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Finite element modeling and experimental results of brass elliptic cups using a new deep drawing process through conical dies

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ABSTRACT

This paper introduces a new technique for deep drawing of elliptic cups through a conical die without blank holder or draw beads. In this technique an elliptic-cup is produced by pushing a circular blank using a flat-headed elliptic punch through a conical die with an elliptic aperture in a single stroke. A 3D parametric finite element (FE) model was built using the commercial FE-package ANSYS/APDL. Effects of die and punch geometry including, half-cone angle, die fillet radius, die aperture length and punch fillet radius on limiting drawing ratio (LDR), drawing load and thickness strain of the cup have been investigated numerically for optimal process design. A die with half cone angle of 18° has shown the best drawability for the new technique. An experimental set-up has been designed, manufactured, and used for experimental production of elliptical shaped sheet-metal cups. A total of seven punches having aspect ratios ranging from 2 to 2.25 and a die with an aspect ratio of 2 have been manufactured and used. Tensile tests were carried out to obtain the stress–strain behavior for the formed sheet metal. Experiments were conducted on blanks of brass (CuZn33) with initial thicknesses of 1.5, 1.9, 2.4 and 3 mm at different clearance ratios (c/t). Effects of blank thickness and clearance ratio on limiting drawing ratio, drawing load and thickness strain were numerically and experimentally investigated. Finite element model results showed good agreement with experimental results. An elliptic cup with a limiting drawing ratio (LDR) of 2.28 has been successfully achieved using the proposed technique and set-up.

1. Introduction

Sheet metal parts are encountered almost everywhere from containers, automotives and buildings to aircrafts. Manufacturing of sheet metal parts by means of press forming is a cost-effective process since it eliminates expensive machining and welding operations giving a better quality finished product (Saxena and Dixit, 2011). Deep drawing is one of the widely used sheet metal working processes in industry to produce cup shaped components at a very high production rate (Kishor and Kumar, 2002). Deep drawing of non-symmetric parts is considered a complicated process due to, irregular contact conditions between blank and die, and the different forming characteristics from those of axisymmetric circular deep drawing (Park et al., 2002).

At certain ratios of blank diameter to blank thickness (d/t) the flange resistance to buckling and wrinkling is sufficient to eliminate the need for a blank holder. Therefore research about deep drawing without a blank holder, for conical and tractrix dies has attracted the attention of many researchers. Hasab-Alla (1993) mentioned that the suitable value of the ratio (d/t) for deep drawing without blank-holder should be less than 50. Deep drawing without blank holder with (d/t) less than 40 gives higher LDR's compared to deep drawing with blank holder. The limiting drawing ratio (LDR) in this case is restricted by wrinkling at the rim of the flange or buckling of the cup wall for thin sheets and by fracture at the punch nose area for thick sheets. In elliptic cups drawing ratio, DR is defined as the ratio of the original sheet perimeter to the perimeter of elliptical punch (Huang and Lu, 2011).

Deep drawing using conical dies without blank holder has many advantages over conventional dies. First, it results in a reduction in the drawing load as reported by Sedighi and Rasti (2008). They investigated the required drawing forces for flat, conical and tractrix dies versus punch travel along the loading stroke. They showed that the required drawing forces for tractrix and conical dies are less than those required for flat-top dies. The second advantage is the increase in LDR. Hezam et al. (2009) developed a new process for producing a square cup through a conical die. They reported that, square cups with drawing ratios of 2.5 for aluminum with 2 mm thickness were successfully produced compared with an LDR of 2 with conventional dies. Deep drawing with simultaneous ironing further increases the LDR. Hasab-Alla (1993) conducted research on the deep drawing process of a circular cup on a conical die without blank holder. The investigation showed that, in cases of drawing with 20% simultaneous ironing ratio, LDR of soft aluminum using a

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rough punch was increased to 2.77 compared to 2.5 in the case of drawing without ironing.

Finite element analysis has been used to optimize the experimental setup parameters and to reduce the number of expensive experimental tests in the design of forming setups. In order to obtain the optimum deep-drawing product with a non-axisymmetric shape, all affecting parameters in deep drawing process must be considered before determining the drawability of the product.

In elliptic cup deep drawing aspect ratio is a major effective parameter. Aspect ratio (a/b) is defined as the ratio of major/minor axis of ellipse. The aspect ratio of ellipse axes lead to uneven flow of the drawn material that restricts the limiting drawing ratio. This is achieved through FE modeling. Chang et al. (1994) investigated the deformation mechanism of the elliptic cup deep-drawing process by the rigid-plastic FEM for the galvanized steel sheet. The analysis showed that, the particle moving velocity distribution, the stress and strain distributions and formation limit are all influenced by the aspect ratio. Increasing aspect ratio leads to reducing the LDR, due to violent deformation at the end of the major axis (Chang et al., 1994). Huh et al. (2000) performed finite element analysis for cold-rolled steel sheet using shell-type element for modeling of an elliptic cup with large aspect ratios up to 2, using LS-DYNA3D in four deep-drawing stages. They found that, there are trends that local deformation will result along the major axis direction, with wrinkles on the minor axis. Kim et al. (2001) have experimentally investigated the effect of aspect ratio on wrinkling behavior of the elliptic cup deep drawing process for aluminum (A6111-T4) with a thickness of 0.914 mm. They found that the first fold was generated at an aspect ratio of 1.333. With the increase of aspect ratio of punch, wrinkles formation tended to be stable and close to the area of the major axis.

