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Characterization of ultrafine-grained aluminum tubes processed by Tube Cyclic Extrusion–Compression (TCEC)

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ABSTRACT

Tube Cyclic Extrusion–Compression as a novel severe plastic deformation technique for tubes was utilized for processing ultrafine grained 1050 aluminum alloy for the first time. In this method, aluminum tube is fully constrained and deformed between mandrel and chamber with a small neck zone. The material deformation during Tube Cyclic Extrusion–Compression processing analyzed and the grain refinement mechanism were described. The capability of Tube Cyclic Extrusion–Compression in grain refinement of the aluminum alloy was demonstrated by transmission electron microscopy observations and X-ray diffraction line profile analysis. The micrographs of the evolved microstructure show grain size of 850 nm and 550 nm after the first and second processing cycles of Tube Cyclic Extrusion–Compression, respectively. Mechanical properties of the initial and processed specimens were extracted from ring-hoop tensile tests. The documented results confirm grain refinement by showing remarkable increase in the yield and ultimate strengths. The main increase in strength and decrease in elongation take place after the first cycle. The microhardness assessments illustrate increase from the initial value of 29 Hv to 44 and 49 Hv respectively after the first and second cycles of Tube Cyclic Extrusion–Compression. There is a good homogeneity in peripheral microhardness and microhardness across the tube thickness.

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1. Introduction

Intensive investigations over the last decade have been devoted to the applications of severe plastic deformation (SPD) in processing materials due to the superior and unique mechanical and physical properties of ultrafine grained (UFG) and nano grained (NG) materials fabricated by SPD techniques [1,2]. Among the developed SPD processes, Equal Channel Angular Pressing (ECAP) [3], Cyclic Extrusion Compression (CEC) [4]; Accumulative Roll Bonding (ARB) [5]; and High Pressure Torsion (HPT) [6] are the most commonly used methods. Most of the SPD methods were proposed for producing bulk and sheet parts and few researches have been devoted for processing tubular shaped materials. However, increasing demands for high strength and at the same time light tubes in nowadays industries have attracted efforts of researchers for proposing SPD methods especially developed for producing UFG and NG tubes. These efforts resulted in development of High Pressure Tube Twisting (HPTT) by Toth et al. [7], Accumulative Spin-Bonding (ASB) by Mohebbi and Akbarzadeh [8], Tube Channel Pressing (TCP) by Zangiabadi et al. [9], Tubular Channel Angular Pressing (TCAP) and Parallel Tubular Channel Angular Pressing (PTCAP) by Faraji et al. [10,11],

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Tube High-Pressure Shearing (t-HPS) [12] and Repetitive Tube Expansion and Shrinking (RTES) by Jafarzadeh et al. [13]. Finally, in line with these efforts, the authors recently presented two novel SPD techniques for tubular materials: Tube Cyclic Extrusion–Compression (TCEC) [14] and Tube Cyclic Expansion–Extrusion (TCEE) [15]. Nowadays, aerospace and automobile industries demand for high strength yet light metals and alloys. Accordingly, aluminum and its alloys are the most attractive materials. In recent years, some of the SPD processes have been applied to pure aluminum and its alloys to obtain UFG and NG microstructures. Commercially pure aluminum 1050 from 1xxx aluminum alloys series is generally known as low strength aluminum compared to the other aluminum series. Low strength in this alloy is attributed to the fewer precipitated particles and solute atoms as barriers against dislocation mobility. Nevertheless, some severe plastic deformation techniques such as accumulative roll-bonding [16], equal channel angular pressing [17,18], friction stir welding (FSW) [19], and high pressure torsion [6] have been utilized for processing Al 1050 to moderate strength with low cost.

TCEC method [14] recently developed for SPD processing of tubular materials has been inspired from CEC which was first introduced by J. Richert and M. Richert [20] and then further discussed [21–24]. In this study, TCEC for the first time was applied to the 1050 aluminum tubes, and ultrafine grained tubes were achieved. The commercial Al 1050 was processed by two cycles of TCEC to demonstrate its applicability and capability in grain refinement. The TCEC processed specimens were investigated in terms of microstructural evolution, mechanical properties and microhardness variations. The results obtained from TCEC and other SPD processes were also compared.

