BUSHVELD VAMETCO ALLOYS
Main Mothotlung Road,
Mothotlung, Brits
P O Box 595, Brits, 0250
T +27 (0) 12 318 3200
F +27 (0) 12 318 3201
e info@bushveldvametco.co.za
www.nitrovan.co.za

How Rolling And Cooling Practices Affect The Properties Of Flat-Rolled Microalloyed Steel

Although an addition of less than 0.1% of a microalloying element can strengthen steel by as much as 50%, optimum strengths are only obtained by controlling the hot rolling and subsequent cooling of the steel slab. These practices, in turn, are influenced by the microalloy used for strengthening – vanadium, niobium (columbium), or titanium.

The goal of these practices is to capitalize on the following mechanisms, which provide as much as 70% of the strength of a microalloyed high-strength steel:

- Grain refinement of the ferrite in the final structure, which provides a unique balance of strength and toughness.
- Fine, uniformly distributed microalloy carbide/nitride precipitates that effectively strengthen steel with only a small decrease in toughness.

Processing That Optimizes Strength

During hot rolling, the microstructure of a high-strength microalloyed steel undergoes the following changes after each pass in the rolling mill:

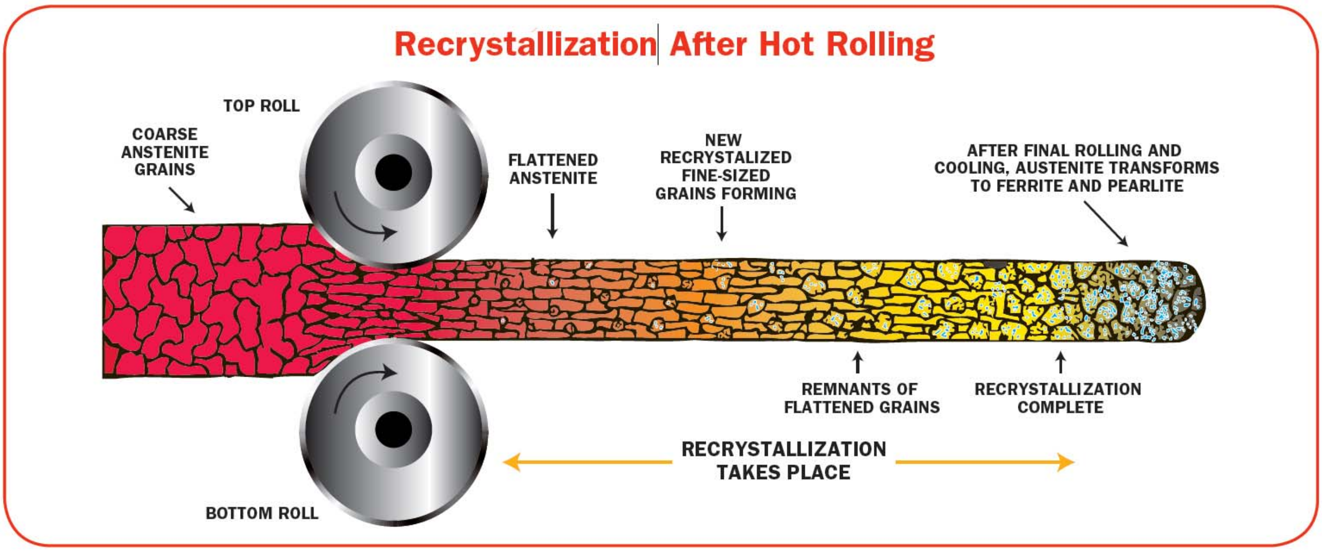

Figure 1 – The coarse austenite grains are flattened during rolling and then recrystallize into fine, equiaxed grains after the slab emerges from the rolling stand.

