LM020- Coherent Research Plan for the 3rd Generation Advanced High Strength Steels (AHSS) for Automotive Applications

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Presentation Outline

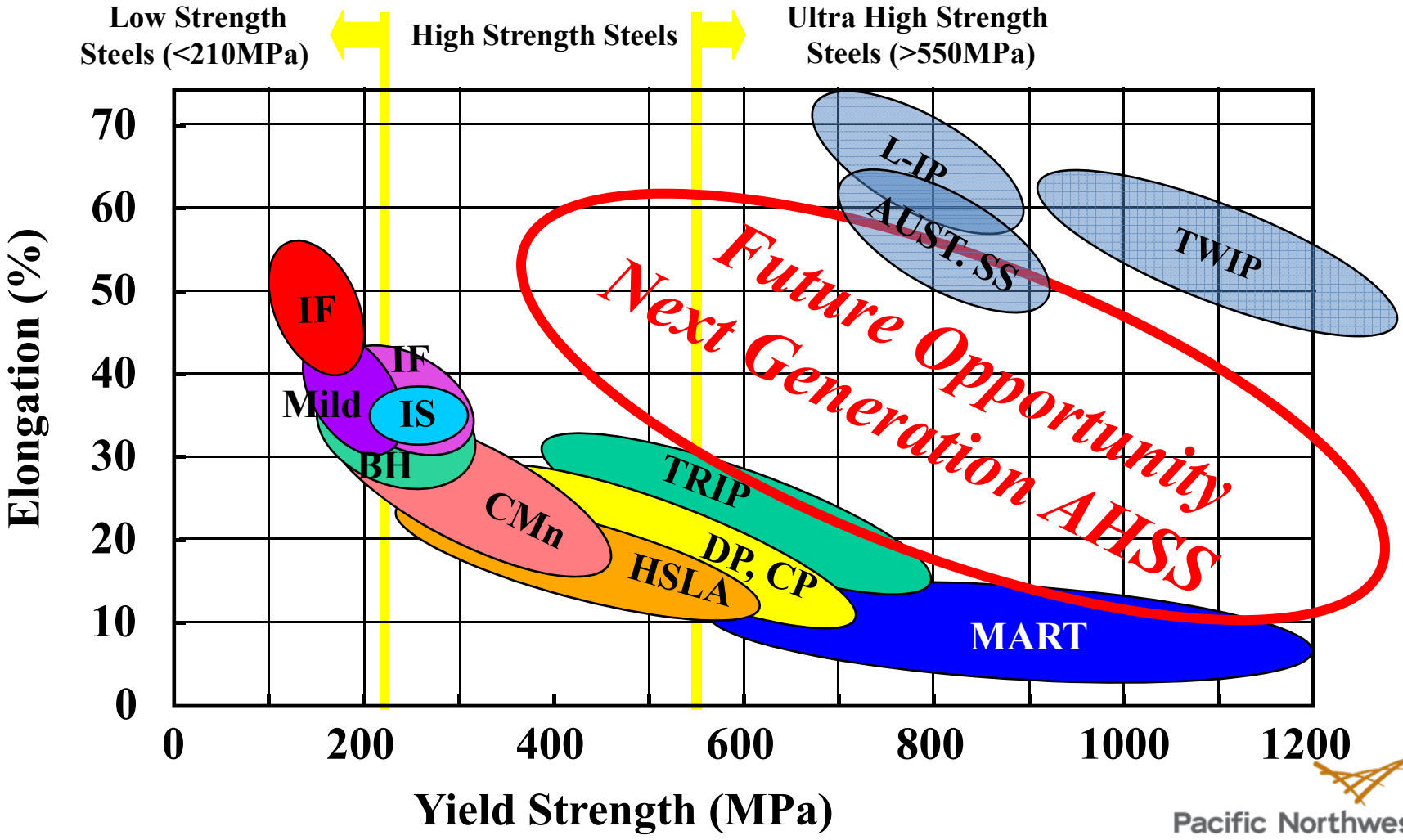
- Ultimate goals and relevance
- Background
- Objectives
- Project timeline and budget
- FY2009 technical accomplishments
- Summary and future work
- Publications

Ultimate Goals – Lightweight Materials Goals

- Validate the *cost-effective* reduction of the weight of passenger vehicle *body and chassis* systems by *50 percent* with *safety, performance, and recyclability* comparable to 2002 vehicles;
- Exhibit *performance*, *reliability*, and *safety* characteristics comparable to those of conventional vehicle materials;
- Enable development and commercial availability of low cost magnesium and its alloys, low cost carbon fiber and its composites, other light metal alloys, and *next generation high-strength steels*, with lifecycle costs equivalent to conventional steel.

