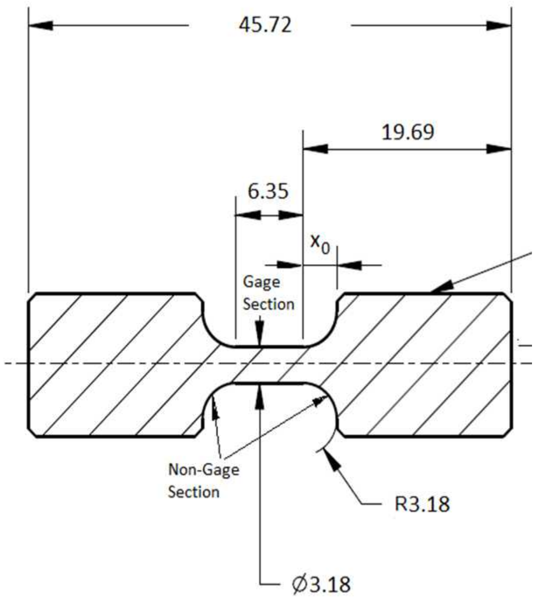
Materials and Specimen

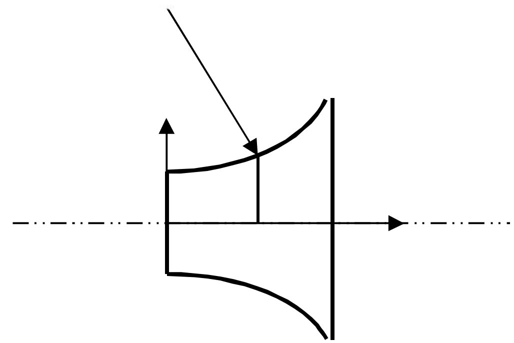
	End	Location	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10
C250	1	1	52.2	47.8	50.0	49.0	48.1	48.2	48.2	48.3	51.7	48.0
		2	50.7	46.9	47.7	47.9	47.8	47.1	47.4	47.6	51.5	47.8
	2	1	51.3	47.9	47.4	46.5	47.3	46.7	48.1	47.2	48.5	48.1
		2	51.1	47.1	46.9	46.4	46.6	46.4	47.7	46.4	47.9	47.9
	Mean (HRC)		51.3	47.4	48.0	47.5	47.5	47.1	47.9	47.4	49.9	48.0
	Yield Strength (MPa)		1752	1538	1576	1546	1546	1529	1567	1538	1670	1576
C300	End	Location	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
	1	1	52.1	52.5	51.4	52.3	51.6	52.0	52.7	52.3	51.9	52.1
		2	51.4	51.1	51.2	50.7	51.4	50.7	50.8	51.6	51.2	50.9
	2	1	51.6	52.3	51.0	51.3	51.3	51.5	52.2	52.1	51.9	52.2
		2	50.6	51.2	50.4	50.4	50.9	50.5	51.5	51.9	51.3	51.7
	Mean (HRC)		51.4	51.8	51.0	51.2	51.3	51.2	51.8	52.0	51.6	51.7
	Yield Strength (MPa)		1758	1781	1733	1746	1752	1746	1781	1791	1769	1775



