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Effect of orientation on self-organization of shear bands in 7075 aluminum alloy

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ABSTRACT

The spatial distribution of shear bands was investigated in the rolled 7075 aluminum alloy through the thick-walled cylinder (TWC) technique with 0°, 90° and 45° angles between the aluminum alloy cylinder axial direction and the rolling direction. Self-organization of multiple adiabatic shear bands was observed in different orientation specimens and investigated by using Schmid factor theories. The experimental results indicated obvious differences in the morphology and self-organization of shear bands for the specimens. At the initial stage, the spacing of the shear bands in the 0° specimen is smaller than in the other specimens. The nucleation of the shear bands in the 90° specimen is early. Due to the shielding effect, fast-developed shear bands block the development of the neighboring smaller shear bands in the 90° specimen. The spacing of the shear bands in the 45° specimen is much larger than in the other specimens under the similar effective strain. At the late stage, a large number of shear bands nucleate in the 0° specimen, and the spacing of the shear bands is small. The shear bands in the 90° specimen are well-developed with obvious shielding effect and the largest spacing. The 45° specimen has the maximum average nucleation rate of the shear bands. Owing to the close Schmid factors of the slip systems of the 45° specimen, the spacing of the shear bands in the 45° specimen is still larger than in the 0° specimen.

1. Introduction

Adiabatic shear band (ASB) is a narrow band-like region where plastic shear deformation is highly localized, and is one of the important failure mechanisms in materials deformed at high strain rates. Shear bands are observed in various types of dynamic experimental processes such as ballistic impact, projectile penetration and machining [1–5].

Shear bands were first observed and illustrated by Tresca at the 19th century [6]. The classic work of Zener and Hollomon [7] triggered intense efforts of the investigation of shear bands after the Second World War. Research [8] has addressed the mechanistic and microstructural features of shear bands. It is recognized that the behavior of ASBs is a significant part of the global high-strain-rate response of a material. The first mechanistic model of Recht [9] considered a simple balance between hardening and softening. Clifton [10], Bai [11], and Molinari and Clifton [12] introduced a perturbation analysis to advanced treatments. However, the research of the behaviors of multiple shear bands is very limited. Nesterenko et al. [13,14] observed the patterns of ASBs in Nb–Si powder mixtures and titanium. Meyers et al. [15] systematically investigated metals (Ti, Ta, Ti–6Al–4V, and stainless steel), granular and prefractured ceramics (Al_2O_3 and SiC), a polymer (Teflon) and a metallic glass ($Co_{58}Ni_{10}Fe_5Si_{11}B_{16}$), finding that shear bands exhibit a clear self-organization, with a characteristic spacing that is a function of a number of parameters. Xue et al. [16,17] analyzed the self-organization character of ASBs in stainless steel, Ti and Ti–6Al–4V, and the shielding factor was introduced. Yang and Wang et al. [18–22] studied the trajectory and spacing model of shear bands in commercial purity titanium [TA2(α-Ti)] and 7075 aluminum alloy, and analyzed the effect of strain rate, heat treatment and pre-notches on the self-organization character of shear bands by means of experiments and numerical simulation. However, the minority of studies addressed the effect of rolling induced microstructural orientation on shear bands. A study by Liu et al. [23] on dynamic mechanical behaviors indicated the effect of fibrous orientation on the susceptibility of tungsten heavy alloys to ASB.

The objectives of this work are to extend these findings by characterizing the evolution of multiple shear bands in the rolled 7075 aluminum alloy and to analyze the spacing characters with the Schmid factor theories. For the first time, the effect of rolling induced microstructural orientation on self-organization of shear bands in 7075 aluminum alloy is investigated.

2. Materials and experimental procedure

7075 Aluminum alloy was selected in this experiment and was heat treated to the T651 condition, which was solid solution fol-

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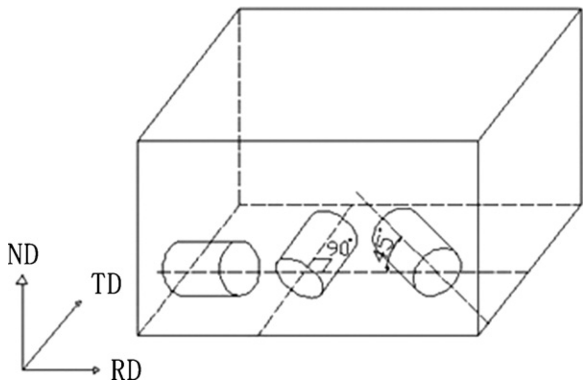

Fig. 1. Schematic of the 0°, 90° and 45° specimens machined off the 7075 aluminum alloy plate.

lowed by plastic deformation with strain about 1–3%, and then aged at 120 °C for 24 h. The cylindrical specimens for the TWC method were machined off the 7075 aluminum alloy plate, with the 0°, 90° and 45° angles between the aluminum alloy cylinder axial direction and the rolling direction, as shown in Fig. 1. Cylindrical specimens were machined with inner radius of 8 mm and thickness of 5 mm. For convenience, the three kinds of specimens were referred to as the 0° specimen, the 90° specimen and the 45° specimen, respectively.

