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Deformation and densification behavior of discrete media filled thin-walled tubes during forward extrusion

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Abstract: Discrete media filled thin-walled hollow profiles are frequently used as integer structures for special purpose, e.g., in certain materials processing or architectural components. To understand the deformation of such composite structures which is a complicate mechanics process, involving coupled elastic-plastic deformation of dense metal, compaction of particle and interaction between the filler and the wall, the forward extrusion of Al 6061 tubes filled with various particles was studied. The analysis regarding internal volume variation of round tubes during forward extrusion indicates that with the diameter reduction the volume of tubes decreases commonly. The cavity shrinkage brings about triaxial pressure on the filler, resulted in compaction and densification of it. Loose powders filling leads to higher extrusion load. Due to dissimilar migration behaviors of the particles, the load−stroke curves of the tubes filled with fine powders and coarse balls are quite different. Small Lankford value of the tube wall material leads to higher hydrostatic pressure of the filler and then more powders are compacted.
Key words: tube; forward extrusion; powder; deformation behavior; densification

1 Introduction

Discrete or porous media filled thin-walled tubes can be utilized as integer structures for special purpose in the fields of manufacturing, construction, transportation, etc. For example, power-in-tube (PIT) technology is so far the main approach to produce superconducting MgB_2 strands [1−3]. During the course, raw materials, namely a mixture of Mg and B powders, are enclosed in a non-reactive metallic tube in advance and drawn with the tube, shrinking the diameter, and finally reacted by sintering to form MgB_2. In the bending of thin-walled tubes, sometimes the hollow workpiece is filled with discrete powders (e.g., sand) before forming, and then the tube wall is supported from inside during deformation and the section distortion can be alleviated to a large extent [4]. Furthermore, ZHAO et al [5] employed solid particles (steel balls) as pressure medium in the expansion of thin-walled tubes, while LEE et al [6] compared the microstructure and characteristics of bulk magnesium consolidated from Mg powder by equal channel angular extrusion (ECAE), with varying temperature and extrusion pass.

Due to special mechanical properties, the application of internally filled hollow profiles such as steel tube confined concrete (STCC) columns or concrete filled steel tubular (CFST) columns has been the interests of many structural engineers [7,8]. Moreover, DARVIZEH et al [9] studied the effect of low density, low strength polyurethane foam on the energy absorption characteristics of circumferentially grooved thick-walled circular tubes. MIRFENDERESKI et al [10] investigated the crushing behavior of empty and foam-filled thin-walled tubes under static and dynamic loading, while DUARTE et al [11] studied the dynamic and quasi-static bending behavior of aluminium foam filled thin-walled aluminium tubes.

The deformations of discrete medium filled profiles are coupled complicated mechanics processes involving multiple affecting factors along with their interactions. Besides the elastic-plastic deformation of dense metal, the filler undergoes different stages of deformation as it is compacted, including particle rearrangement, rotation and deformation, and all contribute to the macroscopic response to the structures. As well known in the field of

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powder metallurgy (PM), the response of the powder mass during compaction has a significant influence on the evolution of density during subsequent stages of the manufacturing process. Many studies have been devoted to understanding the flow and deformation rule of loose powder during compaction [12−14]. However, the studies regarding the frame of mechanics condition during the integral forming of powder filled tubes are very rare. In the preparation of superconducting materials by drawing and so on, it is frequently encountered that the processing parameters were inappropriately selected, resulted in fracture at interface and uneven distribution of microstructure. Therefore, it has theoretical and engineering significance to examine the coupled deformation of discrete medium filled tubes during various forming courses.

In the current study, forward extrusion of thin-walled tubes filled with different discrete particles, which is a typical deformation of these kinds of composite structures, was investigated by means of experiment and finite element method (FEM). The effect of processing and geometrical parameters on the variation of inner volume of tubes under varying extrusion conditions was analyzed, meanwhile, the deformation and densification behavior of the composite structures were examined.

2 Experimental and numerical simulation methods

2.1 Experiment

Figure 1 shows the experiment setup for forward extrusion. The experiments were conducted on an SANS CMT 5105 universal material testing machine. The conical angle θ of the die is 15°. Al 6061 aluminum round tubes (d20 mm × 1.5 mm × 70 mm) were used, and the fillers are reduced iron powders (0.075 μm) and chrome molybdenum alloy steel balls ranging from 0.3 to 0.8 mm in diameter, as shown in Fig. 2. Basic performance parameters of the media are listed in Table 1. The friction angle was tested using a strain-controlled direct shear apparatus (model ZBQ−4)

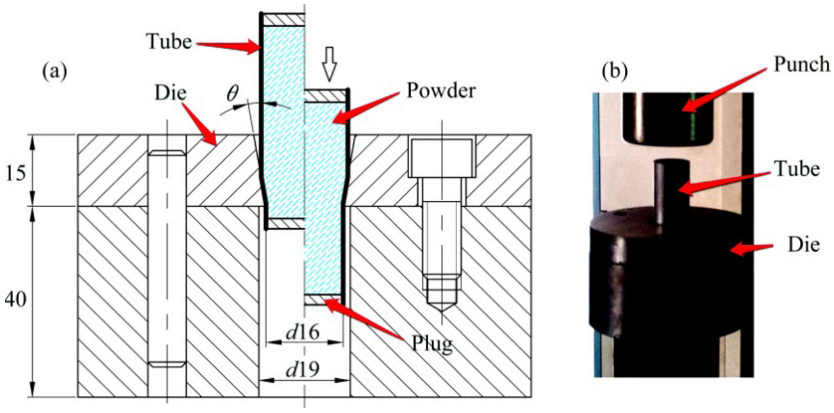

Fig. 1 Forward extrusion of thin-walled tube filled with loose particles: (a) Schematic diagram (unit: mm); (b) Photograph of experiment setup

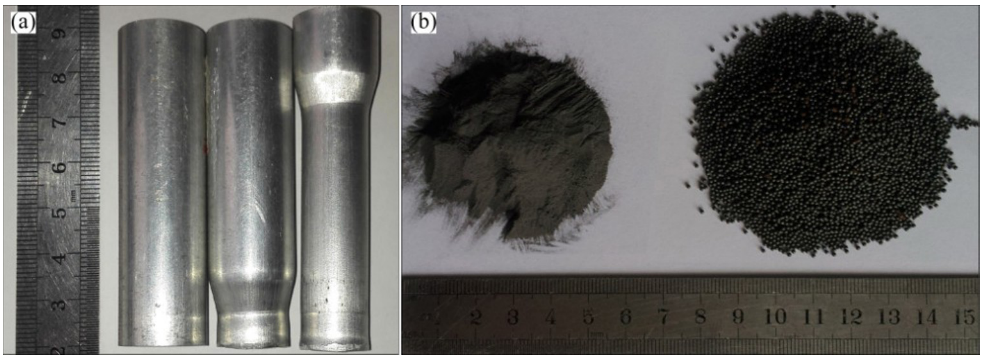

Fig. 2 Tubular samples and fillers in experiments: (a) Al 6061 tubes, from left to right: original tube, before and after extrusion; (b) From left to right: iron powder, steel balls

Table 1 Mechanical parameters of fillers

Filler	Apparent bulk density/(kg·m^{-3})	Elastic modulus (dense state), E/MPa	Poisson ratio (dense state), ν	Internal friction angle, β/(°)
Fe powder	2550	14000	0.3	35.8
Chrome molybdenum alloy steel balls	4330	5900	0.33	31.7