Austempering to Form Bainite

Research Team

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Introduction

Austempering is a heat treatment process based on the isothermal transformation of austenite to bainite, which forms in the temperature range between pearlite and martensite. Bainite was first identified by Davenport and Bain in 1930 [1]. The austempering process includes heating to the austenitizing temperature, soaking for some period for complete austenitization, rapidly cooling to above Ms (martensite start) temperature, holding at that temperature until the transformation of austenite to bainite is complete and then cooling to room temperature. Compared with martensite, which is brittle, bainite is tougher and does not require tempering [2].

The phase transformation from austenite to bainite is 250–550°C and conventionally molten salt is used as quenching media. Due to the environmental concern on molten salt heat treatment industry would like to pursue new austempering process to form bainite without using salt bath quenching.

The objective of the present project includes

- Identify the processing routes to produce Bainitic steels.
- Identify a process that does not use a liquid salt bath.
- Determine the effects of martensite and retained austenite on the properties of these steels.

Methodology

The project focused on the following tasks:

Task 1 – Literature Review

Task 2 – Alloy Selection

- Based on the discussion with the focus group, AISI 5160 and AISI 52100 were selected for investigation.

Task 3 – Austempering process parameters determination

Task 4 – Conduct the austempering process

- Molten salt trials
- Fluidized bed trials
- HIP (Hot Isostatic Pressing) trials
- Oil trials

Task 5 – Microstructural characterization

- Metallography
- Rockwell hardness and Vickers microhardness measurement
- SEM microstructure analysis
- Retained austenite and bainite percentage analysis by XRD

Task 6 – Mechanical testing for various bainite percentage

- Tensile testing
- Impact toughness testing

Salient results

As it is shown in the table below mainly two steels were investigated in this project including AISI 5160 and AISI 52100. The AISI 5160 steel bars used in this project are commercially available steel provided by FCA and the AISI 52100 steel bars are 100Cr6 provided by ArcelorMittal.

Steels		**AISI 5160**	**AISI 52100 (100Cr6)**
Experimental trials	Salt bath	C	C
	Fluidized bed	C	--
	HIP	C	--
	Oil	C	C

Simulation	Salt bath	--	C
	Oil	--	C
	High pressure gas	C	--
Mechanical testing	Tensile	C	--
	Impact	C	--
Remaining Tasks		Complete	Complete

The bainite percentage increases with the austempering holding time increasing. Figure 1 shows the optical micrographs of AISI 5160 austempered in molten salt at 315 ºC with selected austempering holding times including 1, 2, 5, 30, and 90 mins.

