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Process window diagram of conical cups in hydrodynamic deep drawing assisted by radial pressure



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Abstract: Major defects in forming of conical cups are wrinkles and rupture. Hydrodynamic deep drawing assisted by radial pressure (HDDRP) is a sheet hydroforming process for production of shell cups in one step. In this work, process window diagrams (PWDs) for Al1050-O, pure copper and DIN 1623 St14 steel are obtained for HDDRP process. The PWD is determined to provide a quick assessment of part producibility for sheet hydroforming process. Finite element method is used for this purpose considering the process parameters including pressure path, and the blank material and its thickness. Numerical results are validated by experiments. It is shown that the sheets with less initial thickness and higher strength show better formability and uniformity of thickness distribution on final product. The results demonstrate that the obtained PWD can predict appropriate forming area and probability of rupture or wrinkling occurrence under different pressure loading paths.

Key words: conical cups; hydrodynamic deep drawing; finite element simulation; process window diagram

1 Introduction

Hydrodynamic deep drawing (HDD) is a sheet hydroforming process which is a combination of conventional deep drawing and hydroforming, comprising the advantages of both technologies. HDD is known by different titles such as hydraulic counter pressure deep drawing, fluid former, aquadraw and hydromech [1]. HDD is categorized as a flexible forming process, and has a wide range of applications in different industries due to its capability of forming complex parabolic and conical shapes with high limiting drawing ratio (LDR) in a single step. In HDD process, a shaped punch forces the blank into the liquid-filled die cavity, so that the liquid is pressurized and forms the blank around the punch [2,3]. The created frictional force between the blank and the punch allows to apply higher pressures, thus stress concentration is reduced on the blank at the punch tip area and the formability will be improved. On the other hand, the exerted pressure provides a bed for the free portion of the blank between the punch and the die shoulder, pushing the blank upward to create the tensile circumferential stresses that assist in preventing from wrinkles. In this flexible process, the same die can be used in forming of various geometries using different punches.

Hydrodynamic deep drawing assisted by radial pressure (HDDRP) is a special application of HDD, in which the pressurized forming liquid is applied also to the outer edge of the blank at flange area to improve the material flow during the forming process [4]. There is no sealing in the flange area in HDDRP and the gap between the die and blank-holder is slightly bigger than the blank thickness. When the punch moves down and the liquid is pressurized, the sheet is drawn into the die cavity while stuck to the punch surface and the blank-holder. At this time, the pressurized liquid can flow into the gap between the blank-holder and the die. This gap causes a uniform radial pressure around the sheet edge in the flange area assisting in more efficient flow of material into the die cavity [5]. HDDRP has a lot of advantages compared with conventional deep drawing such as higher drawing ratio and dimensional accuracy, uniform thickness distribution, better surface quality and more complex products. The radial pressure can be created around the blank with a little modification in the HDD die set. Figure 1 shows a schematic of this process.

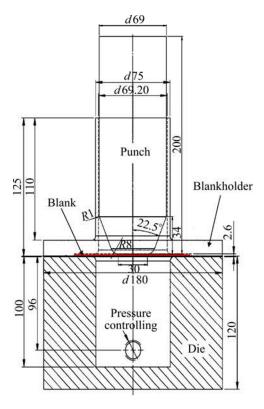


Fig. 1 Die set of HDDRP process used in this research (unit: mm)

During the last decade, a few researches have been conducted in forming of conical parts by hydroforming techniques. KAWKA et al [6] investigated the simulation of wrinkling in deep drawing of conical cups. Finite element results showed that the type and number of meshes are very effective on final results even for minor changes. THIRUVARUDCHELVAN and TAN [7] proposed a new method for forming of conical cups in conventional deep drawing by an annular urethane pad. In this method, the urethane pad prevents the direct contact of punch tip to the blank, and delays the rupture especially at early stages of the process. LANG et al [8] studied the effect of calibration stage on forming of conical cups in sheet hydroforming process. The results demonstrated that the calibration method can prevent the fracture and remove the wrinkles. GORJI et al [9] investigated hydrodynamic deep drawing for conicalcylindrical cups numerically and experimentally. They considered different pressure paths and studied the effect of those paths on thickness distribution and drawing ratio of the products.

Several studies were devoted to designing the process window diagrams (PWD) for different materials in various forming processes. CHU and XU [10] proposed a theoretical PWD for hydroforming of aluminum extrusion tubes. PWD was designed based on the internal pressure versus axial compressive force to

predict buckling, wrinkling and bursting. OH et al [11] used ductile fracture criterion to predict forming limit diagrams in hydro-mechanical deep drawing of steel sheets. VOLLERTSEN and HU [12] investigated the effect of punch velocity on PWD in micro deep drawing. It was concluded that the allowable upper limit of the blank-holder pressure increases with increasing the punch velocity. GAO et al [13] designed PWDs of tube-compression by viscous pressure considering the tube-compression length and tube-blank diameter. PWDs showed that the safe zone and the wrinkles elimination area decrease with increasing the tube-compression length, while the safe zone decreases and the wrinkles elimination area increases with increasing the tube-blank diameter.

In this work, HDDRP process is studied for three types of materials using finite element method considering forming pressure path, initial thickness and material of the blank. The process window diagrams (PWD) for forming of conical parts are determined. The PWD is determined to provide a quick assessment of part producibility for sheet hydroforming process. No PWDs were reported for HDDRP yet. The proposed PWD can predict the proper forming area and occurrence of wrinkles and rupture. It is also possible to approximate the maximum thinning percentage in different forming zones. In order to determine the PWDs, three types of materials including pure copper, Al1050-O and DIN 1623 St14 steel (mentioned as St14 hereafter) with different thicknesses (between 0.5 and 2.5 mm with 0.25 mm interval) were evaluated. Different pressure paths were applied for each specimen in finite element simulations to determine the desirable and undesirable forming areas. Numerical model and PWDs are validated by experiments based on the thickness distribution of final parts. Experimental tests were performed with different pressure paths determined from the PWD to achieve sound parts, wrinkles and failures at different thicknesses.

2 Experimental

Three different materials St14, Al1050-O and pure cupper (99.9%) sheets with different thicknesses are used in HDDRP process to produce conical parts in a single step. Table 1 shows the mechanical properties of these materials obtained from universal tensile tests along three directions: parallel (0°), diagonal (45°), and perpendicular (90°) to the rolling direction of the initial sheet.

Dimensions of the workpiece used in this research are shown in Fig. 2. A 200 kN universal testing machine was used in the experiments. Figure 3 shows the experimental setup. A typical pressure loading path used

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