Optimization of Cooling Rate for Bainite Evolution in AHSS Using Machine Learning






Mechanical properties of advanced high-strength steel (AHSS) are linked to its microstructure, influenced by processing techniques during production, specifically by hot rolling thermomechanical processing. In this article, a novel adaptive machine learning (ML) model coupled with controlled cooling of hot-rolled plates was developed to predict bainite in AHSS. A neural network model of the time-temperature-transformation diagram was used at each cooling step to predict continuous-cooling-transformation kinetics. To verify the bainite fraction, dilatometry experiments were performed with AHSS specimens cooled at rates from 0.1 to 10°C/second. An adaptive-ML model for bainite was trained using inputs from experiments and simulation, offering a predictive tool for optimizing AHSS processing.

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Introduction

Advanced high-strength steels (AHSS) are a class of engineered steels designed to exhibit superior mechanical properties through a controlled microstructural balance of multiple structural phases.[1,2] Unlike conventional high-strength steels, AHSS incorporate one or more structural phases such as retained austenite, bainite or martensite, in addition to ferrite, pearlite or cementite. These unique microstructural features arise from precisely controlled thermomechanical processing during manufacturing, leading to optimized phase transformations and tailored mechanical responses.[1–3] Due to their complex microstructural composition, AHSS demonstrate an exceptional combination of strength, ductility, formability and work-hardening behavior. These attributes are essential for automotive applications, where stringent requirements for crashworthiness, lightweight design, fuel efficiency and reduced greenhouse gas emissions must be met.[1]

Based on their mechanical performance and alloying strategies, AHSS are classified into three generations. First-generation AHSS grades include dual-phase (DP) steel, transformation-induced plasticity (TRIP) steel, martensitic (MART) steel, and complex phase (CP) steel. These steels provide a higher strength-ductility balance than conventional high-strength steels, making them the most widely used AHSS in the automotive industry. Their favorable combination of high strength and lightweight potential makes them ideal for structural components that require improved energy absorption during impact.[4,5]