Materials Letters 143 (2015) 167–171

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

A novel combined severe plastic deformation method for producing thin-walled ultrafine grained cylindrical tubes

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ARTICLE INFO

Article history:
Received 28 November 2014
Accepted 20 December 2014
Available online 30 December 2014

Keywords:
Severe plastic deformation
Thin-walled tube
AZ31
Microstructure
Grain boundaries
Nanocrystalline materials

ABSTRACT

A novel severe plastic deformation (SPD) process entitled combined parallel tubular channel angular pressing (PTCAP) and tube backward extrusion (TBE) is proposed for producing thin-walled ultrafine-grained (UFG) tubes. In this new combined SPD approach, the PTCAP and TBE processes are consequently applied to the tube material in which a severe plastic strain is applied to produce a UFG thin-walled tube. This technique was performed on an AZ31 magnesium tube, and a remarkable grain refinement was achieved. The results showed that this method could easily produce a high strength thin walled tube. The microhardness increased significantly to 70 HV after the process from an initial value of 38 HV.

1. Introduction

Various severe plastic deformation (SPD) techniques have received much attention in recent years due to their efficient in improving properties of metallic materials [1]. In all SPD processes, the intense shear plastic strain is applied to the specimen and results ultrafine-grained (UFG) materials. Due to the Hall–Petch equation, materials with finer grain sizes exhibits higher yield strength. Equal channel angular pressing (ECAP) [2], accumulative roll bonding (ARB) [3], high pressure torsion (HPT) [4], and cyclic extrusion compression (CEC) [5] are successful SPD methods suitable for deforming bulk materials. Despite the need of high strength tubes for a wide range of industrial application, few SPD methods have been proposed for deforming tubular components. Many studies were done in recent years. Mohebbi and Akbarzadeh [6] developed accumulative spin bonding (ASB) inspired from ARB process to manufacture UFG tubes. Tóth et al. [7] proposed a high pressure tube twisting (HPTT) method. This method applies a high hydrostatic stress, but there is a large strain inhomogeneity through the radial direction. Faraji et al. [8,9] proposed tubular channel angular pressing (TCAP) as an effective method. Recently, they developed parallel tubular channel angular pressing (PTCAP) based on TCAP for producing UFG and nanostructure tubes [10,11]. Among these processes, the PTCAP has several advantages compared to other methods. It needs lower process load, in addition, there are a superior strain and hardness homogeneity through the thickness and length direction [10].

In all SPD methods for tubular components, there is a limitation that cannot be used for thin-walled tubes. Because, as the thickness of the tube is reduced, the most of the processing load is the friction force and so the friction is the main obstacle, and the SPD process is technically difficult to perform. In order to facilitate the SPD process for thin-walled tubes, the present work introduces a combined tube backward extrusion (TBE) and PTCAP method as a suitable process for producing nanostructured and UFG thin-walled cylindrical tubes. To investigate the applicability of this new combined SPD approach, an AZ31 magnesium tube is processed.

2. Principles of the process

This new combined method consists of two stages of PTCAP and TBE processes. First, the PTCAP process is applied to the thick tube and then the TBE process is consequently applied to reduce the thickness. The PTCAP process consists of two half cycles shown schematically in Fig. 1. In the first half cycle, the first punch presses the tube material into the gap between mandrel and die including two shear zones to increase the tube diameter (Fig. 1(a)). Then the tube is pressed back using the second punch in the second half cycle, decreasing the tube diameter to its initial value (Fig. 1(b)). In the next step, the TBE process shown schematically in Fig. 1(c) is applied to the UFG PTCAP processed tube. In this stage, the punch presses the tube to reduce its thickness. The equivalent strain

