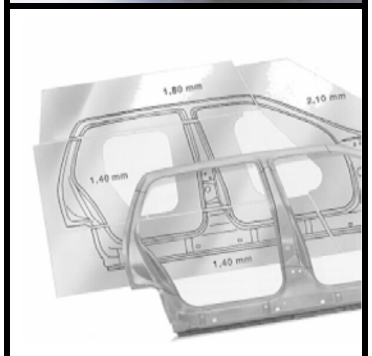
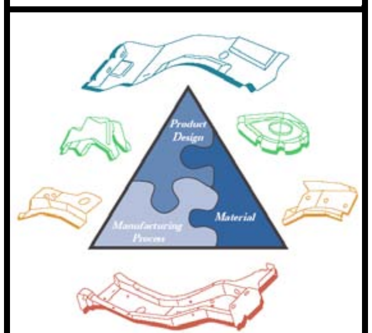




Auto/Steel Partnership:

NSF 3rd Generation Advanced High-Strength Steels

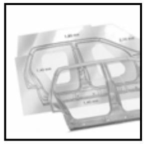
Ronald Krupitzer
American Iron and Steel Institute
Auto/Steel Partnership

June 8, 2010

Project ID #LM016

A/S P Auto/Steel Partnership

www.a-sp.org

OVERVIEW

Timeline

- Start – 10/2007
- End – 09/2010

Barriers

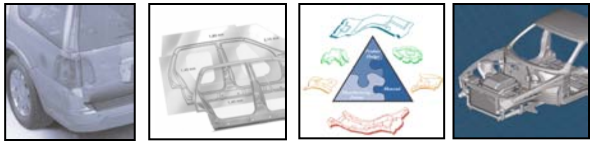
- Follow-up research may be required after third year
- Proof of concept will require scale-up projects for feasibility

Budget (3 years)

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

Partners

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

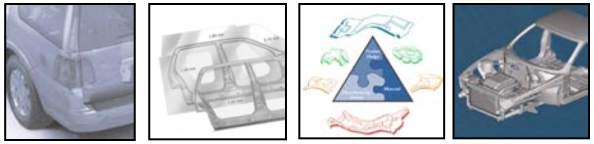


3rd GENERATION AHSS

OBJECTIVES

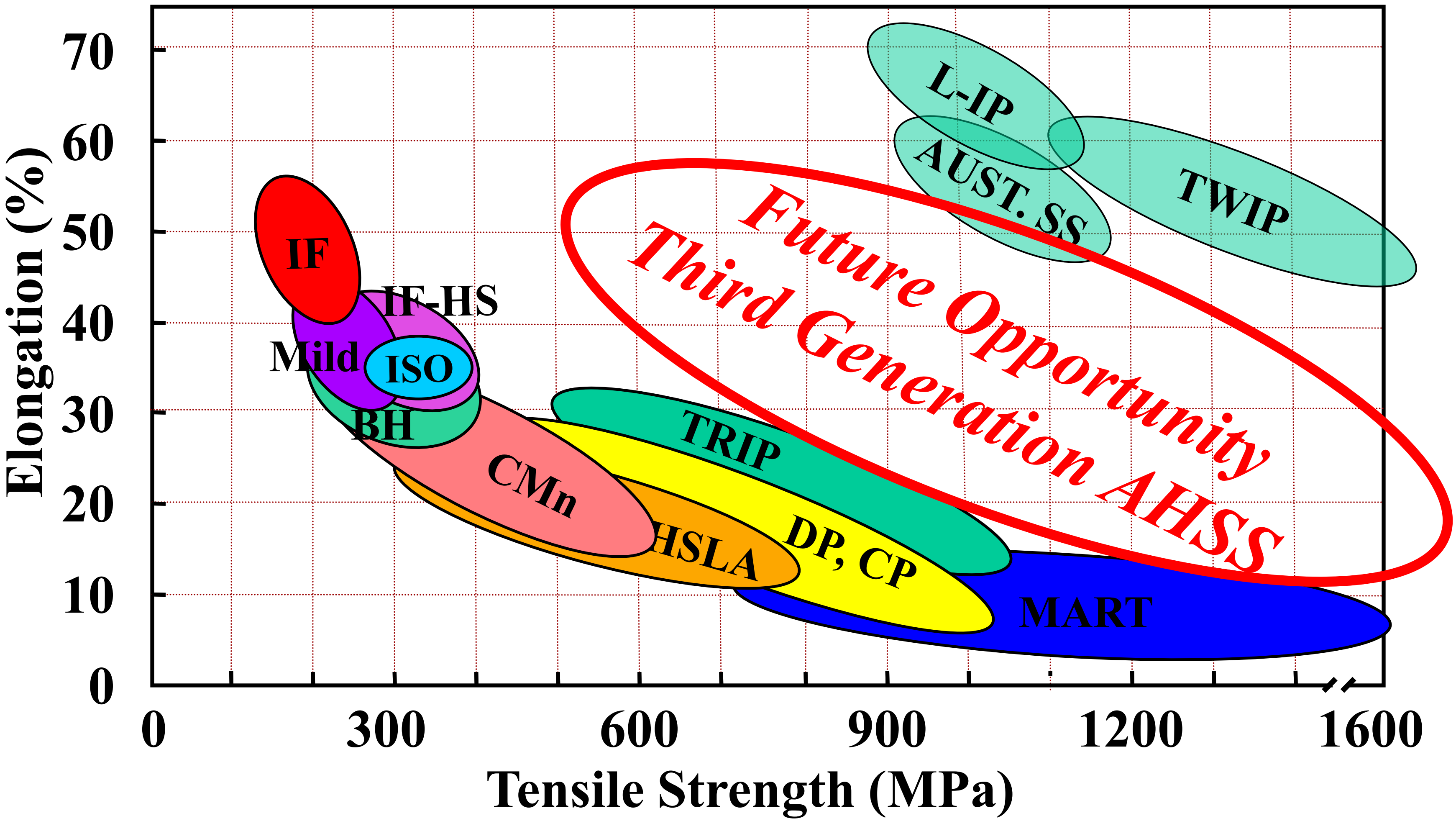
To enhance the capability of AHSS from 25% mass savings to over 35% as an affordable materials approach to improving fuel economy and reducing vehicle emissions.

