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EFFECT OF PULSE MAGNETIC FIELD ON ISOTHERMAL BAINITIC TRANSFORMATION PROCESS IN Cr5 STEEL

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Abstract

In order to investigate the effect of pulse magnetic field on isothermal bainitic microstructure and performance of Cr5 steel, pulse high magnetic field with 1.5T was exerted during isothermal bainitic transformation, continuous cooling + isothermal bainitic transformation and austenitizing + continuous cooling + isothermal bainitic transformation process, respectively. Results showed that, compared with normal isothermal bainitic transformation with the same technology, applying pulse magnetic field during the isothermal bainitic transformation can obviously promote bainitic transformation, the volume fraction of bainite increased by 4.2%, the volume fraction of retained austenite is reduced by 1.7%, and the hardness of Cr5 steel was reduced by 3 HRC.

Introduction

Cr5 steel is commonly used as a back-up rolls material attributing to its high strength, toughness and wear resistance. The comprehensive performance directly determines the quality and production of rolling plate. Cr5 steel is developed on the basis of Cr3 steel by increasing the contents of Cr and other alloying elements (Si, Mo, V, etc.). In this case, not only the toughness of Cr5 steel is improved, but also its service life is increased, which gets extensive application in high energy mill equipment [1]. The manufacturing cost and service life of cold roll have important significance to industrial production.

As is known to all, bainitic steel is prospective in application due to its high strength and good toughness. To promote the bainitic transformation process in alloy steel, researchers took some measures of controlling alloy element [2], austenitizing temperature and holding time [3-5], applying stresses [6] or steady magnetic field [7] in heat treatment process, and so on. However, few studies focus on the impact of pulse magnetic field on bainitic transformation.

At present, pulse magnetic field technology was effective in affecting the structure evolution of phase transformation in metals and alloys. Pulse magnetic field treatment has very obvious refinement effect on solidified structure of metal and alloys [8-11]. Pulsed magnetic field can dramatically influence the solid state phase transformation and recrystallization texture [12], significantly reduce size of primary recrystallization grain and improve the portion of completed recrystallization. Pulse magnetic field can also have greatly improved magnetic property of nanocrystalline soft magnetic materials [13]. Recent studies have found that [14] the effect of pulse magnetic field treatment is related to the orientation of magnetic field. Through the promotion of pulse magnetic field to ferromagnetic transformation product, the phase transformation from austenite to bainite will be accelerated. Based on this, this paper will study the influence of pulse magnetic field on bainitic transformation by applying pulse magnetic field at different heat treatment stages of Cr5 steel, in order to provide basis for further development and application of this steel.

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Experimental Procedure

Experimental material is Cr5 steel developed by a new type of backup roll steel. After homogenization heat treatment, the steel was then quenched and tempered treatment. The chemical composition (wt %) of steel is: 0.48～0.58 C, 4.50～5.50 Cr, 0.40～0.70 Mn, 0.40～0.70 Si, 0.45～0.50 Mo, 0.10～0.20 V, 0.40～0.50 Ni, P、S≤0.015. The original microstructure was composed of ferrite and a large number of scattered tiny carbides, as shown in Fig.1.

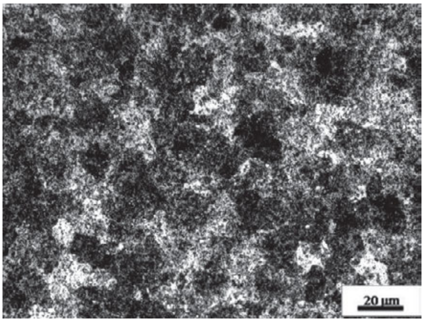

Figure 1. Original microstructure of Cr5 steel

Firstly, samples with the dimension of 3 mm ×10 mm× 30 mm were cut from the experiment materials for heat treatment. Heat treatment technology curve was shown in Fig. 2. Specimens have been heated from room temperature to 940 ℃, held for 20 mins and nitrogen-cooled to 350 ℃ at the rate of 1 ℃/s, then isothermally transformed at 350 ℃ for 5 mins, finally air-cooled to room temperature.

