JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2007, 14(6): 63-67

Effects of Applied Stresses on Martensite Transformation in AISI4340 Steel

ZHAO Hong-zhuang[1,2], Seok-jae LEE[2], Young-kook LEE[2], LIU Xiang-hua[1], WANG Guo-dong[1]

(1. State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang 110004, Liaoning, China;
2. Department of Metallurgical Engineering, Yonsei University, Seoul 120-749, South Korea)

Abstract: This study aims at the experimental analysis of the transformation induced plasticity (TRIP) phenomenon. Experiments are conducted in which martensite is allowed to grow under the influence of a series of externally applied stresses. The magnitude of the applied stresses is less than 67% of the yield strength of austenite $\sigma_\gamma(T_s)$. Since there is no obvious difference between the transformation plasticity under tension and the compression for the lower applied stresses, only compressive stresses are applied. The results confirm that the transformation plasticity is proportional to the applied stress if the latter does not exceed 67% of $\sigma_\gamma(T_s)$. The TRIP-strain, the kinetics, and their dependence on the applied stresses are studied. The comparison between calculated results and experimental results shows that the model accurately describes the phenomenon.

Key words: applied stress; TRIP; martensite transformation; low-alloy steel

Transformation induced plasticity (TRIP) can be defined as the anomalous plastic strain that occurs when material transformation is affected by an external stress lower than the yield stress of the parent phase (weak phase). TRIP strain consists of not only a plastic contribution ("Greenwood-Johnson" effect), but also a contribution owing to the strain caused by the transformation shear component of the martensite (or bainite) variants ("Magee" effect). Both contributions have been studied[1-4].

The briefest equation of describing the Greenwood-Johnson mechanism result for a low, constant, and uniaxial stress is as follows[5]

$$\varepsilon^{tp} = K \cdot \varphi(\xi) \cdot \sigma \tag{1}$$

where K is a material parameter (TRIP coefficient), and $\varphi(\xi)$ is a normalized function governing the TRIP kinetics. Different forms of this function have been proposed to describe the TRIP phenomenon[5,6]. In fact, Eqn. (1) can be used to explain Magee effect, and parameter K may include the two effects mentioned above[3].

The purpose of the present study is to study the effects of externally applied stresses on martensite transformation. The relationship between the stress and the TRIP effects will be shown. Though the maximum value of applied stress σ is only more than half of the yield strength of austenite $\sigma_\gamma(T_s)$, it is shown evidently that M_s is affected slightly because of σ.

1 Experimental and Calculation Methods

1.1 Test material

The composition of the experimental steel AISI4340 (mass percent, %) is: C 0.39, Mn 0.65, Ni 1.60, Cr 0.67, Mo 0.15, Al 0.03, N 0.010, and Fe balance. Cylindrical specimens (10 mm in diameter, 15 mm in length) were machined for the purpose of the dilatometric experiments. In all experiments, the specimens were austenitized at 900 ℃ for 10 min.

1.2 Thermomechanical testing

The thermomechanical tests were carried out in a Gleeble 3500 thermomechanical simulator, which typically has a high speed heating system, a servo hydraulic system, and a computer control and data acquisition system. The thermal cycle is shown in Fig. 1. The sample was heated in a high vacuum chamber. The loading mode is compression. The loading stress levels were 0, 20, 40, 60, and 80 MPa; the

Foundation Item: Item Sponsored by Hi-Tech Research and Development Program of China (2001AA332020)
Biography: ZHAO Hong-zhuang(1966-), Male, Doctor, Lectureship; **E-mail**: zhz1966@sohu.com; **Revised Date**: November 24, 2006

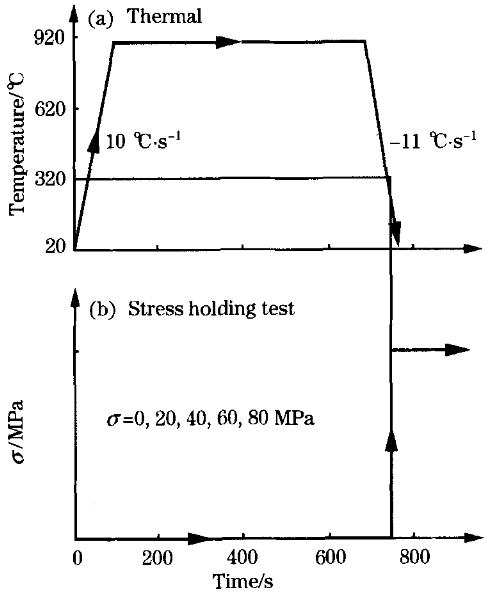

Fig. 1 Thermomechanical loading path

loading temperature was 320 ℃, and the loading speed was 80 MPa • s^{-1}. The heating and cooling rates were 10 ℃ • s^{-1} and 11 ℃ • s^{-1}, respectively.