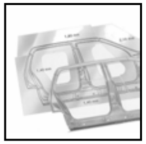
- Develop the metallurgy for a 3rd Generation AHSS with NSF, DOE and A/SP funded university research.
- Improve AHSS mechanical properties defined by the "Third Generation AHSS" field on the following total elongation - tensile strength diagram
- Improve modeling methods for fundamental steel mechanical property development



3rd GENERATION AHSS

OBJECTIVES

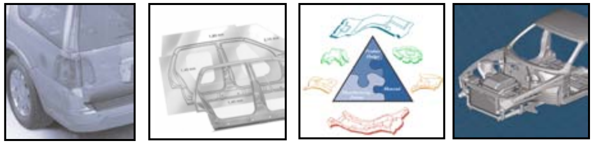




3rd GENERATION AHSS

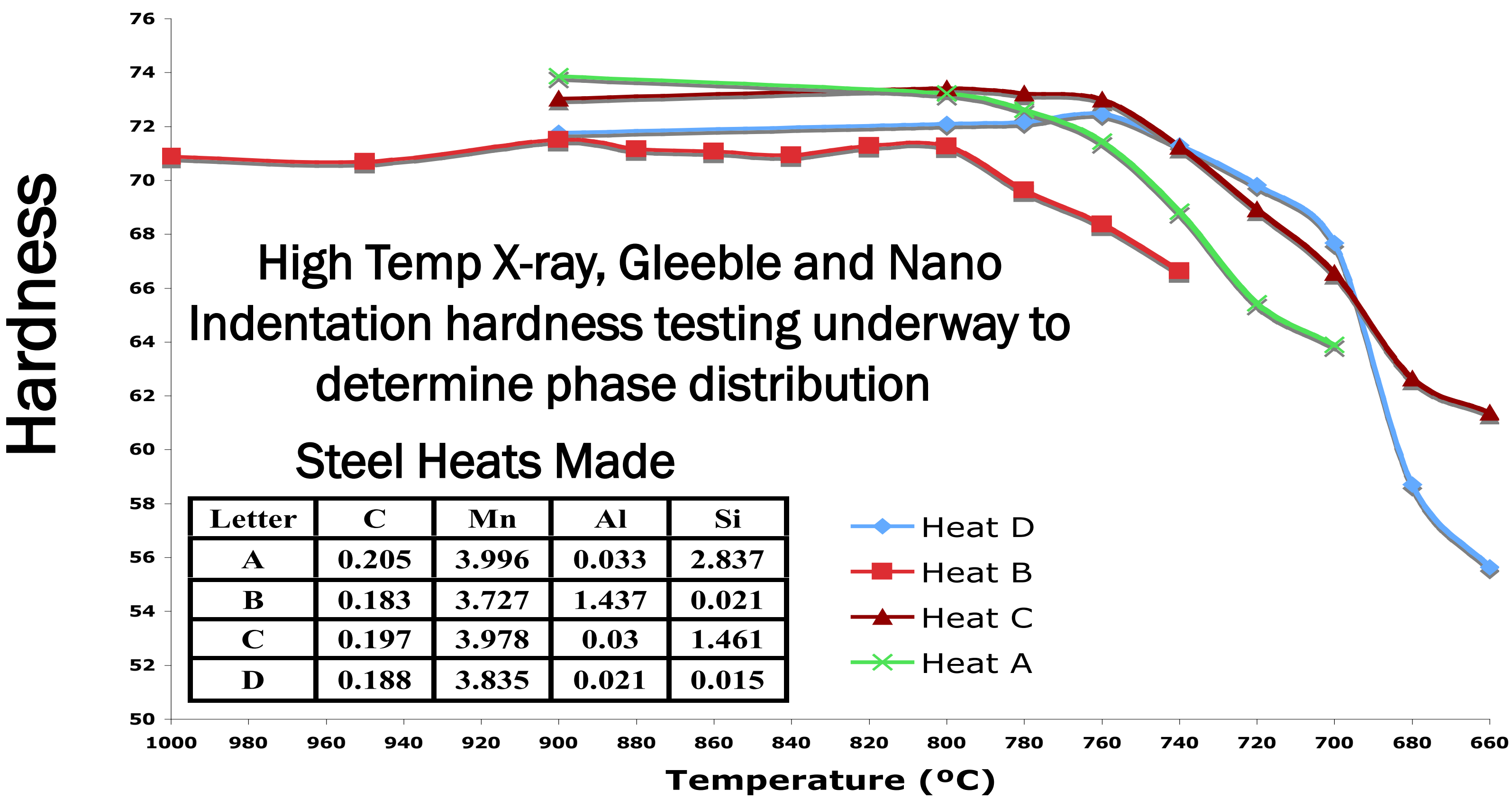
APPROACHES/STRATEGIES

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
Missouri Inst. Of Science & Tech.	David C. Van Aken	AHSS through nano-acicular duplex microstructures
Wayne State University	Susil K. Putatunda	High-strength high-toughness bainitic steel



Garrison – APPROACH/STRATEGY

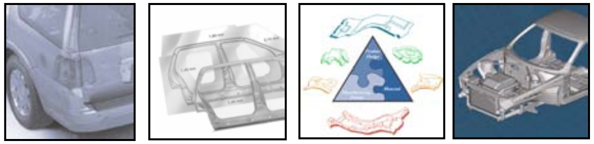
Create Multi-Phase Microstructures by Austenitizing or Annealing in a $\alpha+\gamma$ Field. Then Improve Properties Through Void Nucleation Resistance



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



Garrison – ACCOMPLISHMENTS

- Four heats of laboratory C-Mn-Si-Al steels have been studied after heat treating in the two-phase field.
- The effects of ferrite + martensite and ferrite + bainite structures are being assessed.
- Maximum uniform strains were achieved at relatively high tensile strengths.
- Tensile strengths in the 1200-1400 MPa range were achieved.
- Two additional heats are examining the role of void nucleation at inclusions in achieving high ductility.