- As the steel slab is deformed in a rolling stand, the coarse grains of austenite are flattened into“pancakes.” (Figure 1.)
- After the slab emerges from a stand, the flattened austenite grains will recrystallize into new fine - sized, equiaxed grains. This recrystallization takes place above a minimum temperature that depends on the microalloy used. The minimum temperature is called the “recrystallization-stop temperature.”
- If additional rolling takes place at temperatures above the recrystallization-stop temperature, the recrystallized grains are further refined to form smaller grains than those obtained in previous rolling. If the slab is not rolled again and is allowed to cool slowly, the recrystallized austenite grains mays tart to grow. The rate at which these austentitic grains grow decreases as the strip cools. Grain growth stops when the strip reaches the temperature at which austenite transforms to ferrite in the final microstructure.

To minimize coarsening of the austenite grains during cooling, the microalloyed steel is cooled rapidly on the run-out table. Rapid cooling lowers the austenite-to-ferrite transformation temperature, insuring that fine-ferrite grains form in the cooled product.

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In addition to grain refinement, the solubility of microalloy carbides and nitrides in austenite impacts steel properties. Ideally, these microalloy compounds should be completely soluble in the austenite structure, improving castability and minimizing cracking during rolling. High solubility also reduces the reheat temperature during rolling that is needed to keep these compounds in solution. By delaying precipitation until after ferrite is formed, the fine, uniformly-dispersed precipitates will give predictable strengthening over a broad alloy range.

How Vanadium Affects Processing

Vanadium does not raise the "recrystallization-stop temperature" – the temperature below which the austenite grains do not recrystallize between passes in the rolling mill. Therefore, steelmakers can easily exceed this temperature during rolling, allowing austenite to be refined through repeated recrystallization. This process is therefore known as recrystallization-controlled rolling (RCR).

Fine recrystallized austenite grains are desirable because they insure the formation of small ferrite grains on cooling. A fine ferritic structure gives high strength and good ductility. Rapid cooling on the run-out table lowers the austenite-to-ferrite transformation temperature and prevents the growth of ferrite, yielding a ferrite grain size of 4µm or less in strip products.

In addition, vanadium carbides and nitrides that provide precipitation strengthening are more soluble in austenite at normal rolling temperatures than similar compounds of other microalloys (Figure 2). These vanadium compounds do not precipitate until after the ferrite is formed during cooling, optimizing precipitation strengthening.

How Solubility Optimizes Precipitation Strengthening

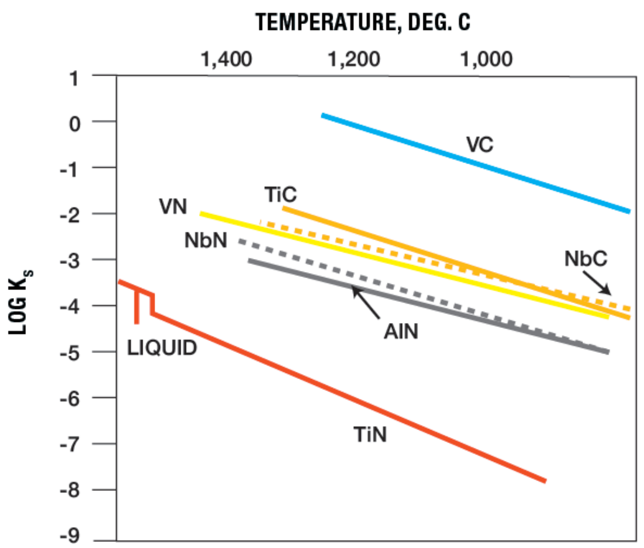

Figure 2 – Vanadium carbides and nitrides are more soluble in austenite than other microalloy compounds and do not precipitate until after ferrite is formed.

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How Niobium Affects Processing

Unlike vanadium, niobium raises the recrystallization-stop temperature. As a result, high temperatures are required for recrystallization to take place. In addition, niobium carbides and nitrides are not as soluble in austenite as vanadium compounds, causing some niobium to precipitate in austenite at hot-rolling temperatures. These precipitates retard recrystallization, causing progressive hardening of the non-recrystallized grains. This effect increases the forces required for hot rolling.