The TWC method was first applied to shear bands by Nesterenko and Bondar [24,25]. The specimen is sandwiched between two copper tubes (Fig. 2). The explosive is axi-symmetrically placed around the specimen. The detonation is initiated on the top. The expansion of the detonation products exerts a uniform pressure on the cylindrical specimen and drives the specimen to collapse inward. Both the inner and external copper tubes were annealed at 300 °C/0.5 h protected by nitrogen. The copper driver was used to protect the specimen and ensure uniform deformation. The inner copper stopper with inner radius of 7 mm was used to control the final strain and prevent cracking of the specimen. The specimen and copper tubes were glued by epoxy resin to reduce shock wave reflection between the tube interfaces. The explosive is No. 4 rock powdery AN-TNT-FO explosive, with density ρ_0 (1000 kg/m^3) and detonation velocity V_d (3600 m/s), multiplex index γ (2.26) and explosive thickness H (35 mm). Specimens for optical metallography were sectioned perpendicular to the axis from deformed specimens, polished conventionally and etched using an acidic solution (10 ml H_2O, 10 ml HNO_3, 10 ml HCl and 5 ml HF). A Reichert Polyvar Met optical microscope was used for the morphologies of ASBs observations. In order to compare the deformation at the different positions on the specimen, an effective strain is used as

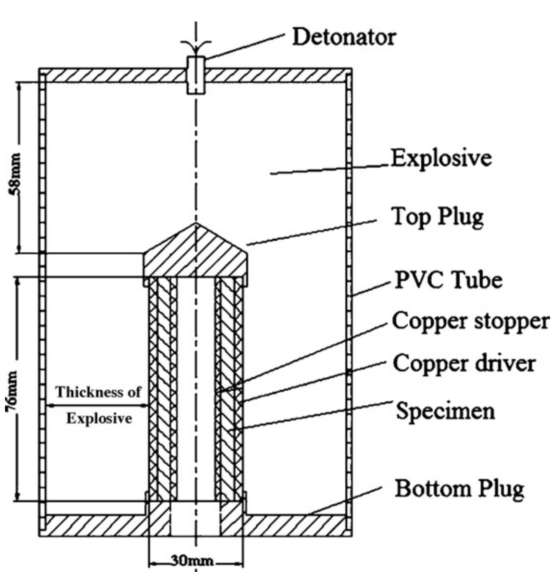

Fig. 2. The schematic of experimental configuration.

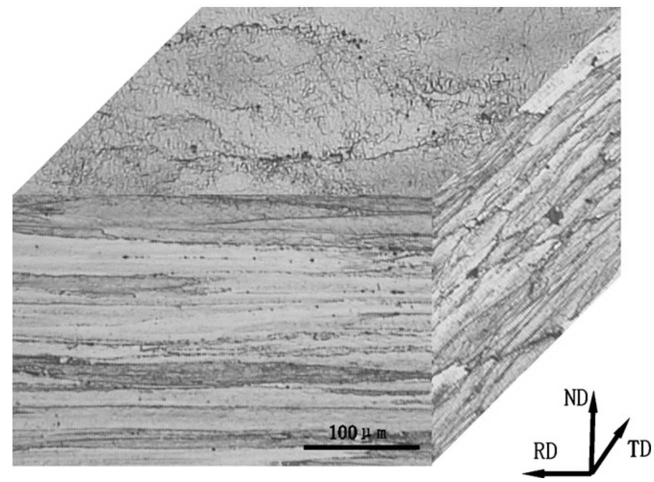

Fig. 3. Microstructure of the 7075 aluminum alloy plate.

$$\varepsilon_{ef} = \frac{2}{\sqrt{3}}\varepsilon_{rr} = \ln\left(\frac{r_0}{r_f}\right) \quad (1)$$

where r_0 and r_f are the initial and final radii of a reference point. The effective global strain at the internal boundary of the specimen is considered as a characteristic value of deformation since all the specimens have the same initial dimensions.

Texture study was performed at the 7075 aluminum alloy plate. A Bruker D8 discover X-ray diffractometer was employed for the data collection and the construction of {1 1 1}, {2 0 0}, and {2 2 0} and {3 1 1} pole figures. Orientation distribution function (ODF) plots were obtained from the pole figure data.

3. Experimental results

3.1. Microstructure of the 7075 aluminum alloy plate

The grain morphology of the 7075 aluminum alloy is represented in Fig. 3. The microstructure of the alloy on front face exhibits poorly discernible grains, which are strongly elongated along the direction of rolling. Material anisotropy is contributed to the fibrous structure formed by second phases, inclusions and elongated grains, which were distributed along the direction of rolling. The top face shows the microstructure on the normal section. Since, the primary deformation is concentrated on the normal compression and the extension along the rolling direction with the dynamic recrystallization in the process of rolling, the grain size of the alloy is large, and the grains is still elongated. On the side face, because of the deformation along the transverse direction, the microstructure exhibits elongated grains and clear grain boundaries unlike the fibrous structure.

The ODF plot is reproduced from four complete pole figures. Fig. 4 shows Φ_2 = 0 and 45 sections of the ODF plot. The texture of the 7075 aluminum alloy exhibits a significant {1 1 0} <1 1 2> of Brass orientation.