Journal of Solid and Fluid Mechanics (JSFM), 13(2): 1-4, 2023

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2023.12597.3685

Manufacturing Engineering of Iran

Numerical Analysis of Hot Deep Drawing Process of Thick Steel Sheet without Using Blank Holder with Tractrix and Pseudo Tractrix Dies

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Received: 01/11/2023 Revised: 05/21/2023 Accepted: 06/26/2023

Abstract

Deep drawing is a process that is usually performed in cold conditions, but it can also be performed in hot conditions to reduce the forming force. The use of a blank holder in the forming process leads to an increase in the forming force and changes the thickness of the sheet. On the other hand, omission of blank holder will cause wrinkling of the sheet due to development of peripheral stresses. In this research, the finite element analysis for forming a hemispherical head from a high strength steel sheet in the hot deep drawing process without using a blank holder is studied. Simulations are done for two types of tractrix and pseudo tractrix dies and for sheets with different thicknesses and diameters, and the results are compared with each other. The results of the analyses show that with the increase in the thickness and diameter of the sheet, the force required by the mandrel for forming increases. In general, fewer forming force is required in the tractrix die and at the same time it brings less thickness changes.

Keywords: Finite Element Analysis; Hemispherical Head; Hot Deep Drawing; Tractrix Die; Pseudo Tractrix

1. Introduction

Deep drawing process is one of the processes widely used in various industries for sheet forming. There are always limitations in the sheet forming processes that must be followed to produce healthy and wrinkle-free parts. Most of the researches carried out regarding the study of the effect of various variables on the amount of environmental stress applied to the sheet, the defects of changes in the sheet thickness after the process, the wrinkling of the sheet during the process, the value of the threshold force of wrinkling in the presence and also absence of a blank holder [1-8]. These variables include mandrel shape and speed, the diameter, thickness, material and homogeneity of blank, die shape and die edge shape.

In this article, the hot deep drawing process of steel sheets in dies without a blank holder is investigated. For this purpose, a suitable die geometry in the hot deep drawing process with a constant temperature of 1100K is suggested, so that HY100 steel sheets can be produced in the shape of a hemisphere with minimal force and free of common defects. In this analysis, with finite element method, the peripheral stresses applied to the sheet, the defects of changes in sheet thickness, the wrinkling of the sheet and the force necessary for deep drawing process of steel sheets in different dies and sheets have been examined.

2. Methodology

The variables of the problem are divided into three general categories including process, die and work piece variables, which are briefly explained below.

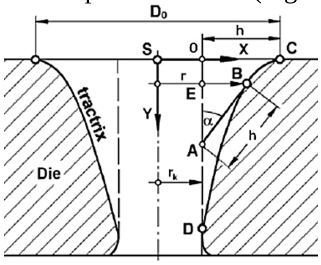
- Friction
- Temperature
- Speed of Process
- Die geometry
- Primary sheet diameter
- Primary sheet thickness
- Sheet material

Coulomb model with penalty method is used to define the friction behavior between the common surfaces of the process components.

The temperature of the process for the material in question is constant and equal to 1100K.

The process time is considered fixed and equal to 15 seconds.

According to previous researches, the deep drawing process with a blank holder requires a press with a very high tonnage [9]. Therefore, in this research, dies without a blank holder is investigated, in which the geometric form of the matrix is in two forms: tractrix and pseudo-tractrix (Figure 1).



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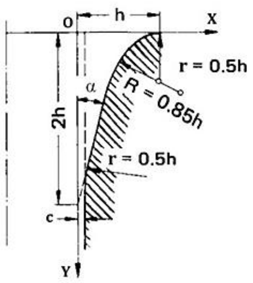

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Figure 1. (a) Tractrix and (b) pseudo tractrix dies [10]

The equation of the tractrix curve in terms of its variables is given in (1):

$$y = h \ln\left(\frac{h + \sqrt{h^2 - x^2}}{x}\right) - \sqrt{h^2 - x^2} \qquad (1)$$

The diameter of the primary sheet has been checked at five values of 3.2, 3.4, 3.6, 3.8 and 4 m and the thickness of the primary sheet is considered in six values 1, 2, 3, 4, 5 and 6 cm.

The material of the sheet is HY100 steel which follows the Johnson-Cook structural model [11, 12].

For finite element analysis, the mandrel and die model are considered as analytical rigid shell and discrete rigid shell, respectively. On the other hand, the sheet model is considered a deformable shell. For the sheet, the 8-node cubic model meshing (C3D8R) is applied. The appropriate element size is selected based on the convergence of the analysis for the maximum Von-Mises stress. Figure 2 shows the layout of the components.

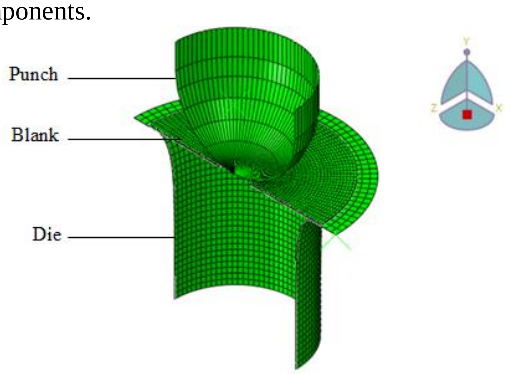


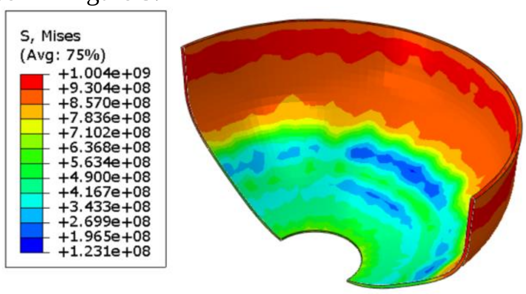
Figure 2. Arrangement of components in the deep drawing process

Through numerous simulations, the following points have been deduced regarding the convergence of the correct answer:

- The problem model is axisymmetric, but wrinkling does not occur symmetrically at the edges of the sheet during process. Therefore, it is not possible to consider axisymmetric model.
- Blank meshing must be symmetric and regular. Because any asymmetry in the meshing causes different stiffness in different sections and the occurrence of unrealistic and early wrinkling.
- Due to the large geometry of the final hemisphere, it is possible to use perforated sheet analysis instead of full sheet analysis. Numerous simulations showed that the presence of a hole in about 10% of the diameter of the blank has no effect on the process results and it reduces the simulation time by about 20%.

