Quenching and Partitioning Process Development to Replace Hot Stamping of High-Strength Automotive Steel

Novel Steel Heat Treatment Process to Produce Third Generation AHSS Allowing Room-Temperature Stamping Operations.

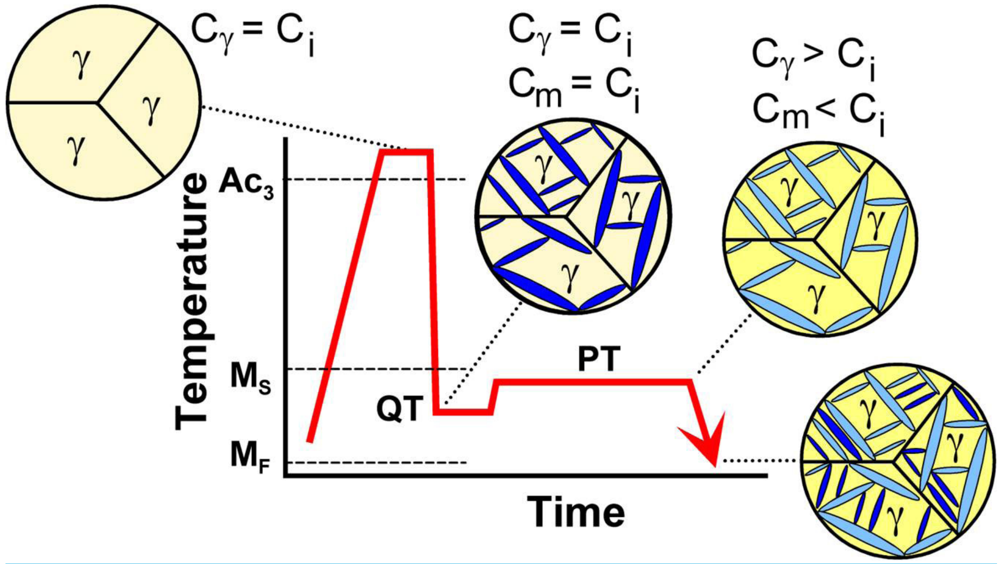

Illustration of time-temperature profile of the Q&P process, and how the steel's structure changes through each stage. *Graphic credit Colorado School of Mines.*

The automotive industry is meeting the challenge of improving fuel efficiency without compromising vehicle safety in part by using lighter-weight materials such as first-generation Advanced High-Strength Steels (AHSS). Producing certain automotive components currently requires an energy-intensive hot stamping process to achieve the necessary strength and ductility. After rolling and annealing, hot stamping typically involves reheating sheet steel blanks to more than 900°C for 4–10 minutes prior to forming. Once hot stamped, the parts are rapidly water-cooled in a specially designed die, giving them high strength. Second-generation AHSS were created with ultra-high strength and exceptional formability for higher-efficiency room-temperature stamping, but they require high levels of alloying, making them too expensive for widespread implementation. Now the industry is in pursuit of Third-Generation Advanced High-Strength Steels (3GAHSS) to provide the needed balance between cost, strength, and formability.

A novel steel processing concept called quenching and partitioning (Q&P) is being developed to meet the demanding 3GAHSS cost and performance targets. A modestly alloyed steel is first continuously cast into slabs of the desired width, hot rolled into coils in a hot strip mill, and then cold rolled into thin sheet. The two-step Q&P process takes place after cold rolling. Step 1 involves heating the steel to a red-hot temperature then Quenching to a critical temperature, which results in partial transformation of the structure of the steel to strike just the right balance between strong martensite and softer but more formable austenite. In Step 2 (Partitioning), the steel's temperature is raised slightly, to force carbon atoms to move from the martensite into the austenite. The carbon-rich austenite becomes stable and does not transform into martensite after further cooling to room temperature. The ability to reliably produce this mixed martensite-austenite structure on a production basis will require careful evaluation and testing of the Q&P process parameters as well as striking just the right balance of alloying elements in the steel.

Benefits for Our Industry and Our Nation

Steel made via Q&P would save energy by avoiding high-temperature stamping. The project team estimates that nearly 5 trillion Btu of energy are consumed annually in heating steel for hot stamping, based on recent production of 300,000 tons. With increased utilization of hot stamping in automotive applications (at an annual rate of 2 million tons), a successful Q&P steel replacement would eliminate nearly 30 trillion Btu of energy use, but also reduce the weight of steel by nearly 20% in critical automotive parts. Additional energy would therefore be saved in steel production because fewer tons of Q&P steel would be needed to obtain the same performance as provided by AHSS, as well as due to the improvement in vehicle fuel efficiency.

Applications in Our Nation's Industry

Novel Q&P steels could be utilized by the automotive industry to design and produce vehicles with similar or improved crashworthiness. Replacement of hot stamping would result in productivity gains for the steel industry by eliminating the time required for heating the part before forming. By removing the need for a reheating furnace and dies, automakers could reduce their energy consumption, as well as the footprint of their process lines and their capital costs.

Project Description

This project will develop Q&P processing for 3GAHSS in automotive applications. The team will use a combination of deep alloy development experience, designed experiments, computational tools, and state-of-the-art characterization instruments and methods in this project. After crafting a series of laboratory heats with different compositions, the researchers will process the steels with different heat treatments and extensively characterize and test the material to find the best combinations for 3GAHSS.

Barriers

- Understanding of microstructural evolution and the effects of variability in process parameters on structure and properties.
- Limited formability data on existing Q&P steels may turn out to be insufficient to guide development.
- Scalability issues between laboratory and commercial practice.

Pathways

The researchers will study the effects of composition and processing on the microstructure and properties. The most common steel alloys used in Q&P are carbon-manganese-silicon, but other alloy additions will be tested. Investigation of the Q&P processing parameters, which determine the microstructure and therefore the strength and ductility, will be guided by computational studies and the results of earlier work by the project team. Customized local formability tests and state-of-the-art microstructure characterization of the sample alloys will be conducted in order to develop the detailed information needed to understand how to adjust the balance of phases in the steel, control metallurgical phenomena, and optimize partitioning parameters.

Milestones

This three-year project began in 2013. Key milestones include the following:

- Complete the experimental design matrix and produce experimental heats within specified limits. Process the material and develop initial mechanical property results (Completed).
- Develop processing parameters that result in 3GAHSS with the targeted minimum ultimate tensile strength of 1200 MPa and 15% elongation (Completed).
- Optimize the processing parameters to result in 3GAHSS with the required tensile properties and local formability properties to allow cold stamping without edge cracking (2016).

Commercialization

Implementing the Q&P process in an industry setting requires continuous annealing equipment with a high level of precision and flexibility. Some project partners have installed or are considering facilities capable of implementing this technology. Successful project implementation would be a critical prelude to industrial trials of full-size steel coils at domestic steel producers. If trials are successful, formed parts could be incorporated in new vehicle designs.

Project Partners

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