Vanadium Applications in Steel

Bob Glodowski
Today we will try to answer these questions:

- Where is Vanadium used in Steel Applications?
- Why is Vanadium used in these Steel Applications?
- What basic metallurgical properties does Vanadium have that are desirable?
- What does the future hold for Vanadium applications in steel?
Where is Vanadium Used?
Specialty Steels

Tool and Die Steels

Aerospace
Where is Vanadium Used?
Heat Treated Steels

Cutlery

Hand Tools
Where is Vanadium Used?

Oil Country Tubular

Line Pipe

Seamless Pipe
Where is Vanadium Used?
Construction Products

Building Construction

Reinforcing Bar
Where is Vanadium Used?
Construction Products

Bridge Construction

Sheet Piling
Where is Vanadium Used?
Automotive Products

Body In White
Where is Vanadium Used?
Automotive Products
Where is Vanadium Used?
Automotive Products

Forged Crankshaft  
Connecting Rods
Where is Vanadium Used?
Power Generation and Transmission

Wind Turbine Generators

Transmission Towers
Where is Vanadium Used?
Rail Transportation

Rail

Railway Wagons
Why is Vanadium Used?

- For Specialty Tool Steels, Vanadium is used as an alloy, forming massive Vanadium Carbides for very high hardness and wear resistance. Vanadium contents can be as high as 4 to 8%.

- For Heat Treated Steels, Vanadium can provide grain refinement and temper resistance. Fine grains provide toughness and strength, temper resistance provides higher strength and hardness after tempering. Vanadium contents can range from 0.03% to 0.30%.
Why is Vanadium Used?

- For as-rolled and as-forged steels most common in Construction Steels, Oil Country Tubular Steels and for Power Generation and Transmission, Vanadium is used for its precipitation strengthening properties in as-rolled or as-formed applications. Vanadium contents are typically in the 0.03% to 0.10% range, but can go higher.

- For Automotive Steels, there are many different applications that demand a variety of contributions from Vanadium, all depending on the final microstructures of the finished part.
Why is Vanadium Effective for Precipitation Strengthening?

- Effective Strengthening at All Carbon Levels
- Predictable Strengthening up to 0.15% Vanadium
- Available Nitrogen Improves the Strengthening Contribution of Vanadium, Turning Nitrogen from an Unwanted Residual into a Useful Alloy
Why is Vanadium Preferred by the Steelmakers?

- Ease of Use during Steelmaking
  - High Recovery of Alloy Additions
  - Good Castability
  - High Solubility during Reheating
  - No Additional Roll Forces Needed
  - Robust tempering response
Important Metallurgical Properties of Vanadium In Steel

- High Solubility of V(C,N) in Austenite
- Low Solute Drag Coefficient of V in Austenite
- Nitrogen is the Preferred Element in V(C,N) Precipitation
- Because VC is in solution at normal heat treating temperatures, V is in solution during the tempering of martensite providing Temper Resistance
Vanadium-Nitrogen Solubility and Strengthening

Solubility of Carbides and Nitrides

Precipitation Strengthening

Increase of Yield Strength, MPa

Vanadium Content, Wt. %
What does the future hold for Vanadium applications in steel?

Some facts and observations:

- New Alloy systems take years for development and acceptance.
- Steelmakers and Users do not like to change alloy systems once they are established.
- Accepted alloy systems can vary significantly from one region to another.
- Eventually, the value of an alloy system will determine its final acceptance.
How do we measure Vanadium acceptance in steel applications?

Specific V Consumption Rates 2015

<table>
<thead>
<tr>
<th>Region</th>
<th>Specific V Consumption Rate (KgV/MT Steel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>0.094</td>
</tr>
<tr>
<td>Europe</td>
<td>0.075</td>
</tr>
<tr>
<td>World Average</td>
<td>0.057</td>
</tr>
<tr>
<td>China</td>
<td>0.055</td>
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<tr>
<td>CIS</td>
<td>0.054</td>
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<tr>
<td>Japan</td>
<td>0.051</td>
</tr>
<tr>
<td>Other</td>
<td>0.039</td>
</tr>
<tr>
<td>Other</td>
<td>0.035</td>
</tr>
</tbody>
</table>

World Specific V Consumption Rate

- 2001-2015 CAGR 1.4%
- 2010-2015 CAGR 4.4%
My Predictions:

- Applications for microalloyed steels will continue to grow at a steady rate.
- Vanadium will remain competitive with other alloys relying on the primary strengths of “Ease of Use” and compatibility with other alloys systems.
- The new Advanced High Strength Steels with complex microstructures will utilize Vanadium for incremental strengthening with optimized properties.
- Continued interest in the new AHSS will help bring interest to upgrading current mild steel applications to HSLA applications.
- Growth of new Vanadium applications will remain near current rates, but will be steady and predictable.
- The largest risk to Vanadium growth is from price instability.
Thank You
- Tensile Strength of Dual Phase Steels with Vanadium Addition

![Bar chart comparing UTS (MPa) for different conditions](chart.png)

- Heat Treatment: D1
- X=A, without V
- X=B, with V

**UTS (MPa)**

<table>
<thead>
<tr>
<th>Condition</th>
<th>UTS (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cr, Mo</td>
<td>650, 700, 750, 800, 850, 900, 950, 1000, 1050</td>
</tr>
<tr>
<td>High Cr, Mo</td>
<td>900, 950, 1000, 1050</td>
</tr>
<tr>
<td>Low Cr, Mo, New Process</td>
<td>900, 950</td>
</tr>
<tr>
<td>High Cr, Mo, New Process</td>
<td>1000, 1050</td>
</tr>
</tbody>
</table>

**Legend**
- X=A, without V
- X=B, with V

**New Process**

**Standard GI**
Global Formability: Banana Diagram (UTS - %TE)

...does not address Local Formability issues
Effect of Reheat Temperature on Maximum Solubility of V and Nb

- V: 50 ppm N, 100 ppm N, 150 ppm N
- Nb: 200 ppm N

Reheat Temperature, Deg F

V, Nb in Solution, Wt %