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ScienceDirect
Trans. Nonferrous Met. Soc. China 26(2016) 2188−2196
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Instability analysis of free deformation zone of cylindrical parts based on hot-granule medium-pressure forming technology

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Received 10 August 2015; accepted 3 December 2015

Abstract: The cylindrical part of sheet metal based on hot-granule medium-pressure forming (HGMF) technology was investigated. The stress functions of the free deformation zone and the fracture instability theory were combined to establish the analytical expression of the critical pressure of punch. The results show that the active friction between the granule medium and the sheet metal, as well as the non-uniform internal pressure presented by the solid granule medium, can obviously improve the forming performance of the sheet metal. The critical pressure of punch increases with the increment of the friction coefficient between the granule medium and sheet metal, as well as the plastic strain ratio, whereas it decreases with the increase of the material-hardening exponent. Furthermore, the impact on the critical pressure from high to low order is the plastic strain ratio, the friction coefficient, and material-hardening exponent. The deep-drawing experiment with HGMF technology on AZ31B magnesium alloy sheet verified the instability theory.

Key words: hot-granule medium-pressure forming; deep-drawing; instability; cylindrical part

1 Introduction

Structural components with lightweight sheets, such as magnesium and aluminum alloys, are widely applied in the automobile, aerospace, and other industrial fields because of the urgent need for low energy consumption and low emission [1]. Traditional forming method by drawing involves serious difficulties, such as high cost, low efficiency, time consuming and human resources used during the die designing, manufacturing and trouble solving because of the poor formability of lightweight alloy sheets at room temperature.

In recent years, warm/hot flexible-die forming technologies, such as warm hydroforming [2−6], super plastic forming process [7], quick plastic forming process [8], and viscous medium forming [9,10], exhibited considerable breakthroughs. In these technologies, fractures and wrinkles are the main issues involved in the sheet-forming task. In Refs. [11,12], the method of combining theoretical analysis with a test was adopted to obtain the critical blank-holder force for the deep-drawing of cylindrical parts. In Ref. [13], the fracture instability for deep-drawing by hydroforming was studied.

The theoretical results and engineering experiences in warm/hot flexible-die forming are extensive, and these technologies have been excellent options for the manufacture of components with lightweight materials. However, current theoretical studies are only based on liquid/gas forming technology with uniform distribution of internal pressure and non-friction.

Hot-granule medium-pressure forming (HGMF) is a technology in which the rigid punch/die (or elastomer, liquid, gas) is replaced by heat-resistant solid granules to conduct warm/hot flexible-die forming on sheet metals, as shown in Fig. 1. This technology overcomes the problem of sealing in warm/hot forming and excessive thinning during forming because of the active friction and non-uniform distribution of internal pressure. Producing certain parts with complex cross-sections using this technology is possible. A number of local and

Foundation item: Projects (51305385, 51305386) supported by the National Natural Science Foundation of China; Project (QN20131080) supported by the Science Research Youth Foundation of Hebei Province Universities, China
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DOI: 10.1016/S1003-6326(16)64335-2

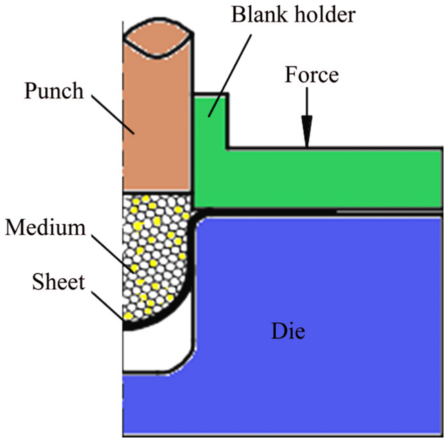

Fig. 1 Schematic of PGMF technology

international researchers have conducted detailed studies on this technology [14−20].

