• General Production Overview

• NanoSteel Grades – Subject Of NanoSteel Patent Filings Directed At Alloy Formulations & Procedures

• Example Process Parameters To Produce Patented Grades
Unique structure and property combinations in NanoSteel 3rd Generation AHSS are the subject of numerous NanoSteel patent filings (US & Foreign)
Nano Steel 3rd Generation Advanced High Strength Steel (AHSS) alloys and grades are suitable for production in conventional steel mills using existing technology.

NanoSteel production may utilize various processing steps for different grades/market applications.
General Steel Making Process
Step 1 Melting

Example Routes To Develop NanoSteel Melts

• Integrated Steelmaking Routes
  • BF > BOF > LMF

• EAF Melting Routes
  • Stainless steel companies
    • EAF > AOD > LMF
  • Plain carbon / low alloy steel
    • EAF > LMF > VD
  • Mixed alloy production
    • EAF > VOD > LMF

Acronym Key
• BF – Blast Furnace
• BOF – Basic Oxygen Furnace
• EAF – Electric Arc Furnace
• LMF – Ladle Metallurgy Furnace
• AOD – Argon Oxygen Decarburization
• VOD – Vacuum Oxygen Decarburization
• VD – Vacuum Degassing

Various approaches can be utilized to produce NanoSteel Grades
Continuous Casting

**Casting Methods**

- The casting process can vary widely depending on specific manufacturing routes and specific targeted goals.
- It can be done by ingot casting, bloom casting, continuous casting, thin slab casting, thick slab casting, belt casting, etc.
- Preferred methods would be continuous casting in sheet form by thin strip casting, thin slab casting, or thick slab casting.

**Casting Products**

- **Slab:** Up to 3000 mm wide and up to 320 mm thick
- **Bloom:** Up to ~ 500 mm, either square or rectangular
- **Billet:** Up to 180 mm square

Casting preferably can be done by continuous casting although other processes are also applicable.
Step 3: Hot Rolling

- Slabs are reheated in a tunnel furnace or walking beam furnace.
- Roughing mill may involve several passes to produce a transfer bar slab.
- Hot rolling in finishing mill is done in one or multiple stages to hit targeted gauges.
- Cooling is controlled prior to coiling to achieve targeted temperature and structure.

- To improve hot band properties, it can be annealed on continuous annealing lines or continuous pickling lines at temperatures with targeted temperatures and time depending on specific characteristics of annealing lines and property goals.

Hot rolling can be done in various stages on a variety of mills including roughing, finishing, and Steckel mills.
General NanoSteel Steel Making Process

Step 4: Pickling

Continuous Pickling Line

- Specific configurations of the continuous lines varies and may included cleaning, shearing, cooling, leveling and other stations depending on production requirements.

Continuous Annealing Pickling (AP) Line

Pickling can done chemically with acids, through grinding, or through media blasting with annealing optional.
General NanoSteel Steel Making Process
Step 5: Cold Rolling

Various Rolling Configurations

2-high  3-high  4-high  6-high  12-high cluster  20-high
Sendzimir Mill cluster

Various rolling configurations can be arranged in rolling mills

- Cold rolling can be applied at various reductions per pass, variable number of passes, and in different mills including tandem mills, Z-mills, and reversing mills.

Cold rolling can be done with various mill configurations and types including tandem, reversing, and Sendzimir mills.
General NanoSteel Steel Making Process

Step 6: Annealing

**Continuous Annealing Furnace**

- Continuous lines can include annealing and pickling (AP), continuous annealing lines (CAL) and variations including additional steps such as cleaning, shearing, cooling, leveling and other stations depending on production requirements.

**Continuous Annealing Lines (CAL)**

**Batch Annealing Furnace**

- Specific configurations of the batch annealing furnace may vary depending on production requirements.

Annealing can be done on continuous lines such as AP and CAL lines and through batch annealing.
Techniques To Produce Coated Steel Product

**HD Method**

- Hot Dipped (HD) and Hot Dipped Galvannealed (HDG) are more common for zinc or zinc alloy coating of sheets.

**EG Method**

- Electro galvanization (EG) is more expensive coating method but potentially provides the best surface quality.

Corrosion resistant coating can be applied through HD, HDG, EG, or other emerging vapor deposition processes such as Jetgal®.
NanoSteel Grades
NanoSteel 3rd Generation AHSS produced in multiple versions with different properties for selective markets.

