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Superplastic forming of bellows expansion joints made of titanium alloys☆

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Abstract

A new forming technology was developed for bellows expansion joints. This technology uses superplastic forming (SPF) method of applying gas pressure and compressive axial load. It is developed and can be used to manufacture large diameter "U" type bellows expansion joints made of titanium alloys. The forming technology for bellows expansion joints made of titanium alloys is presented to make a two-convolution bellows expansion joint of Ti–6Al–4V alloy as an example. Welded pipe bent by a hot bending method with a set of specific dies and welded by plasma arc welding was used as a tubular blank in the SPF. During the SPF process the tubular blank is restrained in a multi-layer die block assembly which determines the final shape of convolution. The forming load route is divided into three steps in order to obtain optimum thickness distribution. This technology can also be used to fabricate stainless steel bellows expansion joints.

Keywords: Bellows expansion joint; SPF; Titanium alloy

1. Introduction

Bellows expansion joints are used to absorb expansions or contractions in piping systems caused by irregular heat expansion, vibration, non-uniform subsidence of the ground, etc. In general, the usual metal materials for bellows expansion joints include: (1) austenite and dual phase stainless steel; (2) anti-corrosion alloys and refractory alloys; (3) colomony; and the manufacturing methods include hydraulic forming, mechanical forming, welding forming and deposit forming.

The material performances of titanium alloys namely service temperature, cycle stress, and corrosion resistant are very suitable for making bellows expansion joints. However, because of their large deformation resistance, severe springback, low plasticity and formability at room temperature [1]. Fabrication of bellows expansion joints using mechanical forming methods is complicated and expensive. Up to now there is little literature about this [2]. On the other hand, titanium alloy is a sort of natural superplastic material. The 'natural' means that many commercial titanium alloys possess stable equiaxed fine grain microstructure and superplasticity. The superplasticity of Ti–6Al–4V titanium alloy is the best among of them, for instance the elongation can exceed 1000% [3]. Therefore "U" type bellows expansion joints can be made by using complex SPF technology and applying gas pressure and compressive axial load.

A bellows expansion joint of titanium alloys has excellent corrosion-resistant performance and can be used to match a press vessel of titanium alloys and replace that of stainless steel and anticorrosion alloy. The new SPF technology of fabricating bellows expansion joints was first developed by the authors.

According to the service requirements of bellows expansion joints, the wall thickness of as-formed parts should have a uniform thickness distribution. The finite element method (FEM) is used to simulate the SPF process. It is in order to predict the thickness distribution, optimum forming pressure and intermediate deformed shapes, and design the dimensions of original material prior to testing. Hence, experimental cost and time can be saved [4–7].

2. The forming principle

The bellows profile is shown in Fig. 1. If only gas pressure load is applied during the SPF process, it would produce a large deformation. The result in severe wall-thickness thinning and non-uniform thickness distribution of as-formed bellows. The

☆ In this paper, the forming technology of titanium alloys bellows, the elastic elements of bellows expansion joints, is presented to make a two-convolution bellows of Ti–6Al–4V alloy as an example.

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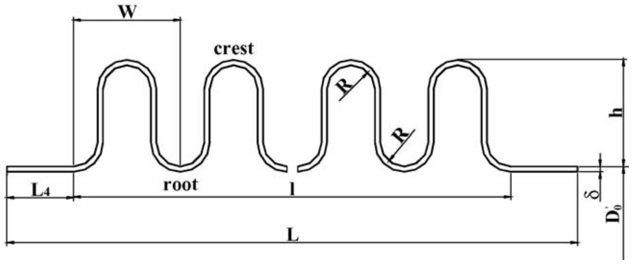

Fig. 1. Bellows profile.

complex SPF method of applying gas pressure load and compressive axial load is adapted. In this method the metal can be pushed into a deformation zone during forming. The forming schematic diagram is shown in Fig. 2. In order to avoid the plate's sticking to dies ahead of time and obtain to uniform thickness distribution. The SPF procedure is designed as follows: (1) The tubular blank is assembled with the die block assembly together. (2) Gas pressure is imposed into the tubular blank to cause suitable plastic deformation. Namely the generating line of the formed tubular blank should be slightly shorter than that of the bellows. (3) The punch is operated downward to close upper, middle and lower dies together. (4) The gas pressure is increased gradually until the whole cylinder wall sticks to the dies.