Carbon Partitioning and Austenite Stabilization

Double Stabilization Thermal Process

SIX COLD ROLLED STEELS HAVE BEEN PROCESSED – The thermal cycle will include:

1) Direct Quench vs. Interrupted Quench to increase retained austenite (initial six steels). COMPLETED
2) Quench and Partition Runs (initial six heats plus new chemistries) to further stabilize austenite and inhibit ferrite formation. A carbon partitioning isothermal hold at a temperature where Cementite and Transition Carbides will not form.) UNDERWAY

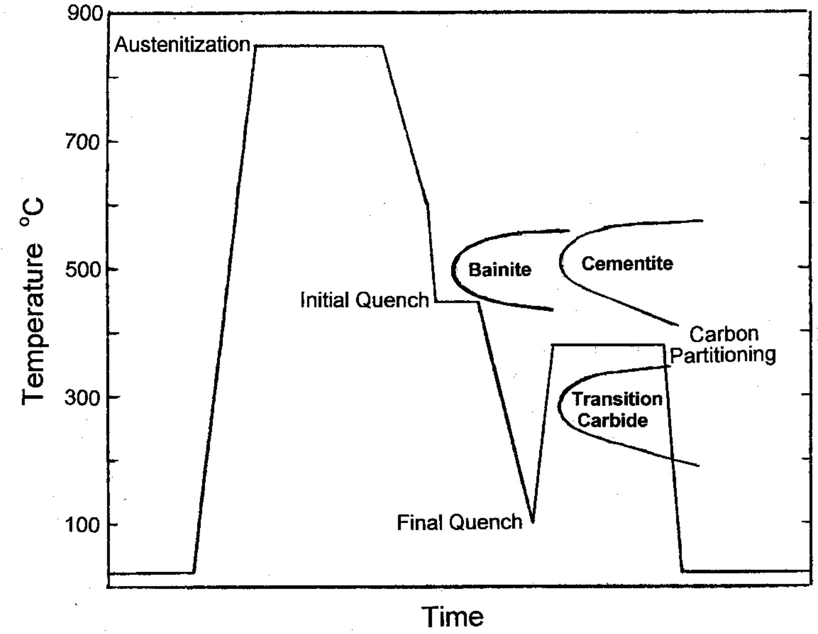
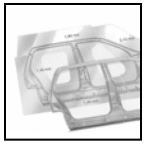


Table 1. Chemical Compositions of the Experimental Steels, wt. %
Cold Reduced Samples

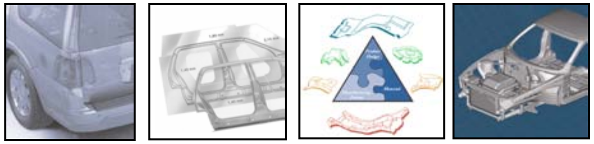
Hot Band	C	Mn	P	S	Si	Ni	Cr	Cu	Mo	N	Nb	V	Ti	Al	B
3A	0.10	2.16	<0.002	0.0008	2.15	0.004	<0.002	<0.002	<0.002	0.0049	<0.002	0.002	0.003	1.48	0.0018
3B	0.092	2.17	<0.002	0.0008	2.17	0.002	<0.002	<0.002	<0.002	0.0046	<0.002	0.002	0.003	1.48	0.0016
4B	0.26	4.12	0.002	0.0008	2.12	0.002	0.47	<0.002	<0.002	0.0080	<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.

Michal, Heuer – ACCOMPLISHMENTS

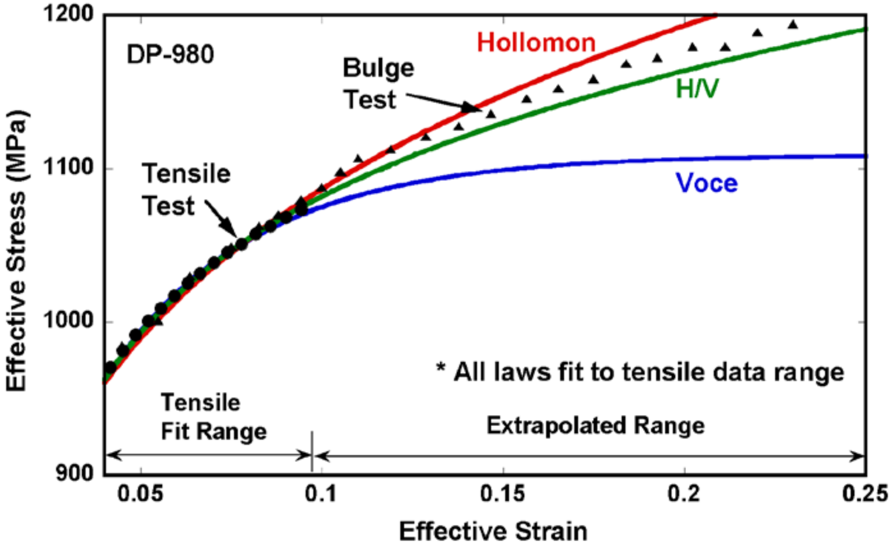
- Validated increase in retained austenite with interrupted quenching of 6 steel chemistries.
- Built and verified thermal cycling equipment including rapid quenching in liquid tin.
- Conducted about 40 quench and partition cycles on test steels and achieved up to 13% retained austenite
- Preparing to process heats of new chemistries to provide 100% austenite before quench.
- Aiming for minimal ferrite content and higher retained austenite with the new steel lab heat chemistries.