Typical Oscilloscope Records



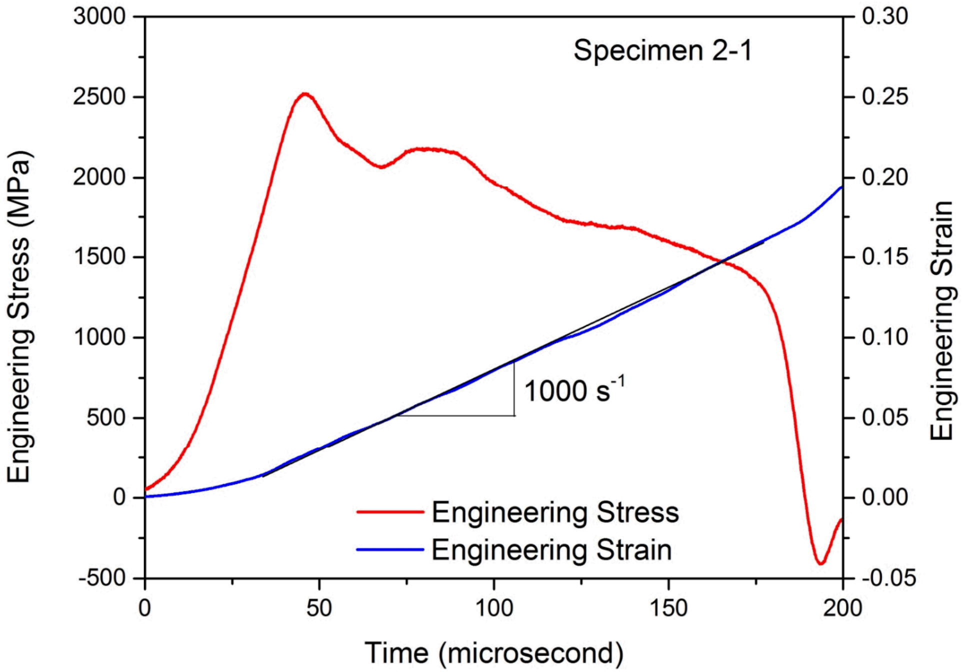


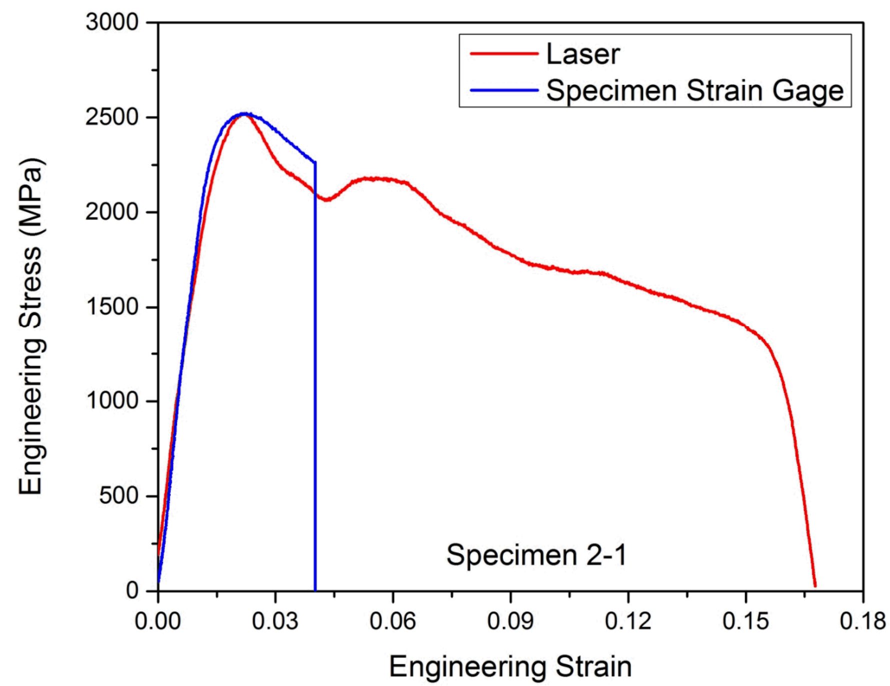


$$\sigma = E_0 \frac{A_0}{A_s} \varepsilon_t \qquad \varepsilon = \begin{cases} c' \cdot \dfrac{L_1 - L_2}{L_s} & (\sigma \le \sigma_y) \\ \dfrac{L_1 - L_2 - (1 - c')(L_1 - L_2)_{yield}}{L_s} & (\sigma > \sigma_y) \end{cases}$$