Industry Vision on the "Banana" Curves

-- Performance and cost targets identified for 3rd GEN AHSS



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Source: R. Heimbuch: NSF-DOE-AS/P AHSS workshop

Objectives of the Coherent Research Plan

- Identify fundamental challenges and technical barriers in achieving the 3rd GEN AHSS vision
- Review state-of-the-art development work on 3rd GEN AHSS
- Identify roles of university, national labs and industry
- Outline the logical approaches in addressing the technical barriers through R&D

FY09 Budget, Milestone and Accomplishments

- FY09:
  - PNNL $325k
  - ORNL $325k
- Milestone document:
  - A Coherent Research Plan for the 3rd Generation Advanced High Strength Steels for Automotive Applications
- Technical accomplishments:
  - Preliminary studies on nano-precipitate strengthened steels
  - Preliminary studies on low cost TWIP steels
  - Preliminary studies on 3rd GEN TRIP steels

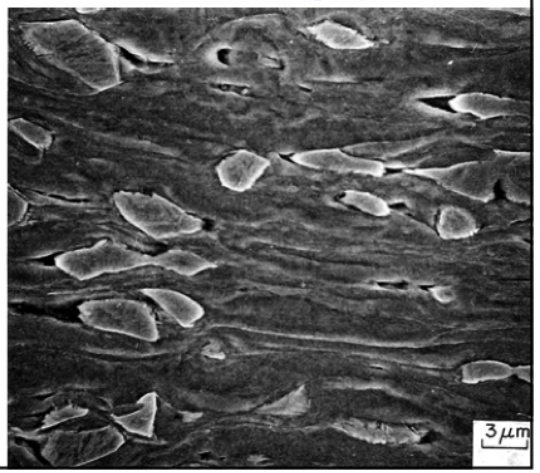
Technical Gaps Identified

- 1st GEN AHSS strengthening mechanisms:
  - Combination of hard and soft phases (micron level, individual grain constituents)
  - Deformation incompatibility between hard and soft phases caused failure along GB boundaries
  - How much more mileage in this approach (ie. Austenite + Martensite phases per Matlock)
- 2nd GEN AHSS
  - How much cost reduction is possible through reduction of Mn in chemistry

Implications of Fracture

- **Lack of "Isostrain Condition" i.e. Non-uniform strain**
- **Void nucleation due to high strength second phase**
- **Fracture**