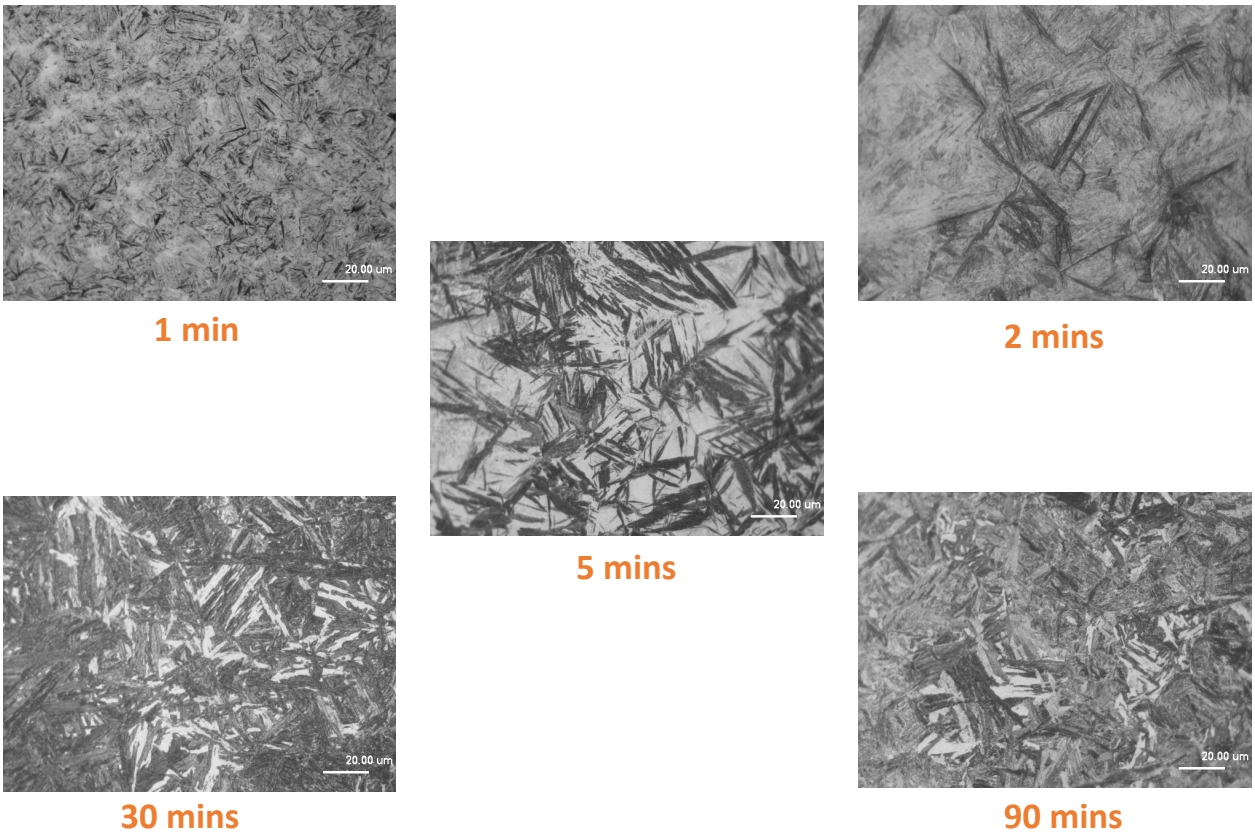

Figure 1 Optical micrographs of AISI 5160 austempered at 600 ºF with selected austempering holding time.

The yield stress, ultimate stress, and elongation of these austempered samples are plotted to correlate austempering holding time as shown in Figure 2. It can be seen that both stress and elongation increase with austempering holding time. This is related to the bainite percentage in the austempered samples. With austempering holding time increase more bainite forms until the bainitic transformation completes to attain all bainite.

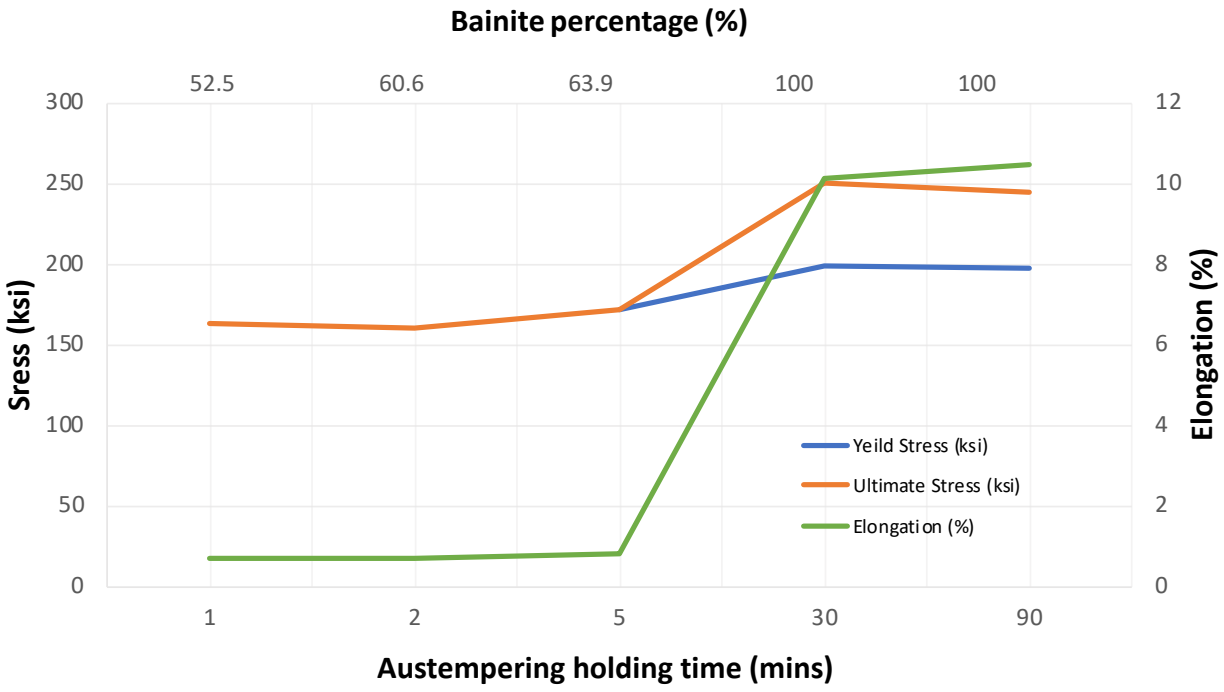

Figure 2 Correlation between mechanical properties and austempering holding time.