A Nitrogen Bonus

When vanadium is added to a steel containing carbon and nitrogen, vanadium is four times more likely to form a nitride than a carbide. These nitrides are highly-soluble in austenite and precipitate as fine particles in ferrite, causing a near-linear increase in yield strength (Figure 3). At 1150 deg. C – the typical maximum temperature of a tunnel reheating furnace – up to 0.15% vanadium will go into solution in the presence of nitrogen. In contrast, the maximum amount of niobium that will go into solution in a 0.10% carbon steel is about 0.03%.

By increasing the effectiveness of precipitation strengthening, nitrogen allows steelmakers to use less vanadium in reaching a given yield strength for steel. This nitrogen can come from the residual nitrogen in the bath or from supplemental nitrogen additions in vanadium alloys, such as Nitrovan® vanadium.

These features make vanadium-nitrogen microalloyed steel very cost-effective in weight-reduction applications. By optimizing processing, microalloyed-steel producers can produce a steel with high strength and good toughness at the low-carbon levels needed to obtain excellent weldability.

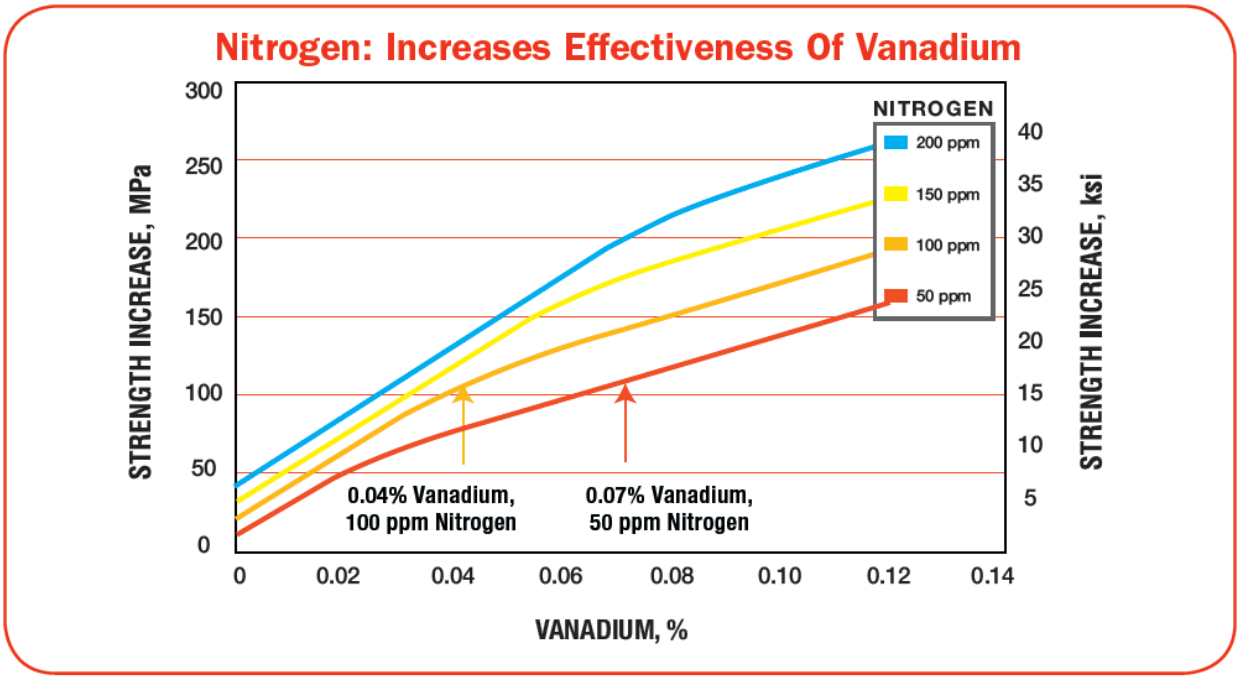

Figure 3 – Increasing levels of nitrogen cause a linear increase in strength, reducing the amount of vanadium required to reach a given yield strength.