Fillet radii of punch and die and blank shape are the most important variables that influence the formability in deep drawing process (Park and Yarlagadda, 2008). Park et al. (2001) studied the effect of variation of punch and die fillet radii to improve the formability of elliptical cups for deep drawing processes at three stages for electro-galvanized sheet steel material with a thickness of 1.6 mm. They reported that for die and punch with diameters of 60 and 56 mm respectively, the optimum fillet radii, were 10, 8 and 5 mm for the dies and 15, 12 and 8 mm for the punches respectively for the three stages. Park and Yarlagadda (2008) investigated the effect of the fillet radii of punch and die and blank shape on formability in the conventional elliptical deep drawing of sheet metal. The study compared the punch load–displacement for three drawing stages using three different types of non-circular blanks. They showed that, the wall and flange of deformation zones are mainly applied to the draw mode, the punch head is applied to the plane strain mode, and the corner is applied to the stretch mode. The maximum punch load was found to be affected by the shape of the blank.

Sheet hydroforming process is an alternative to drawing process where either the punch or the die is replaced by hydraulic medium, which generates the pressure and forms the part. Hama et al. (2007) investigated the deep drawing of sheet metal of elliptic cups with a large aspect ratio using hydroforming for mild steel sheet material with 0.6 mm thickness. They concluded that, the thickness strain distribution in SHF differed from that in the conventional press forming, and the maximum thinning was much smaller in SHF. Their results proved that SHF gave better formability in their product. Moreover, it was confirmed that the friction increasing effect is well reproduced in the simulation. Huang (2012) carried out a FEM and experimental work for drawing of elliptic cups using steel material with a thickness of 0.8 mm by hydroforming with an aspect ratio of 1.57. He mentioned that elliptic cups with an LDR of 2.05 were successfully produced. However the hydroforming process has many disadvantages. These are additional process equipment like a high pressure liquid and sealing and advanced process control (Winklhofer et al., 2010).

Based on the previous paragraphs, it is concluded that, in all previous work, elliptic cups are produced either by complicated (non-conventional) processes and/or in multi stages. Therefore the demand for a simple and economically efficient process is significant. In the present work, a novel, simple process for deep drawing of elliptical cups without blank holder has been proposed. Finite element analysis has been used to optimize the experimental setup design through the exploration of the effects of die and punch geometry on the limiting drawing ratio (LDR) and on the drawing load associated with the new process. Moreover, FE analysis has been employed to optimize parameters of the proposed process such as half-cone angle, fillet radius and aperture (throat) length, of the die together with punch fillet radius. Simulation results were confirmed via experimental work.

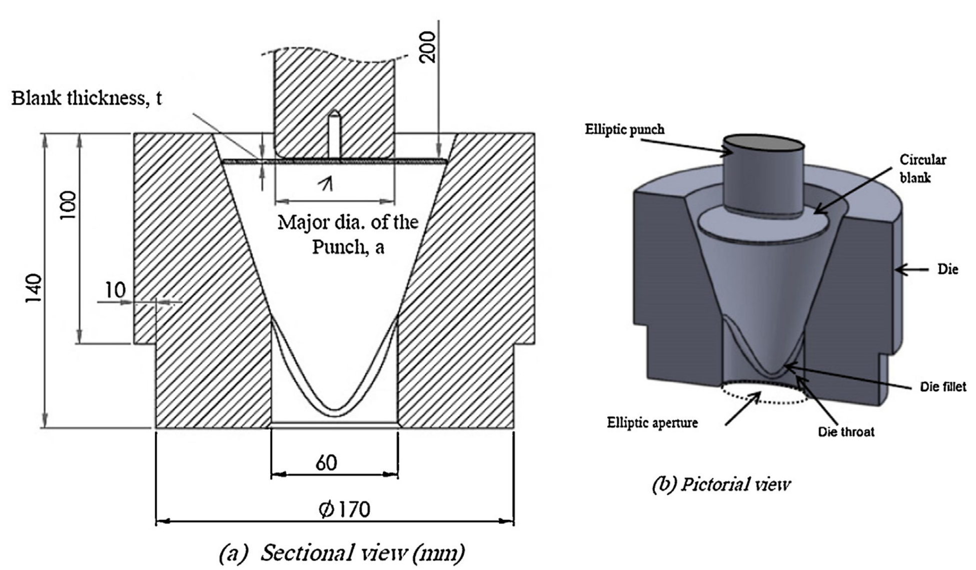

Fig. 1. Elliptic-cup drawing with circular blank using an elliptical punch through an elliptical die.