THE EFFECT OF INITIAL MICROSTRUCTURE ON THE HARDENING OF 100CR6 BEARING STEEL

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Abstract

Bearing steels are used for parts requiring high hardness and wear resistance. Conventional hardening of the bearing steel is carried out at 840-870 °C after reheating of the initial structure of ferrite and carbides. At this temperature range, the hardening occurs without dissolving all carbides in order to prevent coarsening of austenite grains and formation of cracks in martensite plates following the quenching step. In this study, it is aimed to obtain a fine-grained initial microstructure by full austenitization before the hardening. For this purpose, the full austenitization followed by quenching to obtain the initial microstructure of martensite. Finer and well-distributed carbides reprecipitate at the hardening step. The effects of initial microstructure on phase transformations have been investigated by hardening of different initial microstructures namely martensite, martensite and carbide or ferrite and carbide, followed by the hardening treatment at 840 °C using a precision dilatometer. Accordingly, different heat treatment cycles also helped to understand the effect of different austenitizing temperature before the hardening step. Dilatometer tests were carried out to determine to critical transformation temperatures. Microstructural characterization and image analysis performed to determine the carbide size and distribution depending on the initial structure. It was found that phase transformations and final carbide size and distribution are sensitive to the initial microstructure.

Keywords: Bearing steels, dilatometry, martensite, austenitization, carbide

1. INTRODUCTION

100Cr6 steel is most widely used material for bearing components. The traditional production cycle of bearing steels includes intercritical austenitization to avoid grain coarsening and cracks formed during quenching. However, intercritical austenitization causes to remaining coarse spherical carbides in the final microstructure of bearing parts.

Carbide dissolution has been extensively studied in the past years [1-5], although to a less extent as its precipitation depending on initial microstructure. These studies conclude that partial dissolution of carbides occurs by fast carbon diffusion at the austenite boundaries, followed by C and Cr diffusion-depended slow-dissolution mechanism. Different initial microstructures were also studied. For example, cementite coarsening and dissolution from pearlitic initial microstructure were investigated by Zhang et al [5]. They have found that cementite is fully spheroidized and partially dissolved during intercritical austenitization at 860 °C.

In our previous study [6] it has been shown that martensitic initial microstructure yields more homogenous distribution of carbides compare to traditional cementite and ferrite initial microstructure. It is well known from tempering of steels that fine and well-distributed carbides can be obtained from carbon supersaturated martensite including former austenite grain boundaries, packets, blocks, sub-blocks and laths as well as geometrically necessary dislocations [7]. In this study, new heat treatment cycle (NHTC) aimed to provide more nucleation sites for carbide precipitation. Two step hardening process involves fully austenitization followed by a partial austenitization at two phase region. Thus, a martensitic structure obtained in the first step provides a higher density of nucleation sites for the second step of partial austenitization.

2. EXPERIMENTAL

The chemical composition of the bearing steel is given in **Table 1**. Dilatometer experiments, microstructural characterization and image analyses were done to investigate carbide dissolving and precipitation behaviors. ThermoCalc software [8], and TCFE6 database [8] were used to calculate phase diagrams.

Table 1 Chemical composition of investigated steel (wt. %)

C	Si	Mn	P	S	Cr	Mo	Al	Cu
0.97	0.20	0.28	0.024	0.011	1.39	0.01	0.005	0.12

The investigation of transformation behavior was performed in dilatometer tests. The experiments were done in DIL 805 A/D quenching dilatometer (Baehr-Thermoanalysis GmbH) using cylindrical specimens of 4 mm diameter and 10 mm in length. Samples were prepared from the hot rolled steel after spheroidization treatment. To produce different initial microstructures before the hardening step, 3 different cycles were applied in dilatometer experiments as explained in **Table 2**. The thermal cycles had been performed under vacuum of 10^{-4} mbar. Helium was used for cooling. Dilatometric data was recorded using digital acquisition system with computer.

Table 2 Dilatometer heating and quenching cycles.

	Pre-Heat Treatment Heating rate, holding time and temperature, cooling rate	Hardening Heating rate, holding time and temperature, cooling rate
Conventional	-	5K/s, 10 minutes at 840 °C, 125 K/s
NHTC 1	5K/s, 15 minutes at 1050 °C, 125 K/s	5K/s, 10 minutes at 840 °C, 125 K/s
NHTC 2	5K/s, 15 minutes at 920 °C, 125 K/s	5K/s, 10 minutes at 840 °C, 125 K/s

Microstructural investigations were carried out using a light microscope and a scanning electron microscope (SEM) after etching with 4 % Picral. SEM micrographs were taken at 15 kV with the Jeol JSM 6060. Measurement of carbide size was performed with image analysis software using the line intercept method according to ASTM E112-12 [10] and at least 1000 carbides from different regions have been measured for each sample.