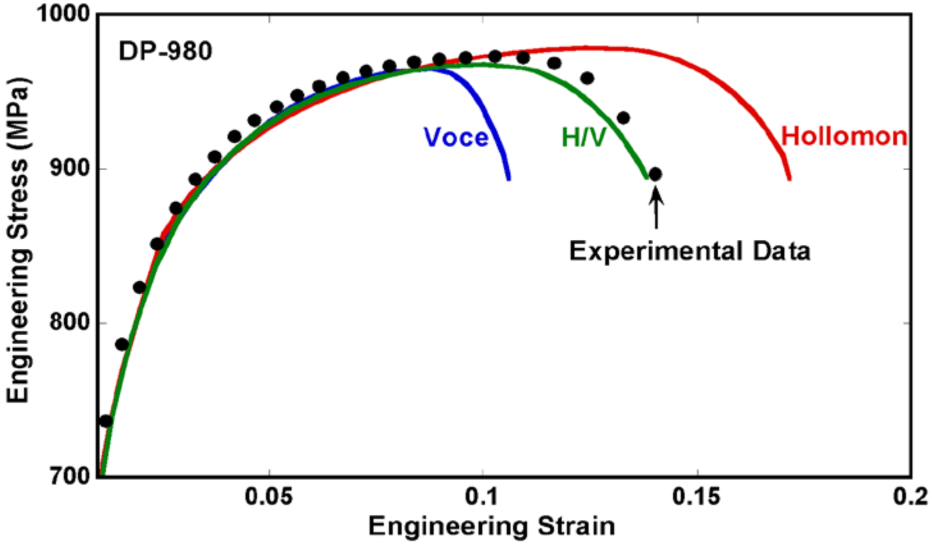
Wagoner – APPROACH/STRATEGY

Performance of "H/V" Model

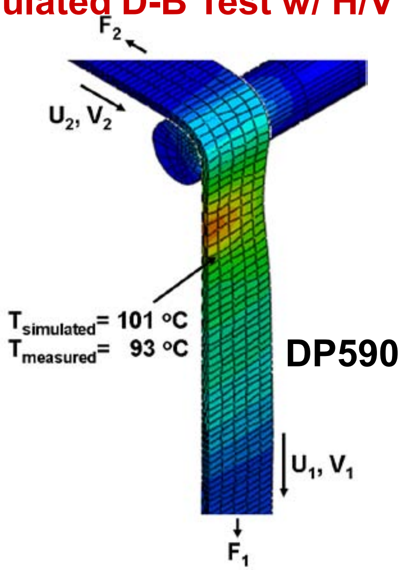
Accurate Extrapolation to Large Strain



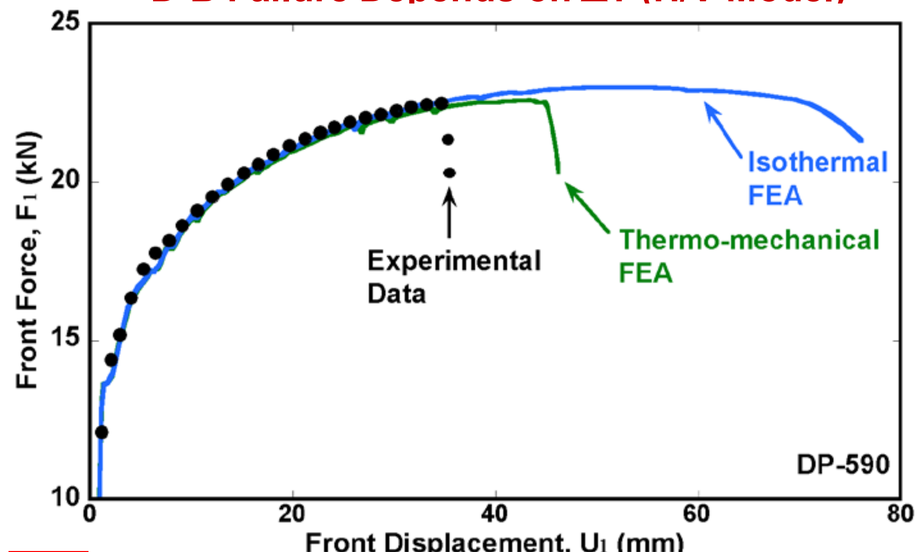
Accurate Prediction of Tensile Elongation

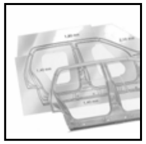


Simulated D-B Test w/ H/V Model



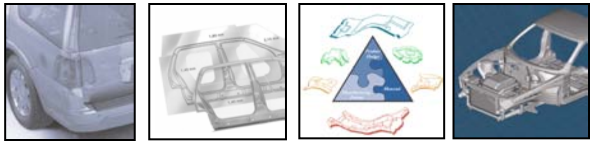
D-B Failure Depends on ΔT (H/V Model)



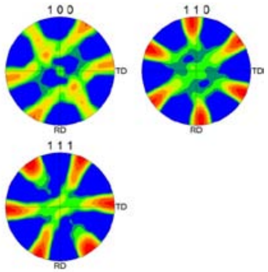
Wagoner – ACCOMPLISHMENTS

- One dimensional (1D) constitutive H/V (Holloman/Voce) equation incorporating strain, strain rate and temperature was completed and predicts necking and failure better than other constitutive laws.
- A draw-bend-fracture test was used to validate the three fracture types: type 1 (tensile), type 2 (mixed) and type 3 (shear) failures which are predicted by a coupled thermo mechanical FEA model
- The principal cause of "shear fracture" of AHSS lies in high deformation-induced heating related to the high energy absorption of thee alloys.

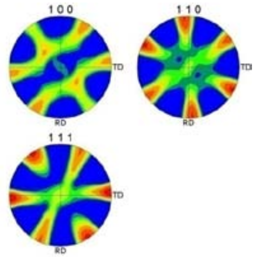


Acceleration of FEA Calculations with Spectral Crystal Plasticity

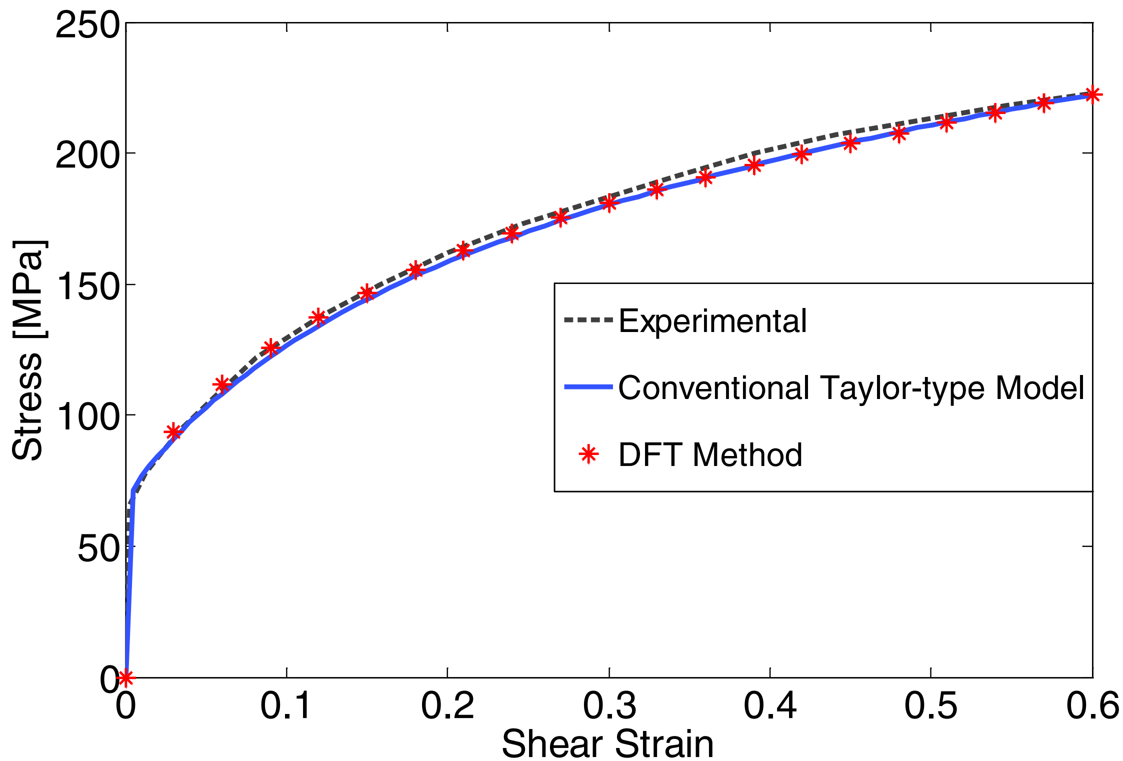
- ❑ **Use crystal plasticity to model AHSS structure-property behavior.**
- ❑ **Use DFTs (Discrete Fourier Transforms) and a spectral approach to speed up computationally expensive computations for multi-scale modeling of AHSS**