SEM Micrograph

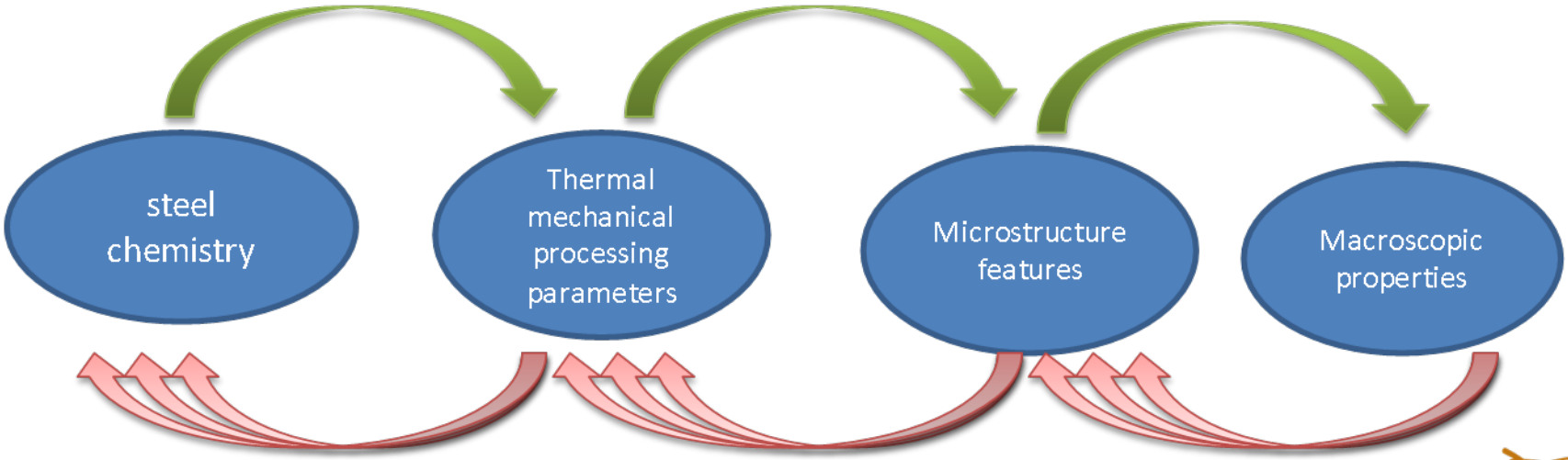


EXAMPLE: 1008 Steel Processed to DP Microstructure True drawing strain= 1.39

Korzekwa *et al.*, Scripta Met (1980)

Fundamental Strengthening Mechanisms

- Solid solution strengthening
- Precipitate strengthening
- Transformation strengthening
- Grain size refinement
- Grain boundary strengthening



Critical elements in steel making

Fundamental Challenges Need to be Addressed

- What types of microstructures are needed to reach the performance and cost targets of the 3rd generation AHSS while avoiding the manufacturability (formability and weldability) issues that hinges the applications of the 1st generation AHSS?
- How to quantitatively relate the material's microstructure to its macroscopic performance, i.e., stress versus strain relationship, forming limit diagram, stretch formability, weldability, etc.?
- How to achieve the required microstructures with a cost effective chemistry and a practical thermal mechanical processing route?

Landscape on 3rd Gen AHSS Development

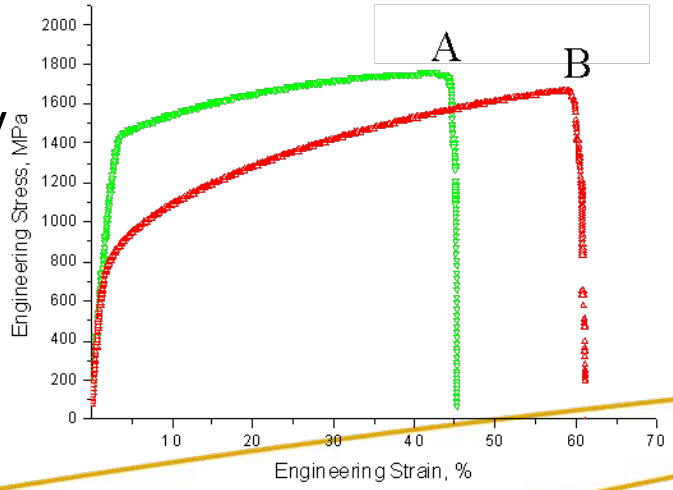
- NSF-DOE-A/SP co-funded 9 university teams in exploring various fundamental approaches in achieving the 3rd GEN goals:
  - Longer term
  - Fundamental research
- Europe and Asia steel producers:
  - Japan and China
    - Nano-Hiten: Nano-sized precipitates strengthened
  - POSCO:
    - Low cost TWIP: 17.5% Mn
  - Germany:
    - TRIPLEX: a stable austenitic solid solution matrix with various volume fractions of nanometer size carbides.
- National Labs (PNNL and ORNL) performed exploratory work to explore additional novel routes for achieving desired properties

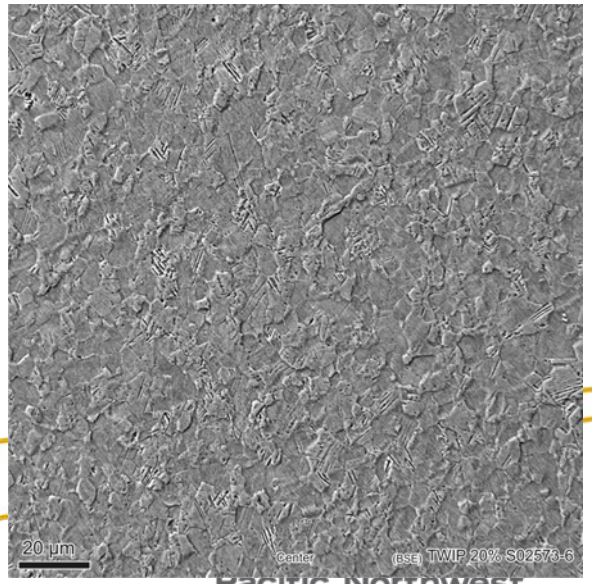
Preliminary Study on Low Cost TWIP Steels