Offset method was applied to the dilatometric curves and Ac1b and Ac1e temperatures were determined as explained in our previous work [11]. According to Yang and Bhadeshia [12], the offset method can be used in determining critical temperatures from dilatation curves.

3. RESULTS

3.1. Phase transformations according to thermodynamical calculations

In order to establish intercritical and full austenization temperatures of investigated structure (see **Figure 1a**), the phase diagrams were calculated using ThermoCalc (**Figure 1b**). According to calculations in **Figure 1b**, the Ac_{1b} and Ac_{1e} temperatures (the starting and finishing temperatures of ferrite dissolution) are 737.91 ºC and 747.20 ºC, respectively. All cementite phase should be dissolved at temperatures above 898.57 ºC. Thus, 920 ºC and 1050 ºC were selected to dissolve cementite and austenitization for the pre-heat treatment steps in **Table 2**. For the hardening step, 2.65 vol. % of cementite should be present at 840 ºC according to the thermodynamical calculations.

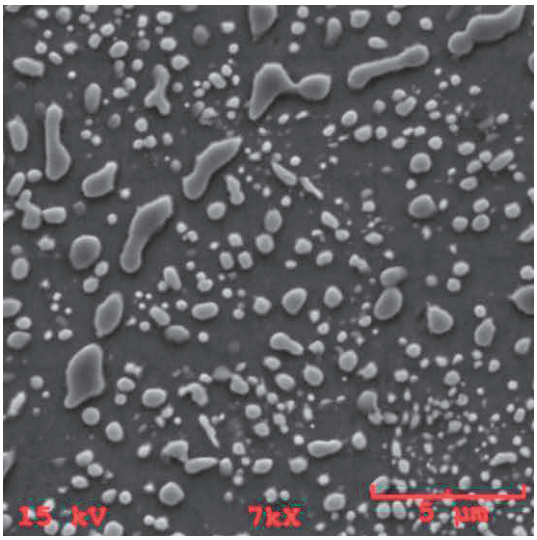

Figure 1a Microstructure of spheroidizated 100Cr6 bearing steel showing cementite particles in ferrite (etchant: picral)

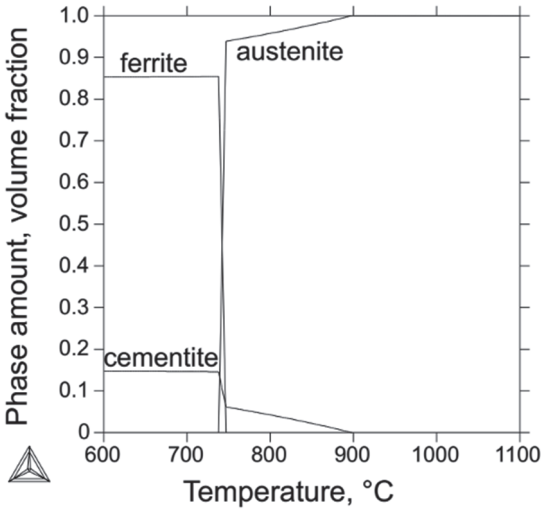

Figure 1b Calculated phase volume fractions for 0.97 C-0.20 Si-0.28 Mn-1.39 Cr steel using Thermo-Calc

3.2. Phase transformations in dilatometer tests

Figure 2 shows the dilatometric curves during heating from room temperature to 1050 °C. The Ac_{1b} and Ac_{1e} temperatures (the starting and finishing temperatures of ferrite dissolution) are clearly indicated by the inflexions of the curves. Thus, it can be assumed that ferrite has transformed completely upon heating and the microstructure consists of cementite and austenite during isothermal holding at 840 °C.

3.3. Phase transformations during partial austenitization at the hardening step

The precision dilatometer made also possible to detect small variations in strain during austenitizing at 840 °C. **Figure 3** shows the dilatometric curves during the austenitization for the hardening step. In the conventional method, the expansion continues at constant temperature as a result of spheroidized carbide dissolution. The dissolution is rapid in first 200 s and then its dissolution gradually slow down. However, pre-heat treated samples at 920 and 1050 °C present different behavior. The curves begin with similar rapid increase, but contraction occurs after approx. 100 s. This could be explained by precipitation of cementite.