Thermocouple was attached centrally to the specimen's surface. Uniaxial loads were applied by using the servo-hydraulic system which allowed either load, displacement, or stress control of the ram position. The specimen temperature, the uniaxial load, and both diametral and longitudinal displacements were measured concurrently.

1.3 Austenite yield strength

Since the value of the austenite yield strength is difficult to measure in the range of martensite transformation, its evaluation method is used. The yield strength is expressed using the empirical model by Young and Bhadeshia[7] as follows:

$$\sigma_y^\gamma = (1-0.26\times10^{-2}T_r+0.47\times10^{-5}T_r^2-0.326\times10^{-8}T_r^3)\times15.4[4.4+23w(\mathrm{C})+1.3w(\mathrm{Si})+0.24w(\mathrm{Cr})+0.94w(\mathrm{Mo})+32w(\mathrm{N})] \quad (2)$$

where, $T_r = T-25$, T is the temperature (℃), and w represents the concentration of the element (mass percent, %). The yield strength of the austenite is given in unit of MPa. The relation between σ_γ and temperature is shown in Fig. 2. σ_γ can be briefly fitted to a function of temperature (T) in the temperature range of 50—350 ℃.

$$\sigma_\gamma(T) = 0.0006T^2 - 0.538T + 226.52 \quad (3)$$

The maximum value of the external applied stress is 80 MPa, amounting to about 67% of $\sigma_\gamma(T_s)$

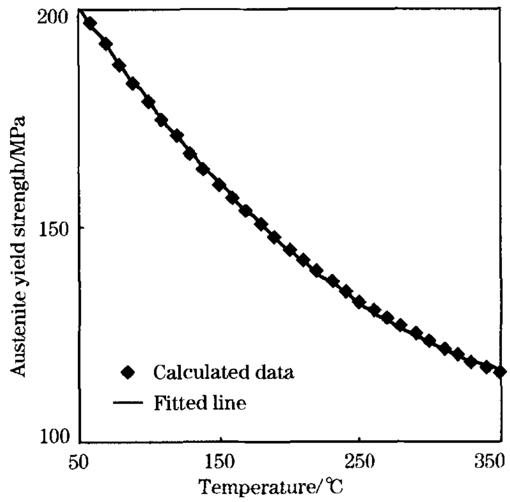

Fig. 2 Austenite yield strength as a function of temperature

at 320 ℃ (120 MPa). Thus, there will be no plastic deformation because of the applied stresses before martensitic transformation.

1.4 Martensite transformation start temperature

The calculated M_s was found to be 280 ℃. The effect of stress on the M_s was examined, with M_s measured as the temperature at which the slope of the radial strain vs. temperature graph began to change during quenching. Since the load will affect the M_s, the loads were applied at 320 ℃ at the same loading rate of 80 MPa • s^{-1}, just before the martensite transformation start temperature.

The M_s for steel AISI4340 can be estimated using the following equation[8]:

$$M_s = 561-474w(\mathrm{C})-33w(\mathrm{Mn})-17w(\mathrm{Ni})-17w(\mathrm{Cr})-21w(\mathrm{Mo}) \quad (4)$$

For this steel, M_s = 280 ℃, and M_f(90% martensite transferred) = 210 ℃. This indicates that the temperature at the end of martensite transformation is well above the room temperature (RT), and therefore, a quench directly to RT transforms almost all the austenite to martensite. Martensite can be furnished without any additional cooling.

1.5 Analysis of strain in martensitic continuous transformation

Specimens were cooled to the test temperature in the same way. The load was applied to the specimen at 320 ℃; since the cooling rate is 11 ℃ • s^{-1}, the full load could be applied to the specimen above 310 ℃. Radial and longitudinal strains (ε_R and ε_L) were measured simultaneously. The cylindrical