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Influence of Initial Microstructure on Warm Deformation Processability and Microstructure of an Ultrahigh Carbon Steel

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Abstract: Various isothermal compression tests are carried out on an ultrahigh carbon steel (1.2% C in mass percent), initially quenched or spheroidized, using a Gleeble-3500 system. The true stress is observed to decrease with increasing temperature and decreasing strain rate. The true stress of the initially quenched steel is lower than that of the initially spheroidized steel at high deformation temperature (700 ℃) and low deformation strain rate (0.001 s^{-1}). The value of the deformation activation energy (Q) of the initially quenched steel (331.56 kJ/mol) is higher than that of the initially spheroidized steel (297.94 kJ/mol). The initially quenched steel has lower efficiency of power dissipation and better processability than the initially spheroidized steel. The warm compression promotes the fragmentation and the spheroidization of lamellar cementites in the initially quenched steel. The fragmentation of lamellar cementites is the spheroidizing mechanism of the cementites in the initially quenched steel. Results of transmission electron microscope investigation showed that fine grains with high angle boundaries are obtained by deformation of the initially quenched steel.

Key words: ultrahigh carbon steel; initially quenched steel; initially spheroidized steel; deformation activation energy; high angle boundary

Ultrahigh carbon steels (1.0%−2.1% C in mass percent) are hypereutectoid steels, and their high carbon content leads to the segregation of carbon and the occurrence of coarse carbide network in the traditional processing and casting. Thus, ultrahigh carbon steels are considered to have such high brittleness at room temperature that they have very limited applications in the past. It was first found by Sherby[1−3] in the 1970s that ultrahigh carbon steels contain fine equiaxed ferrite grains and uniformly distributed spheroidized cementites after thermomechanical processing, which have excellent superplasticity.

According to recent research, processes with severe plastic deformation (SPD) are defined as metal-forming processes in which an ultra large plastic strain is introduced into a bulk metal to create an ultra-fine grained metal[4−8]. However, the severe plastic deformation of ultrahigh carbon steels at medium temperature has not been studied systematically. This paper investigated the behavior and the processability of an ultrahigh carbon steel (UHCS, 1.2% C in mass percent), which was initially quenched or spheroidized, under warm deformation compression.

1 Experimental

The ultrahigh carbon steels studied in this work had the following chemical composition (mass percent, %): C 1.26, Si 0.23, Mn 0.22, P 0.012, S 0.012 and Fe balance. Because of the hypereutectoid components, high temperature ($>A_{c1}$) quenching caused an increase in the residual austenite and a decrease in hardness. Thus, after machining cylindrical samples with size of $\phi 8$ mm × 12 mm, the obtained specimens were austenitized at 780 ℃ for 30 min and then quenched in brine. The initial quenched micro-

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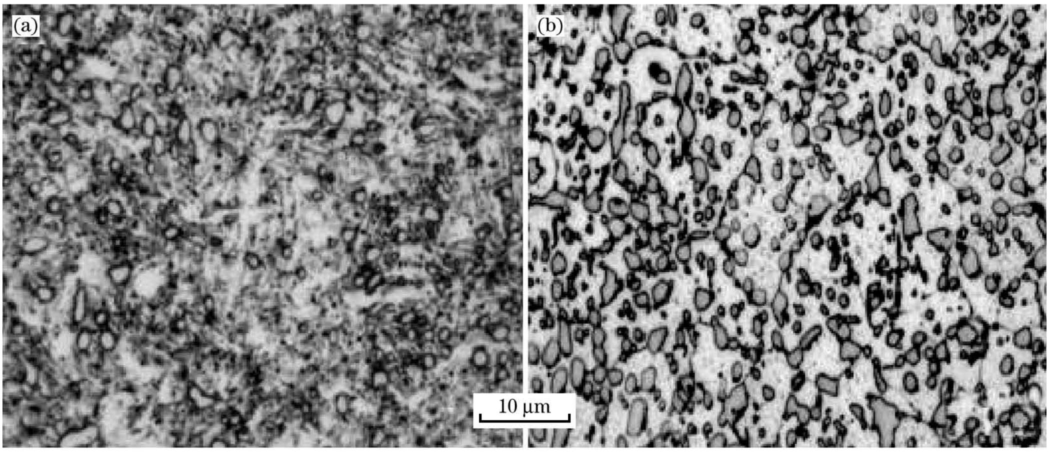
structure was plate martensite, with little residual austenite, and undissolved cementite particles. Other samples were isothermally and spheroidally annealed at an "oscillating" temperature between approximately 680 and 760 ℃ to obtain ferrite and granular cementites. The initial microstructure is shown in Fig. 1.

The samples were heated to 550, 600, 650, and 700 ℃ at a rate of 10 ℃/s and were compressed by 50% at a strain rate of $10^{-4}-1\ s^{-1}$ with a Gleeble-3500 thermal simulation testing machine. Tantalum plate was placed between the pressure head and the sample. MoS_2 was smeared on the end face of the samples for lubrication.

The microstructures of the samples before deformation were studied on an Axiovert 200 MAT metallographic microscope. Changes in the cementites and grains during warm deformation were examined using a KYKY-2800 type scanning electron microscope (SEM) operated at 20 kV and a JEM-2010 type transmission electron microscope (TEM) operated at 200 kV.



(a) Initially quenched; (b) Initially spheroidized.

Fig. 1 Optical micrographs of initial microstructure of 1.2% C (mass percent) steel

2 Results and Discussion

2.1 Influence on warm deformation mechanism

The effect of initial structure on warm temperature deformation has been frequently omitted in the literature. This effect was tested for ultrahigh carbon (1.2% C in mass percent) steels having distinctly differentiated structures, from a very stable structure (spheroidized) to the most unstable, the structure obtained after quenching.

Fig. 2 shows the true strain-true stress curves of initially quenched and initially spheroidized steel (1.2% C in mass percent) during warm compression deformation at temperatures of 550, 600, 650, and 700 ℃ for strain rates of 10^{-3}, 10^{-2}, 0.1, and 1 s^{-1}.

As can be seen, the true stress increased with decreasing temperature at a given strain rate and with increasing strain rate at a given temperature. The true strain-true stress curves of the initially quenched steel reached a peak stress and then decreased to a steady value with increasing strain, while the curves of the initially spheroidized steel reached a peak stress and then kept steady even with increasing strain. As reported in the literature[9,10], the flow stress curves of the initially quenched steel were work hardening, dynamic recovery and recrystallization curves, while the flow stress curves of the initially spheroidized steel were dynamic recovery curves. Moreover, an intersection point was present between the flow stress curves of the initially quenched and initially spheroidized steels. It should be noted that at a deformation temperature of 700 ℃ and a strain rate of 0.001 s^{-1}, the flow stress of the initially quenched sample was always lower than that of the initially spheroidized sample.

The relationship between the temperature and the strain rate could be explained using constitutive equations derived by Zener, Tegart[11] and Hollomon[12].

$$\dot{\varepsilon}=A[\sinh(\alpha\sigma)]^{n}\exp[-Q/(RT)] \quad (1)$$

where, α, n and A are constants; Q is the activation energy of deformation; R is the gas constant; $\dot{\varepsilon}$ is the strain rate; T is the absolute temperature of deformation; and σ is the peak stress.

Eq. (1) could be conveniently expressed in terms of a temperature-compensated strain rate parameter, the Zener-Hollomon parameter (Z),

$$Z=\dot{\varepsilon}\exp[Q/(RT)] \quad (2)$$