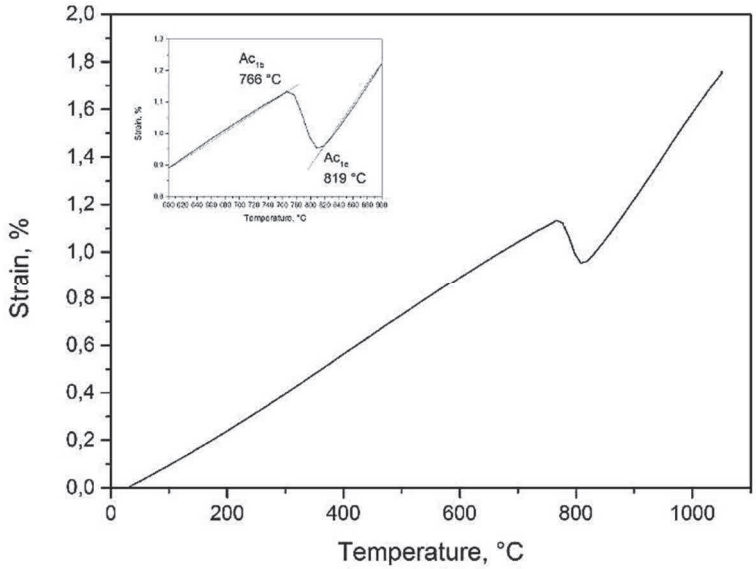

Figure 2 Dilatometric curve during heating to 1050 °C

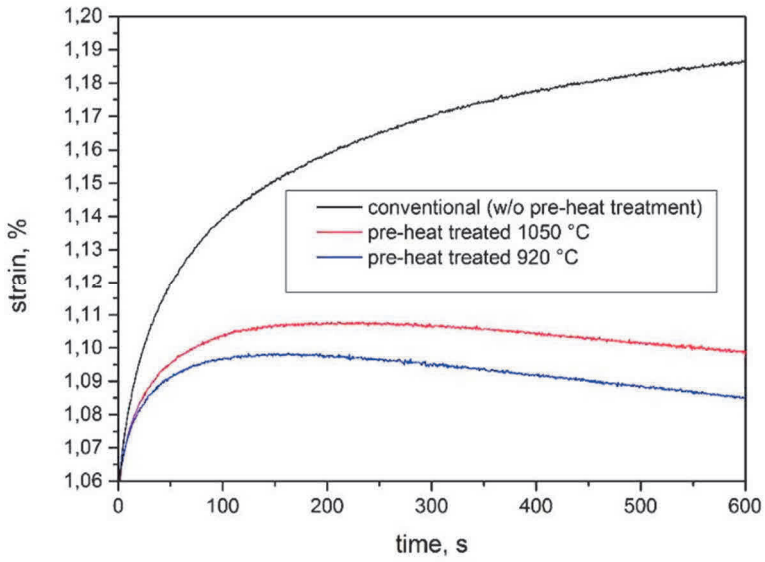

Figure 3 Dilatometric strains during intercritical annealing treatments at 840 °C for 600s with different initial microstructures

3.4. Phase transformations during intercritical annealing treatment

Figure 4 shows the change of carbide size in final microstructures of conventional, NHTC1 and NHTC2 samples as well as in microstructure of spheroidizated 100Cr6 steel. It was observed that the coarse carbides (average 0.36 μm) were formed in the spheroidized 100Cr6 steel hardening annealing was not performed. By applying the conventional heat treatment, these carbides are partially dissolved and the carbide size varies on a wide scale. The average carbide size is 0.32 μm. On the other hand, it is seen that much finer carbides are obtained in NHTC 1 and 2 compared to the conventional heat treatment cycle. Before the hardening step, pre-heat treatment was used to dissolve the carbides. Thus, much finer carbides are formed during the hardening. Pre-heat treatment at 920°C, the average size of carbides is 0.18 μm. It is clearly seen that very few carbides are formed over 0.25 μm. Pre-heat treatment at 1050°C, the average carbide size is 0.15 μm. Almost half of the carbides appears to be under 100 nm and below. According to this, it can be said that increasing the austenitization temperature increases the solubility of cementite and finer carbides can be obtained.

