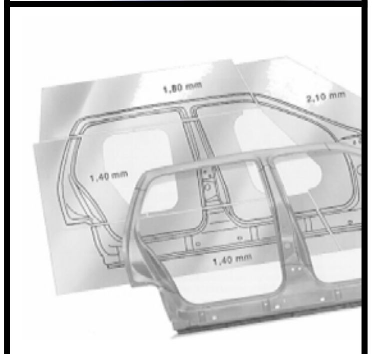


Auto/Steel Partnership:

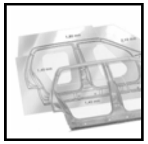
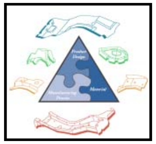
NSF 3rd Generation Advanced High-Strength Steels

Ronald Krupitzer
American Iron and Steel Institute

Project ID: lm_24_heimbuch

A/S P Auto/Steel Partnership

www.a-sp.org


Timeline

- Start – 10/2007
- End – 09/2010
- 50% Complete

Budget

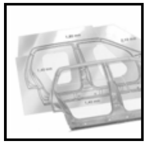
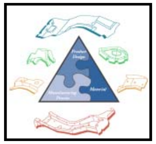
- Total Project Funding
  - DOE - $1,500K
  - NSF - $1,500K

Barriers

- Long range development of these objectives may take more than 3 years
- Proof of concept will require scale-up projects for feasibility

Partners

- National Science Foundation
- Auto/Steel Partnership
- American Iron and Steel Institute
- Nine Selected Universities

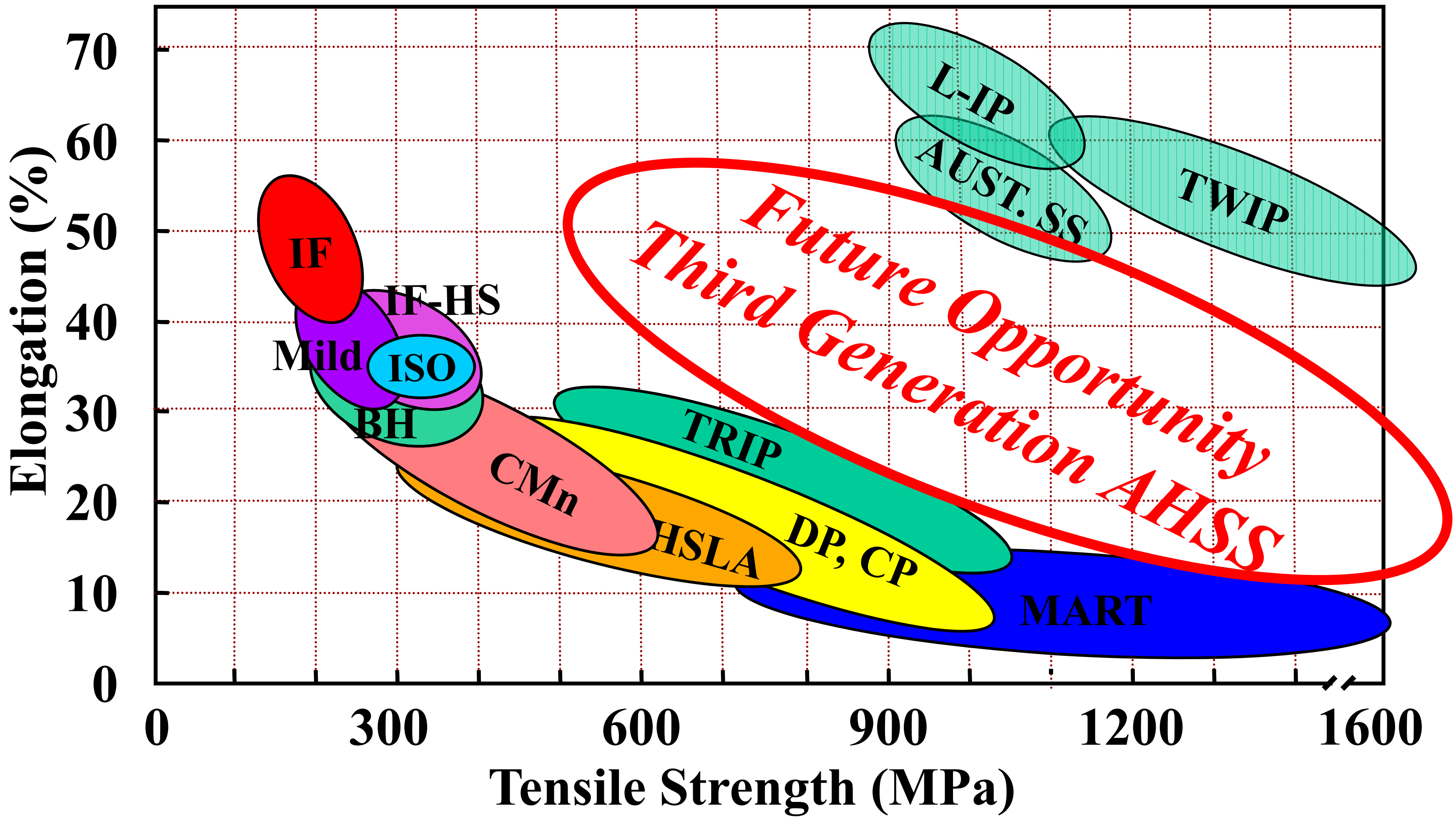




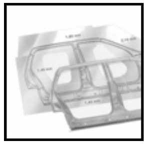
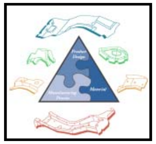

3^{rd} GENERATION AHSS

PROJECT GOALS

- Development of 3rd Generation AHSS through university research sponsored by NSF, DOE and A/SP
- Improved properties defined by the “Third Generation AHSS” field on the familiar total elongation - tensile strength diagram
- Improved modeling methods for fundamental steel mechanical property development
- Funding of the research to be shared among NSF, DOE, AISI, and A/SP
- Monitoring and support of the research by AISI and A/SP member companies