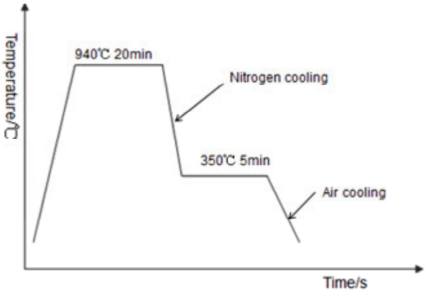

Figure 2. Heat treatment process curve

At different stages of heat treatment process, pulse magnetic field with 1.5T was exerted to study the bainitic transformation under the effect of pulse magnetic field. Samples were divided into four groups: the first group is normal heat treatment, marked as NT-a; the second group of applying pulse magnetic field of 1.5 T during isothermal transformation at 350 ℃ for 5 mins, marked as PMT–b; the third group of applying pulse magnetic field of 1.5 T during cooling and holding at 350 ℃ for 5 mins, marked as PMT–c, the fourth group of applying pulse magnetic field of 1.5 T during the whole process of austenitizing, cooling and isothermal transformation at 350 ℃ for 5 mins, marked as PMT-d.

After different heat treatment, samples undergo a series of wire cutting and polishing. Samples were etched with the acid of 4% nitric acid alcohol solution, then take optical photos by the Zeiss optical microscope (AXIO IMAGE A2M model). Image Pro Plus software is used to investigate bainite transformation fraction of four groups of microstructure by quantitative statistics. SUPRA40 thermal field emission scanning electron microscope is introduced to observe the bainite microstructure. X-ray stress meter was used to measure content of retained austenite in samples with different heat treatment. Ten field of vision in samples NT–a, PMT–b, PMT–c and PMT-d was selected randomly to measure content of retained austenite, respectively, then, took the average value. The HR-150 DT Rockwell apparatus is used to test the hardness of samples.

Results and Discussion

The microstructure of four group samples is shown in Fig.3. It can be seen that the microstructure in four group samples is all composed of martensite matrix, needled lower bainite, granular carbides and a small amount of residual austenite. The fraction of bainite in samples NT–a, PMT–b, PMT–c and PMT-d is 12.2%, 16.4%, 14.1% and 12.5%, respectively. Spectrum diagram of retained austenite by X-ray stress meter is shown in Fig.4. The bottom of the diagram is spectra of the standard sample, of which content of retained austenite is 5%. X-ray stress meter and X-ray diffraction meter are based on the same principle in theory, namely the content of residual austenite is proportional to its diffraction peak intensity. X ray stress meter can measure the content of residual austenite of samples directly, and it is simple and convenient, this paper take ten random fields in four group samples respectively, the average is the content of residual austenite. Content of retained austenite of samples NT–a, PMT–b, PMT–c and PMT-d is 7.1％、5.4％、5.8％、6.8％, respectively. Results showed that, comparing with normal isothermal bainitic transformation, applying pulse magnetic field during isothermal bainitic transformation reduced the content of retained austenite by 1.7%. However, the content of retained austenite in sample PMT-d is nearly the same as sample NT–a. It can be concluded that the fraction of retained austenite is inversely proportional to the fraction of isothermal bainite transformation. Super-cooled austenite will transform to martensite after isothermal bainite transformation. Applying pulse magnetic field with 1.5T during isothermal bainitic transformation can promote the bainite transformation and the fraction of retained austenite was reduced. Above all, applying pulse magnetic field of 1.5 T during isothermal bainite transformation has the most obviously accelerated effect on the bainite transformation. But, applying pulse magnetic field during austenitizing + continuous cooling + isothermal bainitic transformation does not accelerate the isothermal bainite transformation.