- TWIP
  - Can we reduce the cost (Mn content) from 2nd Gen AHSS while still retain twinning deformation dominant?
  - Chemistry of two experimental TWIP grades

	C	*Mn*	*P*	*S*	*Si*	*Cr*	*Ni*	*Mo*	*Cu*	*Co*	*Nb*	*Ti*
A	0.05	22.47	0.007	<0.001	1.90	<0.01	<0.01	0.11	0.02	<0.01	0.02	0.01
B	0.52	17.53	0.007	0.008	0.98	<0.01	<0.01	0.05	0.02	<0.01	0.01	0.01

- Good weldability
- Very good ductility
- Need to evaluate stretch bendability





Cost Comparison of Two Experimental TWIP Steels and HSLA

- **TWIP**

	C	*Mn*	*P*	*S*	*Si*	*Cr*	*Ni*	*Mo*	*Cu*	*Co*	*Nb*	*Ti*
A	0.05	22.47	0.007	<0.001	1.90	<0.01	<0.01	0.11	0.02	<0.01	0.02	0.01
B	0.52	17.53	0.007	0.008	0.98	<0.01	<0.01	0.05	0.02	<0.01	0.01	0.01

- **HSLA**

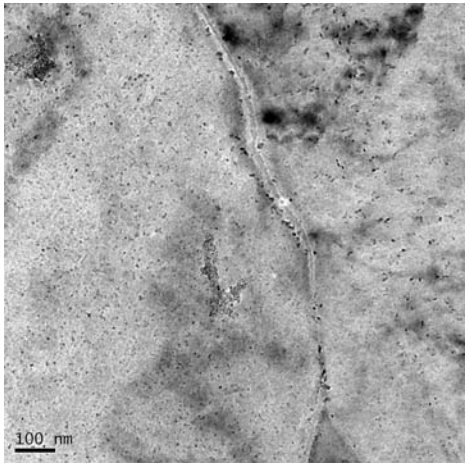
Table 21.4 Chemical compositions of steels analyzed by Abraham and Arend [6].

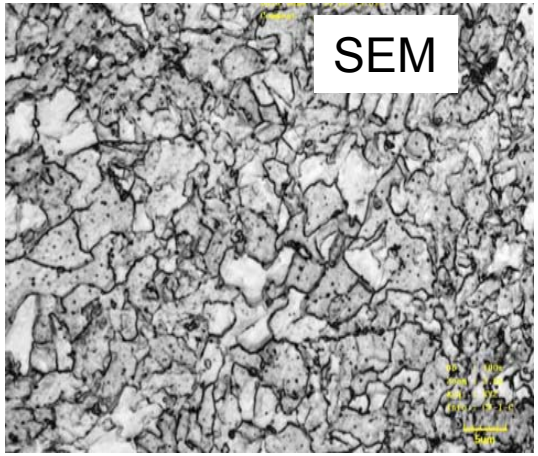
Steel	Chemical composition, wt%						
	C	Mn	Si	N	Nb	V	Ti
Low Nb + V	0.04	0.38	0.06	0.005	0.035	0.060	-
	0.04	0.39	0.05	0.005	0.030	0.090	-
	0.045	0.40	0.06	0.005	0.040	0.110	-
	0.046	0.40	0.06	0.005	0.038	0.150	-
High Nb + V	0.049	0.41	0.06	0.005	0.071	0.150	-
	0.046	0.40	0.05	0.005	0.100	0.150	-
	0.040	0.37	0.05	0.005	0.090	0.060	-
Nb + Low Ti	0.057	0.40	0.05	0.005	0.050	-	0.090
	0.050	0.35	0.04	0.005	0.090	-	0.080
Nb + High Ti	0.052	0.38	0.05	0.005	0.050	-	0.140
	0.054	0.35	0.02	0.005	0.100	-	0.140

