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Review on hot spinning for difficult-to-deform lightweight metals

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Abstract: Hot spinning process has attracted significant attention because it can be used to manufacture complex parts, extend the forming limit of materials, decrease forming forces and reduce process chains. In this paper, we review researches on lightweight metals spun at elevated temperatures since they are difficult to deform at room temperature. These metals include light alloys, such as titanium, magnesium and aluminum alloys, and metal composites. Then, the heating methods used in the hot spinning process and the treatment methods employed for the temperature boundary condition in finite element analyses for the process were discussed. Finally, the future development directions for the hot spinning process of lightweight but difficult-to-deform alloys were highlighted.
Key words: hot spinning; lightweight metal; heating method; temperature boundary condition; future development direction

1 Introduction

Metal spinning refers to a type of forming process that allows for the production of hollow, mainly axisymmetric components. These components are used widely in the aviation, aerospace, weapons and automobile industries as items such as the supporting cones of jet motors, turboshafts, tailing spouts, the nose cones of rocket engines, the end plates of oil pockets and the connecting rods of automobiles [1−5], as shown in Fig. 1. In recent years, there is an increasing demand for structural components with high strength, light weight and good corrosion resistance to meet the requirements for faster flight speed, longer voyages and lifetimes. Therefore, light metals with the above properties such as titanium alloys, magnesium alloys, aluminum alloys and metal composites have been used more and more widely. Because of the high resistance to deformation and limited ductility at room temperature while large deformation is required, these metals usually have to be formed by heating to specific temperatures to improve their spinnability, decrease forming forces, and reduce process chains [6−8].

Several reviews on spinning have been published in recent years. XIA and XIAO [9] reviewed the novel spinning processes that were used to manufacture complex geometry parts which include non-axisymmetrical spinning, non-circular cross-section spinning, and tooth-shaped spinning. MUSIC et al [10] conducted a thorough survey of academic work on the analysis and application of spinning mechanics and proposed several gaps in the current knowledge of spinning mechanics. WONG et al [11] reviewed the process details of spinning and described developments in terms of researches and industrial applications as well as directions in researches and development for future industrial applications. NEUGEBAUER et al [12] provided an overview on research activities in the field of forming operations at elevated temperatures. JESWIET et al [13] reviewed the progress of metal forming since 2000, including microforming, single-point forming and sheet forming process such as hot spinning. YANG et al [14] reviewed the forming techniques including spinning, used for large-scale integral complex components of titanium alloys. WANG et al [15] introduced the spinning forming of AZ31 and AZ31B magnesium alloys in Japan before 2008. However, none of these reviews focused on the hot spinning of difficult-to-deform lightweight metals.

Because of its many advantages, hot spinning technique has been studied quite extensively on various

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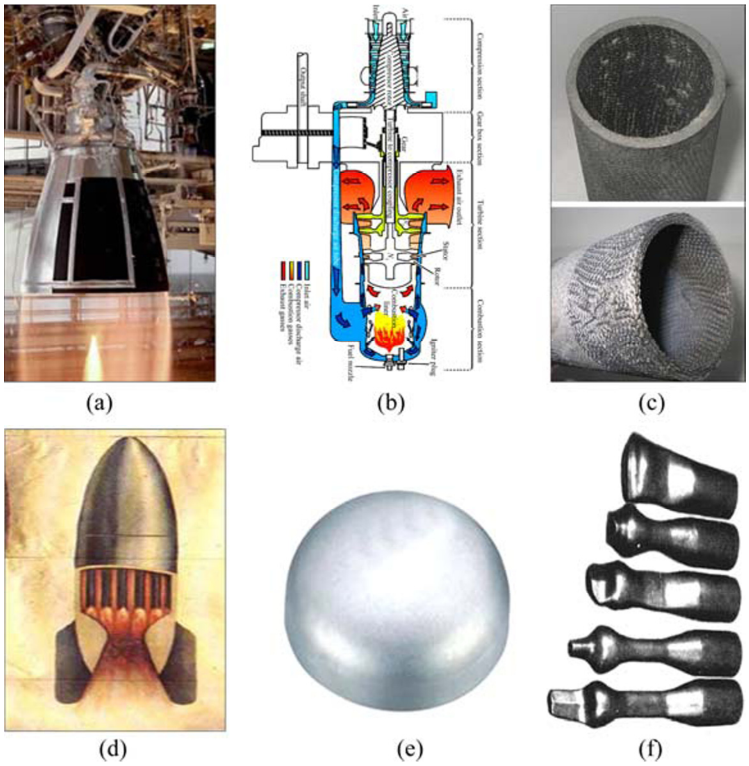

Fig. 1 Spun components used in aviation, aerospace, weapon and automobile industries: (a) Supporting cone of jet motors; (b) Turbo-shaft; (c) Tailing spout; (d) Nose cone of rocket engines; (e) End plate of oil pockets; (f) Connecting rod of automobiles [1−5]

lightweight materials. One of the key techniques in hot spinning of lightweight materials is temperature control, and different materials have different temperature requirements due to their different properties. The control for spinning temperature is closely related to the heating methods used in practical spinning process. And this control in the finite element analysis (FEA) for hot spinning process is the treatment method for temperature boundary conditions in the process. So, in this work, the hot spinning technique by considering the lightweight workpiece materials and the heating methods used in practical spinning processes, and the treatment methods employed for the temperature boundary condition in the finite element analysis (FEA) related to hot spinning were reviewed.

2 Lightweight workpiece materials

The lightweight workpiece materials used for hot spinning in recent years include mainly light alloys such as titanium, magnesium and aluminum alloys and metal composites.

2.1 Titanium alloys

Titanium alloys are advanced materials with high specific strength, excellent heat resistance and corrosion resistance. They have been widely used in the aerospace, aviation, marine and chemical engineering fields [16−18]. There are three types of titanium alloys, including near-alpha titanium alloys, alpha-beta titanium alloys, and metastable beta titanium alloys.

2.1.1 Near-alpha titanium alloys

Near-alpha titanium alloys are of medium or low strength, excellent notch ductility, high temperature creep, good weldability and thermal stability. They include TA12, TA15 (BT20 in Russia), TC1 and TC2. Many researches have been conducted on these alloys, especially on TA15.

LI et al [19] established a three-dimensional (3D) elastic-plastic macro FE model coupled with the thermal-mechanical effect for the hot shear spinning process of a TA15 thin-walled cone. Using this model, ZHAN et al [20−22] investigated the distribution and variation features of temperature, microstructure, stress and strain fields, as well as the influence of process parameters on the process. They found that the effects of contact heat exchange and friction heat can cause a large temperature gradient along the thickness direction of the cone, which can result in remarkable inhomogeneous deformation. They also obtained significant factors on the difference in wall thickness, the fittability of the workpiece with the mandrel and the wrinkling trend.

HUANG and ZENG [23] established a 3D elastic–plastic coupled thermo-mechanical FE model of