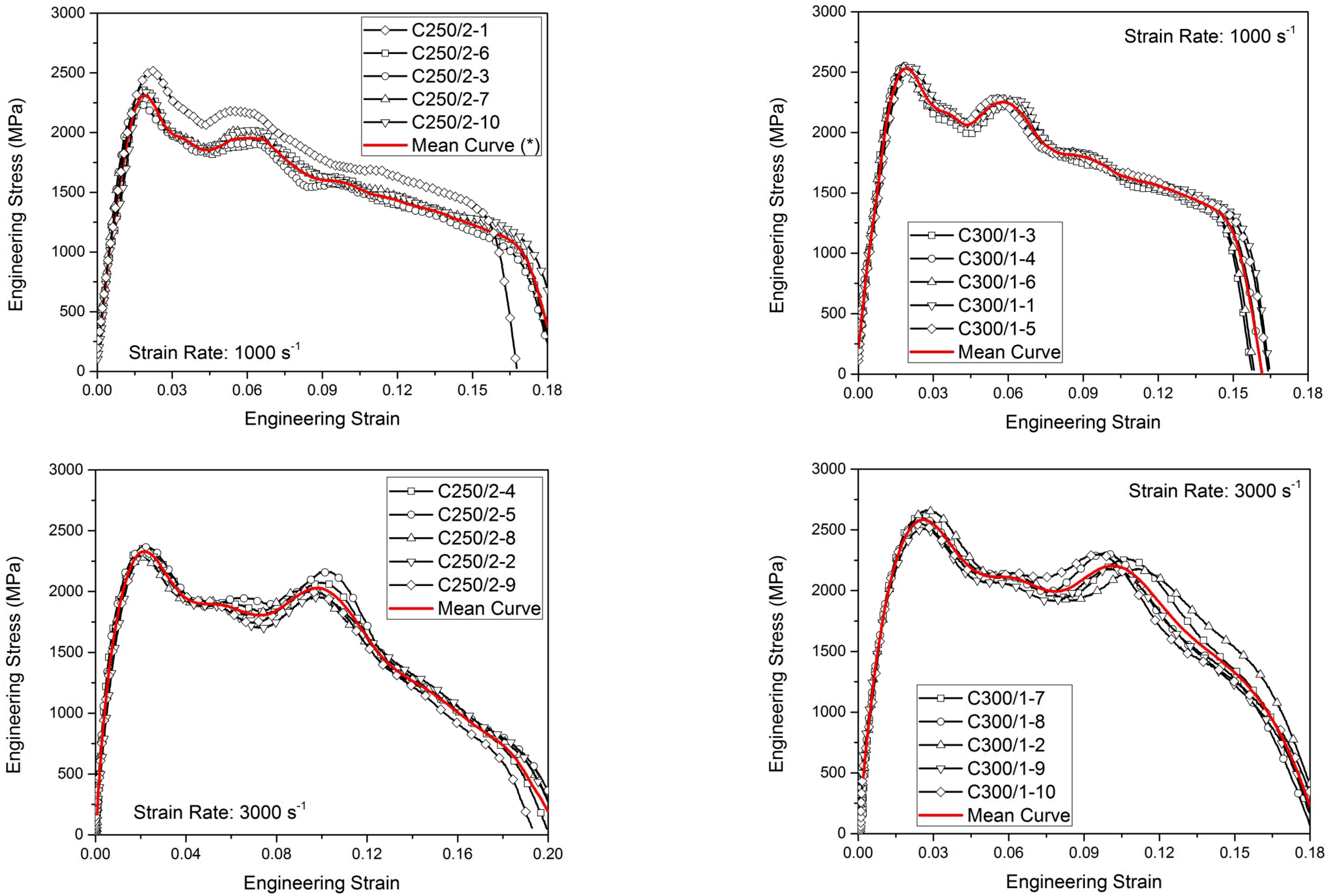
Song et al., Experimental Mechanics, 2013
Song et al., Journal of Dynamic Behavior of Materials, 2015