- **Cost of alloy elements (USGS):**
  - **Mn: $0.69/lb.**
  - **Cr: $4.5/lb.**
  - **Nb: $7.62/lb.**
  - **Ni: $28.5/lb**
  - **V: $37.5/lb.**

Preliminary Work on Nano-Precipitate Strengthened Steels

TEM





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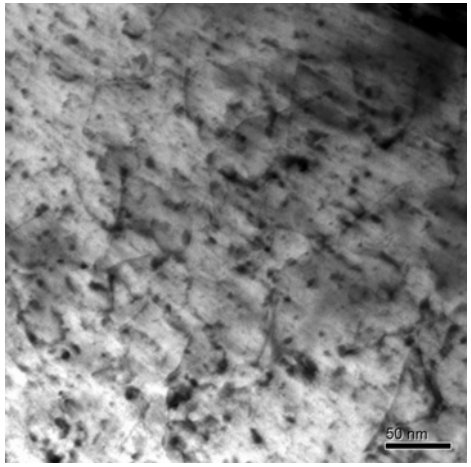
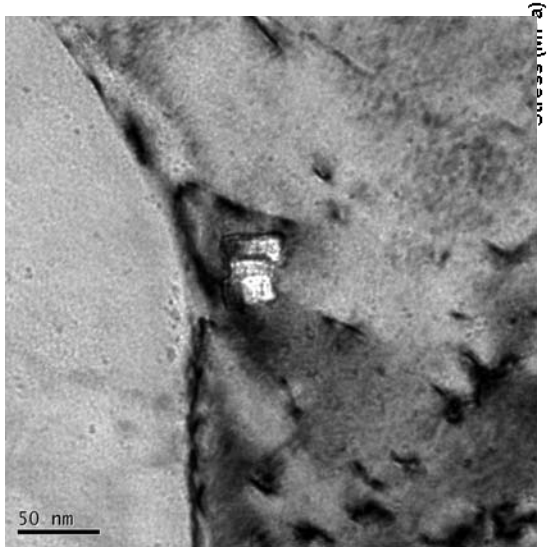
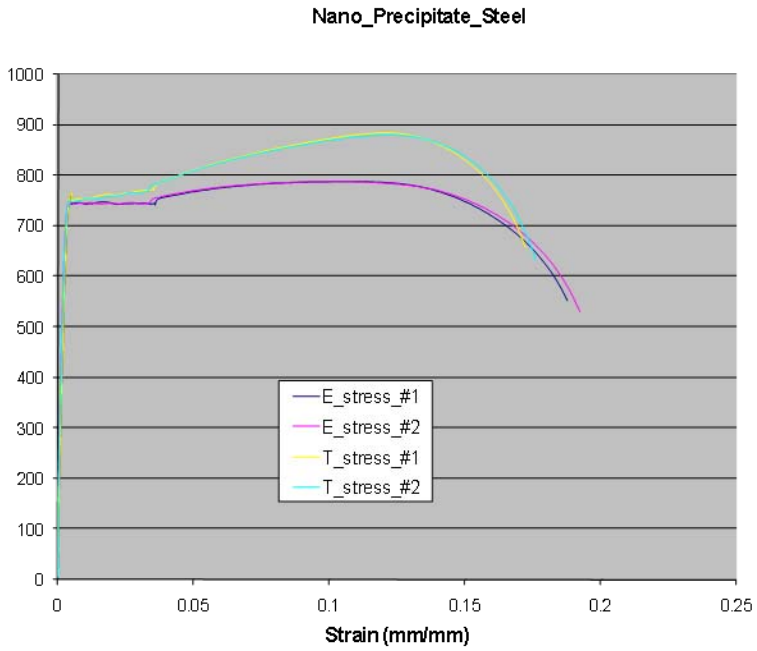




