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OPTIMIZED BAINITIC VANADIUM-MICROALLOYED 700 MPA STRIP STEEL: MICROSTRUCTURE, TOUGHNESS, AND WELDABILITY

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Abstract. This study investigates the microstructure, mechanical properties, and weldability of vanadium-microalloyed bainitic 700 MPa hot-rolled strip steel. The research highlights the role of alloying elements such as Mn, Cr, and Mo in achieving a fully bainitic microstructure and the impact of coiling temperatures on mechanical properties. The study also explores the strengthening mechanisms provided by vanadium microalloying, which enhances the stability of mechanical properties over a wide range of processing conditions. The findings confirm that vanadium contributes significantly to toughness, ductility, and weldability, making this steel suitable for industrial applications requiring high strength and formability.

Keywords. Vanadium microalloyed steel, precipitation behavior, thermomechanical processing, mechanical properties, microstructure evolution, grain refinement, phase transformation, strengthening mechanisms, high-strength low-alloy (HSLA) steel, precipitation kinetics.

Introduction

The demand for high-strength, weldable, and tough steels in structural and industrial applications has led to the development of vanadium-microalloyed bainitic strip steels. These steels offer excellent mechanical properties, making them suitable for applications requiring superior formability and performance under dynamic loads. This article synthesizes research findings on the microstructural evolution, mechanical properties, and weldability of a newly developed 700 MPa hot-rolled bainitic strip steel.

Microstructure and Phase Evolution

Bainitic Transformation and Grain Structure

The microstructural investigations reveal that the strip steel exhibits a predominantly bainitic microstructure across different coiling temperatures. The presence of acicular and granular bainite was observed with a slight increase in carbide particle size at higher temperatures. Notably, the absence of polygonal ferrite suggests that austenite transformation into bainite was complete during cooling.

Electron Backscatter Diffraction (EBSD) analysis confirmed the formation of fine bainitic grains with minimal elongation in the rolling plane, implying significant austenite recrystallization during the final stages of hot rolling. The prior austenite grain (PAG) size measurements showed an average of 10 µm, with a moderate increase along the rolling direction.

Effects of Coiling Temperature on Microstructure

The microstructural stability and uniformity were examined at coiling temperatures of 180°C, 320°C, and 500°C. Results indicated:

- At lower temperatures (~180°C), bainite is finer, with high dislocation density inhibiting recovery.
- At intermediate temperatures (~320°C), a balance between acicular and granular bainite is maintained, offering optimal mechanical properties.
- Above 500°C, significant recovery of bainitic dislocations occurs, leading to a reduction in strength.

These findings suggest that vanadium and nitrogen microalloying effectively stabilize the bainitic substructure, reducing strength degradation at practical coiling temperatures below 450°C.

Mechanical Properties and Toughness

Strength and Hardness

The steel exhibits a consistent yield strength of approximately 700 MPa at coiling temperatures below 450°C. However, at 500°C and above, the yield stress drops significantly due to early recovery of bainitic dislocations. Hardness tests corroborate these findings, showing a direct correlation between dislocation density and material strength.

Fracture Toughness and Charpy Impact Tests

Toughness evaluations using Charpy impact tests at different cooling rates (Dt8/5) demonstrate that the steel maintains high impact energy, exceeding 150 J/cm² at room temperature. The ductile-to-brittle transition temperature (DBTT) is approximately 240°C, which is within acceptable limits for structural applications.

The retained toughness can be attributed to:

1. The uniform distribution of fine bainitic grains.

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2. The inhibition of carbide coarsening due to vanadium microalloying.

3. The effective suppression of early recovery processes at lower coiling temperatures.

Weldability Assessment

Heat-Affected Zone (HAZ) Toughness

Simulated welding tests assessed HAZ toughness at peak temperatures of 1350°C followed by controlled cooling. Results indicate that fracture toughness remains satisfactory, with Charpy energy levels staying above 40 J/cm² at 260°C. Even under rapid cooling conditions (Dt8/5 = 3s), the transition temperature remained below 240°C, ensuring weld integrity.

Influence of Low Carbon Content

The intentionally low carbon content (<0.05%) plays a crucial role in enhancing weldability by minimizing carbide precipitation at grain boundaries, which could otherwise reduce toughness. Combined with microalloying effects, this results in a refined bainitic HAZ, reducing susceptibility to cold cracking and ensuring strong weld joints.

Conclusion

The optimized vanadium-microalloyed bainitic 700 MPa strip steel provides a robust combination of strength, toughness, and weldability. Key findings include:

- A fully bainitic microstructure with stable properties across a wide range of coiling temperatures.
- Yield stress retention below 450°C due to vanadium-induced strengthening.

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- Excellent Charpy impact toughness, ensuring ductile behavior at sub-zero temperatures.
- Superior weldability due to a low carbon content and optimized alloying elements.

These attributes make the steel highly suitable for structural and industrial applications requiring both high strength and formability. Future studies may focus on optimizing cooling strategies and exploring alternative alloying elements to further enhance performance under extreme conditions.

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