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Flexible die drawing of magnesium alloy sheet by superimposing ultrasonic vibration

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Abstract: Combining solid granule medium forming technology with ultrasonic vibration plastic forming technology, ultrasonic vibration granule medium forming (UGMF) technology was proposed. To reveal the effect of ultrasonic vibration on flexible-die deep drawing, an ultrasonic vibration with a frequency of 20 kHz and a maximum output of 1.5 kW was on the solid granule medium deep drawing of AZ31B magnesium alloy sheet. The results revealed that ultrasonic vibration promotes the pressure transmission performance of the granule medium and the formability of the sheet. The forming load declines with the ultrasonic amplitude during the drawing process as a result of the combined influence of the "surface effect" and the "softening" of the "volume effect".
Key words: ultrasonic vibration; magnesium alloy sheet; deep drawing; solid granules

1 Introduction

With the rapid development of light industry, automobile, aerospace, and electronic industries, the requirement of saving energy and reducing consumption has become increasingly urgent, and the demand for the deep drawing of lightweight alloy components has increased. However, these materials are characterized by poor plasticity and therefore susceptible to tearing during the process. The formability of the sheets can be enhanced with ultrasonic vibration plastic forming technology or flexible-die forming technology at elevated temperatures.

Some scholars have discovered that the forming load can be reduced and the sheet metal forming limit can be improved by superimposing ultrasonic vibration in the deep drawing experiment of the cylindrical cup [1−3]. WEN et al [4] conducted the ultrasonic vibration drawing experiments of magnesium alloy sheet at room temperature and analyzed the influence of high-frequency vibration on the deformation behaviors of AZ31B magnesium alloy sheets. SIDDIQ and SAYED [5] and ASHIDA and AOYAMA [6] found that wrinkling and cracking could be avoided in the press-forming process using ultrasonic energy because of the reduction of the friction force between the sheet metal and the die. Earlier studies on the effects of ultrasonic oscillations superimposed on metal plastic forming revealed two possible effects: volume and surface effects [7−9]. The volume effects are related to a decrease in the flow stress, whereas the surface effects are related to a change in the frictional conditions at the die/specimen interface.

Most of studies on the applications of ultrasonic vibrations on metal forming seem to reach the same conclusions on the benefits of ultrasonic oscillations: reduction of the forming loads, reduction of the flow stress, reduction of the friction between die and workpiece, and production of better and higher-precision surface qualities. Despite these benefits, the application of this technology remains limited. The cost of designing an ultrasonic system and the cost associated with the energy required to induce the vibrations are expensive [10].

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The flexible-die forming of sheet metals is another effective method for lightweight alloys; it can be divided into the following processes: hydroforming [11−13], gas bulging [14], semi-solid flexible-die forming [15], and solid flexible-die forming, corresponding to the various physical properties of the pressure-transfer medium.

In this study, ultrasonic vibration granule medium forming (UGMF) technology was proposed. This technology uses a heat-resistant granule medium, instead of the liquid, gas, or viscous medium in existing flexible-die technology, by superimposing ultrasonic vibration, to achieve sheet metal forming. Based on the properties of the granule medium, such as heat-resistance, resistance to pressure, and good filling capacity, among others, this forming technology has several advantages, such as a wide range of forming temperature, easy sealing and loading. Therefore, it provides a convenient forming method for light alloy tube and sheet metal parts that form difficultly at room temperature.

The flexible-die forming technology based on the solid granule medium has been used to form the sheet metal parts of stainless steel, aluminum alloy, and magnesium alloy in one stage, and parts with a large ratio of height to diameter can be gained [16−18]. The friction between the granule medium and sheet is noted to be beneficial to the forming process. Moreover, a large friction coefficient indicates better sheet formability. The good liquidity and pressure transmission performance of the granule medium are the keys to this technology; hence, ultrasonic vibration is introduced to the technology.

In this study, the experiment of typical cylindrical parts forming with AZ31B sheet was conducted based on UGMF technology. And the influence of vibration parameters on the deformation behavior and formability of magnesium alloy sheet was researched in the deep drawing process .

2 Mechanism of UGMF technology

A schematic of UGMF technology is presented in Fig. 1. The forming equipment consists of the die, blank holder (BH), granule medium, ultrasonic vibration system, and punch, and so on. The BH also acts as the solid granules store, and solid granules are filled in a closed cavity composed of the BH, sheet, and punch. During the forming process, the punch compresses the granules, and the sheet is gradually deformed. JIMMA et al [2] noted that axial vibration contributes strongly to the rise of limit drawing ratio (LDR) rather than the radial one and that ultrasonic axial vibration may be classified into three types: punch (type 1), blank holder (type 2), and die (type 3) vibration as shown in Fig. 1.

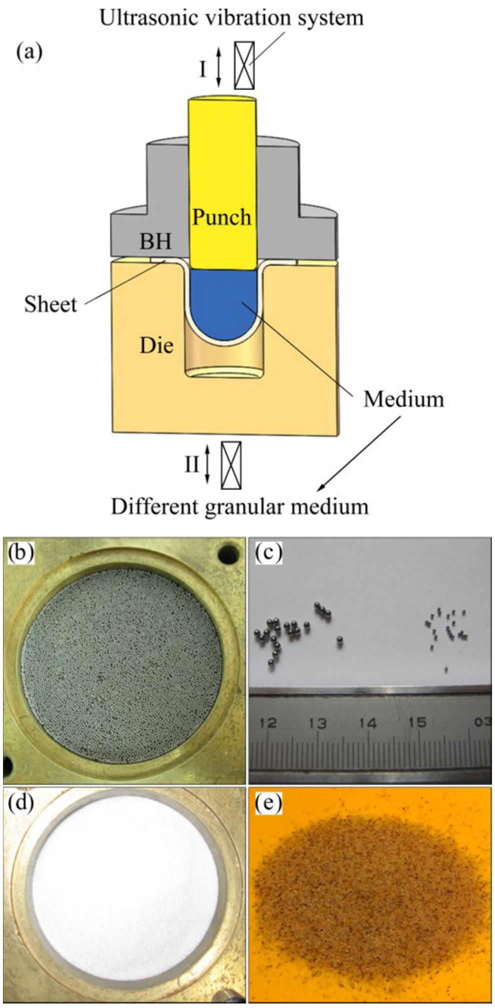

Fig. 1 Schematic of UGMF technology (a) and different granular medium: (b) Metal granular medium; (c) Metal granular medium with different sizes; (d) Non-metallic granule medium with high temperature resistance; (e) Non-metallic granular medium of room temperature

Using the finite element method, ASHIDA and AOYAMA [6] studied the influence of ultrasonic vibration on the friction state of the die, die fillet, punch, and BH during deep drawing with a rigid mold, and the results showed that the effect of friction reduction was the best when vibration and lubrication were applied to the shoulder ring of the die. In addition, vibrating the die can result in a large relative motion between the die and workpiece. Thus, ultrasonic vibrations were imposed on the die in this study, and the vibratory motion was assumed to be not transmitted to the punch.

The granule medium slides at a constant velocity v_0 and is compressed by the punch. The die has an oscillatory motion of amplitude a and angular frequency ω along the same line of v_0 and its oscillations velocity $v_D=-a\omega\sin\omega t$, as shown in Fig. 2. v_D is larger than the velocity of the sheet to be deformed. Given the relative velocity between the die and sheet, the micro gaps