Tensile test



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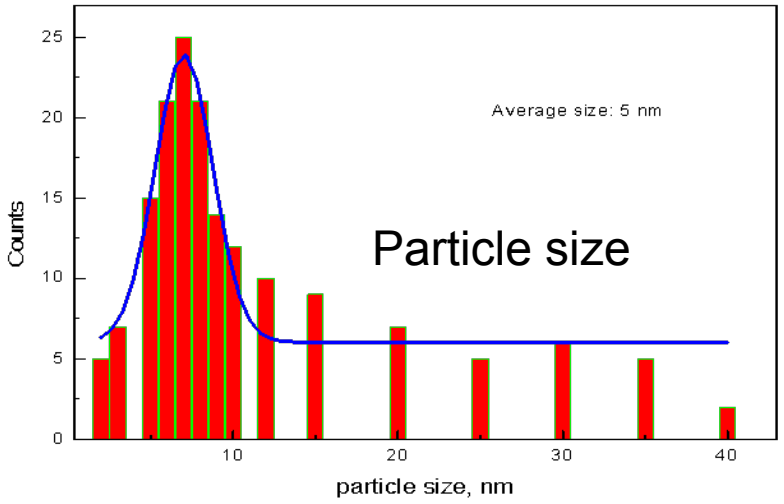
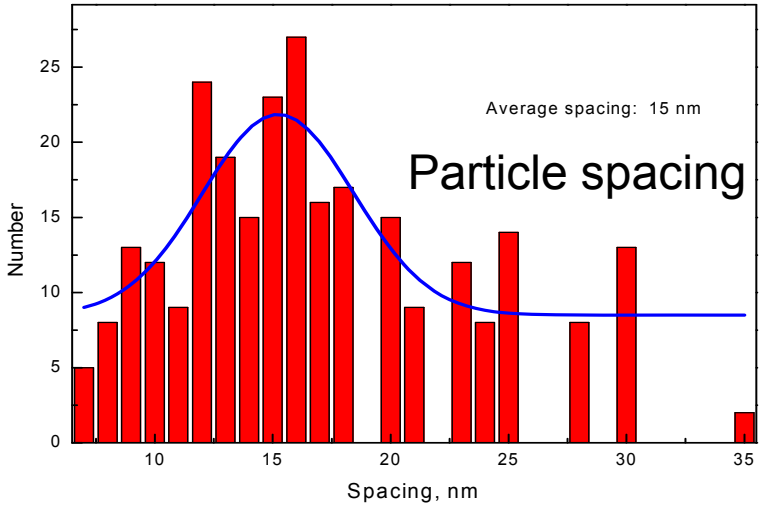
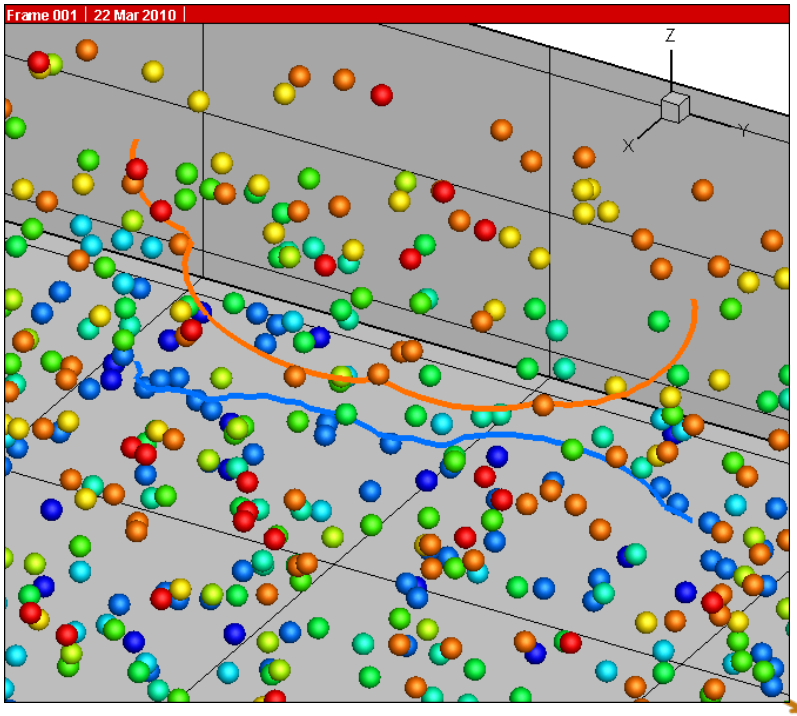
Preliminary Work on Nano-Precipitate Strengthened Steels





Dislocation Dynamics Calculations Illustrating interactions of dislocations with nano particles