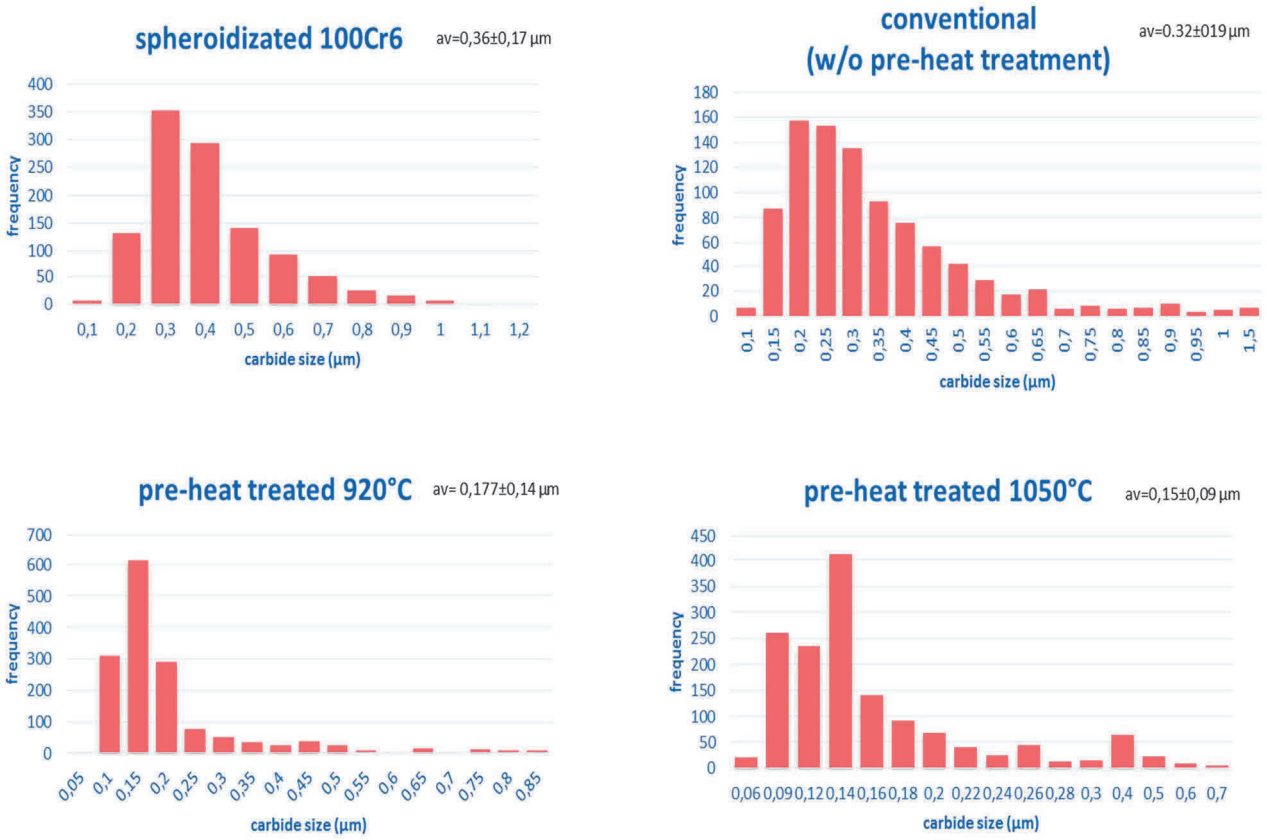

Figure 4 Change of carbide size depending on initial microstructure

4. CONCLUSION

It is known that the hardening annealing decreased the carbide size of spheroidized 100Cr6 bearing steel. In this study, a new heat treatment cycle was developed which consist of the austenitizing before hardening. The initial microstructure was altered with the new heat treatment cycle. The effect of the initial microstructure on the carbide size was investigated.

It was observed that apply a full austenitization before the hardening step is an effective method to obtain finer carbides.

On the other hand, the effect of austenitization temperature on carbide size was studied. Phase transformations examined by thermodynamic calculations and dilatometer tests to set up critical temperatures. 920 and 1050 °C were selected for the pre-heat treatment steps. The average sizes of carbides are 0.18 µm pre-treated at 920 °C and 0.15 µm at 1050 °C. Almost half of carbides were formed at 100 nm and below as the smallest average carbides were obtained at 1050 °C.

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