Stress-Strain Histories

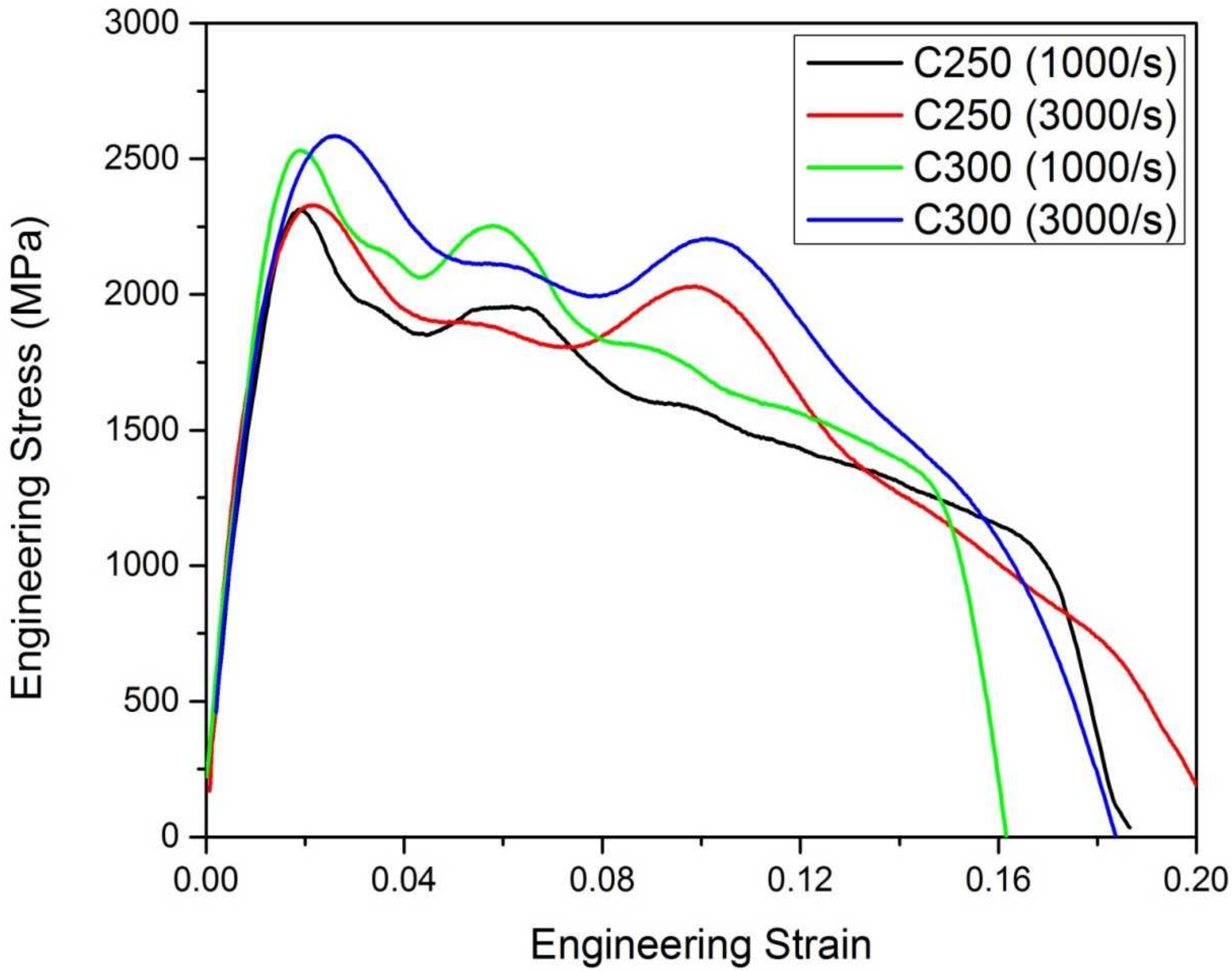




Dynamic Tensile Stress-Strain Curves



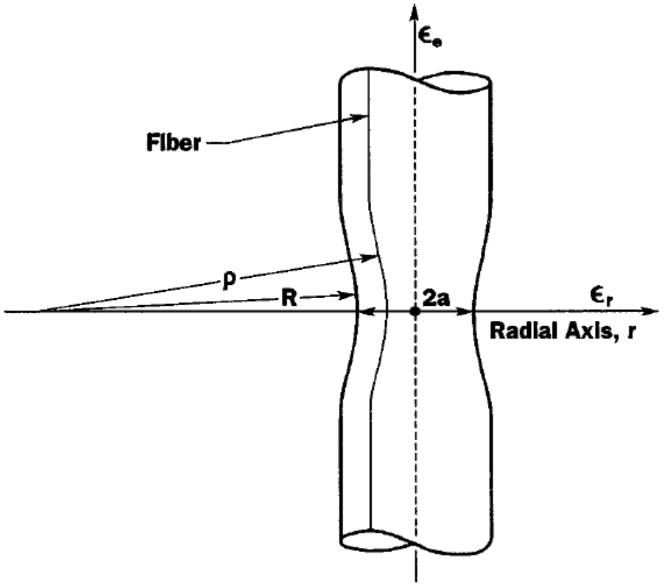
Strain-Rate Effect



Necking Corrections

Bridgman Correction

- Assumptions:
  - Uniform strain distribution in the minimum section
  - A longitudinal grid line deformed into a curve at the
- Good for rod