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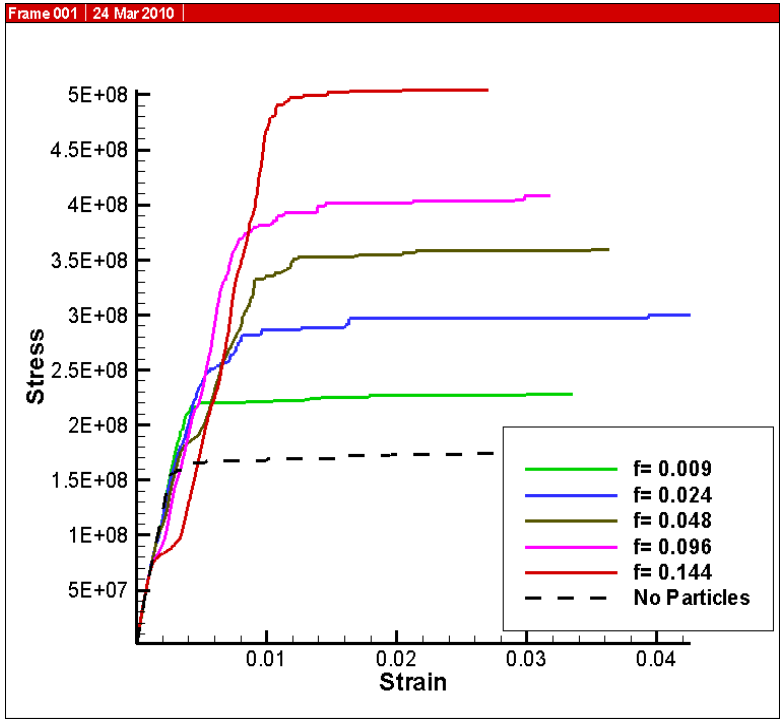
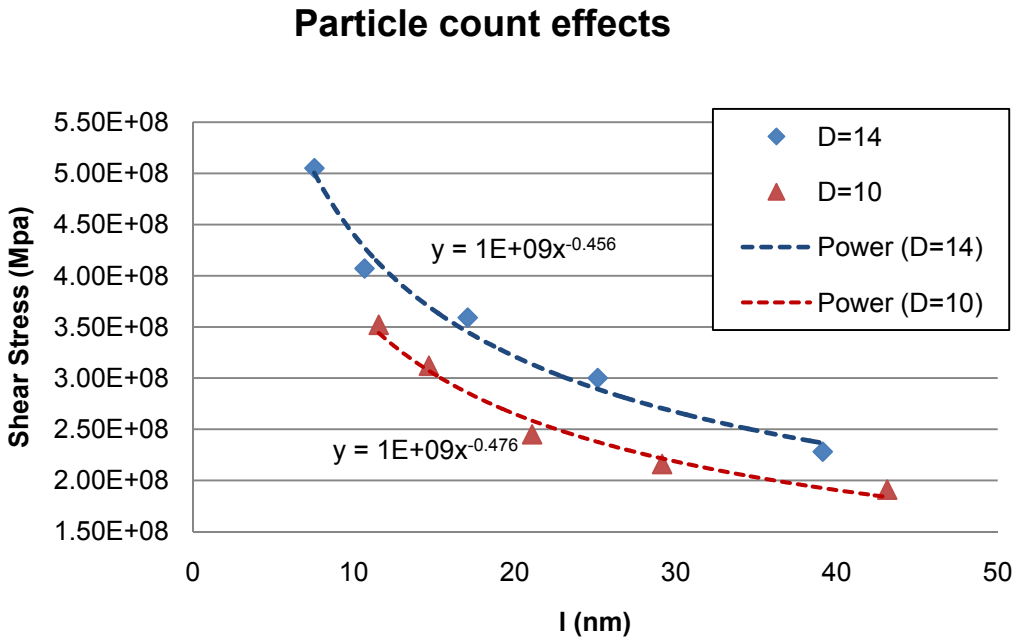
Effects of Particle Size, Spacing and Volume Fraction on Strength





