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The effect of normal stress on hydro-mechanical deep drawing process

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A B S T R A C T

Normal stress has some role in the deformation analysis of hydroforming processes. In this study, analytical modeling is pursued to evaluate the effect of normal stress on the hydro-mechanical deep drawing (HDD) process. Analyses are carried out for axisymmetric elements of the formed cup-shaped part for increments of the punch travel. The formulations are obtained using mechanical and geometrical relations and the finite difference method, thereby being solved by proper numerical algorithms. Furthermore, in the present work, part thickness is variable, the loading and straining are non-proportional, and bending/unbending effects over the part curvature are considered. The results show that there are some differences between thickness values, radial and circumferential strains and stresses, and punch force under plane stress and three-dimensional stress conditions. Thus, the normal stress should be considered in the design of HDD processes in order to improve accuracy.

1. Introduction

Normal stress has an effect on the deformation analysis of any hydroforming process due to the fact that forming occurs with the application of fluid pressure. There are three main types of hydroforming processes: shell hydroforming, sheet hydroforming (SHF), and tube hydroforming (THF) [1]. Hydro-mechanical deep drawing (HDD) is a proposed method of sheet hydroforming (SHF), which has been recently applied widely in some industries such as automotive and aerospace because of its advantages over conventional deep drawing (CDD). Higher limiting drawing ratio (LDR), reduction in residual stresses and springback, better surface quality, higher dimensional accuracy, more uniform thickness distribution, and the possibilities of drawing complex parts in one step are its great merits [2].

The HDD process possesses three important attributes: (i) wrinkle prevention as a result of the first stage of prebulging in which the material is initially stretched over the die cavity; (ii) fracture prevention due to the friction-holding effect between the punch and the blank, which occurs when the punch goes down and the fluid pressure (counter pressure) increases, and (iii) resistance-reduction effect as a result of the leak flow, which is the fluid flow under the flange when the hydraulic pressure is sufficient to lift the blank from the draw die. These features improve the fracture limit and lead to larger drawing ratio and to sounder surface for products manufactured by the HDD process [3].

Due to the elaborate geometry and mechanics, the researches concerning SHF processes have been mainly performed using the finite element method and experimental studies. However, Yossifon and Tirosh [4–7] conducted several researches in order to analyze rupture and wrinkling in the hydroforming processes. They, joined by Kochavi, [4] used the energy method to predict a critical hydraulic pressure path (with respect to the punch travel) above which buckling (wrinkling) can be suppressed. In another work [5], the two researchers divided the formed part into three zones and employed the classical theory of plasticity to obtain the strain and stress fields in the flange and blank curvature, thereby predicting the critical fluid pressure curve below which rupture by tensile instability is not likely to occur. The authors also unified and enlarged these two bounding solutions in a work [6] and predicted a proper working zone between two critical loading paths of rupture and wrinkling along which the hydraulic pressure is both sufficient and high enough to prevent the wrinkles and rupture, respectively. Following this approach, they proposed the concept of maximum drawing ratio (MDR), using the same methodology based on the energy method, theory of plasticity, and plane strain failure [7]. They explained that one can reach MDR when the two critical counter pressure curves approach each other leaving almost zero gap for the pressure path.

In the above papers, the authors rely on some assumptions to simplify the analysis such as neglecting normal stress in the constitutive equation or plane stress condition, constant part thickness throughout the process, proportional straining and loading paths and that the strain and stress principal axes do not rotate, plane strain condition, and not taking into account the effect of bending and unbending in the part curvature at the top of the cup wall.

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