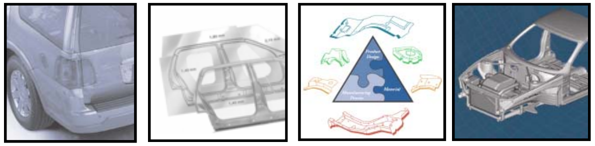
PROJECT GOALS



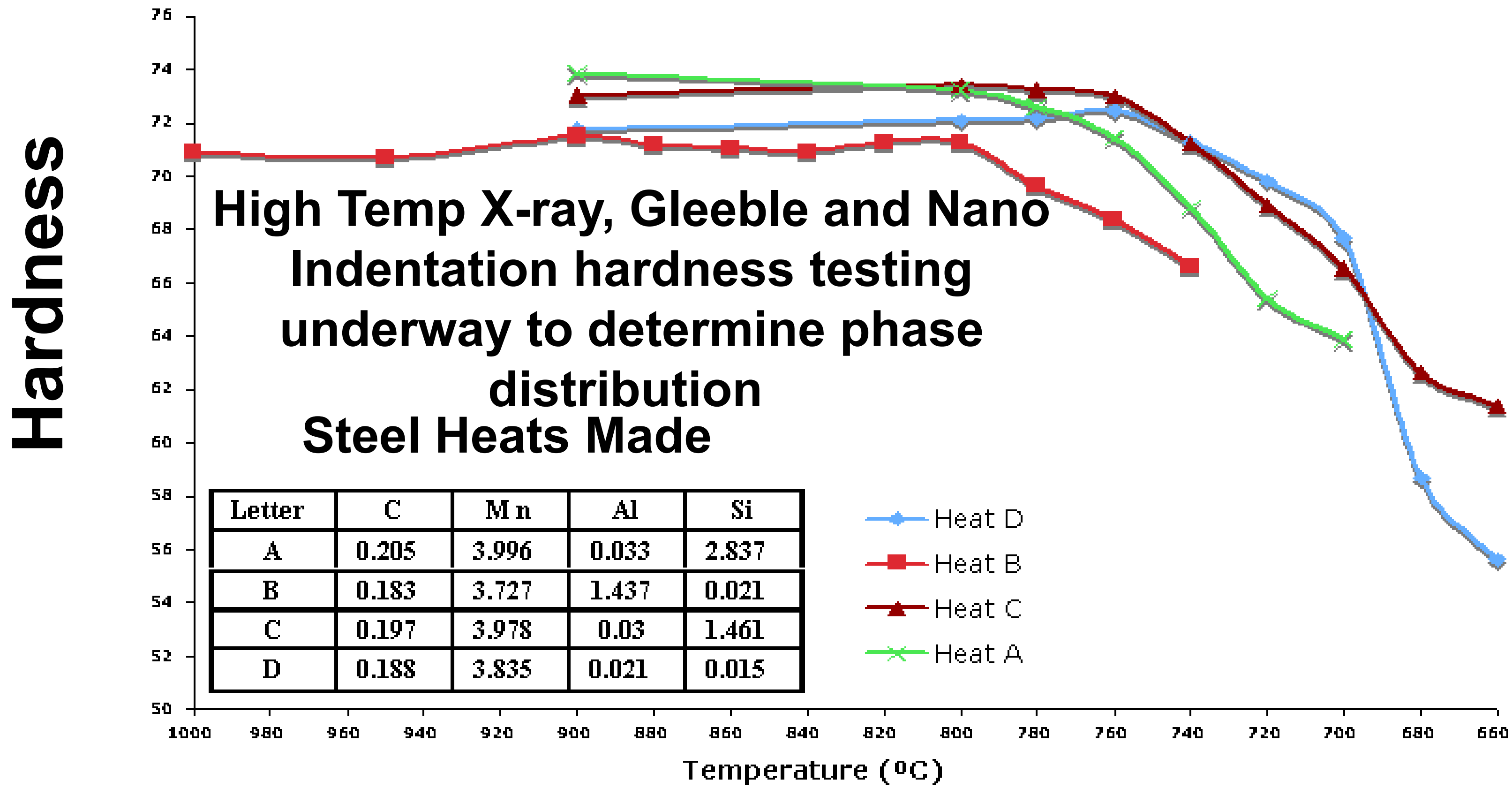

3rd GENERATION AHSS
PROJECT APPROACHES

University	Professor	Topic
Carnegie Mellon University	Warren Garrison	AHSS through microstructure and mechanical properties
Case Western Reserve Univ.	Gary Michal	AHSS through C partitioning
Texas A & M	Abu Al-Rub Rashid	AHSS through particle size and interface effects
Colorado School of Mines, Ohio State University	David Matlock (CSM) and Robert Wagoner (OSU)	Collaborative GOALI Project Formability and Springback of AHSS
Drexel University	Surya Kalidindi	FEM using crystal plasticity simulation modeling tools
University of Pennsylvania	Ju Li	Multiscale modeling of deformation for design of AHSS
University of Missouri Rolla	David C. Van Aken	AHSS through nano-acicular duplex microstructures
Wayne State University	Susil K. Putatunda	High-strength high-toughness bainitic steel



Garrison – APPROACH/RESULTS

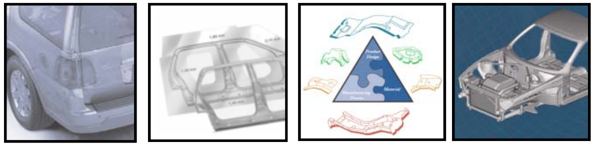
Create MultiPhase Microstructures by Austenitizing or Annealing in a $\alpha+\gamma$ Field. Then Improve Properties Through Void Nucleation Resistance