Volume fraction

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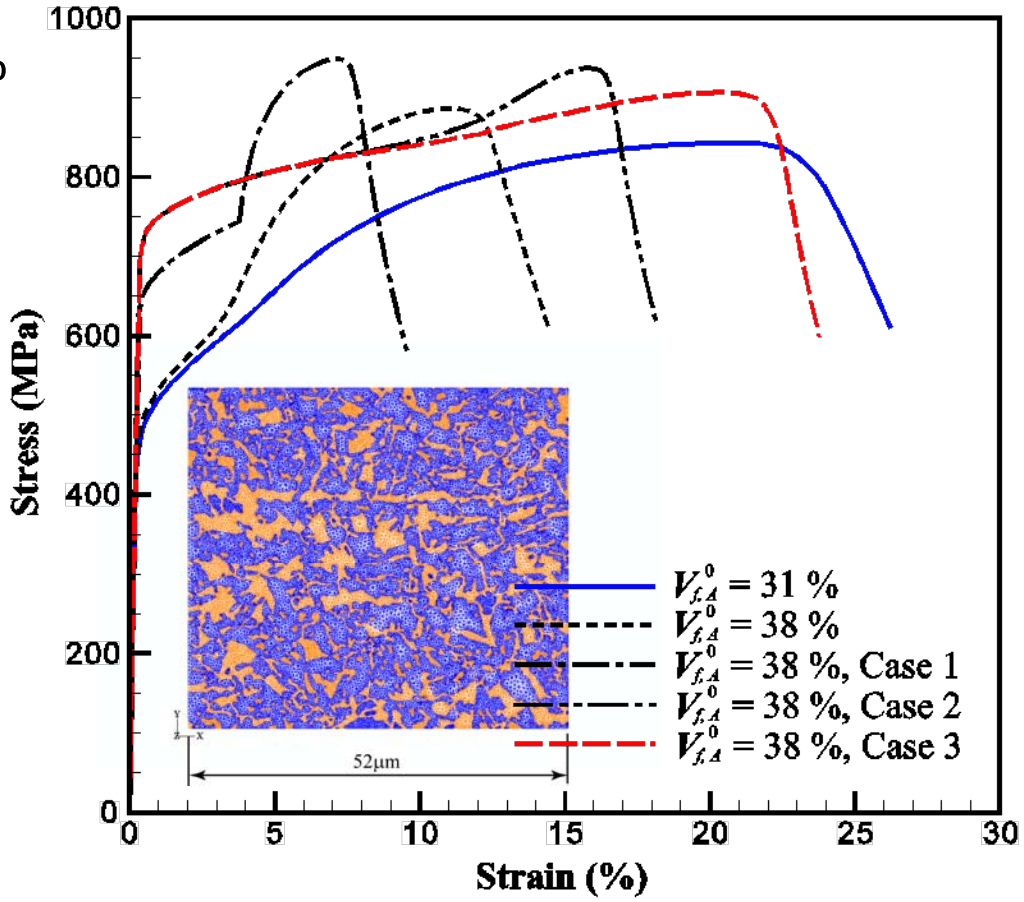
3rd GEN TRIP Steels - Computational Materials Design

- Start with TRIP steel with 31% RA volume fraction
- Increase RA volume fraction to 38% only
- Case 1: increase ferrite strength
- Case 2: increase strength of retained austenite
- Case 3: decrease strength of freshly formed martensite



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Summary and Future Work

- Nano precipitate strengthened steels:
  - Fundamentals on nano-precipitate phase formation
  - Quantify the strengthening effects of nano precipitates in nano steels
- Low cost TWIP steel development
  - Investigate effects of steel chemistry on stacking fault energy and develop physically-based phenomenological model for TWIP steels
  - Develop micromechanics model to simulate the strengthening effects of micro-twins
- Explore “extra mileage” from allotropic approach by further refining the microstructure and individual phase properties and by identifying the associated thermo-mechanical processing routes

Technology Transfer

- Received strong supports from and maintained close interactions with OEM, steel suppliers and A/SP committees
  - A/SP AHSS Stamping Team
  - Joining Technologies Team
  - A/SP Sheet Steel Fatigue Committee
  - A/SP Lightweight Chassis Structure Team
- Research approaches and results have been adopted and further developed/refined by the OEMs and industry consortiums
  - Initial version of integrated weld model licensed and transferred to industry
  - Weld fatigue life improvement technique and predictive model are under further evaluation by industry

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