2. Principles of TCEC

Fig. 1 depicts schematic illustrations of TCEC process. In TCEC, the initial tube is placed between the chamber and mandrel. The mandrel diameter is equal to the inner diameter of tubular specimen and a short thicker cross section was devised on it which provides a small neck zone between mandrel and chamber as shown in Fig. 1(a). Then, as shown in Fig. 1(a), the tube is fully constrained from all sides by fastening two end caps to the top and bottom sides of the chamber. These caps are fitted to the mandrel with a small clearance and allow mandrel to easily slide and move inside them. The developed space among the mandrel, chamber and two end caps fully encloses the tubular specimen during the deformation. The enclosed tubular specimen can be processed by pushing the mandrel downward until all the cross sections of the specimen passes the neck zone shown in Fig. 1(a). TCEC method is a cyclic process in which the cross section of the processed tube is first reduced while extruding from the neck zone between mandrel and chamber and subsequently compressed to initial thickness after passing the neck zone. No need for back pressure, low amount of friction, no restriction on the cross-section and length of tubes because of low friction and forming loads, low cost, simplicity of tools and process operation are the main advantages of the TCEC method. The amount of total accumulated strain after N cycles of TCEC process (ε_{tN}) can be calculated using the following equation [14] derived from the geometry of Fig. 1:

$$\varepsilon_{tN} = N\varepsilon_t = 2N \times \left[Ln\left(\frac{R^2 - r^2}{{R_0}^2 - {r_0}^2}\right) + \frac{4}{\sqrt{3}}\cot\left(\frac{\phi}{2}\right)\right]. \quad (1)$$

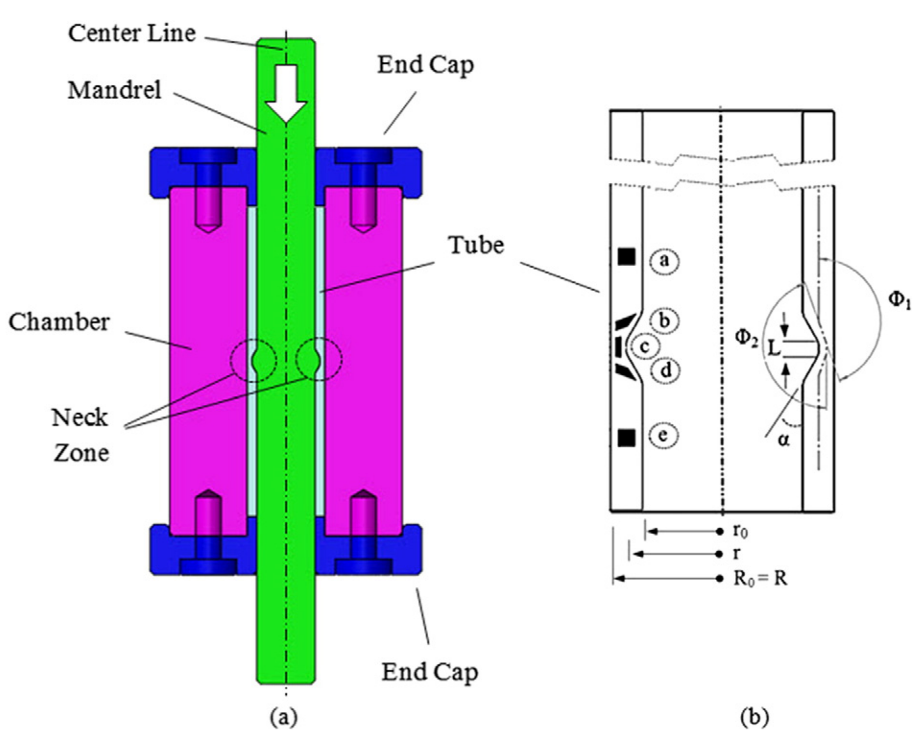

Fig. 1 – (a) Schematic of TCEC and (b) deformation regions and major processing parameters.

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