High Temp X-ray, Gleeble and Nano Indentation hardness testing underway to determine phase distribution

Steel Heats Made

Letter	C	Mn	Al	Si
A	0.205	3.996	0.033	2.837
B	0.183	3.727	1.437	0.021
C	0.197	3.978	0.03	1.461
D	0.188	3.835	0.021	0.015



Michal & Heuer – APPROACH/RESULTS

Carbon Partitioning and Austenite Stabilization - Michal & Heuer (CWRU)

Double Stabilization Thermal Process

FOUR EXPERIMENTAL HEATS ARE BEING PROCESSED – The thermal cycle will include:

First, a hold of a few seconds during the initial quench after the austenitization
Second, a carbon partitioning isothermal hold at a temperature where Cementite and Transition Carbides will not form

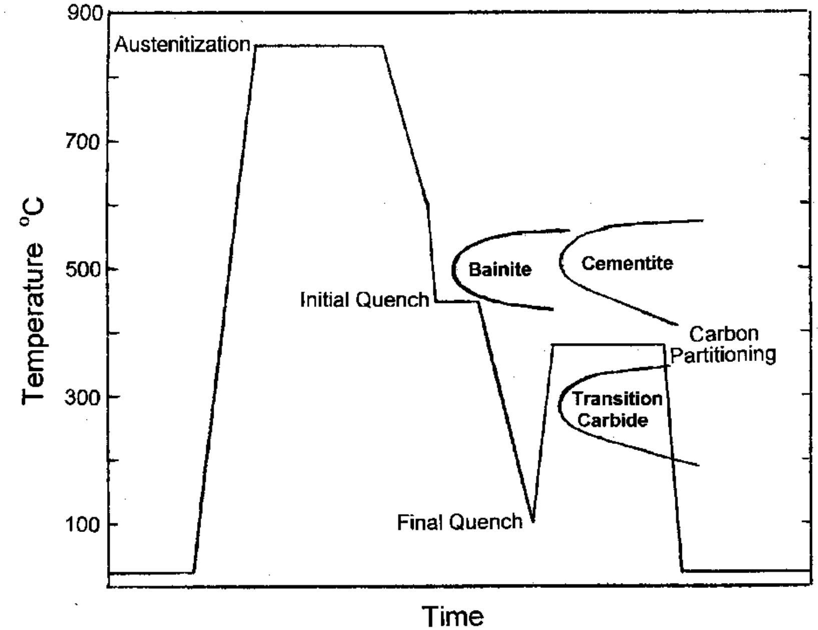
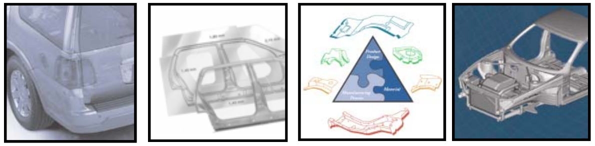


Table 1. Chemical Compositions of the Experimental Steels, wt. %
Cold Reduced Samples

Hot Band	C	Mn	P	S	Si	Ni	Cr	Cu	Mo	N	Nb	V	Ti	Al	B
3A	**0.10**	**2.16**	<0.002	0.0008	**2.15**	0.004	**<0.002**	<0.002	<0.002	0.0049	<0.002	0.002	**0.003**	**1.48**	**0.0018**
3B	**0.092**	**2.17**	<0.002	0.0008	**2.17**	0.002	**<0.002**	<0.002	<0.002	0.0046	<0.002	0.002	**0.003**	**1.48**	**0.0016**
4B	**0.26**	**4.12**	0.002	0.0008	**2.12**	0.002	**0.47**	<0.002	<0.002	0.0080	<0.002	0.002	**0.002**	**1.58**	**0.0014**
5A	**0.25**	**1.95**	0.002	0.0007	**2.08**	0.002	**0.013**	<0.002	<0.002	0.0055	<0.002	0.002	**0.002**	**1.46**	**0.0016**
5B	**0.25**	**1.95**	0.002	0.0008	**2.06**	0.003	**0.014**	<0.002	<0.002	0.0039	<0.002	0.002	**0.002**	**1.44**	**0.0015**
6B	**0.29**	**3.99**	0.002	0.0008	**2.12**	0.002	**0.48**	<0.002	<0.002	0.0047	<0.002	0.002	**0.022**	**1.50**	**0.0011**

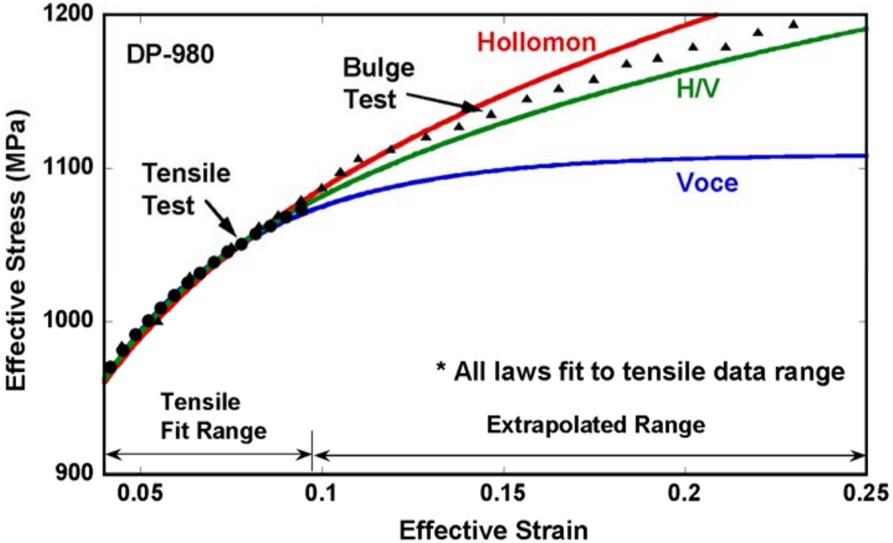
Boron was determined by extraction and back extraction procedure followed by ICP spectroscopy.



