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Effects of heat treatment influencing factors on microstructure and mechanical properties of a low-carbon martensitic stainless bearing steel

Shaohong Li [a], Xiaohong Yuan [a], Wen Jiang [a], Hudai Sun [a], Jun Li [a], Kunyu Zhao [a,*], Maosheng Yang [b]

[a] School of Materials Science and Engineering, Kunming University of Science and Technology, Kunming 650093, China
[b] Department of Structural Materials, Central Iron and Steel Research Institute, Beijing 100081, China

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ABSTRACT

The effects of different heat treatment parameters and cryogenic treatment (-75 °C) on microstructural changes and mechanical properties of a low-carbon martensitic stainless bearing steel were investigated. These analyses were performed via the optical microscope (OM), transmission electron microscope (TEM) and X-ray diffraction (XRD). The obtained results showed that the execution of cryogenic treatment on quenched and tempered bearing steel increases hardness, tensile strength and decreases toughness with the increment of cryogenic treatment and tempering cycles. This paper also showed that the cryogenic cycle's treatment incorporating tempering can refine the martensite laths resulting in improvement of tensile strength. In addition, cryogenic treatment further reduces the retained austenite content but it cannot make retained austenite transform into martensite completely even tempering at high temperature.

1. Introduction

Bearing is the joint that allows one part to rotate or move in contact with another part of a machinery. The property requirements of bearings are high strength and stability, good corrosion resistance and toughness and so on. In addition, the geometry of bearings can dramatically influence the choice of material, bearing performance and its ability to bear loads [1]. Generally, small bearings are usually through-hardened, the steels with carbon concentrations in the range of 0.8–1.1 wt% and the total substitutional solute content less than 3 wt%. Large bearings can be through-hardened by increasing the hardenability of the steel using larger concentrations of alloying elements. Authors [2] have researched the effects of alloy elements on the bearing hardening, such as variations in C and Ni contents have a strong impact on the martensite-start temperature and Cr, Mn, Mo and Si influence solid solution hardening and precipitation kinetics.

The conventional heat treatment of bearing steel is quenching and tempering. However, the major problem associated with the conventional heat treatment is the content of retained austenite, which is soft, unstable at low temperature and tends to transform into brittle martensite during service [3]. Transformation of austenite to martensite causes volume expansion resulting in distortion of the bearings. Cryogenic treatment is proposed to eliminate the amount of retained austenite in high alloy steels (tools and bearings) as a supplementary process to conventional heat treatment. Barron [4] has found that deep cryogenic treatment (DCT) can improve wear resistance of SAE 52100 bearing steel. Harish et al. [5] have investigated the microstructural changes of cryogenically treated En 31 bearing steel and concluded that the cryogenic treatment should be followed by tempering to promote secondary carbide precipitation which is essential for hardness augmentation and wear resistance improvement. This has also been discovered in tool steels by internal friction method [6,7] and experimental verification of the fine carbide particles formation on subsequent tempering was verified by analyses of transmission electron microscope [8]. Authors [9] have pointed out that cryogenic treatment could improve the hardness and the fatigue life while decreasing the toughness of the material slightly by research on the 4340 stainless steel. Finite element method (FEM) simulation and experimental verification of temperature field and phase transformation have recently shown a theoretical guidance to further evaluate the material properties and make the reasonable DCT procedure in deep cryogenic treatment [10]. Li

* Corresponding author.
E-mail address: zhaokunyu.kmust@gmail.com (K. Zhao).

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et al. [8,11,12] have measured the internal friction changes during the process of deep cryogenic treatment, including the transformation of retained austenite to martensite and there is more carbide precipitated from the matrix during tempering after DCT can improve the service life of tools and dimension stability and measured the internal friction of phase transformations during the process of deep cryogenic treatment [13]. Cryogenic treatment is widely used for high precision parts and components, since it enhances the comprehensive mechanical properties and fatigue behaviors. The interesting positive effects were noticed on carburized bearing steels [14–17], tool steels [18–20] and stainless steels [21,22] and on other materials [23–26].

The main objective of this work is to study the effect of quenching temperature, tempering temperature and cryogenic treatment cycles on the microstructure and mechanical properties of a low-carbon martensitic stainless bearing steel.

2. Material and experimental methods

The tested steel is produced in a vacuum induction-melting furnace and the ingots are forged into ∅20 mm × 50 mm bars. The chemical composition of the tested steel is shown in Table 1. For all hardness measurements, Rockwell hardness tester was used. The major load of 150 kg was applied for HRC scale for a duration of 30 s and the depth of resistance to indentation was automatically recorded on the dialgauge. Each effective hardness value of a sample is the average hardness of seven points. The impact toughness is determined for Charpy V-notched specimens $10 \times 10 \times 55\ mm^3$ in size. The volume fraction of retained austenite in the steel is determined by D/max-2200 X-ray diffraction. The microstructure was etched by a solution consisting of 50 ml HCl, 2 ml HNO_3, 1 g $CuCl_2$, 2.5 g $FeCl_3$, 50 ml alcohol and 50 ml H_2O and tested by PHILIPS optical microscope and the JEM-2100 transmission electron microscope (TEM).

