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Effect of bainite layer by LSMCIT on wear resistance of medium-carbon bainite steel at different temperatures

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A B S T R A C T

In this work, bainite layer was prepared by Laser surface melting combined with isothermal treatment (LSMCIT) at 250 °C. The microstructures of the samples were analyzed by scanning electron microscopy (SEM), X-ray Diffraction (XRD) and transmission electron microscopy (TEM). Their wear resistances at 20 °C, 100 °C and 200 °C were measured using reciprocating tribometer. After the wear test, the confocal laser scanning microscope and SEM were used to characterize the topography of all abrasion surfaces, and the phase transformations occurred on the contact surfaces were analyzed by XRD. The results show that the microstructure of the LSMCIT sample has been refined to nanoscale. The wear volume reduction ratio of LSMCIT sample is 40.9% at 20 °C. The wear resistances of the samples are decreased with increasing of the temperature, however, the decrease in amplitude of the bainite is relatively small. The harder surface of the LSMCIT sample can provides higher mechanical support, and the white-etching layer on surface are difficult to remove by the reciprocating friction. The wear resistances of the LSMCIT samples at 20 °C, 100 °C and 200 °C are excellent, which shows the wide temperature ranges in wear applications.

1. Introduction

Nanostructure carbide-free bainite are equipped with excellent strength and high hardness. Moreover, the nanobainite steels can be obtained by an uncomplicated manufacturing route [1,2]. In nanobainite, the microstructure consist of exceptionally fine plates of bainitic ferrite (BF) and nanoscale carbon-enriched retained austenite (RA) film [3,4]. The nanobainite can be obtained at low bainite transformation temperature when the carbon content of the steel is high. In this way, ultrahigh hardness levels of 600 HV and good combinations of strength and toughness can be obtained by transforming at temperatures as low as 200 °C [5]. The major goal of the nanobainite used in the industrial application is to obtain the high surface property parts that withstand large loads and without suffering damage [6]. Another important factor in the widespread application of nanobainite is the excellent wear resistance.

It was reported that the abrasive wear exists greatly in mechanical equipment moving and machine assemblies, and approximately 50% of the material loss is due to abrasive wear [7]. The wear resistance of the bainite steel have been investigated largely. Bakshi et al. [8] found that the bainitic structure is hardened at the surface, and white-etching layer with martensitic transformation which causes wear resistance to increase. Chang [9] investigated that the good toughness of carbide-free bainite steels can increase the wear resistance under rolling/sliding, because the high hardness and good combination of the white-etching layers are formed at the surface. The studies further suggest that the retained austenite (RA) has been identified as an important factor in the formation of white etching layer. Leiro et al. [10,11] reported that the wear resistance can be improved by transformation of austenite into martensite during wear, and the hardness of the white etching layer could be increased by the decrease of RA fraction, so the wear resistance of the steels were enhanced. Solano-Alvarez et al. [12] studied that the white-etching layers on the bearing steel spalling from the surface as the cracks bring together into larger networks, and the less RA exist in the steels is the main reason.

In general, the microstructure and the fraction of RA influenced the formation of the white-etching layers, and then has impact on the wear resistance. Meanwhile, it is worth noting that the combined thermal and mechanical stability of the RA, and the mechanically induced austenite transformation is significantly affected by the temperature [13]. The wear resistance on the surface of bainitic steel in high wear test temperatures need to be resolved.

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Table 1
Chemical compositions of the steel (wt%).

Element	C	Si	Mn	Cr	Ni	Mo	Fe
wt%	0.55	2.53	1.82	1.08	0.45	0.32	Bal.

In our previous study, the laser surface treatments with advantage of self-quenching, intense energy flux and small heat affected zone have been used to surface modification of a medium carbon bainite steel [14]. The austenite nano-twin has been detected abound in the surface modified bainite, and the hardness of this layer is reached 600 HV. However, the wear resistance of bainitic steel, which is improved by laser surface hardening was still less reported.

In this paper, a medium carbon bainite and the Laser surface melting combined with isothermal treatment (LSMCIT) bainite were used to characterize the wear resistance of the samples at different temperature, and then the RA transformation induced by wear deformation at different temperature are studied.

2. Experimental procedure

2.1. Experimental materials

The steel were prepared as a cast ingot, the samples were homogenized at 1200 °C for 24 h. The actual chemical composition of the steel used in this work is given in Table 1.

The M_s temperature of the mid carbon high silicon steel was measured by Gleeble-3800 thermal mechanical simulator equipped, which is 230 °C. The steel was austenitized at 1000 °C for 15 min and then isothermally transformed at 250 °C for 24 h to obtain a bainite microstructure, marked as Sample A. The steel samples with the dimension of 40 × 20 × 10 mm^3 were machined and cleaned in ethyl alcohol, and then the samples were laser remelted by CO_2 laser device in an Ar protection box. The laser process parameters are listed in Table 2.