- True strain $\varepsilon_T = ln\frac{A_0}{A}$

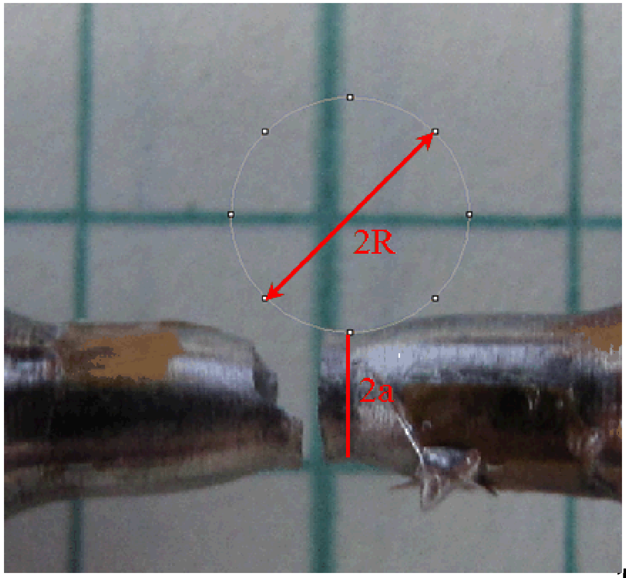
- Average true axial stress at the smallest cross section

$$(\sigma_a)_{av} = \frac{F}{A} = \sigma_E\frac{A_0}{A}$$

  - Uniaxial stress correction

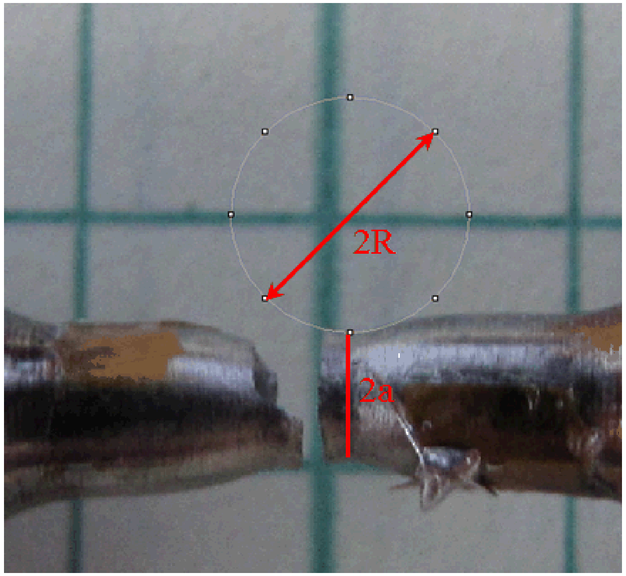
$$\sigma_T = k(\sigma_a)_{av}$$

$$k = \left[\left(1 + \frac{2R}{a}\right) ln\left(1 + \frac{a}{2R}\right)\right]^{-1}$$



- Requires instantaneous measurements of minimum cross sectional area, *A*, and radius, *R*.