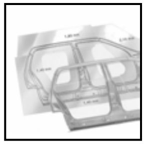
DFT Model
2.4 seconds



Conventional Taylor-type Model
107 seconds

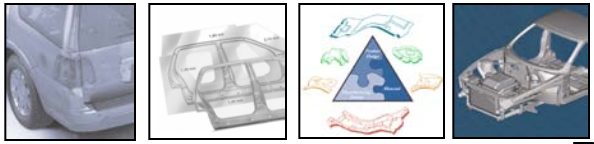


Validation of DFT Method with an IF Steel

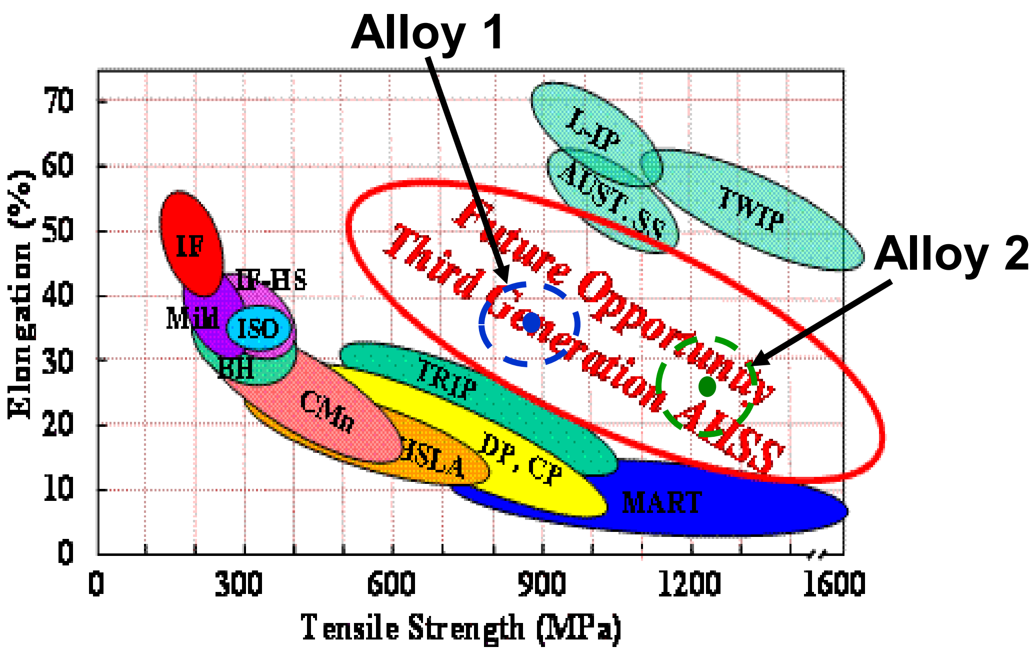
Kalidindi– ACCOMPLISHMENTS

- Crystal plasticity calculations were accelerated by two orders of magnitude using DFTs (Discrete Fourier Transforms) through a spectral approach.
- The crystal plasticity modeling approach enables orientation and deformation to be considered in developing more accurate constitutive relationships.
- The improved speed of computation enables crystal plasticity FEA modeling to be used in multi-scale modeling of bulk materials properties.
- The improved calculation efficiencies are being considered for commercial metal forming simulation software.



Van Aken – APPROACH/RESULTS

Development of AHSS Nano-acicular Duplex Steel



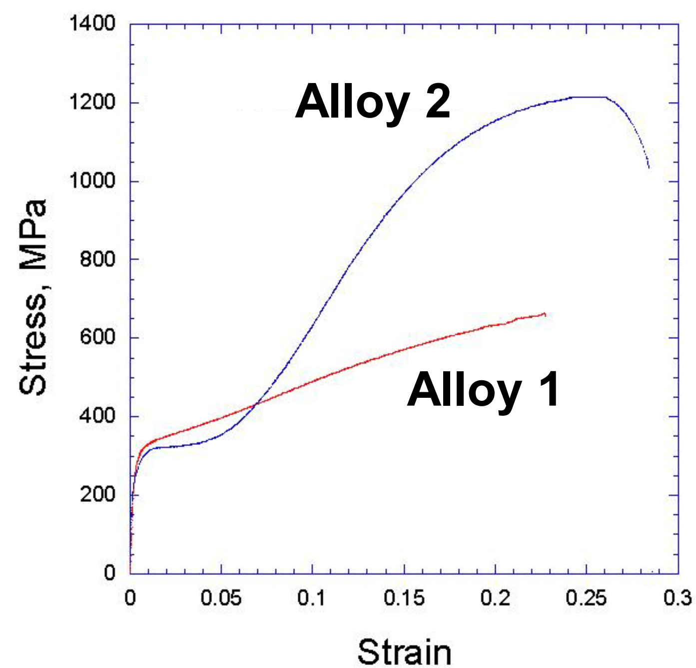
Two Steels Processed

Alloy 1

0.14C, 13.9Mn, 3.5 Al, 1.4Si

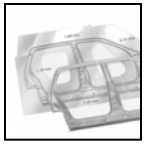
Alloy 2

0.06C, 14.2 Mn, 2.4 Al, 1.8Si



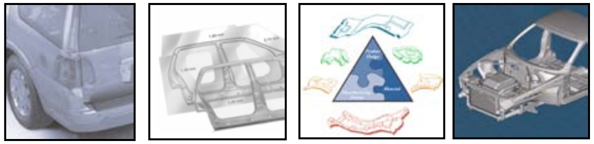
Duplex ferrite and austenite

- greater strength than 1st generation AHSS
- less alloy than 2nd generation AHSS (TWIP)