Bainite transformation is a process of nucleation and growth, which usually needs an incubation period. Some carbon-rich zone and carbon-poor zone would be formed during the incubation period due to the redistribution of carbon atoms in austenite. The crystal nucleus of bainitic ferrite usually forms at the site of carbon-poor area. When pulse magnetic field is applied during isothermal bainite transformation, the Gibbs free energy of ferromagnetic product phase-bainitic ferrite will be largely reduced, but, the Gibbs free energy of paramagnetic parent phase-austenite is not obviously affected by pulse magnetic field. Thus, the driving force of isothermal bainite transformation is increased and the bainite transformation process is promoted by applying pulse magnetic field. However, when pulse magnetic field is applied during austenitizing and cooling process, carbon atoms in austenite will distribute more uniformly due to its better diffusion ability induced by pulsed magnetic field. This leads to the decrease of quantity of poor carbon area in austenite and the extension of incubation period of bainitic transformation. So, although pulse magnetic field could increases the driving force of isothermal bainite transformation, but the incubation period of bainitic transformation is extended. Therefore, compared with other two applying periods, applying pulse magnetic field during isothermal bainite transformation is the most effective way of accelerating bainite transformation.

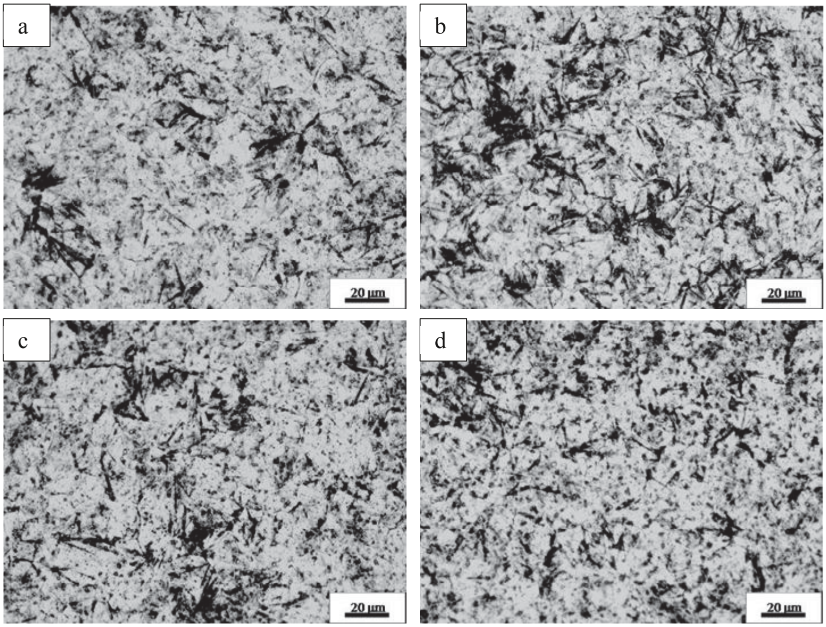

Figure 3. microstructure of samples applying pulse magnetic field in different process
(a) NT-a (b) PMT-b (c) PMT-c (d) PMT-d

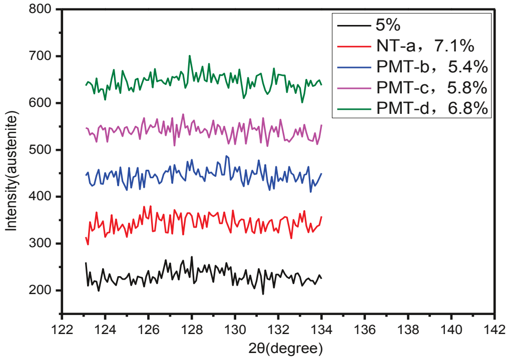

Fig. 4. Spectrum diagram and content of retained austenite

SEM microstructure of samples NT–a, PMT–b, PMT–c and PMT-d is shown in Fig.5. As is shown, compared with lower bainite in samples NT–a, PMT–c and PMT-d, flake carbides in bainitic ferrite of sample PMT–b are tiny in size, distributing at random. In samples NT–a, PMT–c, flake carbides arrange along 55 to 60 ° direction to the long axis of flake ferrite. But, in sample PMT-d, flake carbides approximately parallel to the long axis of ferrite. The formation of carbides in lower bainite needs supersaturated carbon atoms and alloying elements. Applying pulse magnetic field during isothermal bainite transformation influences the formation of carbides by affecting the diffusion of carbon and alloy elements. However, the formation of carbides is not influenced by applying pulse magnetic field during austenitizing + cooling.

