Overview of a New Category of 3rd Generation AHSS

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The NanoSteel Company
Outline: New Approach to AHSS

- NanoSteel 3rd Generation AHSS – Developmental History
  - > 15 years of research and development

- Existing strategies for 3rd Generation AHSS
  - Optimization of 1st and 2nd Generation approaches

- Key differentiators for 3rd Generation AHSS - NanoSteel
  - Chemistry
    - Developmental pathway much different than current autobody steels
  - Structural Formation
    - New mechanism to create nanoscale structures at elevated temperature
    - New strain hardening mechanism to develop high strengths and usable ductility
  - Tensile Behavior
    - Compelling combinations of strength and ductility allowing cold formability

A Number Of Breakthroughs Occurred To Allow A New Generation Of AHSS
NanoSteel Sheet Steel Developmental History

- 'Eureka' Moment
  Discovery - New Class of Nano-Structured Steel

- DARPA Funding
  Structural Amorphous Metal (SAM)

- The NanoSteel Company is Created
  Technology Spin-off from Idaho National Lab

- U.S. Department of Energy Funding
  Nano-Structured Steel

- General Motors Target
  Provided for 3rd Generation AHSS

- GM Ventures
  Investment in NanoSteel

- Achievement of GM Spec
  Independent Verification

- 3rd Generation AHSS Sheet Steel
  Industrial Production Trials

- 1996
- 1996-1999
- 2000-2003
- 2002
- 2010
- 2011
- 2012

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3rd Generation AHSS Opportunity

3rd Generation AHSS Targeted For 2017 - 2025

For 2017-2025, new formable AHSS grades will enable more steel mass reduction.
3rd Generation AHSS Development: Conventional Approaches

- Enhanced Dual-Phase (DP)
- Modified TRIP
- Ultrafine Bainite

- Quenching and Partitioning (Q&P)
- Lower Mn TRIP/TWIP
- Higher Mn TRIP

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Enhanced TRIP with Modified γ

Enhanced DP

B-Modified Hot Formed

TWIP with Lower $$

“Q&P”

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NanoSteel (NS) resulted from paradigm changing developmental strategies.

Key differentiators will be detailed; chemistry, structural formation, tensile behavior.
Key Differentiator

CHEMISTRY
# P-Group Elements

## Periodic Table

![Periodic Table Image](image-url)

### Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Electron Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td>1s²</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>3</td>
<td>1s²2s¹</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Be</td>
<td>4</td>
<td>1s²2s²2p²</td>
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<tr>
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<td>B</td>
<td>5</td>
<td>1s²2s²2p³</td>
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<tr>
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<td>C</td>
<td>6</td>
<td>1s²2s²2p²</td>
</tr>
<tr>
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<td>N</td>
<td>7</td>
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<td>8</td>
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<td>Fluorine</td>
<td>F</td>
<td>9</td>
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<tr>
<td>Neon</td>
<td>Ne</td>
<td>10</td>
<td>1s²2s²2p⁶</td>
</tr>
</tbody>
</table>

### Continuation...

- P-Group Elements
- Periodic Table
- Electronegativity
- Atomic Radius

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atsby: www.autosteel.org
P-Group Elements are utilized in all NanoSteel Products

P-Group Elements Enable Mechanistic Responses Leading To Nanoscale Structure Creation
P-Group Elements in NanoSteel Products

Results in dramatic increases in strength, hardness, wear resistance
- Surface Technology for heavy construction / mining, oil and gas, power industries, concrete
- Thin Monolithic Technology for replacement of aluminum honeycomb and polyamide fibers

Surface Technology
- Waterwall Panels / Bollers
- Tool Joint / Drill Pipe
- Portable Electronics Exteriors
- Concrete Reinforcement

Thin Monolithic Technology
- Dipper Liner / Oilsands Mining
- Wear Plate / Haul Truck
- Armoring / Ballistic Applications
- Honeycomb Applications

NanoSteel Products Providing Solutions For A Wide Variety of Mainstream Industries
P-Group Elements in NanoSteel Products

- **Results in dramatic increases in strength, hardness, wear resistance**
  - Surface Technology products for heavy construction / mining industries
  - Thin Monolithic products for replacement of aluminum honeycomb and polyamide fibers

- **Enables mechanistic responses to achieve nanoscale structures**
  - Glass Formation $\Rightarrow$ Devitrification to form amorphous, devitrified nanocomposite structures
  - Glass Formation $\Rightarrow$ Spinodal decomposition to form spinodal glass matrix microstructures