Theoretical researches on HGMF technology with friction and non-uniform distribution of internal pressure are not mentioned in existing studies. Therefore, in the present study, the instability of free deformation zone of cylindrical parts was investigated based on the HGMF technology. The influences of process parameters on critical pressure of punch, such as friction coefficient between granule medium and sheet metal, comparison between plastic-strain ratio and material-hardening exponent, and the feasibility of AZ31B magnesium alloy sheet using HGMF technology were explored.

2 Basic assumptions

Based on the characteristics of HGMF technology, the following hypotheses are proposed: the sheet is in the plane-stress state with the normal stress ignored; the thickness of the sheet metal is considered to be constant during the drawing process; the shear stress generated by friction is very small, and thus the direction of the deformation principal axis of the sheet metal does not change; and the stress–strain relationship of the sheet metal conforms to the Holloman constitutive equation [21,22] as follows:

$$\bar{\sigma} = K\bar{\varepsilon}^n \tag{1}$$

where $\bar{\sigma}$ is the equivalent stress, K is the strength coefficient, n is the material hardening exponent, and $\bar{\varepsilon}$ is the equivalent strain.

The transfer pressure (p_h) by solid granule medium regularly attenuates with the pressure-transfer distance, and the attenuation law is expressed as follows [14]:

$$p_h = Mh + N \tag{2}$$

where $M = -2a\mu_w p_1^{1+b}/r_b$; $N=p_1$ and μ_w is the friction coefficient between granule medium and sheet metal; a and b are the constants of lateral pressure coefficient, which are measured by a test; h is the pressure-transfer distance of the granule medium; r_b is the radius of the granular charging barrel system; p_1 is the pressure of punch; and p_h is the transfer pressure at the distance of h.

The sheet metal during the HGMF process is in a free drawing-bulging state before it adheres to the bottom of the die. The free deformation zone can be approximately regarded as a spherical cap and its meridian plane can be denoted by a circle function.

Fracture instability mostly occurs in the free deep-drawing zone according to the HGMF test, as shown in Fig. 2. When the sheet metal adheres to the cylinder wall of the die, the free-forming process can be divided into two stages, namely, the forming stages of die fillet and straight wall.

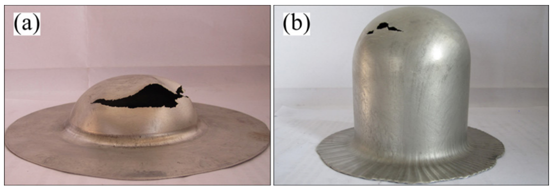

Fig. 2 Cylindrical parts with fracture instability (material: AZ31B): (a) Forming stage of die fillet; (b) Forming stage of straight wall

3 Stress distribution in free deformation zone

The stress analysis was conducted in the free deformation zone based on PGMF technology with the forming stages of die fillet and straight wall.

3.1 Forming stage of die fillet

The forming stage of the die fillet on the part is presented in Fig. 3. The sheet metal is gradually drawn into the die fillet under the internal pressure of granule medium, and the wrap angle α of the sheet metal to the

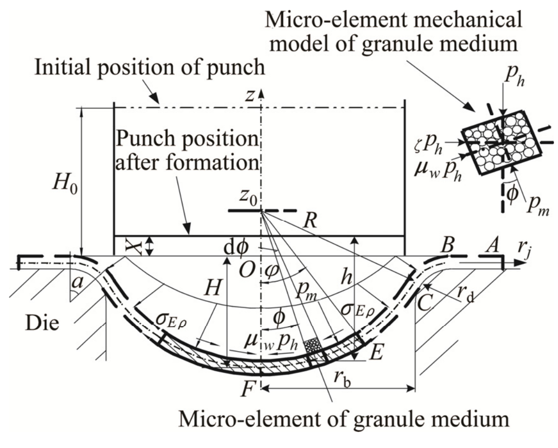

Fig. 3 Mechanical analysis of free deformation zone (0<α<90°)