The specimens are austenized at 1020–1040 °C for 1 h and quenched into oil then cooled down to room temperature. The specimens are put into a refrigerator at −75 °C for 2 h and warmed up to room temperature in the air and then tempered at 480 °C, 495 °C and 510 °C for 2 h. And then, the samples are executed the second cryogenic treatment and the second tempering in the same condition. The detailed treatment processes of the tested steel are given in Table 2.

Table 1
Chemical composition of the tested steel (wt%).

C	Cr	Co	Mo	Ni	Si	Fe
0.1–0.15	12.0–14.0	12.0–13.0	3.5–4.5	1.5–1.9	0.05–0.07	Bal

3. Results and discussion

3.1. Influence of austenized temperatures on microstructure and properties

The microstructure of specimens austenized at different temperatures from 1020–1040 °C and then cryogenic treated at −75 °C for 2 h is presented in Fig. 1. It shows that the microstructure of the specimens after austenizing at different temperatures and cryogenic treating at −75 °C is mainly composed of lath martensite and a small number of retained austenite. In addition, the δ-ferrite distributes along with the original austenite grain boundaries in the shape of a long strip or ellipsoid. The amount and dimension of the δ-ferrite increased slightly with the quenching temperature up to 1040 °C. This is because the ferrite stabilizing elements such as Mo and Cr enriched in the tested steel, which increased the chromium equivalent (Cr_{eq}) of the steel and made the δ-ferrite produce easily when austenized at a higher temperature [27]. The original austenite grain is separated by several martensitic laths beams. The size of the original austenite grain is increased (Fig. 2) and the martensitic lath beams become coarse with the increasing of quenching temperature.

The variation of the impact energy (A_k) and hardness of specimens quenching at different temperatures ranging from 1020 to 1040 °C and then being cryogenic treated at −75 °C for 2 h are shown in Fig. 3. The impact energy (A_k) of the tested steel is

Table 2
Detailed treatment processes of the steel.

Heat treatment	Quenching temperature (Q)	1st Cryo-treatment (QC)	1st Tempering (QCT)	2nd Cryo-treatment (QCTC)	2nd Tempering (QCTCT)
A	1020 °C × 1 h	−75 °C × 2 h	–	–	–
B	1030 °C × 1 h	−75 °C × 2 h	–	–	–
C	1040 °C × 1 h	−75 °C × 2 h	–	–	–
D	1040 °C × 1 h	−75 °C × 2 h	510 °C × 2 h	–	–
E	1040 °C × 1 h	−75 °C × 2 h	510 °C × 2 h	−75 °C × 2 h	–
F	1040 °C × 1 h	−75 °C × 2 h	510 °C × 2 h	−75 °C × 2 h	510 °C × 2 h
G	1040 °C × 1 h	−75 °C × 2 h	495 °C × 2 h	−75 °C × 2 h	495 °C × 2 h
H	1040 °C × 1 h	−75 °C × 2 h	480 °C × 2 h	−75 °C × 2 h	480 °C × 2 h

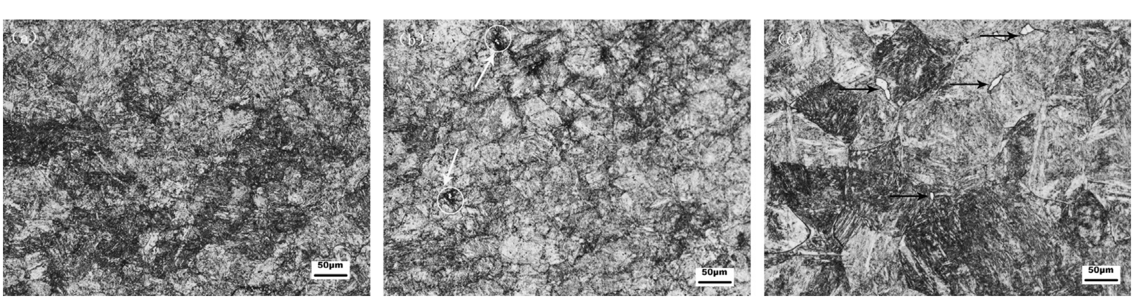

Fig. 1. Microstructure of specimens quenching at different temperatures and then cryogenic treated at −75 °C for 2 h: (a) 1020 °C; (b) 1030 °C; and (c) 1040 °C.