Induction and Furnace Tempering

Research Team

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Introduction

Tempering is usually doing after quenching to increase toughness of martensitic steels. As a result of the previous work on tempering carbon steels by Cohen and his colleagues [1][2][3], the tempering process can be divided with three stages: stage (1) formation of transition carbides; stage (2) decomposition of retained austenite; stage (3) replacement by final microstructure of ferrite and cementite.

Both furnace and induction tempering methods are widely used in industry. Furnace tempering is a mature and well characterized heat treating process and induction heating has multiple advantages, such as rapid heating, fast setup, energy saving, high production rates, lower costs and distortion. The decreases of hardness after tempering by both furnace and induction is caused by carbon content decrease in tempered martensite to form carbides during heating process. Carbides will precipitate along grain boundaries, such as prior austenite grain boundaries, packet grain boundaries, block grain boundaries and lath martensite grain boundaries [4]. According to Hollomon Jaffe analysis [5], induction tempering process with higher temperatures will achieve the same surface hardness as the furnace tempering process with lower temperatures.

The objective of this project is to develop a fundamental understanding of the furnace and induction tempering process in terms of the effects of the temperature and time on microstructure and mechanical properties. A detailed comparison is made between parts that are tempered by induction heating and furnace heating separately. The comparison is focused on microstructures and mechanical properties (hardness, impact toughness, tensile strength and fatigue life) for selected steels.

Methodology

The project focused on the following tasks:

Task 1 - Literature Review

- Tempering
- Furnace tempering
- Induction tempering

Task 2 – Alloy Selection

- Based on discussion with the focus group, furnace hardened AISI 4140 was selected for experimental testing. The samples are 1/2 inch diameter rods, 1 foot length.

Task 3 – Design of Experiments

- All rods were furnace hardened (i.e. austenitized and quenched). The 4140 samples were quenched in oil in Bodycote Co. The hardened rods were tempered at five temperatures with five different times for each temperature by induction and furnace tempering separately.

Task 4 – Characterization

- All samples were fully characterized by using optical microscopy, scanning electron microscopy, X-ray diffraction, hardness and microhardness measurements. These results were correlated with temperatures and times by using the Hollomon-Jaffe equation as well as the phase distribution after the tempering.

Task 5 – Mechanical Property Measurement

- Based on the results of Task 4, samples were tested for tensile strength, impact toughness and tensile fatigue.

Task 6 – Comparison of Induction and Furnace Tempering

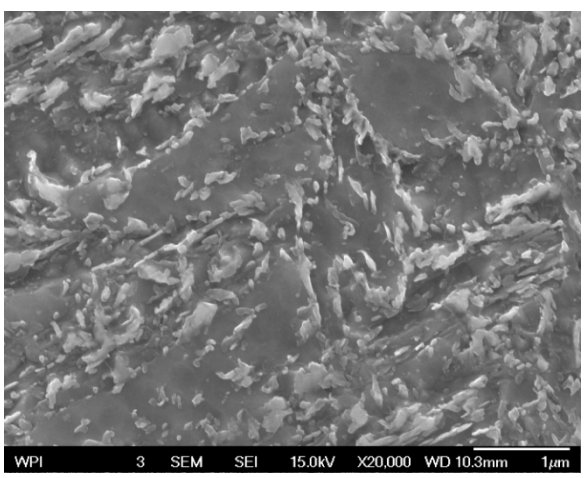
- Based on experimental results, tempering conditions with the same surface hardness are named as equivalent conditions. One couple was selected for the comparison, furnace tempered at 450°C for 1hr and induction tempered at 550°C for 1min.
- The comparison included mechanical properties (impact energy, tensile strength, yield strength, fatigue life) and microstructure (carbides type, size and shape)

Salient results

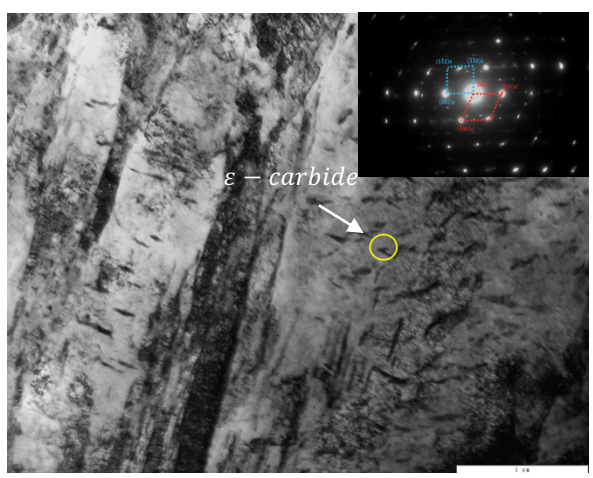
Based on the experimental results of surface hardness, furnace tempered at 450℃ for 1hr (FT450) and induction tempered at 550℃ for 1min (IT550) could achieve the same surface hardness which is 40 HRC. The comparison of mechanical properties, microstructure and carbides identification are presented in the Table 1, Figure 1-2. It can be seen that when the samples tempered by induction and furnace tempering process separately achieve the same surface hardness, the induction tempered sample with higher heating rates has higher impact energy. Based on the SEM results of cross section etched samples and XRD results of extracted carbides powder, furnace tempering process with lower heating rates could have transition carbides (ε carbides) and smaller crystallite domain size of cementite.

Table 1 The mechanical properties of equivalent conditions.