Full bainite is successfully formed for AISI 5160 using fluidized bed, HIP, and oil austempering in the present work.

Full bainite is also successfully formed for AISI 52100 using oil austempering. Simulation using DANTE is conducted to investigate the size effect of oil austempering on AISI 52100. Figure 3 shows the simulation results. The austempering temperature is 240 ºC.

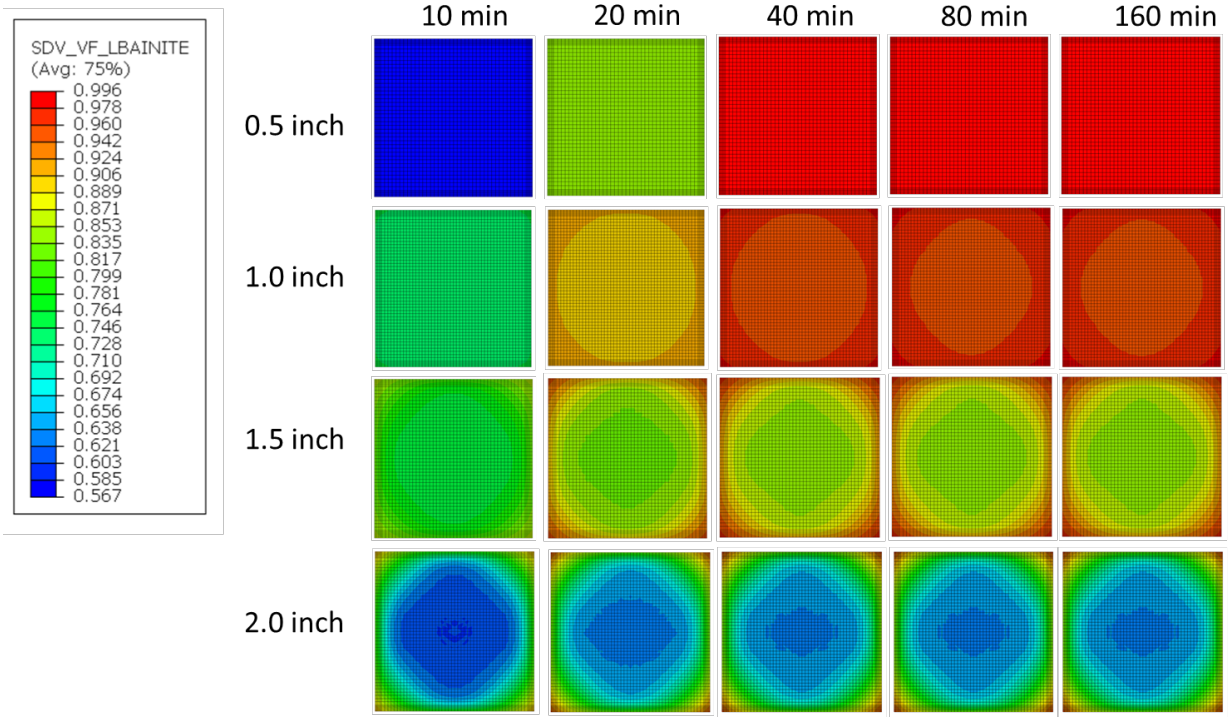

Figure 3 Bainite percentage distribution on the cross section of cubic sample with selected size at selected austempering holding time

References

1. Davenport, E., E.C. Bain, and H.W. Paxton, *Transformation of austenite at constant subcritical temperatures.* J Metallurgical Transactions, 1930. **1**: p. 3473-3530.
2. Lefevre, J. and K.L. Hayrynen, *Austempered materials for powertrain applications.* Journal of materials engineering and performance, 2013. **22**(7): p. 1914-1922.