Square-Cup Deep Drawing of Relatively Thick Sheet Metals through a Conical Die without Blankholder

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ABSTRACT

The present study introduces a finite element analysis and experimental verification of the square cup drawing. Experimental results are presented for deep drawing using two different sheet metal: an annealed aluminum (AL99.5w) and brass alloy (CuZn37) having nominal thickness $t$, of 2, 2.5 and 3 mm. The experiments were conducted using a conical die of $18^\circ$ half cone angle with square aperture at the die exit of $44 \times 44$ mm and different relative punch/die clearances 1.5, 1.0, 0.9, and 0.8$t$. The last three values for relative punch/die clearance give nominal simultaneous corrective ironing ratios 0, 10, and 20% respectively. Flat-bottomed square punches with nose radius of 4 mm and different sizes of side wall lengths were used. The corner radii for the punch and die aperture were 8 and 10 mm respectively. The experimental and finite element results showed a very good agreement between results of the deep drawing loads, limiting drawing ratios and modes of failures.

Keywords: Conical Die, Deep Drawing Without Blankholder, Finite Element Analysis, Limiting Drawing Ratio, Relatively Sheet Metals, Square Cup

1. INTRODUCTION

The square cups of sheet metals are widely used in many industrial fields. Commonly, the square cups are manufactured by deep drawing using flat blanks of sheet metal. The traditional design of drawing dies are complicated and tedious procedure, in spite of all precautionary measures there are several chances of denting, cracking and wrinkling which needs to be rectified. Using these techniques leads to high rates of scrap from sheet metal drawing processes. Therefore, it is very important to replace these techniques by a computer aided method to determine the strain distributions, tool forces and potential sources of defects and failures. One

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of the most popular methods in simulating and optimizing the sheet metal forming today is the finite element (FE) simulation (Yoon, 2014). FE simulation allows to capture behaviour that cannot be readily measured it provides deeper insight into the sheet metal forming. Nowadays, FE simulation is highly adopted in by modern industry to reduced production cost and time prototyping, improved formability and easy modification of part design. In deep drawing processes FE simulation have been applied to understand the deformation mechanism, improve the quality of deep drawn parts, facilitate the metal flow into die cavity, maximizing the height of drawn cup, and shorten design cycle (Regueras, 2014); (Li et al, 2006).

The deep drawability and quality of deep drawn products depend upon many process parameters such as; blank thickness, blank and die geometries, holding pressure, blank materials, friction conditions at tools(blank interface surfaces, and so on. Many researchers have been carried out using diverse technologies in order to better understand square cup drawing processes. The work of (Marumo et al, 1999,1998);(Kuwabara et al, 1993); and (Kawai,1987) investigated the effects of drawing process parameters on the deep drawability of square cups made of aluminum sheets, while (Chen & Lin, 2007) investigated the effects of deep drawing parameters on the deformation characteristics for the forming square cups of stainless steel. (Kitayama et al,2010) introduced an algorithm to determine the trajectory of the blank holder force in square cup drawing process. (Modi & Kumar, 2013) developed a method to determine the path of the variable blank holder force for successful hydroforming of the cups with the assistance of programmable logic controller and data acquisition system. The main aspect to be considered in drawing of square cup is that deformation states vary along the contour of the cup cross section which leads to metal flow concentration at the square cup corners (Saxena & Dixit, 2009).

Deformation concentrations at the cup corners can be reduced by cutting the corner edge of the blank or by using an optimum blank shape. A large part of the published work aimed to obtain the optimum blank design (Lee& Chun, 2005); (Lang et al, 2005). The authors and their coworkers have developed different techniques to obtain optimum blank shape that producing deepest and near net-shaped cup. (Lee & Chun, 2005) conducted both experimental and FE analysis on the deep drawing of stainless steel square-cup to develop the optimal blank design. Optimum blank design was determined in order to eliminate the wrinkles. (Naceur et al, 2004) used an inverse approach coupled with an evolutionary algorithm to optimize the shape of the initial blank. This method simply eliminating material elements subjected to an only small plastic deformation. (Pegada et al, 2002) proposed an algorithm for optimal blank design problem that included the effect of anisotropy and friction for deep drawing of cups without ears. (Shim et al, 2000) proposed a method for blank shape design based on sensitivity analysis for the non-circular deep drawing of arbitrary shape cups. The initial blank has been modified in order to obtain the final shape of drawn cup based the shape error and sensitivity. (Kitayama et al, 2010) calculated the optimum blank shape based on the difference between the target and final deformed contour shape using a roll-back method. (Lee & Huh, 1998) developed an inverse algorithm based on the FE analysis for direct prediction of blank shapes and strain distributions from desired final shapes. (Gea & Ramamurthy, 1998) used the optimization method to maximize the drawability used the blank parameters as the design variables and subject to the constraint that fracture failure does not occur. (Kuwabara & Si, 1997) determined the optimum blank shapes for the production of irregularly shaped prismatic shells with an arbitrarily flange by using the slip-line field theory. (Wang et al, 2009) used the FE techniques to determine the optimum blank shape design for deep drawing of arbitrary shaped cups with a uniform trim allowance at the flange. The total time of the central process unit was reduced due to dividing forming process into stages and correcting blank geometry. (Yeh & Li, 2007) suggested an accurate predictor corrector scheme
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