Hardness of sample NT–a, PMT–b, PMT–c and PMT-d is HRC58.4, 55.4, 57.8 and 56.6, respectively. Hardness corresponds to mixed microstructure. Microstructure of sample NT–a, PMT–b, PMT–c and PMT-d is all composed of martensite matrix, needled lower bainite, granular carbides, and a small amount of retained austenite. The more content of bainite in the microstructure is, the fewer content of martensite matrix is, the smaller the hardness of sample is. Although the fraction of bainite transformation in sample NT–a is nearly the same as that in sample PMT–d, the content of retained austenite in sample NT–a is also nearly the same as that in sample PMT–d, the hardness of sample PMT–d is 1.8HRC lower than that of sample NT–a. It may be related to the number of M7C3 type carbides and the orientation of flake carbides in bainite ferrite in sample PMT–d.

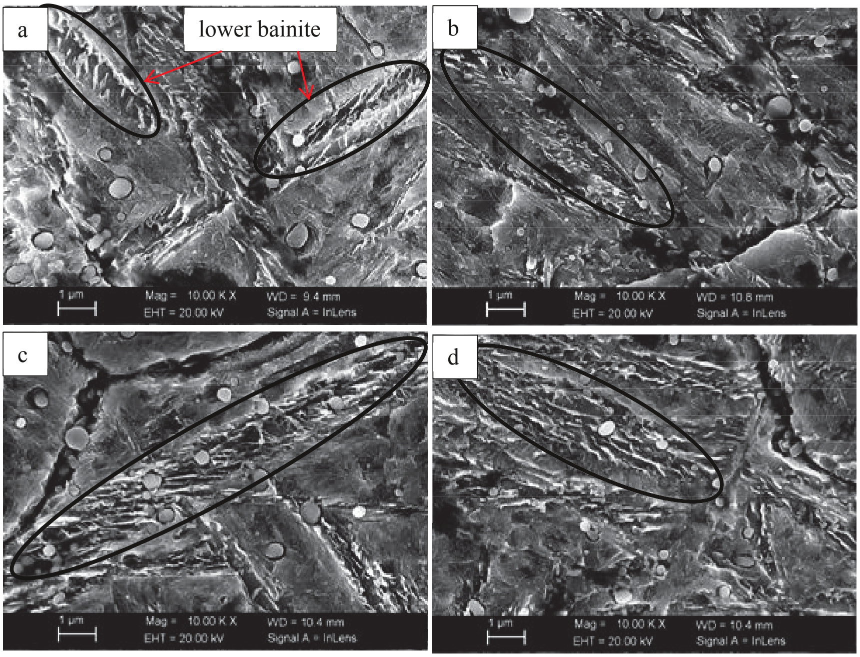

Fig.5. SEM microstructure of samples applying pulse magnetic field in different process
(a) NT-a (b) PMT-b (c) PMT-c (d) PMT-d

Conclusions

Applying pulse magnetic field during isothermal bainite transformation can obviously promote bainite transformation, the volume fraction of bainite increased by 4.2%, the volume fraction of retained austenite is reduced by 1.7%, and the hardness of Cr5 steel was reduced by 3 HRC. Flake carbides in lower bainite are dispersive and tiny in size. But, applying pulse magnetic field during austenitizing + continuous cooling + isothermal bainitic transformation does not accelerate the isothermal bainite transformation.

Acknowledgements

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