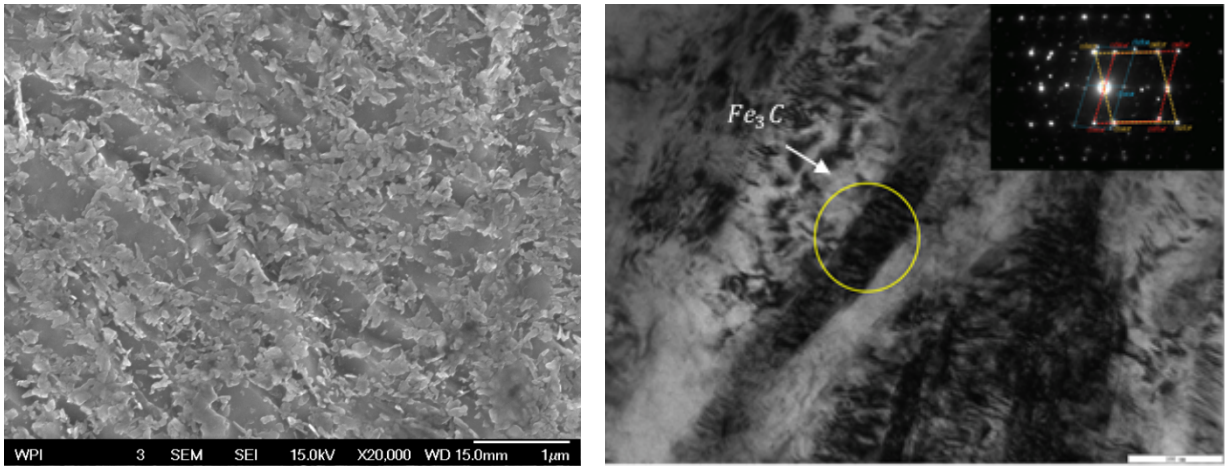
	Surface Hardness	Impact	UTS	YS	Elong
FT450	40.2HRc	25 ft-lbs	212.7ksi	193.3ksi	10%
IT550	39.7HRc	44 ft-lbs	200ksi	182.9ksi	14%



(a)



(b)



(c) (d)

Figure 1 SEM images of (a) (b) FT450 and (c) (d) IT550.

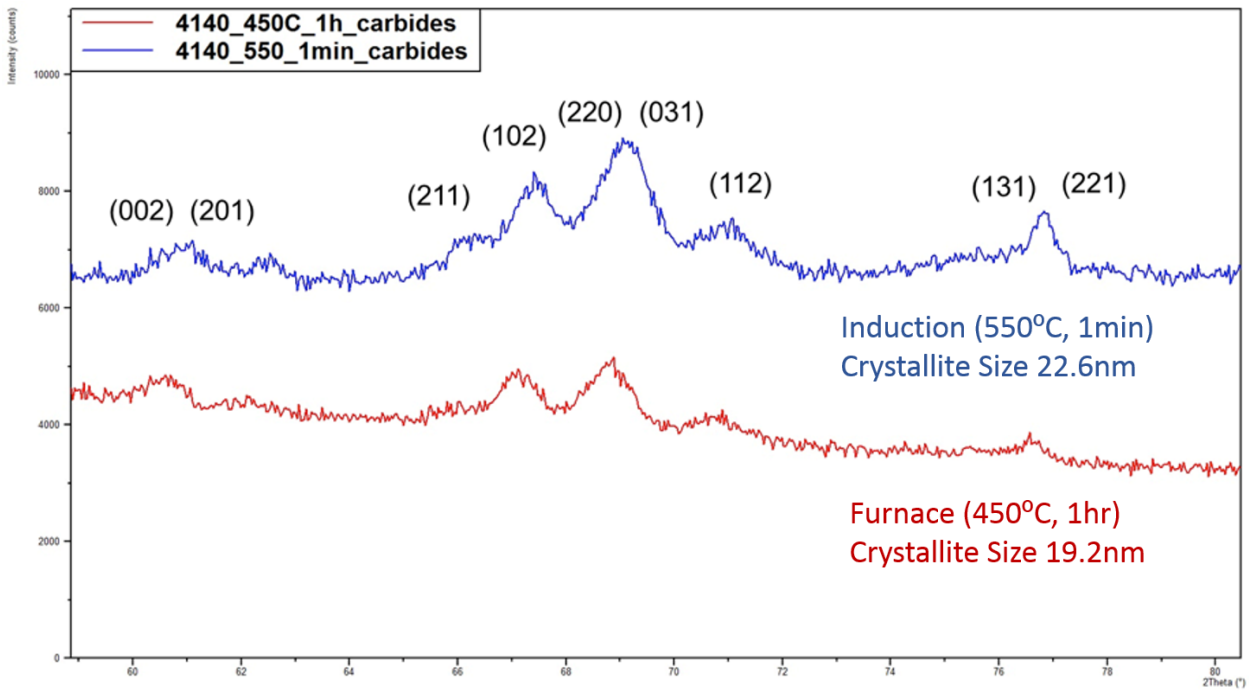


Figure 2 XRD results (cementite) of extracted carbides powder.

Reference

[1]. Roberts CS, Averbach BL, Cohen M. THE MECHANISM AND KINETICS OF THE 1ST STAGE OF TEMPERING. Transactions of the American Society for Metals. 1953 Jan 1;45:576-604.

[2]. Lement BS, Averbach BL, Cohen M. Microstructural Changes on Tempering Iron Carbon Alloys. Transactions of the American Society for Metals. 1954 Jan 1;46:851-81.

[3]. Werner FE, Averbach BL, Cohen M. The Tempering of Iron-Carbon Martensite Crystals. Trans. ASM. 1957;49:823-41.

[4]. Furuhara T, Kobayashi K, Maki T. Control of cementite precipitation in lath martensite by rapid heating and tempering. ISIJ international. 2004;44(11):1937-44.

[5]. J.H. Hollomon, L.D. Jaffe, "Time-temperature Relations in Tempering Steel," Metals Technology, Vol 162, 1945, p223-249.