True Stress-Strain Response



Before onset of necking

$$\varepsilon_T = ln(1 + \varepsilon_E)$$

$$\sigma_T = \sigma_E(1 + \varepsilon_E)$$

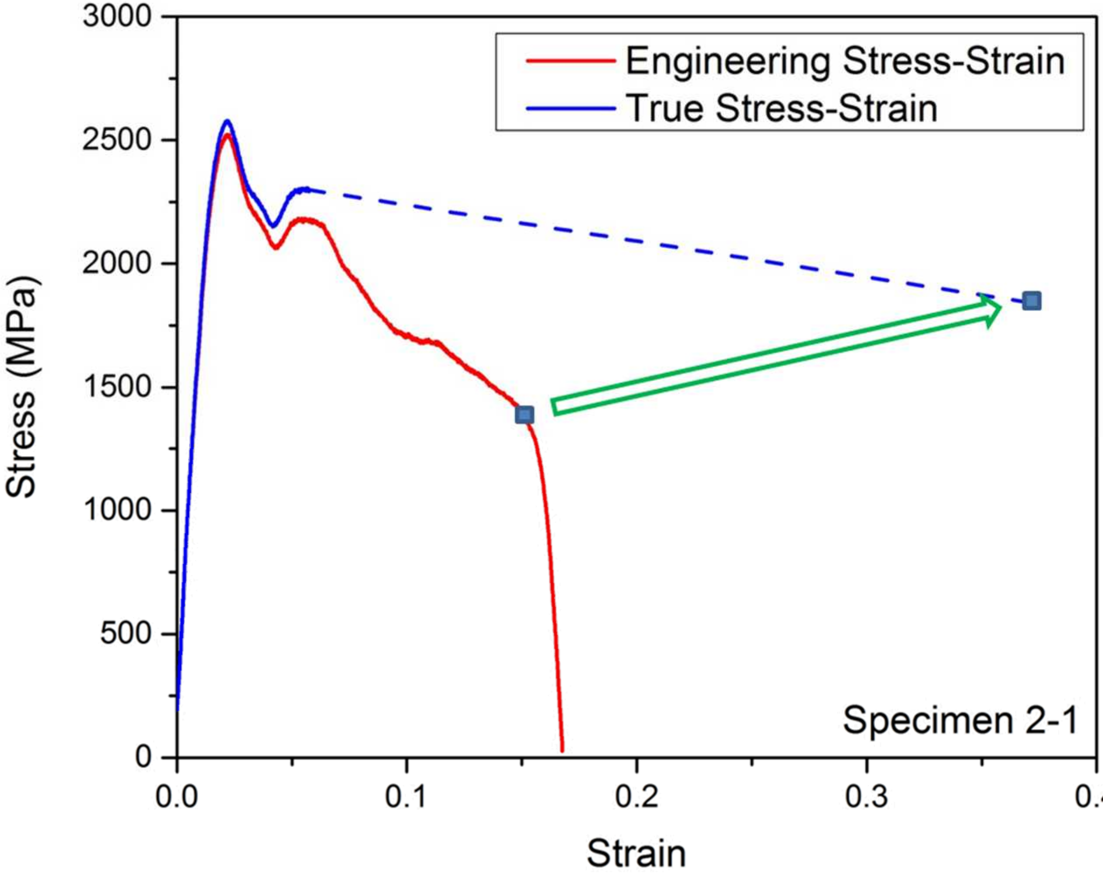
At the failure

$$\varepsilon_{T,failure} = 0.3717$$

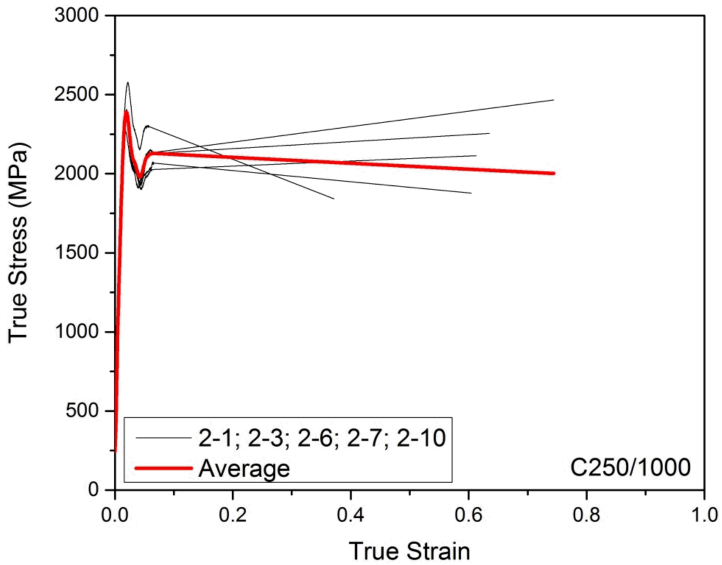
$$k = 0.8923$$

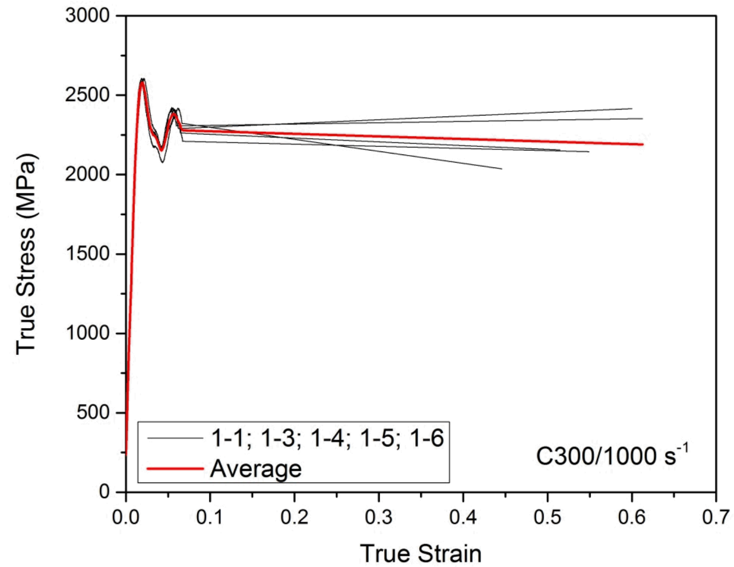
$$\sigma_E = 1423\ MPa$$

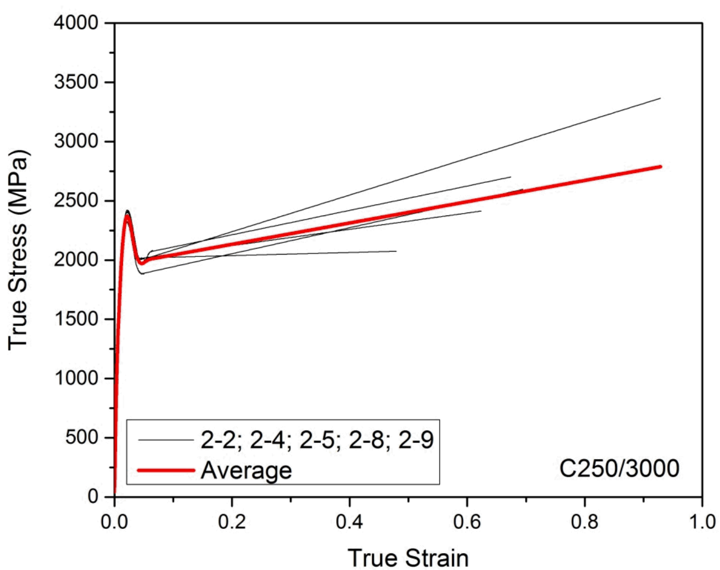
$$\sigma_{T,failure} = 1841\ MPa$$

