

Investigation on Dynamic Recovery Behavior of Boron Steel 22MnB5 under Austenite State at Elevated Temperatures

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ABSTRACT

Hot forming process of ultrahigh strength boron steel 22MnB5 is widely applied in vehicle industry. It is one of the most effective approaches for vehicle light weighting. Dynamic recovery is the major softening mechanism of the boron steel under austenite state at elevated temperatures. Deformation mechanism of the boron steel can be revealed by investigation on the behavior of dynamic recovery, which could also improve the accuracy of forming simulations for hot stamping. Uniaxial tensile experiments of the boron steel are carried out on the thermo-mechanical simulator Gleeble3800 at elevated temperatures. The true stress-strain curves and the relations between the work hardening rate and flow stress are obtained in different deformation conditions. The work hardening rate decreases linearly with increasing the flow stress. A flow stress model is derived based on Kocks model, and the derivative of the dislocation density with respect to the true strain, which is expressed by the peak stress and initial yield stress, is also deduced considering the dynamic recovery effect. A dynamic recovery efficiency factor h is defined as the ratio of the dynamic recovery effect and the dislocation accumulation effect. The effects of the deformation conditions on the h are analyzed.

INTRODUCTION

Hot stamping technology of boron steel 22MnB5 is one of the main effective approaches to realize automotive light-weighting^[1]. Its process is that the boron steel is first heated to austenite state (about 1173K), and transferred into the tools quickly. Then the steel sheet is formed and quenched simultaneously, finally a component with full martensitic micro structure is obtained. Hot stamping of boron steel at

austenite state is different from forging process. The temperature is higher when forging, and dynamic recovery and dynamic recrystallization will occur during this forming process^[2, 3]. Since the temperature in the hot stamping process is about 300K lower than forging, the dynamic recovery dominates the softening mechanism, and the hardening behavior of boron steel during forming is the result of the combination effects of dislocation accumulation and dynamic recovery. Its evolution can be expressed by an equation with single variable,

$$\frac{d\rho}{d\varepsilon} = \frac{d\rho_+}{d\varepsilon} + \frac{d\rho_-}{d\varepsilon} \quad (1)$$

where $d\rho_+/d\varepsilon$ is the effect of dislocation accumulation, and $d\rho_-/d\varepsilon$ is the effect of dynamic recovery, and the $d\rho/d\varepsilon$ is the work hardening behavior expressed with dislocation density considering dynamic recovery.

Many scholars have investigated the expression of $d\rho/d\varepsilon$ with dynamic recovery effect. Most of them made further extensions based on Kocks model^[4]. Nes and Marthinsen^[5, 6] investigated the dynamic recovery behavior according to the annihilation mechanism of dislocation dipole and the dynamic recovery model was demonstrated by experimental data of four kinds of metal. Yoshie et al.^[7] and Liu et al.^[8] have theoretically deduced the expressions of $d\rho/d\varepsilon$ and a flow stress model, respectively. There are few reports about the dynamic recovery behavior of the boron steel 22MnB5 and even about the dynamic recovery efficiency. In this paper, the relationship between work hardening rate and flow stress of the boron steel is obtained according to the flow stress strain curves at elevated temperatures. Based on Kocks

model, the expression of $dp/d\varepsilon$ is derived and described by a flow stress model and macroscopic stress parameters. The dynamic recovery efficiency factor h is defined as the ratio of the dynamic recovery effect ($dp/d\varepsilon$) and the dislocation accumulation effect ($dp_+/d\varepsilon$) and its expression is deduced. The influences of temperature and strain rate on the h are also analyzed and conclusions are drawn.

1. UNIAXIAL TENSILE EXPERIMENTS OF BORON STEEL AT ELEVATED TEMPERATURES

1.1. SPECIMENS

The steel sheet employed in experiments is 22MnB5 produced by Arcelor. Its chemical composition is shown in Table 1. The thickness of the specimens is 1.7mm and other dimensions of the specimens are shown in Fig.1. Fig.2 illustrates the flow properties of the as-received material at room temperature. As shown in Fig.2, its initial yield strength is about 383MPa. Since the material 22MnB5 exhibits no significant dependence on the rolling direction at elevated temperatures^[9], the specimens with length direction in the rolling direction were only be used.

Table 1. Material composition of 22MnB5

Alloy Elements	Content (wt%)
C	0.221
Mn	1.211
P	0.019
S	0.003
Si	0.258
Al	0.036
Ti	0.039
B	0.0037
Cr	0.190

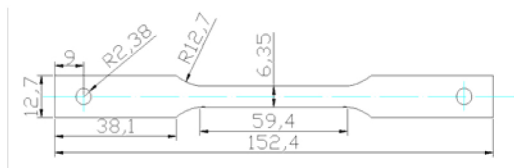


Figure 1. Sketch of the specimen for uniaxial tensile experiments (units in mm)

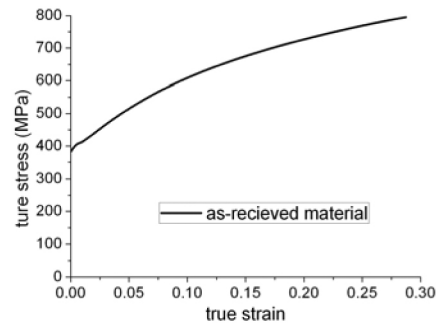


Figure 2. The flow property of the as-received material

1.2. EXPERIMENTAL EQUIPMENT

Gleeble 3800 thermal-mechanical simulation system shown in Fig.3 is chosen for the tensile experiments.