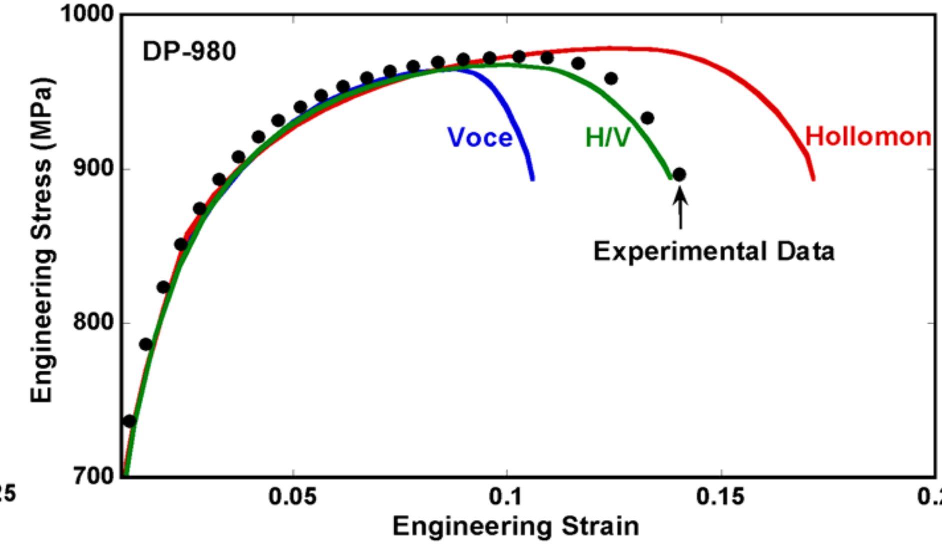
Wagoner – APPROACH/RESULTS

Performance of "H/V" Model

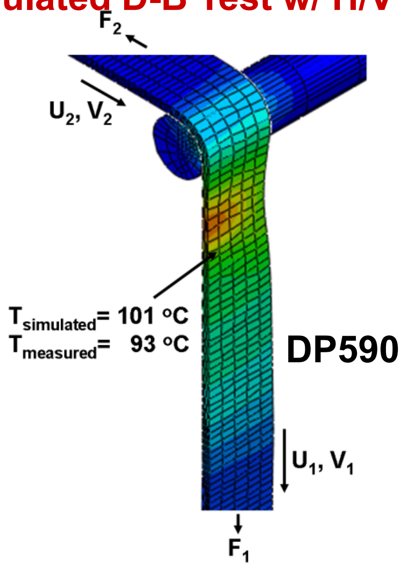
Accurate Extrapolation to Large Strain



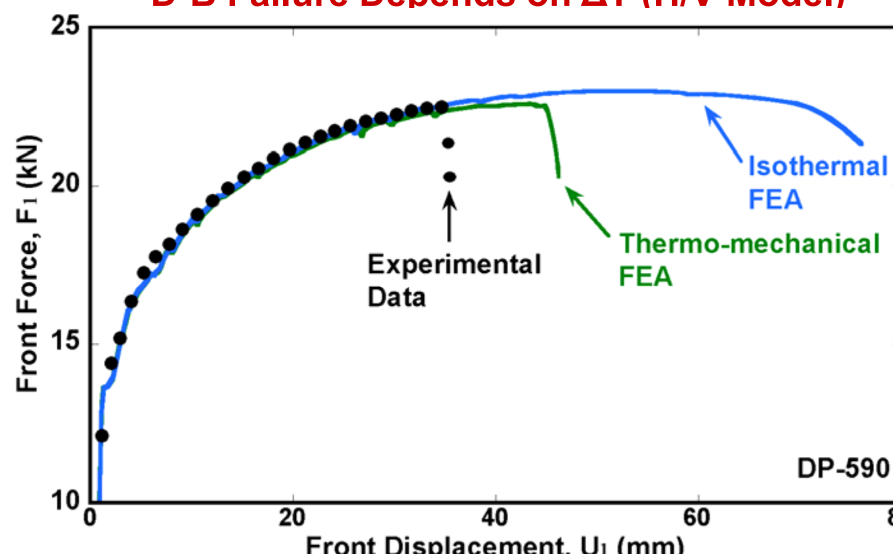
Accurate Prediction of Tensile Elongation

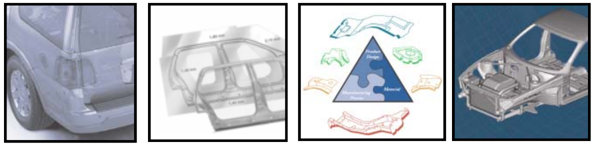


Simulated D-B Test w/ H/V Model



D-B Failure Depends on ΔT (H/V Model)