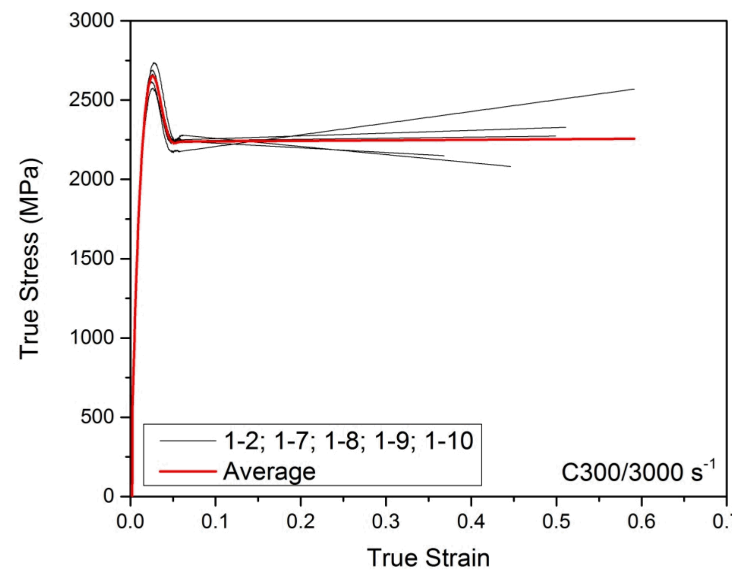


True Stress-Strain Curves

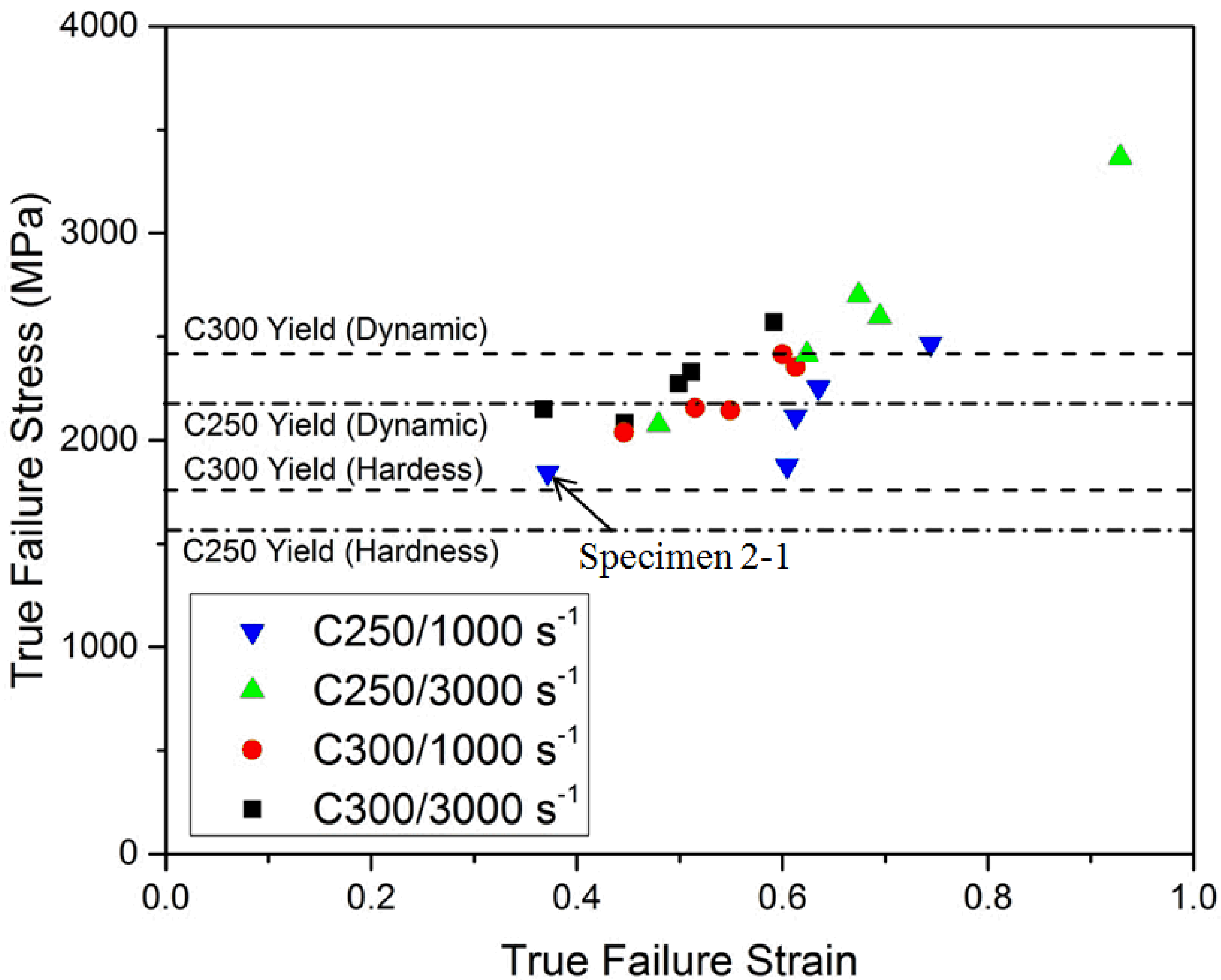








True Failure Stress/Strain



Conclusions

- Kolsky tension bar was used to characterize maraging C250 and C300 steels in tension at two strain rates: 1000 and 3000/s. Both alloys show very similar dynamic stress-strain characteristics with insignificant difference at 1000 and 3000/s. The yield and flow stresses for C300 are approximately 10% higher than C250.

- Necking correction was performed to estimate the true failure response. Both C250 and C300 steels exhibit nearly perfect plasticity in true stress-strain response.

- The true failure stress for C250 is close to that for C300 steels; however, true failure strain for C250 seems larger than that for C300 steel
  - C250 seems more ductile than C300 steel