Van Aken – ACCOMPLISHMENTS

- Alloying effects with Mn, Si and carbon in austenite and ferrite show significant magnetic effects and may help in understanding austenite stabilization.
- Alloying with Mn, Al, and Si destabilizes cementite, lowers overall density, and enables acicular duplex microstructures to form.
- Two steels with various levels of these alloying elements have resulted in hot rolled mechanical properties in the target range of 3rd generation AHSS,
- The microstructures of these steels contain 58% austenite (0.06 C) and 29% austenite (0.14C), respectively.

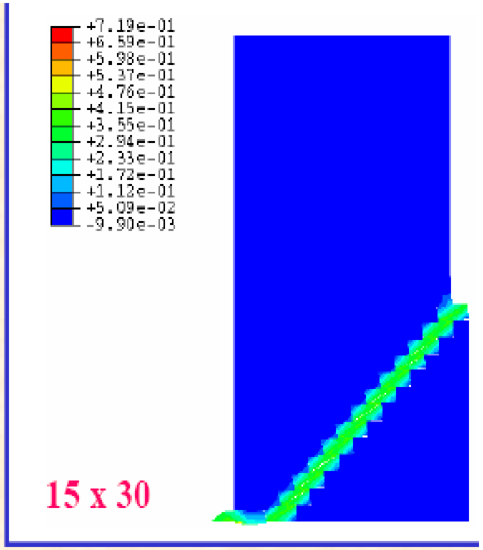


Al-Rub – APPROACH/STRATEGY

Particle Size and Interface Effects

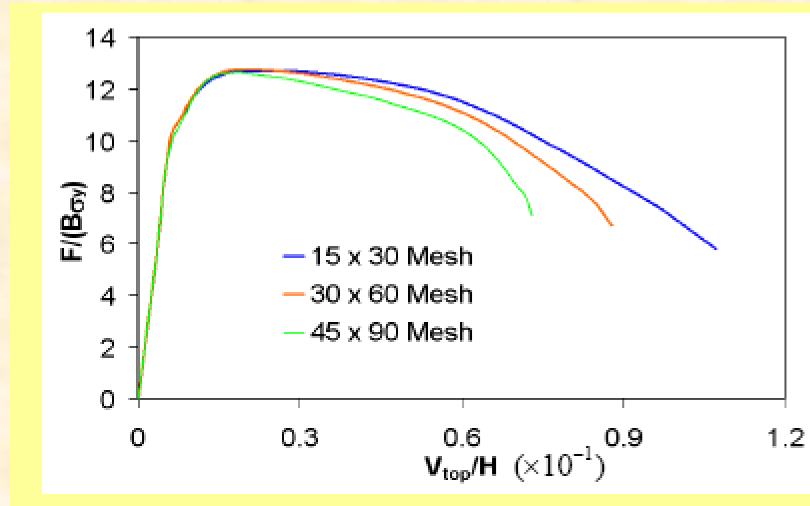
Local Theory