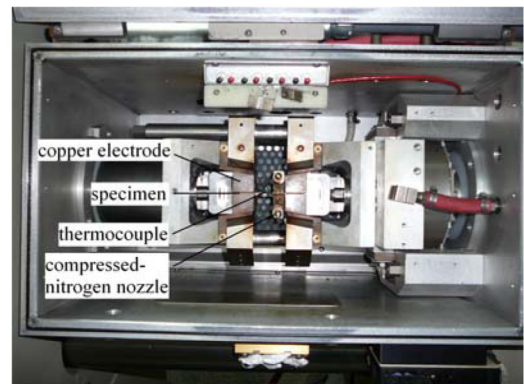


Figure 3. The thermo-mechanical simulator Gleeble 3800

1.3. EXPERIMENTAL METHOD

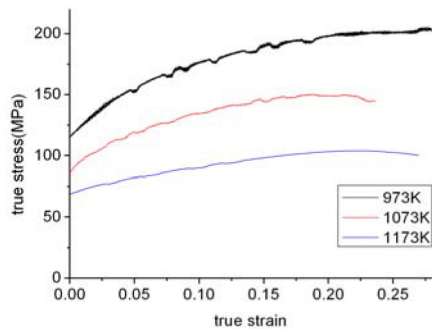
Two thermocouples were spot-welded at the middle of the specimens in advance. Then the specimens were fixed to the clamping apparatuses of the machine and the uniaxial hot tensile experiments were carried out. During the deformation, the temperature of the specimen was maintained isothermal.

The tensile experiments were performed in the following order: heat specimens to 1173K at a rate of 15K/s, and maintain the specimen at 1173K for about 5 minutes for soaking austenitization, then cool the specimens by two high pressure nitrogen nozzles to experimental temperatures with a cooling rate up to 90K/s and hold the specimen at experimental temperatures for 2 seconds, and then perform isothermal tensile experiments till fracture; finally, cool them with 90K/s to room temperature. Please note that the specimen with a deformation temperature of 1173K has no cooling phase after austenitization.

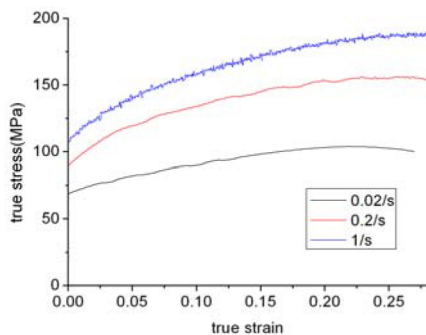
2. EXPERIMENTAL RESULTS AND ANALYSES

2.1. THE FLOW STRESS-STRAIN CURVES OF THE BORON STEEL AT ELEVATED TEMPERATURES

Figs.4a and 4b show the true stress-strain curves at different temperatures when strain rates are 0.02/s, 0.2/s and 1/s respectively. The flow stresses of the boron steel increase with increasing strain and become steady at larger strains in hot deformation conditions of this paper. Since the curve will increase firstly and then decrease to a steady state if a recrystallization effect exists, it can be seen from the curves in Fig.4 that there is no recrystallization effect. Therefore, the softening mechanism of boron steel at the experiment temperatures is dynamic recovery.



(a). The strain rate $\dot{\epsilon}$ is 0.02/s and the temperature varies from 973K to 1173K



(b). The deformation temperature is 1173K but the strain rate varies from 0.02/s to 1/s

Figure 4. The flow stress curves of the boron steel 22MnB5 under hot deformation

2.2. RELATIONSHIP BETWEEN THE WORK HARDENING RATE AND THE FLOW STRESS

The deformation process of boron steel at elevated temperatures can be understood as the competition of hardening and softening mechanisms, namely, the competition of dislocation accumulation and dynamic recovery effects. The competition results can be expressed by the work hardening rate as

$$\theta = f(\sigma) = \left. \frac{\partial \sigma}{\partial \epsilon} \right|_{T, \dot{\epsilon}} \quad (2)$$

The work hardening rate θ is a function of the flow stress σ when the temperature T and the strain rate $\dot{\epsilon}$ are unchanged. The obtained θ - σ relationships are shown in Figs.5 and 6. The work hardening rate θ decreases linearly with increasing the flow stress. When θ is close to 0, it means the flow stress becomes steady and doesn't increase. Due to almost linear relationship between θ and σ , it can be described by Kocks model by numerical fitting.

$$\theta = \frac{d\sigma}{d\epsilon} = A - B\sigma \quad (3)$$

where A and B are material constants and are shown in Table 2.

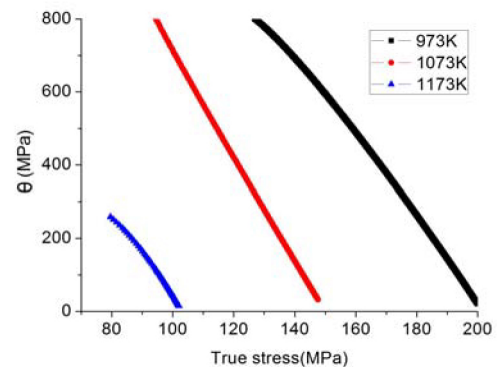


Figure 5. Relation between work hardening rate and flow stress at different temperatures