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Teflon-pad shaping process of circular metal blanks into quasi-cup specimens by theoretical and experimental methods

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Abstract: Teflon-pad shaping process of circular metal blanks into quasi-cup specimens is investigated by theoretical and experimental methods in the quasi-static condition. In the experiments, circular metal sheets are formed into the quasi-cup samples by compressing them between a Teflon-filled die and a rigid punch with desirable shape. To investigate influences of different parameters on the forming progress, 12 rigid punches with different dimensions, two blank material types of aluminum and galvanized iron, three blank thicknesses of 0.6, 1.1 and 1.5 mm, and two Teflon-fillers of PVC and polyurethane are used in several experimental tests. In the analytical part, theoretical deformation models of metal blank and Teflon-filler are introduced and based on energy method, energy absorptions by the blank and Teflon-filler are calculated to derive a theoretical formula for predicting total required energy of the forming process. For this purpose, several energy absorption mechanisms are considered in the blank and filler. Furthermore, predictions by theoretical equation are compared with the corresponding experimental tests to study the verity of the calculated formulas. Theoretical and experimental results illustrate change trend of forming energy with respect to blank thickness. Also, the performed forming tests show that when external cone angle of rigid punch with respect to the horizontal direction increases, forming energy increases nonlinearly; and when the depth of spherical part of rigid punch increases, the probability of rupture increases. Additionally, the experiments demonstrate that there is a direct relationship between the forming energy and flow stress of the blanks. Furthermore, experimental observations illustrate that forming energy of a certain blank with PVC Teflon-filler is higher than that of a similar specimen with polyurethane Teflon-filler; but, the probability of wrinkling decreases when PVC Teflon-pad is used as the filler; and it is advantage of PVC Teflon-filler with respect to polyurethane Teflon.

Key words: Teflon-pad forming; circular metal blank; quasi-cup specimen; PVC Teflon-filler; polyurethane Teflon-filler; forming energy

1 Introduction

Innovations introduced in metal forming processes during the last 50 years can be placed in several categories. These include the use of unconventional tools such as those using high hydraulic pressure, flexible tools, the use of both fluid and solid friction to aid forming, and techniques such as experimental and finite element analysis of forming problems. Flexible tool materials such as polyurethane and rubber are being used increasingly in the design of metal forming tools [1].

THIRUVARUDCHELVAN [1] discussed several novel applications of urethane in the design of metal forming tools. RAMEZANI et al [2] presented a theoretical approach to model the static and kinetic friction in rubber-pad forming process that considered local contact conditions and to evaluate influences of friction models on finite element results. FE simulations were carried out using commercial software ABAQUS/ Standard for an axisymmetric rubber-pad forming operation using the defined friction models. Experiments of rubber-pad forming were also carried out using natural rubber as the flexible punch. The results of finite element simulations using the defined friction models were compared with the experimental results [2].

Wrinkling is a common failure in the sheet metal forming. It is important to predict wrinkling accurately in the sheet metal forming without costly trials [3]. SUN et al [3] predicted wrinkling and influence of rubber hardness on the winkling behavior in the rubber forming of convex flange and the predictions were validated by experimental results of rubber forming process. BROWNE and BATTIKHA [4] represented an experimental study of the rubber-pad forming process, which was used widely to produce aerospace and