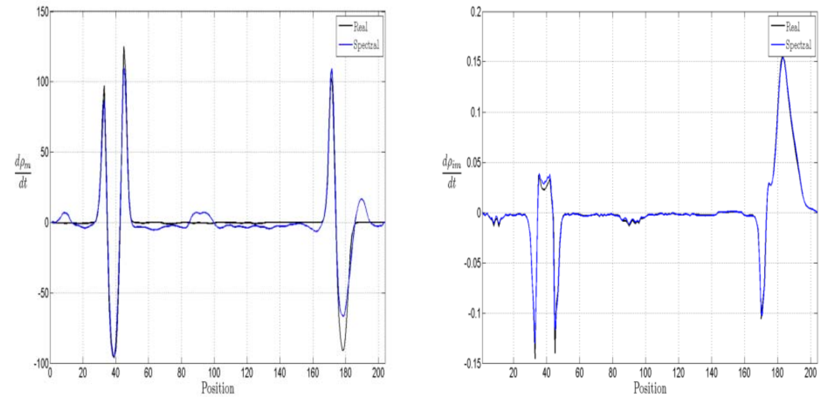




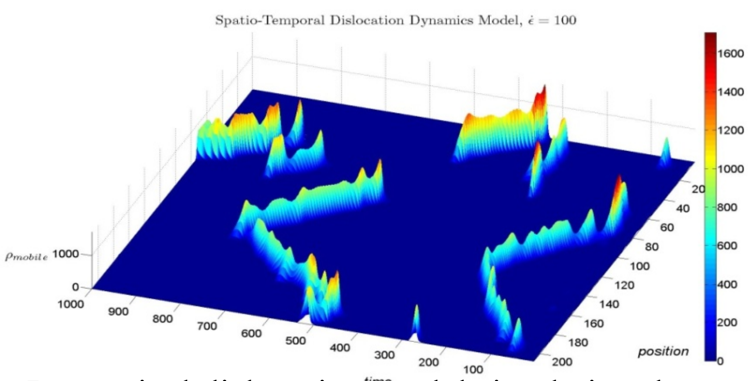
Kalidindi – APPROACH/RESULTS

Spectral Linkages Applied to Dynamical Dislocation Models

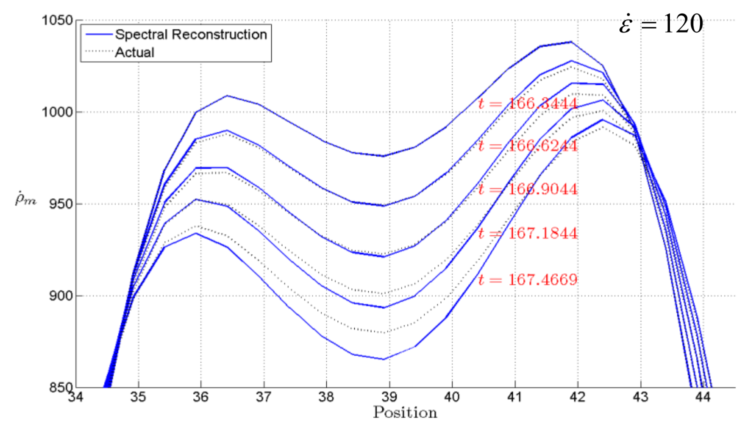
- ❑ **Following the quantification of the spectral linkages, macroscopic stress/strain values can be extracted and implemented in coarser FEM models.**
- ❑ **Incorporation of the PLC into macroscopic models allows for optimization of forming processes effected by PLC effect**



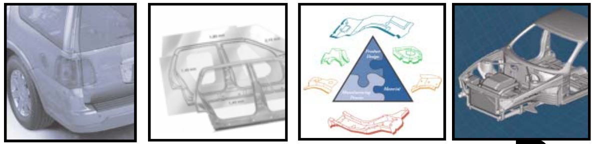
Instantaneous mobile and immobile dislocation bands from DD model and spectral linkages



Dynamical dislocation model simulating the propagation of dislocation bands in one dimension

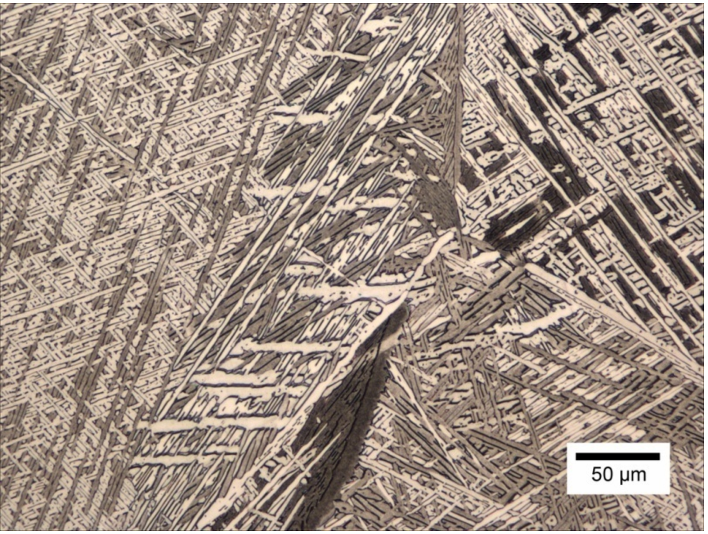


Propagation of dislocation bands from the DD model compared to the spectral coefficients



