Q&P PROCESSING OF PLATE STEELS

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[John G. Speer*]: jspeer@mines.edu, Rachael A. Stewart*, Brian G. Thomas*, Amy J. Clarke* and Emmanuel De Moor*
***Advanced Steel Processing and Products Research Center**
Colorado School of Mines

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1 General Introduction

The quenching and partitioning (Q&P) concept originated about 15 years ago. The process involves quenching to a carefully controlled temperature during which a partial transformation to martensite occurs, followed by a thermal treament wherein carbon is transported from the supersaturated martensite into the untrasformed austenite, thereby stabilizing "retained" austenite in the microstructure [1]. Early research focused on fundamental studies to develop some mechanistic understanding of microstructure evolution, and mechanical property evaluation to demonstrate promising combinations of strength and ductility. These studies continue, along with applied research to develop high strength steel with retained austenite. Q&P has been employed to develop Advanced High Strength Steel (AHSS) sheet products for automobile body applications requiring high strength (~1 to 1.5 GPa) and formability, which are now being commercialized. A concept for Q&P processing of thicker hot-rolled steels was also developed, and applied recently for abrasive wear-resistant applications [2,3]. Plate Q&P processing was first explored by Hong and co-workers in 2007, with encouraging strength/toughness combinations obtained in a 0.1 wt. pct. carbon steel [4]. Plate steel Q&P concepts have been developed further; this paper highlights recently developed Q&P process-design models to help predict and understand temperature and microstructure gradients in thicker plates, and to help select processing parameters relevant to industrial plate production [5,6,7]. Some early property results are also summarized.

2 Thermal Modeling

Thermal modeling was conducted to define the thermal histories in steel plates during potential quenching and partitioning treatments that might be encountered in heavy plate production, where thermal gradients are more substantial than encountered in sheet processing. Fig. 1 illustrates one such thermal history, for an 18 mm thick plate quenched for 10 s, followed by reheating in a furnace held at 600°C.

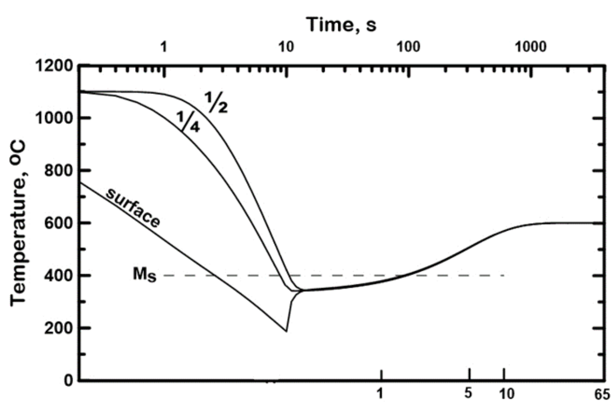

Fig. 1. Modeled Q&P thermal profile. Temperatures at the surface, ¼ thickness and ½ thickness (center) locations are indicated, along with a M_s temperature of 400°C for reference [6].

For a steel alloyed to achieve suitable hardenability, the microstructure at the end of the quenching step can be predicted based on martensite transformation principles, from the undercooling achieved at each position relative to the M_s temperature. The furnace reheating, or partitioning step, has been designed using principles of time-temperature equivalence [7] in combination with results from earlier Q&P literature.

3 Experimental Verification

Experimental verification involved heat treatment simulation using a quenching dilatometer, along with hardness and microstructure characterization, including retained austenite measurements by x-ray diffraction. Various positions in the through-thickness were simulated based on calculated thermal histories for realistic plate processing. A summary of several experimental simulations using modeled plate steel processing conditions for a 0.4 C (wt. pct.) steel with an elevated silicon concentration is shown in Fig. 2. The retained austenite in the final microstructure is plotted vs. the quenching temperature achieved before partitioning in Q&P plate or tempering in conventionally quenched and tempered (Q&T) plate, for different partitioning processes characterized using the Hollomon-Jaffee tempering parameter, TP = T(log t + c), where T is in Kelvin and time t is in seconds. The "c" is a constant that depends on the steel carbon content. The results confirmed that substantial fractions of retained austenite (in excess of 20%) are achievable through industrial plate processing, and these results were obtained while simultaneously achieving high hardness. Such steels should be of interest in applications requiring high strength with toughness and/or wear resistance.

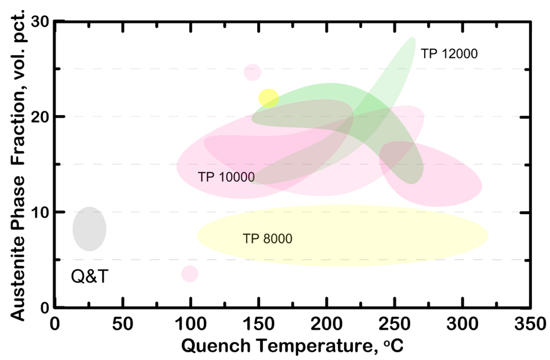

Fig. 2. Retained austenite in Q&P and Q&T plates, plotted vs. quench temperature, for three partitioning treatments represented by their Hollomon-Jaffee tempering parameters (TP).

4 Acknowledgements

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