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automotive parts. They indicated some advantages of the rubber-pad forming process as follows: only one rigid tool half is required to form a part; parts with excellent surface finish can be formed as no surface tool marks are created; thinning of the work piece is reduced considerably; and different metals with various thicknesses can be formed using the same tooling. SUN et al [5] experimentally investigated effects of different punch and rubber hardness on the limit principal strain distributions. They established finite element analysis models of samples to analyze friction coefficients of different interfaces and studied effects of various friction coefficients on the strain distributions in detail. THIRUVARUDCHELVAN [6] presented brief survey of several uses of elastomers such as urethane in metal forming and described properties of flexible tool materials (urethane) during the process. He considered elastic modulus and friction characteristic of urethane which are needed for calculations. AL-QURESHI [7] investigated feasibility of elastomer forming for the simultaneous forming, embossing and shearing of sheet metals to produce special panels. In his work, the confined system was adopted, where the elastomer was housed in a container. Also, a simplified analytical treatment was presented for predicting the applied load and total ram movement required for the forming process. THIRUVARUDCHELVAN [8] introduced a urethane clamp that is able to generate a maximum axial force of about 45 kN to be used in the forming process. It was realized that there are several other metal forming situations which need the mentioned clamp. Then, THIRUVARUDCHELVAN [9] calculated an approximate theory for determining the initial yield pressure and required final forming pressure on an internal urethane rod to bulge a tube using an empirical friction characteristic for urethane under pressure.

DONG et al [10] conducted experiments on physical properties of solid granule medium at high stress levels, and based on this, a numerical analysis on sheet metal was performed. Based on material performance experiments, numerical analysis in respect of flexible-die forming process with solid granule medium was conducted. WANG and YUAN [11] proposed a numerical method for coupled deformation between sheet metal and flexible-die. Elastoplastic deformation of sheet metal was analyzed with finite element method and bulk deformation of flexible-die was analyzed with element-free Galerkin method [11]. RAMEZANI et al [12] carried out rubber-pad forming experiments for stamping of the aluminum blanks. The effect of rubber type and stamping velocity on the process was described. In order to investigate the process and deformation mechanisms during rubber-pad forming, a nonlinear finite element analysis was conducted and subsequently validated with experimental results.

Rubber pad forming as a novel stamping technique has been widely used in the deep drawing, bulging, blanking and flanging processes [13]. LIU et al [13] analyzed deformation characteristics of two deformation styles in detail with numerical simulation and experimental methods. They determined proper application conditions of concave and convex deformation styles used to fabricate a certain metallic bipolar plate. CHEN et al [14] analyzed wrinkling by shrink flanging in rubber forming process with orthogonal experimental design. They analyzed four affecting factors of die radius, flange length, die fillet radius and forming pressure, and used three types of alloy materials. WANG et al [15] performed sheet metal bulging experiments with three kinds of pressure-carrying media, viscous medium, polyurethane and steel. The results showed that specimens formed with VPF have less wall-thinning; and consequently, a more uniform wall thickness distribution and shape of parts are closer to the desired hemisphere, in comparison with the formed specimens with polyurethane and steel. LIU and WANG [16] developed a sectional finite element method (SFEM) for analysis of the coupled deformation of sheet metal and viscous medium. They proposed a wrinkling criterion based on the energy method and a ductile fracture criterion on the basis of Lemaitre damage theory; and wrinkling and fracturing defects occurring in viscous pressure forming were predicted. MOROVVATI et al [17] used a theoretical approach based on a well-known energy method, FE simulations, and experimental observations to study the wrinkling phenomenon in two-layer sheet deep drawing. NIKNEJAD et al [18] experimentally performed Teflon-pad forming process on circular metal blanks using a concave die with a ring groove. The influences of material type and thickness of sheets, depth and width of ring groove of die and thickness of Teflon-pad on forming process were investigated. Also, they studied effects of geometrical and material characteristics on required energy for the forming process.

In this work, we investigate Teflon-pad forming of circular metal blanks into quasi-cup specimens by compressing metal sheets between a Teflon-filled die and a rigid punch with desirable shape by theoretical and experimental methods. A theoretical relation is derived to estimate required energy for shaping the circular blanks into the quasi-cup samples based on the energy method. In the experimental part of the present research work, several compression tests are performed on galvanized iron and aluminum blanks with the same diameter of 50 mm and with different blank thicknesses of 0.6, 1.1 and 1.5 mm on 12 different rigid punches with two Teflon-filler types of PVC and polyurethane to study