3. Results and Discussion

In this section, the results of the simulations have been analyzed. In the simulations, by changing the input parameters (sheet thickness, initial diameter of the sheet and the geometrical components of the die), the amount of force required by the mandrel and the change of its thickness have been investigated. An example of the results of the peripheral stress distribution of the sheet for a sheet with a radius of 1.7 m and a thickness of 2 cm in two different dies can be seen in Figure 3.



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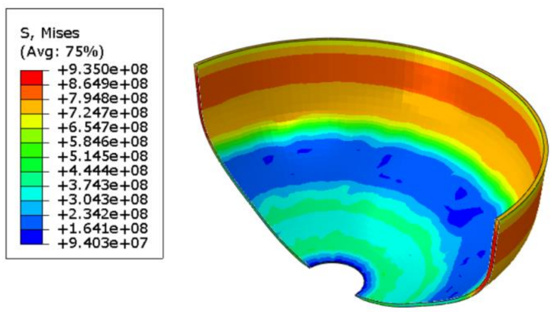

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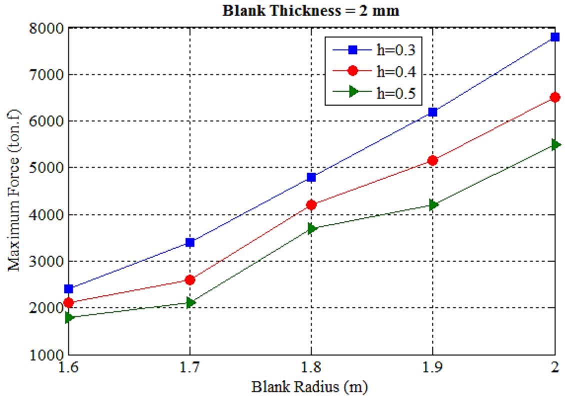
Figure 3. Stress distribution of sheet in (a) tractrix and (b) pseudo tractrix dies in Pascal

For brevity in the text, only the results related to the maximum force of the mandrel for three tractrix dies with constants of 0.3, 0.4 and 0.5 in two states of constant sheet thickness and constant sheet radius are given in Figure 4. As it can be seen, in all three dies, with the increase of the radius and thickness of the sheet, the required mandrel force has increased. In smaller radii, the die with a constant of 0.5 m has the lowest mandrel force, while it has the highest value in the die with a constant of 0.3 m. In Figure 4-b, the slope of the graph in the die with a constant 0.3 m is more than the others and the main reason for this issue is the greater slope of the die in this die compared to the other two dies.



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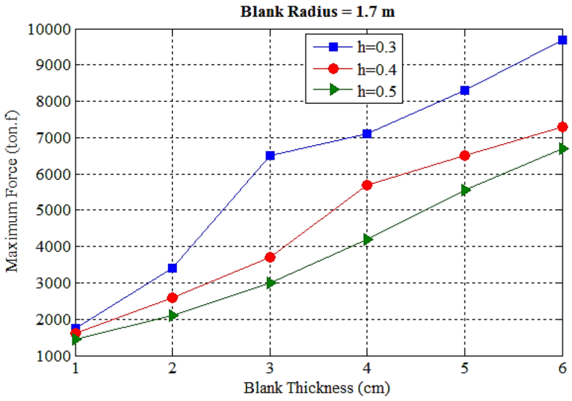

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Figure 4. Comparison of maximum mandrel force in tractrix dies in (a) fixed sheet thickness and (b) fixed sheet radius

Other important results related to the rest of the simulations are summarized in the next section.

Since it is difficult and costly to carry out the process experimentally in the dimensions and conditions related to this research, the results of previous related researches have been used to verify the paper results [13].

4. Conclusions

In this paper, the finite element analysis was presented for the hot deep drawing process of hemispherical caps from HY100 steel sheets without a blank holder. Simulations were conducted using ABAQUS software for the two types of dies: tractrix and pseudo-tractrix. Sheets with different thicknesses and diameters were considered and the results were compared with each other. The most important findings can be summarized as follows:

- The results of analyzes show that in both types of dies, with the increase in the thickness and radius of the sheet, the maximum force required by the mandrel increases.
- As the angle of the pseudo tractrix die increases, the maximum force required by the mandrel decreases.
- As the radius of the sheet increases, the behavior of the two types of tractrix and pseudo tractrix dies are different. Sheet thinning in the tractrix die increases with a positive slope.
- As the thickness of the sheet increases in both types of tractrix and pseudo tractrix dies, the sheet thinning increases.
- By increasing the thickness of the sheet in both types of tractrix and pseudo tractrix dies, the thickening of the sheet edge increases.
- In general, less forming force is needed in the tractrix die, and also there are less thickness changes.
- The forming of cylindrical hemispheres with a radius of less than two meters and a thickness of more than one centimeter will be healthy and free of wrinkles.

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