**Surface Technology**

Model CCT

- Glass Devitrification
- Devitrified Nanocomposite Structure

**Thin Monolithic Technology**

Model CCT

- Glass Devitrification
- Spinodal Decomposition
- Spinodal Glass Matrix Microconstituent Structure (SGMM)

Unique Chemistries Enabling Specific Characteristic NanoStructures To Be Created
P-Group Elements in NanoSteel Products

- **Results in dramatic increases** in strength, hardness, wear resistance
  - Surface Technology products for heavy construction / mining industries
  - Thin Monolithic products for replacement of aluminum honeycomb and polyamide fibers

- **Enables mechanistic responses to achieve nanoscale structures**
  - Glass Formation $\Rightarrow$ Devitrification to form amorphous, devitrified nanocomposite structures
  - Glass Formation $\Rightarrow$ Spinodal decomposition to form spinodal glass matrix microstructures

- **Achieving tensile ductility** is the paramount issue
  - Brittle structures are the normal and expected results of alloying with P-group elements
  - Ductility is only achieved through formation of specific microstructures / microconstituents

Tensile Property Summary: NanoSteel Products

Continuous Focus on Improving Tensile Ductility In NanoSteel Products
P-Group Elements in NanoSteel 3rd Generation AHSS

NanoSteel Technology: Elongation vs. At% P-Group

Increases in Ductility Through Decreasing Content Of P-Group Elements
P-Group Elements in Autobody Sheet Steel

Modified Banana Plot: Elongation vs. At% P-Group

Decreases in Ductility Through Increasing Content Of P-Group Elements
Comparison of NanoSteel and Autobody Steel

NanoSteel (NS) vs. Conventional Autobody Steel

NanoSteel
3rd Generation
AHSS

Thick Monolithic Technology

Existing Autobody Steels

Thin Monolithic Technology

Surface Technology

Elongation (%) vs. Atomic % P-Group Element
Comparison of NanoSteel and Autobody Steel

NanoSteel (NS) Exhibits Clear Departure in Chemistry and Expected Performance
Key Differentiators
STRUCTURAL FORMATION
NanoMaterial Response – Elevated Temperature Exposure

Nanocrystalline Grains
750°C for 1 hour

Nanocrystalline Grains
950°C for 24 hours

- Grain / phase growth is deleterious
  - Resulting in a drop of targeted properties

- Nanomaterials exposure to elevated temperature
  - Grain / phase growth (Ostwald Ripening) – expected
NanoMaterial Response
Elevated Temperature Exposure

Nanocrystalline Grains
750°C for 1 hour

Zener Pinning
750°C for 24 hours

- Grain / phase growth is deleterious
  - Resulting in a drop of targeted properties

- Nanomaterials exposure to elevated temperature
  - Grain / phase growth (Ostwald Ripening) – expected
  - Grain / phase growth through effective Zener Pinning – delayed

Elevated Temperature Exposure A Key Problem For All Prior Nanomaterials
Static NanoPhase Refinement

Extensive Grain Refinement Occurs During Elevated Temperature Exposure
 Dynamic NanoPhase Strengthening

- Dynamic process occurring after yielding
- Stress induced nanoscale phase formation
- Results in high rates of strain hardening

X-Ray Diffraction

Undeformed

Deformed
Key Differentiators

TENSILE BEHAVIOR
NanoSteel Combines High Strength With High Ductility / Formability
Example tensile curves will be shown for Class 1, Class 2, and Class 3
- Indicated by the specific data points shown
NanoSteel Exhibits Unique Strain Hardening and High Fractions of Usable Ductility
Tensile Behavior: True Stress vs True Strain

NanoSteel Exhibits Unique Strain Hardening and High Fractions of Usable Ductility

Competitive Data From: World Auto Steel AHSS Application Guidelines V4.1, June 2009
Conclusion: New Approach to AHSS

3rd Generation AHSS

- *Needed by the marketplace* to expand the application of automotive AHSS
- Existing strategies are a *modification* of 1st and 2nd Generation approaches

3rd Generation AHSS – NanoSteel (NS) Key Differentiators

- Chemistry
  - *Clear departure* in chemistry and expected performance
- Structural Formation
  - *Static NanoPhase Refinement*
    - New mechanism to *create* nanoscale structures at elevated temperature
  - *Dynamic NanoPhase Strengthening*
    - New Room Temperature *strain hardening mechanism*
- Tensile Behavior
  - Compelling combinations of tensile properties focused on cold formability
    - Unique strain hardening behavior allowing strength and usable ductility
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