Source: WorldAutoSteel
Change in post processing schedule and steps results in production of different grades.
General NanoSteel Steel Making Process
Production of NXG™1200 Version 1- Example

1. Electric Arc Furnace (EAF) Process
2. Thick Slab Casting
3. Hot Rolling
4. Pickling
5. Cold
6. Continuous / Batch Annealing

Version 1 Tensile Properties

Yield Stress ~ 400 MPa
Ultimate Tensile Strength ~ 1200 MPa
Tensile Elongation ~ 50 - 55%

Annealing as a preferred final step provides unique property combination of the NXG™1200 Version 1
General NanoSteel Steel Making Process
Production of NXG™1200 Version 2 - Example

Version 2 Tensile Properties

Yield Stress ~ 800 MPa
Ultimate Tensile Strength ~ 1200 MPa
Tensile Elongation ~ 40 - 50%

Warm rolling as a preferred final step resulted in higher yield strength of the Version 2
General NanoSteel Steel Making Process
Production of NXG™1200 Version 3 - Example

1. Electric Arc Furnace (EAF) Process
2. Thick Slab Casting
3. Hot Rolling
4. Pickling
5. Cold Rolling
6. Continuous / batch Annealing
7. Cold Rolling

Version 3 Tensile Properties

Yield Stress ~ 1200 MPa
Ultimate Tensile Strength ~ 1500 MPa
Tensile Elongation ~ 20-25%

Cold rolling as a preferred final step indicates an increase in strength characteristics of the Version 3
Example Process Parameters To Produce Grades
• Cast to a desired thickness and hot roll to desired thickness
Example 1
Version 1 Hot Band

Casting At Target Thickness and Hot Rolling To Second Desired Thickness

Tensile Properties For Example 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hot Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 % YS (MPa)</td>
<td>309</td>
</tr>
<tr>
<td>0.5 % YS (MPa)</td>
<td>372</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>1191</td>
</tr>
<tr>
<td>TE (%)</td>
<td>59.0</td>
</tr>
</tbody>
</table>

Version 1 property combination was demonstrated in hot band
Example 2
Version 2 Warm Rolled

- Hot roll to a first desired thickness and warm roll to a second desired thickness

Annealed hot band may be subsequently warm rolled to produce Version 2
Warm rolling of hot band allows an increase in yield strength while maintaining ductility.
• Hot roll to a first desired thickness and cold roll to a second desired thickness

Hot band may be subsequently cold rolled to produce Version 3
Example 3
Version 2 and Version 3 Cold Rolled

Cold Rolling At Different Levels Of Reduction To A Desired Thickness

<table>
<thead>
<tr>
<th>Properties</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 % YS (MPa)</td>
<td>720</td>
<td>853</td>
<td>1028</td>
</tr>
<tr>
<td>0.5 % YS (MPa)</td>
<td>827</td>
<td>995</td>
<td>1195</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>1344</td>
<td>1507</td>
<td>1640</td>
</tr>
<tr>
<td>TE (%)</td>
<td>37.0</td>
<td>28.6</td>
<td>20.5</td>
</tr>
</tbody>
</table>

Cold rolling of hot band provides high strength characteristics
• Hot roll to a first desired thickness, cold roll to a second desired thickness, and anneal

Hot band may be processed to Version 1 by cold rolling and annealing
Cold Rolling At Different Reduction To A Desired Thickness Followed By Annealing

<table>
<thead>
<tr>
<th>Prop.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 % YS (MPa)</td>
<td>365</td>
<td>347</td>
<td>376</td>
<td>370</td>
</tr>
<tr>
<td>0.5 % YS (MPa)</td>
<td>396</td>
<td>381</td>
<td>409</td>
<td>402</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>1191</td>
<td>1199</td>
<td>1186</td>
<td>1175</td>
</tr>
<tr>
<td>TE (%)</td>
<td>59.0</td>
<td>57.6</td>
<td>58.9</td>
<td>56.0</td>
</tr>
</tbody>
</table>

Version 1 through cold rolling and annealing demonstrates high ductility with high strength.
Hot roll to a first desired thickness, warm roll to a second desired thickness and anneal.

Warm rolled hot band may be subsequently annealed to produce Version 1.
Example 5
Version 1 Warm Rolled and Annealed

Warm Rolling At Various Reduction To A Desired Thickness Followed By Annealing

Tensile Properties For Example 5

<table>
<thead>
<tr>
<th>Properties</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 % YS (MPa)</td>
<td>450</td>
<td>394</td>
</tr>
<tr>
<td>0.5 % YS (MPa)</td>
<td>481</td>
<td>420</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>1207</td>
<td>1191</td>
</tr>
<tr>
<td>TE (%)</td>
<td>60.2</td>
<td>60.0</td>
</tr>
</tbody>
</table>

Version 1 can be produced through warm rolling as intermediate step prior to annealing
• Hot roll to a first desired thickness, cold roll to a second desired thickness, anneal, and warm roll to a third desired thickness

