U.S. DEPARTMENT OF
ENERGY
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ENERGY EFFICIENCY & RENEWABLE ENERGY

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

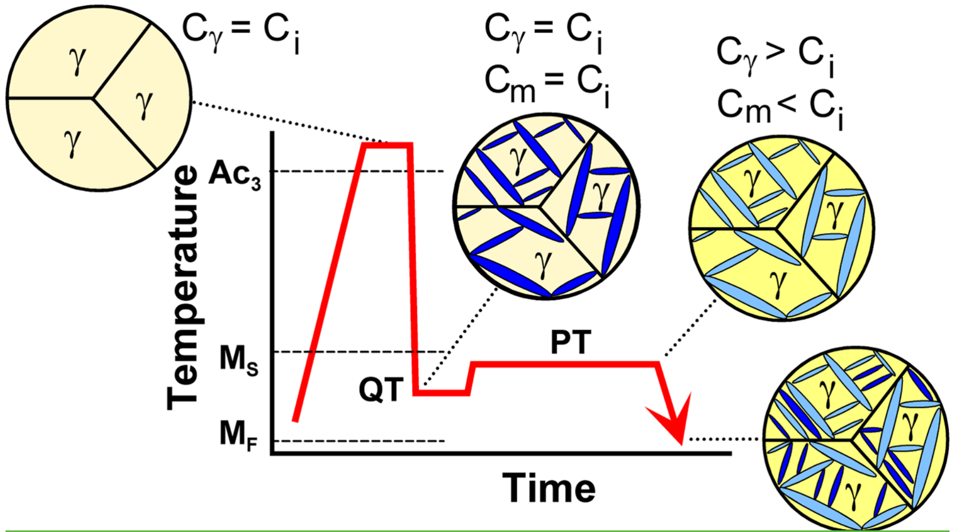

Figure 1. Illustration of time-temperature profile of the Q&P process, and how the steel's structure changes through each stage
Photo credit Colorado School of Mines.

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 quenching and partitioning (Q&P) steel processing concept was developed during this project 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 before undergoing the two-step Q&P process (see Figure 1. The steel is first heated to a red-hot temperature (above Ac3) to obtain a fully austenitic microstructure then quenched to a critical temperature (QT between MS and MF) to produce a mixed austenite-martensite microstructure, which results in just the right balance between strong martensite and softer but more formable austenite. The steel's temperature is then raised slightly (PT), to force carbon atoms to move from the martensite into the austenite to form a carbon enriched austenite phase. Throughout this project, researchers carefully evaluated the Q&P process parameters as well as balancing the alloying elements in the steel to reliably produce the mixed martensite-austenite structures.

Benefits for Our Industry and Our Nation

Steel made via the Q&P process can save energy by avoiding high temperature stamping. The project team estimates that more than 3 trillion Btu of energy are consumed annually in heating steel for hot stamping, based on an average of 24 pounds of hot-stamp boron steel in a typical vehicle. With increased utilization of hot stamping in automotive applications a successful Q&P steel replacement would also reduce the weight of steel by nearly 20% in critical automotive parts with associated improvements in vehicle fuel efficiency. 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 AHSS.

Applications in Our Nation's Industry

Novel Q&P steels can 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 developed a Q&P process for 3GAHSS in automotive applications. The team used a combination of deep alloy development experience, designed experiments, computational tools, and state-of-the-art characterization instruments and methods. After crafting a series of laboratory heats with different compositions, the researchers processed the steels with different heat treatments and extensively characterized and tested the material to find the best combinations for 3GAHSS.

Barriers

- Understanding microstructural evolution and the effects of different 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

Researchers studied the effects of composition and processing on the microstructure and properties of 12 unique alloys. The steel alloys developed were based on modifications of a common carbon-manganese-silicon Q&P alloy.

Investigation of the Q&P processing parameters, which determine the microstructure and therefore the strength and ductility, were guided by computational studies and results of earlier work by the project team. Customized local formability tests and state-of-the-art microstructure characterization of the sample alloys were 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 project began in 2013 and was completed successfully in September 2016. Key milestones include the following:

- Designed an experimental matrix and produced experimental heats within specified limits. Processed the material and developed initial mechanical property results
- Developed processing parameters that resulted in 3GAHSS with the targeted minimum ultimate tensile strength of 1200 MPa and 15% elongation
- Optimized the processing parameters to result in 3GAHSS with the required tensile properties and local formability properties to allow cold stamping without edge cracking

Accomplishments

- Demonstrated the potential for Q&P as an advanced high strength sheet steel development strategy that can form steels at room temperature without the need for reheating.
- Designed and laboratory produced twelve alloys with the best combinations of tensile properties at approximately 1550 MPa and total elongation in excess of 20%, surpassing the targeted properties (see Figure 2).

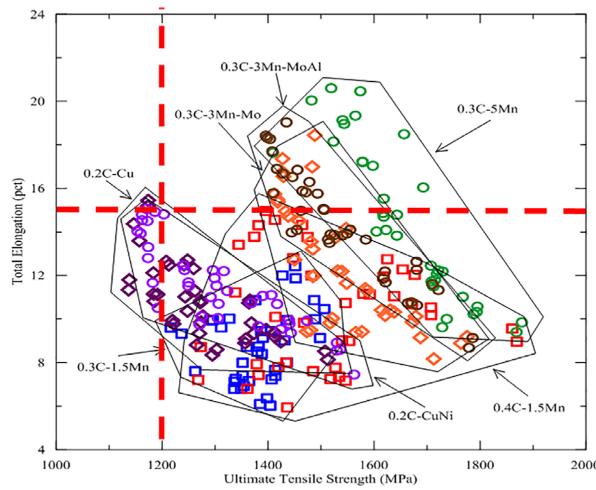

Figure 2. Total elongation as a function of ultimate tensile strength for data generated during the course of this project. Minimum project target properties are indicated by the red dashed lines.

Technology Transition

Q&P processing of cold rolled sheet steels is showing great promise as an alternative to hot stamped steels. Industrial implementation and commercialization of the Q&P process depends on the industrial capability to implement desired heat treating cycles, in particular the ability for controlled heating and cooling. Continuous annealing with flexible heating and cooling capability is hence required. A number of industrial initiatives towards the further development of annealing capabilities in support of advanced high strength sheet steels are underway. Some project partners have installed or are considering facilities capable of implementing this technology. The successful implementation of this project is a critical step 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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DOE/EE-1682 · March 2019