Van Aken – APPROACH/RESULTS

Development of AHSS Nano-acicular Duplex Steel



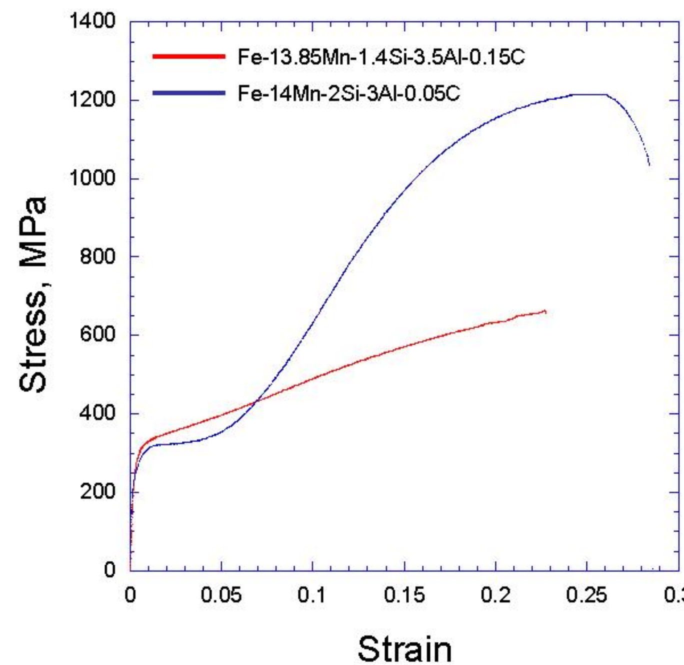
Heats Processed

Hard Bainitic Steel

Fe-2.1Mn-4Co-1.2Si-0.6C-0.2Mo

Lightweight steel

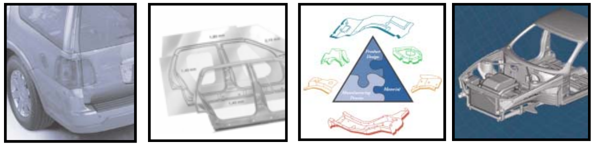
Fe-13.88Mn-3.5Al -1.4Si-0.15C



Target microstructure to look like β-processed Ti-6Al-4V cooled to produce acicular α+β basket weave.

Duplex ferrite and austenite

- **greater strength than 1st generation AHSS**
- **less alloy than 2nd generation AHSS**



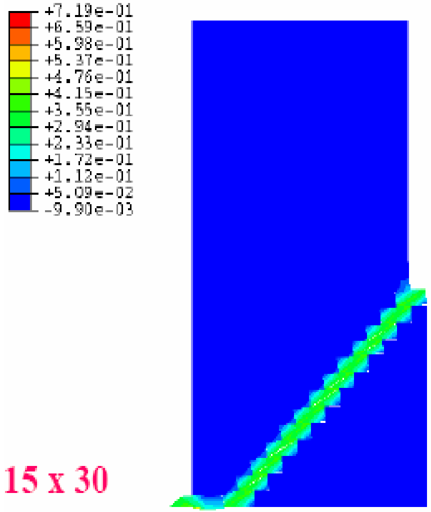
Al-Rub – APPROACH/RESULTS

Particle Size and Interface

Local

Theory

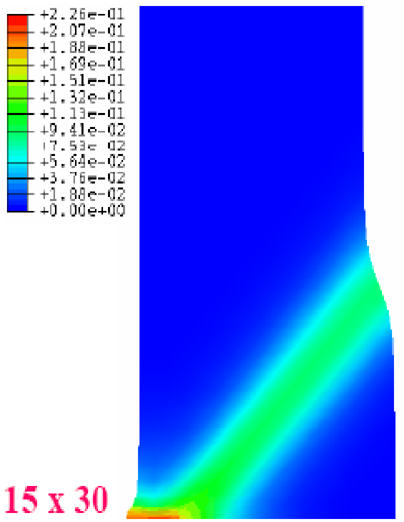
$\ell = 0$



Gradient

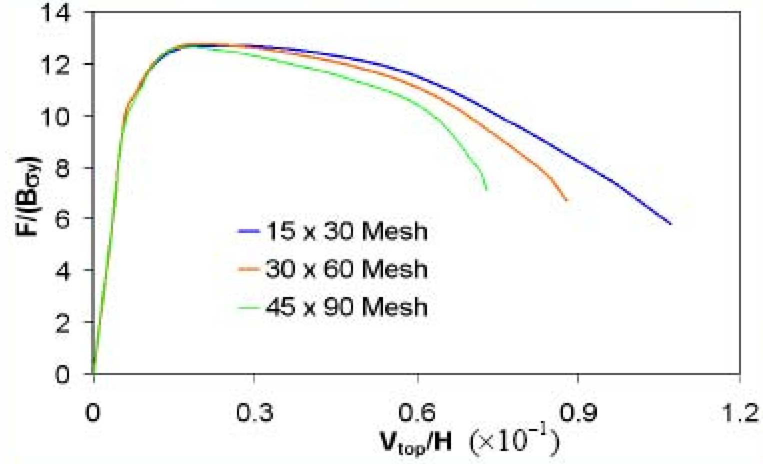
Theory

$\ell = 7.3\mu m$



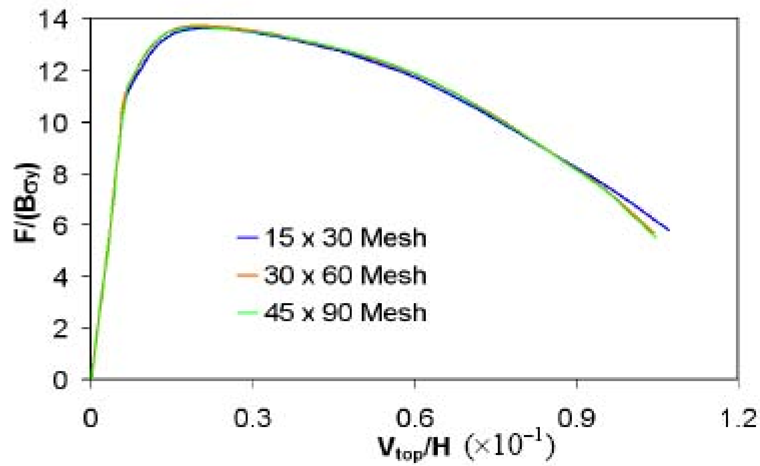
Local Theory

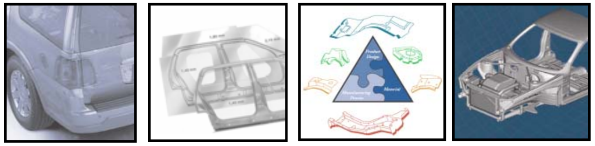
$\ell = 0$



Gradient Theory

$\ell = 7.3\mu m$





Li – APPROACH/RESULTS

Multi-scale Modeling of Deformation Mechanism for Design of New Generation of Steels