Cold rolled and annealed strip may be subsequently warm rolled to produce Version 2
Example 6
Version 2 Cold Rolled, Annealed, and Warm Rolled

Warm Rolling At Different Levels of Reduction To A Desired Thickness

Tensile Properties For Example 6

<table>
<thead>
<tr>
<th>Properties</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 % YS (MPa)</td>
<td>938</td>
<td>901</td>
</tr>
<tr>
<td>0.5 % YS (MPa)</td>
<td>1077</td>
<td>1033</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>1322</td>
<td>1230</td>
</tr>
<tr>
<td>TE (%)</td>
<td>51.5</td>
<td>40.5</td>
</tr>
</tbody>
</table>

Warm rolling allows production of Version 2 from annealed cold band
• Hot roll to a first desired thickness, cold roll to a second desired thickness, anneal, and cold roll to a third desired thickness

Cold rolled and annealed strip may be subsequently cold rolled to Version 2 or Version 3
Example 7
Version 2 and Version 3 by Multiple Cycles

Cold rolling allows achievement of Version 2 and Version 3 properties from cold rolled and annealed condition.

**Cold Rolling At Different Levels Of Thickness Reduction To A Desired Thickness**

**Tensile Properties For Example 7**

<table>
<thead>
<tr>
<th>Properties</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 % YS (MPa)</td>
<td>628</td>
<td>877</td>
<td>1027</td>
</tr>
<tr>
<td>0.5 % YS (MPa)</td>
<td>793</td>
<td>1044</td>
<td>1235</td>
</tr>
<tr>
<td>UTS (MPa)</td>
<td>1370</td>
<td>1544</td>
<td>1667</td>
</tr>
<tr>
<td>TE (%)</td>
<td>41.8</td>
<td>23.9</td>
<td>19.0</td>
</tr>
</tbody>
</table>
Example 8
Version 1 Through Different Rolling Cycles

- Cast, cool down to ambient temperature or charge directly, hot roll to a desired thickness

Simulations conducted on Version 1 production by hot rolling in various multi-stand mills
Version 1 can be produced by hot rolling with different starting temperatures in 7-stand hot rolling mill

- Hot roll to a desired thickness using seven stands at selected rolling temperatures and selected targeted reductions
Hot Roll to a desired thickness using nine stands at selected rolling temperatures and selected targeted reductions.

Version 1 can be produced by hot rolling with different starting temperatures in 9-Stand hot rolling mill.
Example 9
Version 1 Batch Annealed

• Hot roll to a first desired thickness, cold roll to a second desired thickness, and batch anneal

Cold band may be subsequently batch annealed to produce Version 1
Example 9
Version 1 Batch Annealed

- Batch annealing can be done at various temperatures and times

Version 1 can be produced by batch annealing of cold band in a wide range of time at temperature
Hot roll to a first desired thickness, cold roll to a second desired thickness, and partially anneal.
### Partial Annealing At Selected Temperatures And Times To Achieve Desired Properties

#### Tensile Properties For Example 10

<table>
<thead>
<tr>
<th>Condition</th>
<th>0.2% Yield Strength (MPa)</th>
<th>0.5% Yield Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1140</td>
<td>1173</td>
</tr>
<tr>
<td>2</td>
<td>936</td>
<td>1052</td>
</tr>
<tr>
<td>3</td>
<td>802</td>
<td>885</td>
</tr>
<tr>
<td>4</td>
<td>650</td>
<td>693</td>
</tr>
<tr>
<td>NXG™ 1200</td>
<td>415</td>
<td>467</td>
</tr>
</tbody>
</table>

Increasing yield and tensile strength obtained through variations in process conditions.
Example 11
Version 2 Warm Rolled at Various Parameters

Processing Diagram

- Hot roll to a first desired thickness, warm roll to a second desired thickness

Hot band may be subsequently warm rolled to produce Version 2
Example 11
Version 2 Warm Rolled with Various Reduction

Warm Rolling At Different Levels Of Reduction To Achieve Desired Properties

<table>
<thead>
<tr>
<th>Rolling Reduction</th>
<th>0.2% Yield Strength (MPa)</th>
<th>0.5% Yield Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>509</td>
<td>574</td>
</tr>
<tr>
<td>2</td>
<td>732</td>
<td>836</td>
</tr>
<tr>
<td>3</td>
<td>857</td>
<td>1015</td>
</tr>
<tr>
<td>Hot Band</td>
<td>281</td>
<td>341</td>
</tr>
</tbody>
</table>

Yield strength in Version 2 varies with changes in warm rolling reduction