The dimensions of the bellows are controlled by dies. A multi-layer die block assembly is designed to fabricate multi-convolution bellows. So for a two-convolution bellows, forming dies include upper, middle and lower dies. For the convenience of taking out the deformed bellows from the die, all except upper and lower dies have a half structure and the straight segments of both upper and lower dies have a little slope. The whole die block assembly is machined from cast heat-resisting alloy.

3. Forming process of the bellows

The forming process of the bellows includes a tubular blank fabrication process and SPF process, their flow process diagrams are as follows, respectively:

- Tubular blank fabrication process:

  cutting plate material → bending tubular blank
  → welding tubular blank → radiographing
  → sizing tubular blank
  → welding cover with gas entrance connection

- SPF process:

  painting graphite power on dies and high temperature
  anti-oxidize on tubular blank → assembling
  → bulging → furnace cooling → demoulding
  → turning the straight segment → grit blasting

The material used was commercial mill-annealed Ti–6Al–4V alloy thin plate of 1.28 mm thickness.

3.1. Tubular blank fabrication

According to the results of experiments and simulation, the width W and the length L of the plate blank fabricating tubular blank can be calculated from formulae (1) and (2), respectively, and the diameter D of end cover can be determined from formula (3)

$$W = 2L_4 + nC(2\pi R + 2h + \pi\delta) + 10 \quad (1)$$

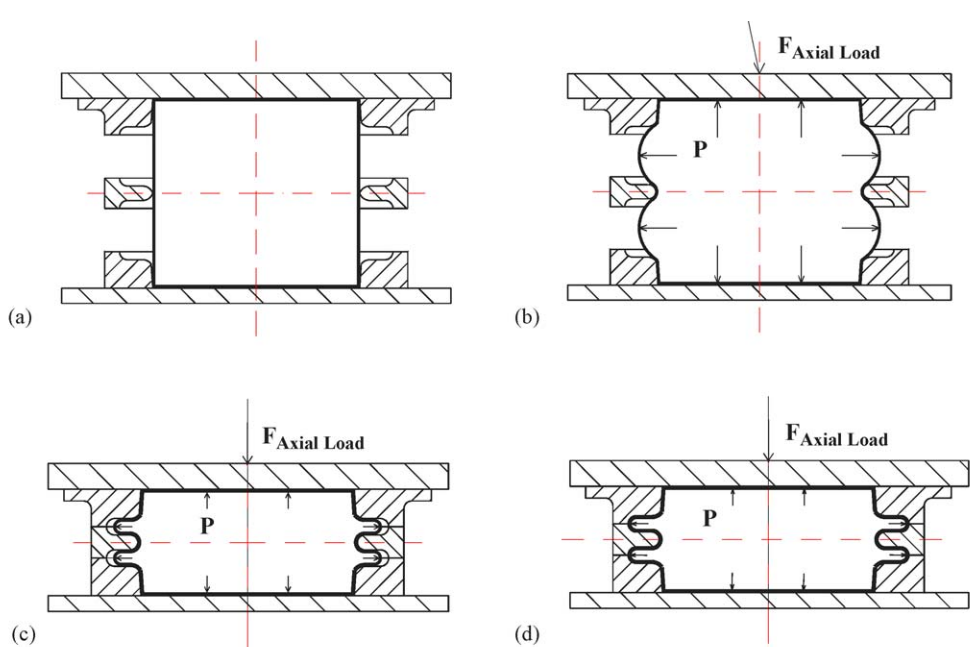

Fig. 2. SPF procedure: (a) original state, (b) bulging, (c) dies clamping, (d) shape forming.