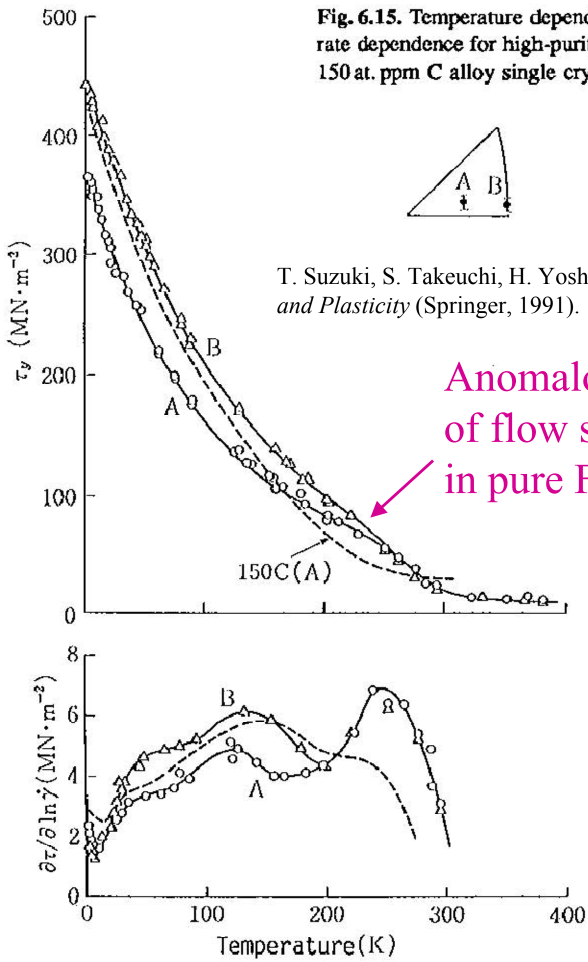
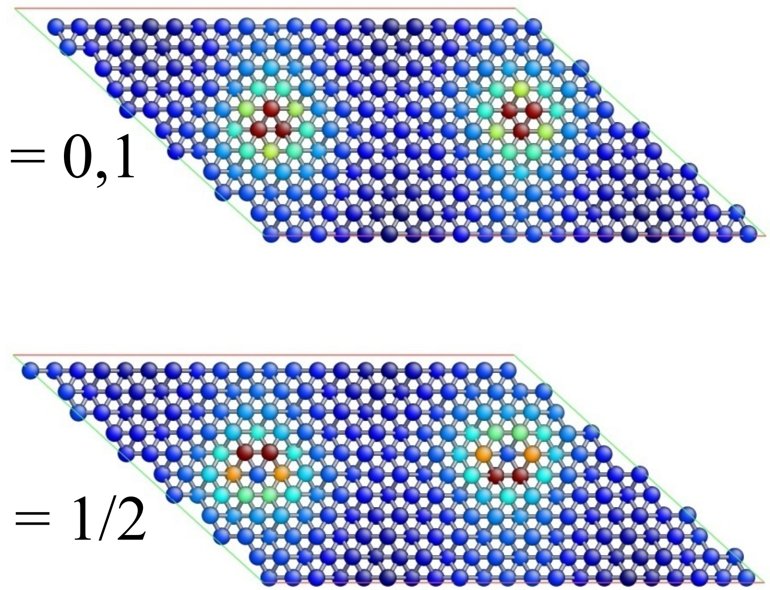


Fig. 6.15. Temperature dependence of the yield stress and its strain rate dependence for high-purity single crystals (solid lines) and Fe-150 at. ppm C alloy single crystals (broken lines) [6.34]

T. Suzuki, S. Takeuchi, H. Yoshinaga, *Dislocation Dynamics and Plasticity* (Springer, 1991).

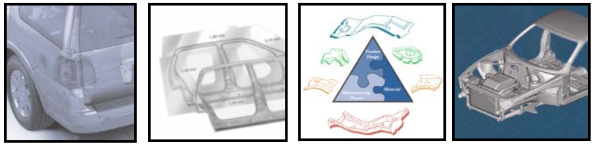
Anomalous "knee" of flow stress vs T in pure Fe

$x = 0,1$

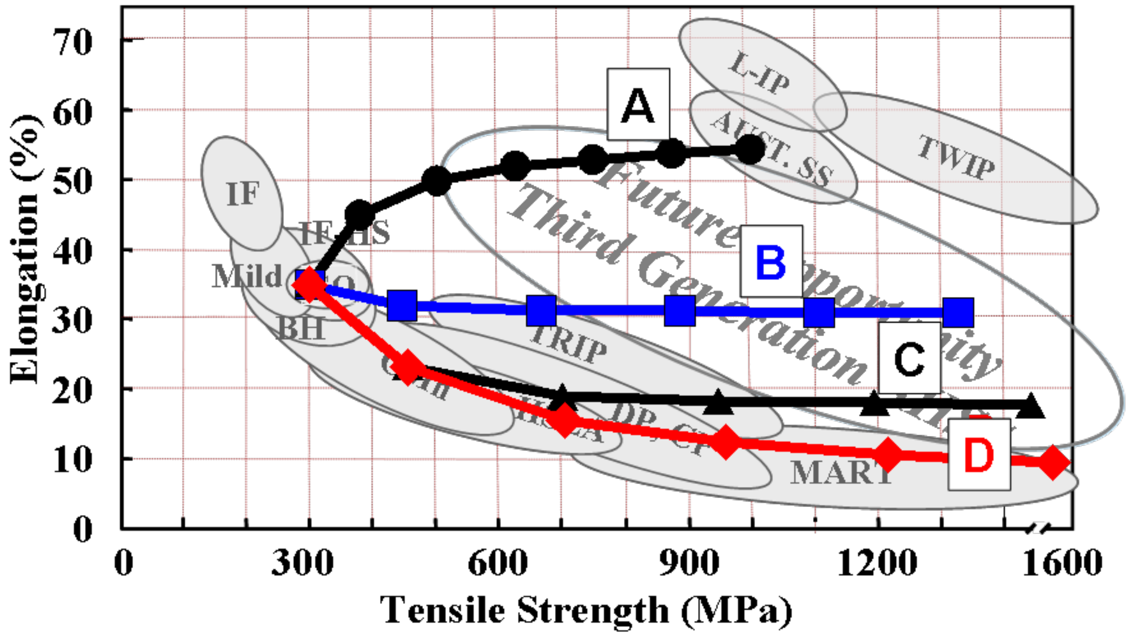


$x = 1/2$

1. Using *ab initio* calculations, we discovered a new metastable screw dislocation core structure centered at half lattice position in BCC Fe. Then based on nudged elastic band transition-state theory calculation and MD simulation of the double kinking process, we can now fully explain the anomalous "knee" in flow stress vs T of pure Fe