$\ell = 0$



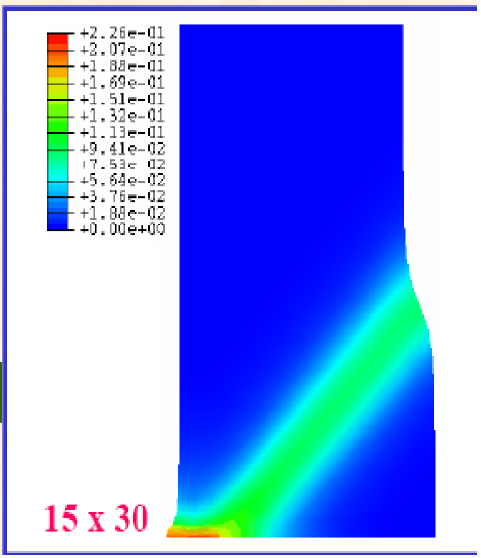
Local Theory

$\ell = 0$



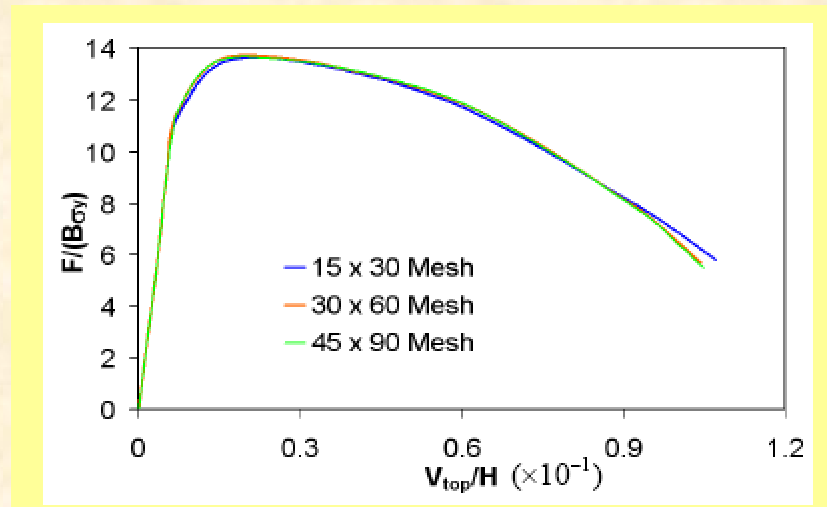
Gradient Theory

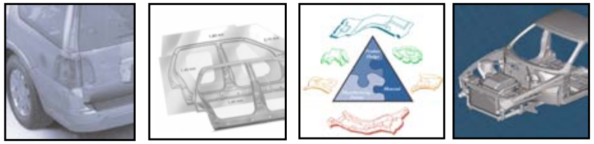
$\ell = 7.3\mu m$



Gradient Theory

$\ell = 7.3\mu m$





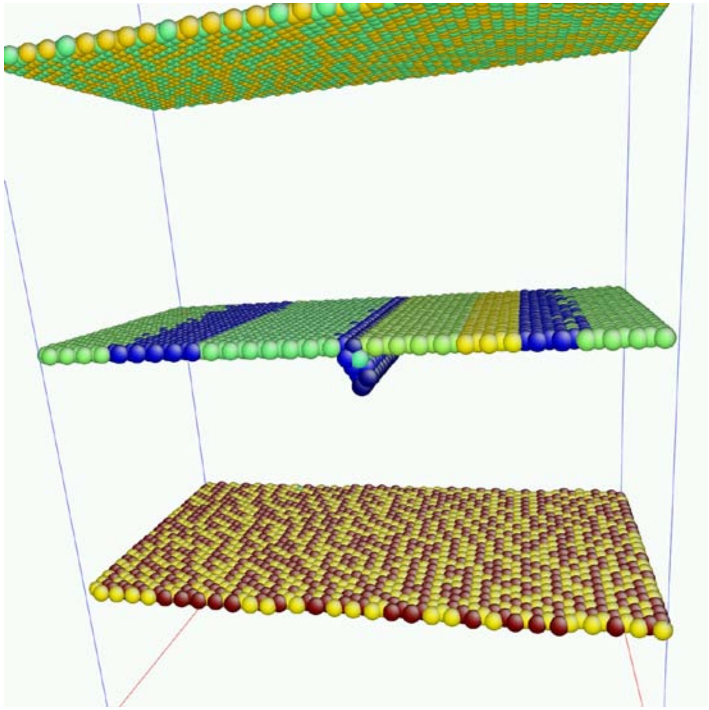
Al-Rub – ACCOMPLISHMENTS

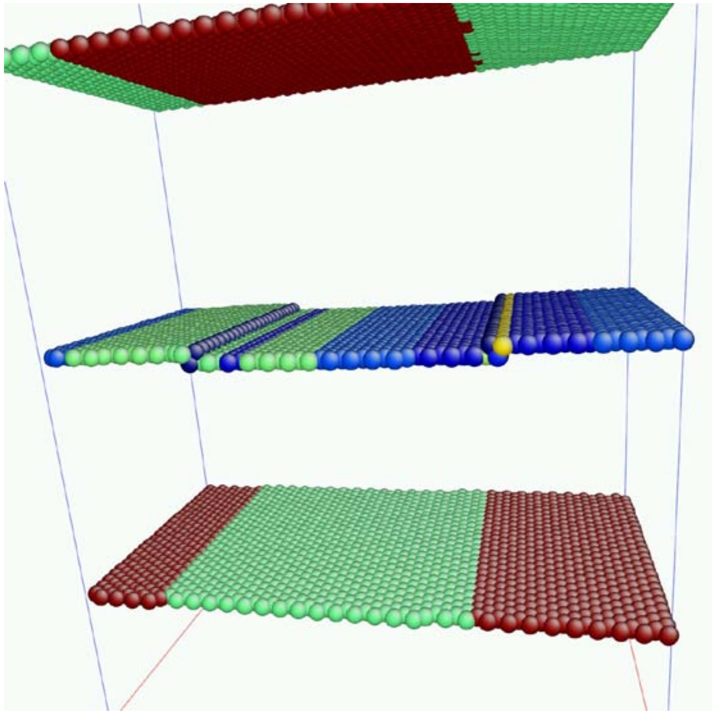
- Nonlocal strain gradient model developed and validated.
- Model predicts increase in yield strength and strain hardening rate by decreasing particle size and increasing particle stiffness.
- An optimum combination of hard and soft second phase particles can simultaneously increase both strength and ductility in AHSS,
- Model enables future parametric design of AHSS microstructures and properties.