The steel was laser remelted in an Argon protection box and followed isothermal transformation at 250 °C for 24 h, and the sample was air cooled to room temperature after the isothermal treatment, marked as Sample B.

2.2. Experimental methods

Filed emission scanning electron microscopy (FESEM, Hitachi S4800) and transmission electron microscopy (TEM, JEM-2010) were used to observe the microstructures of the samples. X-ray diffractometer (XRD, D/max-2500/PC) with Cu Kα radiation at 40 kV and 20 mA was performed to determine the phase constitution. During the test, 40° < 2θ < 120° with a step size of 0.02° was set and the collection time was 2 s. The XRD results were analyzed by Rietveld method of refinement combining with the Materials Analysis Using Diffraction (Maud) software from three or more XRD scan data for each sample. The weighted profile factor R_{wp} is considered to be the most relevant to follow the progress of structure refinement, which can be expressed as follow.

$$R_{wp} = \left[\frac{\sum w_i(x_i - y_i)^2}{\sum w_i x_i^2}\right]^{1/2} \quad (1)$$

Table 2
laser process parameter.

Laser power output	Defocusing amount	Laser scanning speed	Laser spot diameter	Overlap rate
1.8 kW	5.0 mm	10 mm/s	Φ3.0 mm	8%–12%

Table 3
Friction and wear test parameters.

Load	Frequency	Max liner speed	Test distance	Times	Test temperature
5 N	1.6 Hz	40 mm/s	8 mm	60 min	20 °C 100 °C 200 °C

where x_i is the discrete observed intensity and y_i the corresponding calculated intensity w_i is the observation weight, assigned the value x_i^{-1}.

The analysis were performed to impose a body-centred tetragonal lattice ($I\frac{4}{m}mm$) for ferrite phase during Rietveld method of refinement, as the body-centred cubic ($Im\overline{3}m$) performed to impose a higher R_{wp}. The retained austenite well-fitted using a face-centred cubic (fcc) structure.

The austenite carbon content can be calculated by Eq. (2) [3]

$$a_\gamma = 3.5780 + 0.033w_C + 0.00095w_{Mn} - 0.0002w_{Ni} + 0.0006w_{Cr} + 0.0056w_{Al} + 0.0031w_{Mo} + 0.0018w_V \quad (2)$$

where a_γ is the lattice parameter of austenite, and w_i is the concentration of element in wt%.

The austenite carbon content can be calculated by Eq. (3) [15]

$$c/a = 1 + 0.045x_w \quad (3)$$

where a and c are the evolution of the tetragonal ferrite unit cell parameters and x_w is the concentration of carbon in wt%.

The M_d temperature is the major critical factor to present the deformation-induced martensite transformation, which can be calculated by Eq. (4) [16]

$$M_d = 551 - 462(C(\gamma) + N(\gamma) - 9.2Si(\gamma) - 8.1Mn(\gamma) - 13.7Cr(\gamma) - 29Ni(\gamma) - 29Cu(\gamma) - 18.5Mo(\gamma)) \quad (4)$$

Microhardness tester (FM-ARS 9000) with a load of 100 gf (0.98 N) was conducted for hardness determination, and the dwell time is 10 s. 10 random positions were used to detect the microhardness of the material, and the distance between the two adjacent indentations was more than three times the length of the indentation diagonal. Nano-mechanical tester (CPX-NHT^2) equipped with a diamond Berkovich tip was conducted for hardness determination using the load of 10 mN and dwell time of 10 s during the test. A 30° angular between the linear locus of the cross-sectional nanohardness gradient and the sample

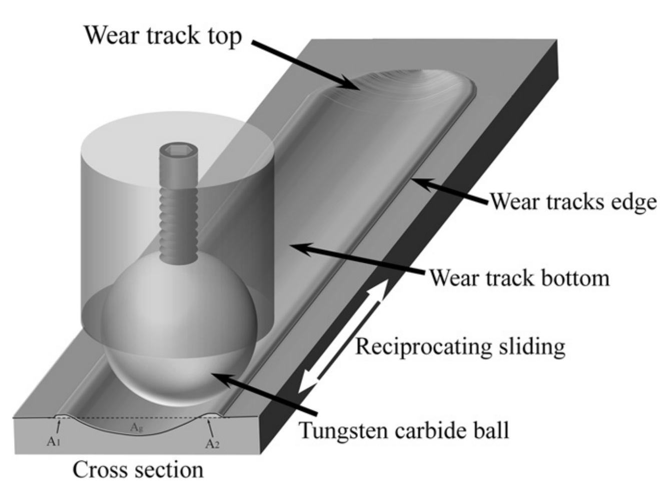

Fig. 1. Schematic diagram of worn surface morphology.