

# Microalloying in Ferrous and Non-Ferrous Alloys

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## 1. Introduction

Under the dual-carbon goals of achieving carbon peak and neutrality, lightweighting of materials has emerged as a critical strategy to reduce energy consumption and greenhouse gas emissions across industries [1–4]. Advanced high-strength alloys are central to this effort, as they enable significant weight reduction while maintaining or enhancing structural performance [5–7]. By reducing material use, enhancing energy efficiency, and enabling durable, recyclable designs, they address emissions at every lifecycle stage—from production to end-use.

Conventional high-strength alloys, such as quenched-and-tempered (Q&T) steels [8] or maraging steels [9], often rely on high expensive alloying content (e.g., Cr, Ni, Mo) to achieve strength, which introduces challenges in cost, scalability, and weldability. Microalloyed alloys address these limitations by leveraging small additions of strategic microalloying elements combined with optimized thermomechanical processing (TMP), offering a sustainable and cost-effective alternative.

In ferrous alloys, particularly high-strength low-alloy (HSLA) steels, the addition of small quantities of elements such as niobium (Nb), vanadium (V), titanium (Ti), and occasionally boron (B) or nitrogen (N) can be expected to significantly enhance the overall mechanical properties [10–12]. The microalloying role in ferrous alloys involves grain refinement through inhibition of grain growth during TMP, precipitation strengthening via fine precipitates, and controlling phase transformations to achieve the desired microstructures [10–13]. This leads to improved strength, toughness, and weldability without requiring high carbon content or extensive heat treatments. In non-ferrous alloys, e.g., Al, Mg, Ti, Cu, and Ni-based alloys [14–20], microalloying involves adding trace amounts of elements (typically <0.1–0.5 wt%) to refine microstructure, enhance mechanical properties, and improve functional performance. Unlike ferrous alloys, where microalloying focuses on carbide/nitride formation, non-ferrous systems often rely on solute interactions, grain boundary engineering, and nanoscale precipitation.

## 2. Contributions

A Special Issue of *Metals*, entitled “Microalloying in Ferrous and Non-ferrous Alloys”, was initiated in 2023 by Professor Minghui Cai to advance the role of microalloying in ferrous and non-ferrous alloys. Bibliographic details are listed for each contribution.

Liu et al. (contribution 1) studied the Nb-V-Ti-N microalloyed X70 pipeline steel, and clarified the effect of nitrogen content on the microstructure evolution and tensile properties of typical pipeline steels. This work provides important guidance for further optimizing the microstructure and mechanical properties of X70 pipeline steel.



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Wen et al. (contribution 2) investigated the strengthening mechanism of Nb, V, and Nb-V microalloyed high-strength bolt steels. The results show that the Nb-V microalloyed steel with respect to Nb or V microalloyed steel exhibited higher strength contributions due to the combined effects of precipitation strengthening and dislocation strengthening through multi-scale characterizations and modeling. This facilitates a cost-efficient approach for producing high-strength bolt steels with comprehensive, excellent properties.

Zhu et al. (contribution 3) focused on the prior austenite grain growth behavior in the Al- and Nb-microalloying 20MnCr gear steel during pseudo-carburizing heat treatments, demonstrating the effect of Nb addition on preventing austenite grain growth. In addition, the kinetics model for austenite grain growth under the process of the pinning and coarsening of the precipitated particles was established.

Liang et al. (contribution 4) reported the effect of different lubricant materials on the wear of novel high-performance rails (U77MnCrH). The microstructure of the deformation layer with two kinds of lubricated states was coarser and denser than that without lubricants. However, the changes in lubricants did not have a significant effect on the average grain size of the deformation layer.

Jiang et al. (contribution 5) investigated the effect of Nb content on the microstructure and impact toughness of high-strength X80 pipeline steel. The underlying mechanisms of Nb addition governing low-temperature toughness was further revealed. The findings of this study can serve as a useful reference for the effective design and control of high-strength pipeline steel.

Tian et al. (contribution 6) carried out a series of cyclic oxidation tests to investigate the cyclic oxidation behavior of TNM alloy and 4822 alloy at 800 °C. The Nb and Mo elements enhance the antioxidant performance of the TNM alloy by inhibiting the dissolution and diffusion of oxygen, Ti, and Al atoms in the TiAl alloy. The effect of thermal stress on oxide layer cracking was also quantitatively analyzed.

Li et al. (contribution 7) studied the effect of nitrogen doping on V microalloyed P460NL1 steel in terms of microstructures and impact toughness. The fine precipitates of V (C,N) effectively pin the prior austenite grain boundary, resulting in the refinement of the austenite grain.

Zhang et al. (contribution 8) analyzed the evolution of recrystallization texture in A286 iron-based superalloy rolled thin plates, indicating the significant effect of recrystallization texture on the overall mechanical properties and oxidation resistance of superalloys. Recrystallization texture develops through two independent mechanisms related to different deformation microstructures, including the recrystallization texture inherited from the deformation texture and the recrystallization texture dependent on deformation twins.

Liu et al. (contribution 9) targeted the long-term aging of the second-generation single-crystal superalloy DD6 under load-free conditions in air at 980 °C, indicating the emergence of W-rich and Re-, Mo-, and Ni-poor phenomena. The microstructure evolution and the stress rupture characteristics of this alloy during long-term aging were tested via microstructure characterization. The findings offer support for the application of DD6 single-crystal superalloy into aircraft engines.

Peng et al. (contribution 10) investigated the effects of casting and different heat treatment processes on the corrosion resistance of AlFeCoNiMo<sub>0.2</sub> high-entropy alloy. The presence of Mo element increases the selective dissolution of Fe, and the aggregation of Mo element at grain boundaries after annealing weakens the corrosion resistance of the alloy and leads to the dissolution of the passive film.

Fei et al. (contribution 11) compared the improved microstructural homogeneity and the ductility of the Mn-segregated 10Mn lightweight steel, together with a comparison with the conventional intercritical annealing. The underlying deformation behavior upon

tensile loading was also be discussed by combining the martensitic transformation rate and transformation kinetics with strain hardening behavior.

### 3. Conclusions

This Special Issue is dedicated to works related to microalloying in ferrous and non-ferrous alloys. Contributions to research on the correlation between processing, properties, and microstructures are welcome. The scope includes, but is not limited to, the following technical topics: ferrous alloys; non-ferrous alloys; heat treatment; thermo-mechanical processing; precipitation behavior; phase transformation; recrystallization behavior; the microstructure–property relationship; the microalloying mechanism; and industrial applications.

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