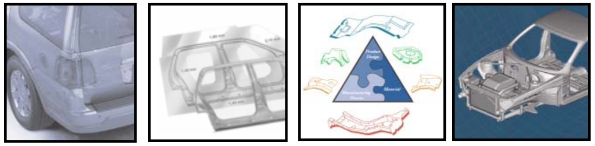


Austenite Stability in AHSS Microstructures



Two Alloy Systems Selected and Being Processed

Alloy System 1 (3 high Mn steels): 0.1 C with 5.2, 5.8, or 7.1 Mn
Alloy System 2: (2 high Si steels): 1.5 Mn, 1.2 Si, with 0.1 or 0.15 C

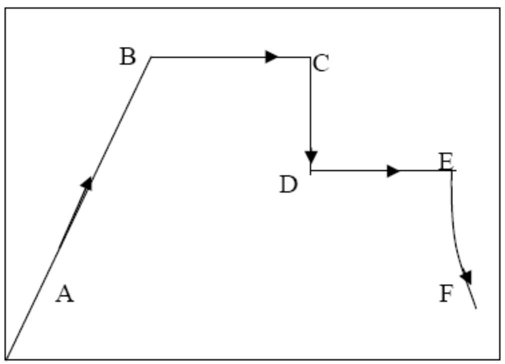


Putatunda – APPROACH

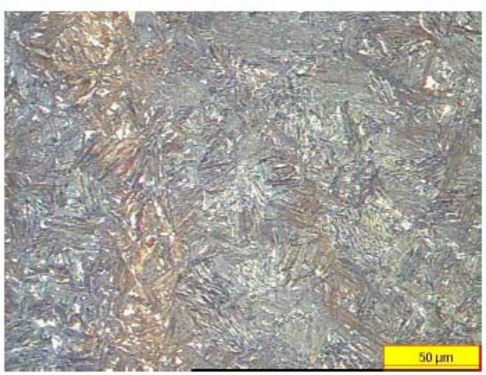
Use of Austempering for fine structure and high ductility and toughness.

Current Work

C=0.4 %, Si=2.0 %, Mn=0.4 %, Ni = 1.0 %, Cr = 0.8 %, Mo = 0.3 %



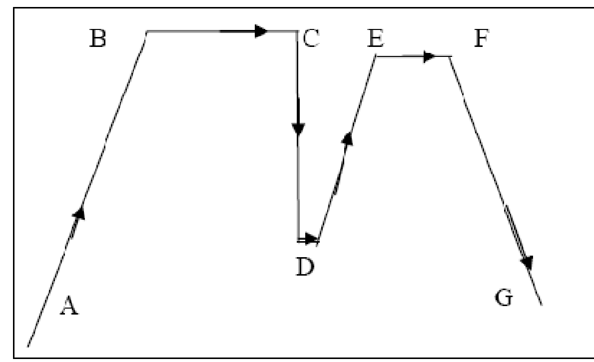
Conventional Austempering



YS = 1336 MPa
TS = 1653 MPA
EL = 11.5%
FT = 116.2 MPa m $^{1/2}$

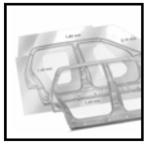
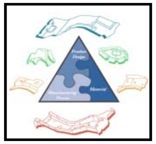
Proposed Work

C=0.4 %, Si=2.0 %, Mn=0.6 %, Ni = 1..0 %, Cr = 1.0 %, Mo = 0.2 %



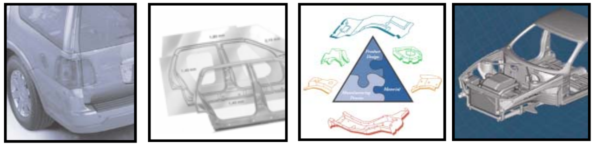
Two-Step Austempering

Repeat experiment with two step process, then lower carbon content

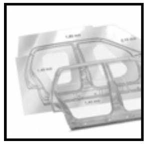
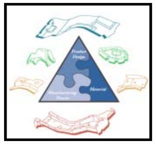

PROJECT RESULTS

- Website developed and now used for sharing of results among investigators.
- Two workshops for communication among principal investigators on April 10, 2008, and May 12, 2009.
- Results grouped into two categories, microstructure/property development and modeling to determine mechanical behavior.
- First-year findings to be reviewed May 12 in an AISI – A/SP – sponsored workshop and later reported in normal NSF format.



TECHNOLOGY TRANSFER

- April 10, 2008: Initial meeting of researchers.
- Posting of research updates on A/SP-NSF-DOE website from 2008 and 2009 workshops.
- Visits to universities and production of laboratory heats, etc., by A/SP representatives as programs proceed.
- May 12, 2009: Second workshop meeting of researchers at Laurel Manor, Livonia, Michigan.


NEXT FISCAL YEAR ACTVITIES

- Next year’s work in mechanical property development will be governed by results of the first year’s research in each project and the microstructures and properties developed in these concept studies.
- Next year’s work on modeling validation will depend on the establishment of effective working models in the first year’s research.
- Work is planned to continue for a total of three years in each project.