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http://dx.doi.org/10.1016/j.matlet.2014.12.107
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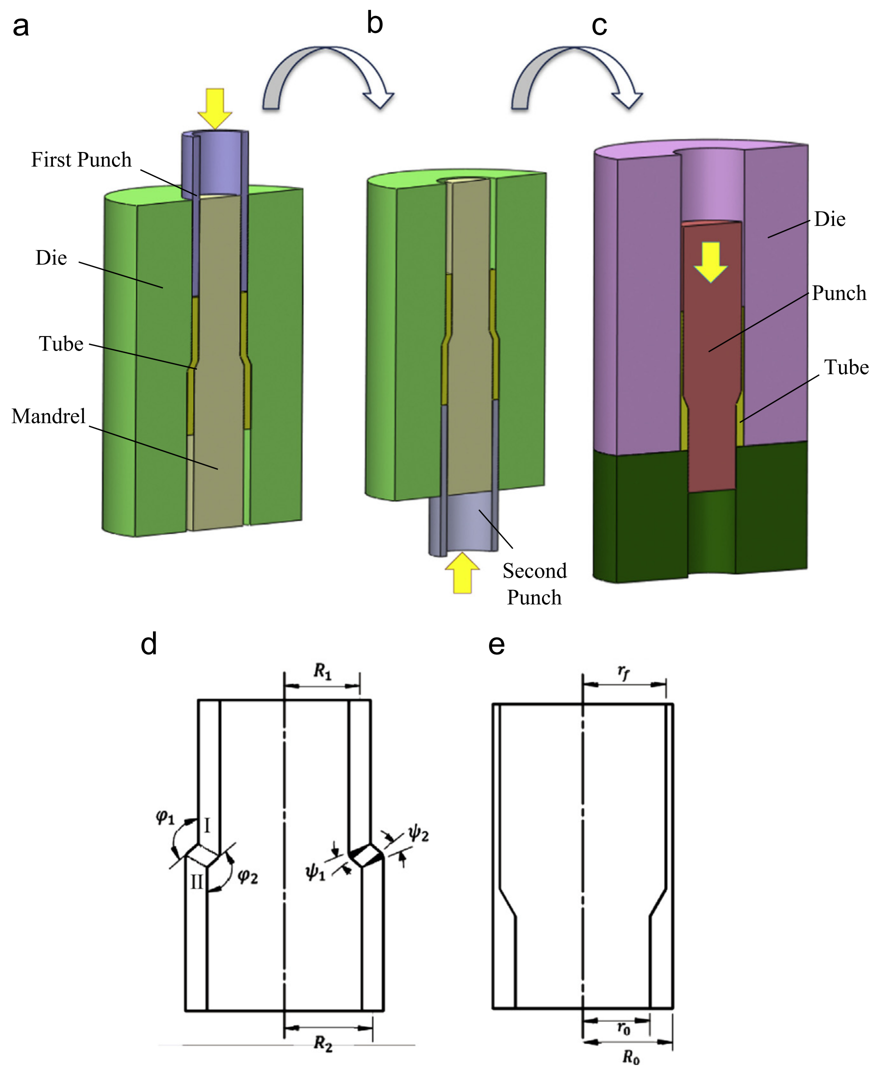

Fig. 1. Schematic of the combined process; (a) the first and (b) the second half cycles of PTCAP and (c) TBE and die parameters of (d) PTCAP and (e) TBE stages.

achieved from the N passes of PTCAP stage can be estimated via the following equation [10]:

$$\bar{\varepsilon}_{PTCAP} = 2N\left\{\sum_{i=1}^{2}\left[\frac{2\cot(\phi_i/2+\psi_i/2)+\psi_i\,\mathrm{cosec}(\phi_i/2+\psi_i/2)}{\sqrt{3}}\right]+\frac{2}{\sqrt{3}}\ln\frac{R_2}{R_1}\right\} \quad (1)$$

where R_1, R_2, φ and ψ were shown in Fig. 1(d). With assuming the uniform deformation, the following equation can be used for the equivalent strain in the TBE stage of the combined process:

$$\bar{\varepsilon}_{TBE} = \ln\frac{A_0}{A} = \ln\frac{R_0^2-r_0^2}{R_0^2-r_f^2} \quad (2)$$

where t_1 and t_2 are shown in Fig. 1(d). The total equivalent strain at the end of the combined process is equal to the sum of Eqs. (1) and (2):

$$\bar{\varepsilon}_{tot} = 2N\left\{\sum_{i=1}^{2}\left[\frac{2\cot(\varphi_i/2+\psi_i/2)+\psi_i\,\mathrm{cosec}(\varphi_i/2+\psi_i/2)}{\sqrt{3}}\right] + \frac{2}{\sqrt{3}}\ln\frac{R_2}{R_1}\right\} + \ln\frac{R_0^2-r_0^2}{R_0^2-r_f^2} \quad (3)$$

The total equivalent accumulative plastic strain after PTCAP (1.6) and TBE (1.2) considering the parameter used in this study is about 2.8.

3. Experimental procedures

The material used in this study was an AZ31 magnesium alloy. Tubular samples of 20 mm in outer diameter, 2.5 mm in thickness and length of 35 mm were prepared. The PTCAP and TBE dies were manufactured from hot-worked tool steel and hardened to 55 HRC. Die parameters for PTCAP and TBE stages were shown in Fig. 1(d) and (e), respectively. Die parameters are as following: the channel angles $\varphi_1=\varphi_2=150^\circ$, the angle of the curvature $\psi_1=\psi_2=0^\circ$, $r_0=15$ mm, $R_0=15$ mm, $r_f=9.25$ mm, $r_0=15$ mm, $R_0=15$ mm and $r_f=9.25$ mm. In TBE process, the thickness of the tube is reduced from the initial value 2.5 mm to 0.75 mm (extrusion ratio is 70%). The PTCAP and TBE processes were performed at the ram speed of 10 mm/min at 250 °C. The MoS_2 lubricant was sparyed on the specimens and dies to reduce the friction. All the samples were cut along the axial direction and microstructural and microhardness investigations were done in this cross section at the point near the middle of the thickness. The