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

Bulk 1 screw dislocation

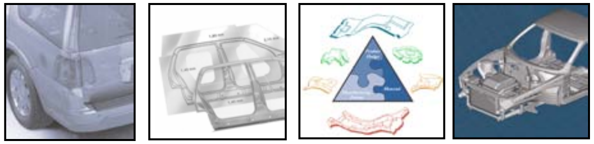
Interfacial dislocations





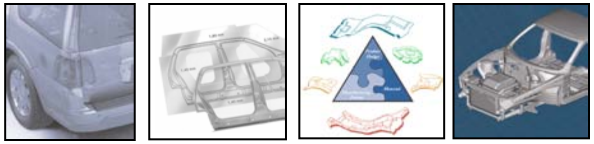
Bulk incompatibility ρ_{bulk}

Interfacial incompatibility ρ_{int}

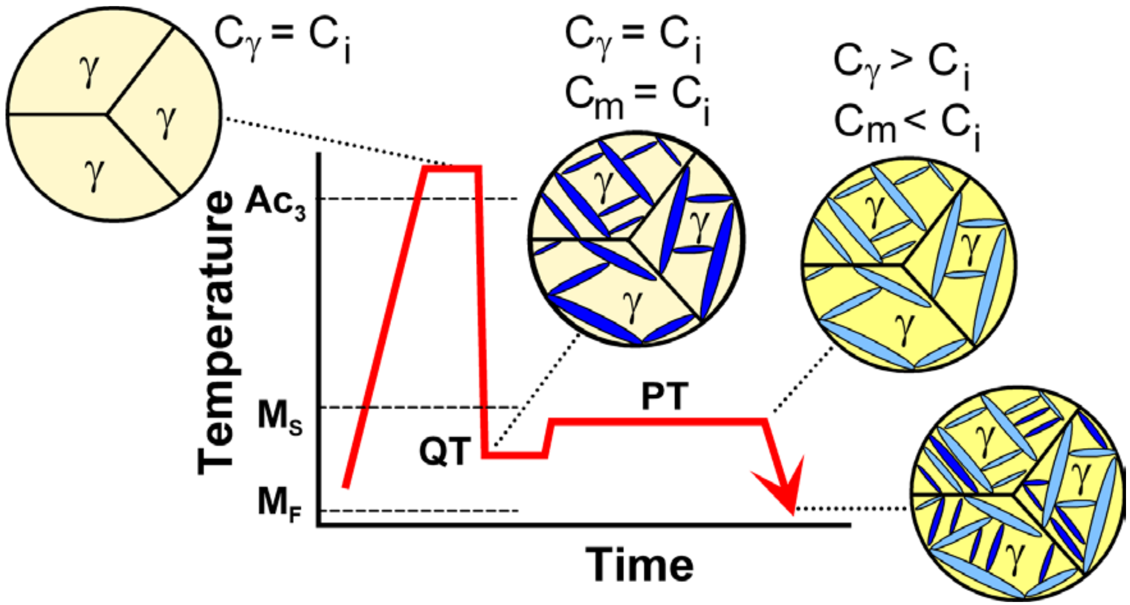


Li – ACCOMPLISHMENTS

- Found a detailed atomistic pathway in climb of screw dislocations with split partials using DMD (diffusive molecular dynamics).
- Successfully studies sintering and grain rotation in nanocrystals with DMD.
- Investigated pole mechanisms and grain size effects in deformation twinning with DMD.
- This advanced simulation method will accelerate the development of new materials like new AHSS steels into industry.

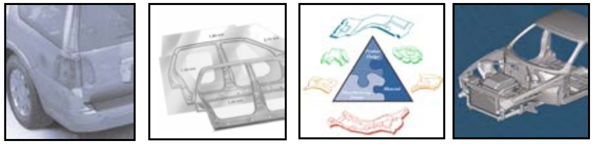


Quenching and Partitioning Thermal Cycles to Produce New AHSS Microstructures with High Retained Austenite



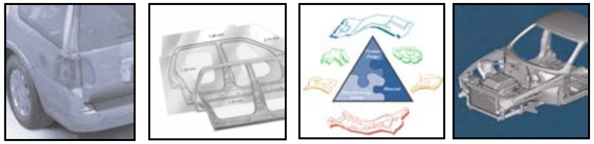
Two Alloy Systems Selected and Being Processed

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



Matlock – ACCOMPLISHMENTS

- A systematic method has been developed for intercritically heat treating to promote Mn partitioning
- Experimental cold rolled steels with Mn content between 5 and 7 percent have been obtained for laboratory heat treatment which is now underway.
- The process allows for the enrichment of Fe_3C with Mn which can be a benefit to developing desirable microstructures.

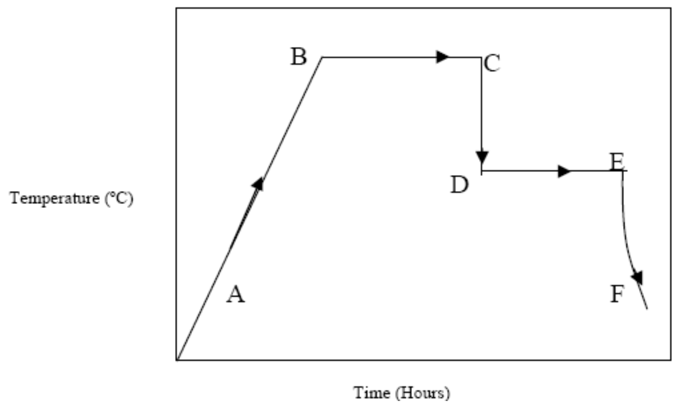


Putatunda – APPROACH

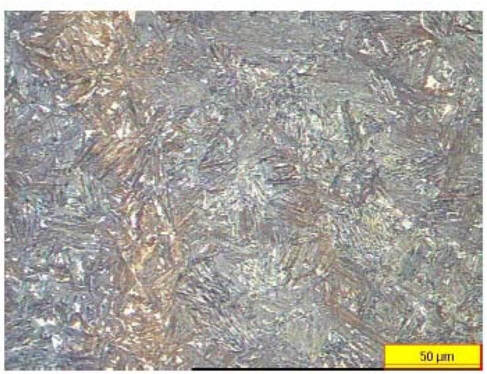
Use of Austempering for fine structure and high ductility and toughness.

Completed Validation Work

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



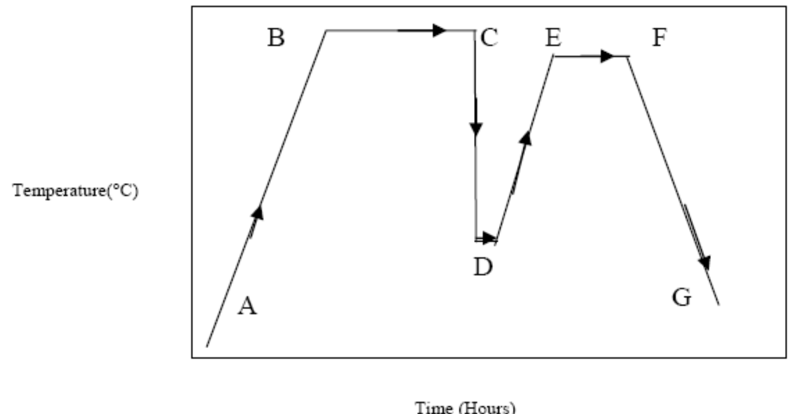
Conventional Austempering



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

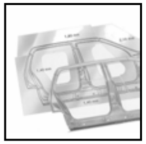
Proposed Work

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



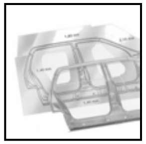
Two-Step Austempering

Repeat experiment with two step process, then lower carbon content

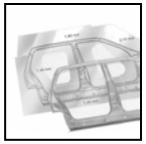
PROJECT RESULTS

- Website developed and now used for sharing of results among investigators.
- Two workshops held with principal investigators on April 10, 2008, and May 12, 2009.
- Results grouped into two categories, microstructure/property development and modeling to determine mechanical behavior.
- Third-year findings to be reviewed in 2010 in a third AISI – A/SP – sponsored workshop at which potential for future work will be discussed.

TECHNOLOGY TRANSFER

- Annual workshop with researchers have been held in 2008 and 2009 with the next planned for June 2010 or later.
- Posting of research updates on A/SP-NSF-DOE website.
- Visits to universities and production of laboratory heats, etc., by A/SP representatives.
- Publication of results in engineering and scientific journals.

NEXT FISCAL YEAR ACTVITIES

- 2010 is the final year for many of the projects.
- The 2010 workshop of investigators targeted for June will be directed at examining the potential for future work in these project areas.
- Depending on the individual projects, some third year work on several projects will be completed in the next fiscal year because of variations in the scheduling and funding for these projects.