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Numerical Simulation of Hole-flanging Process of Aluminum Sheet

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Abstract—**A hole-flanging operation on a flat circular sheet with a hole in the center is simulated by an incremental elasto-plastic finite-element method, which incorporates strain-hardening and isotropy, with care taken to describe the boundary conditions of penetration, separation and the alternation of the sliding sticking state of friction. The simulation clearly demonstrates the processes of generation of deformation shape until unloading. In the course of analysis, if blank thickness is equal to fractured thickness, it is considered that the forming limit of the flange has been reached.**
The experimental results were compared with FEM-simulated results. It is found that using the elasto-plastic FEM can effectively predict the generation process of the deformed shape until unloading. The calculated sheet geometries and the relationship between punch load and punch travel are in good agreement with the experimental data.

***Index Terms*—Elasto-plastic, finite element method, hole-flanging & metal forming.**

I. Introduction

Hole-flanging is one of the most important techniques of sheet metal forming and it has been used widely in manufacturing industrial parts. Hole-flanging is a process used to displace the material around a hole in a flat sheet to form a cylindrical or conical neck or flange. It's away to provide material for thread cutting and to provide additional support for press fit for bolts or for making solder. It can be observed that the deformation of the sheet around the hole periphery is a combination of bending and stretching. The circumferential strain induced at the edges of these flanges, however, is often too large to cause failure by necking or tearing. So far, there has been a sheer volume of literature related to the sheet metal forming process. Yoshida [1] applied a total strain; an isotropic theory of plasticity to analyze the formation of flanges by using flat and spherical punches. Yoshida also achieved many experimental results on the rupture of the hole periphery in the neck or flange. Johnson et al. [2] reported a simplified analysis of hole-flanging using a conical punch to predict the formation of the flange as well as the rupture of the material in this process. Johnson et al [3] analyzed and performed an experimental study on the deformation of circular plates leading to the fracture of the lip in the hole-flanging process. They applied the plastic anisotropy of Hill onto the plane stress condition. The objectives are first to forecast the change in thickness along the edge of expanded hole on the sheet material, and second to discuss the distortion pattern of the expanded hole of the curving flanged part after the sheet material was burst. They also discussed the influence of the plastic properties of the material and the processing geometry on hole-flanging. A finite-element analysis of flanged hole forming is proposed by Tang [4] using the membrane shell theory while ignoring the bending effect. Daw-kwei leu [5] made use of the instability of uniaxial tension, an approximate relationship to determine the onset of necking of the hole periphery in the hole-flanging process. The latter is derived and it is found to be influenced by the process geometry and the plastic properties of the material, such as the stress-concentration factor, strain-hardening and normal anisotropy, and the estimated value goes together with the experimental data. He used four different punch shapes, i.e. hemispherical, ellipsoid, cylindrical and conical to analyze the distribution of the sheet material's stress and strain during the hole-flanging process. The simulation results reveal that the strain path during the forming process is not affected by the punch shape, but the maximum punch load depends on the punch shape. Besides the plastic properties of material, such as strain-hardening and anisotropy, which affect the formability in the hole-flanging process [12,6], other external influencing factors include the lubrication condition, the punch shapes and the clearance between the punch and the die [7]. Huang and Chien [8] employed the incremental updated lagrangian elasto-plastic finite element method to analyze the hole flanging of circular plates with a pre-determined smaller hole at the center of the sheet metal. Hyun et al.[9] performed the hole flanging experiments on flat circular plates with a hole in the center to investigate the fracture and lip shape behaviors of TRIP steels and ferrite–bainite duplex steels. Li et al.[10] performed the hole-flanging process on flat circular plates with a hole in the center to investigate the forming limit, and the experimental result revealed a forming limit ratio of 2.70. Haung and Tsai [11] examines the influence on forming limit of blank and fractured thickness and analyzed the square cup drawing process and the elliptical hole-flanging process, and calculated the forming limit ratio for each process.The purpose of this work is to provide an elasto-plastic finite-element computer program, based on the updated Lagrangian formulation, and adopted to simulate the hole-flanging process until unloading for a conical punch. The simulation results of punch load and the final shape show good agreement with the experimental results. The characteristic of lip wall thinning and the limitation of

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formability in the hole-flanging process are discussed in this work

II. Numerical analysis and experiment

The analytical model and the experimental setup of hole-flanging process were developed under axisymmetric case of a flat, annular shaped piece of steel sheet clamped along its outer boundary. The analysis of the hole flanging process is based on the consideration of the axisymmetric condition. Because of the symmetry of the sheet, only the right half portion of the tools and workpiece are modelled. A conical punch with a cone angle of 60° and a diameter (Dp) of 12.0 mm was used. The clearance (Cr) between the punch and the die (Dd) was controlled by changing the inside diameter of the punches (Dp). Setting the ratio of clearance to thickness $C_r = (D_d - D_p)/2t$ was applied to the blank Figure.1. The spring-back phenomenon influences significantly the finished shape in the sheet forming process, so the unloading process must be performed after sheet forming.

The experiments were carried out by a 200 KN hydraulic sheet metal forming test machine and a computer controller to display the stroke of the punch and the forming load. To realize satisfactory lubrication between the tool and the sheet, a friction coefficient μ = 0.2 is assumed in the calculation.

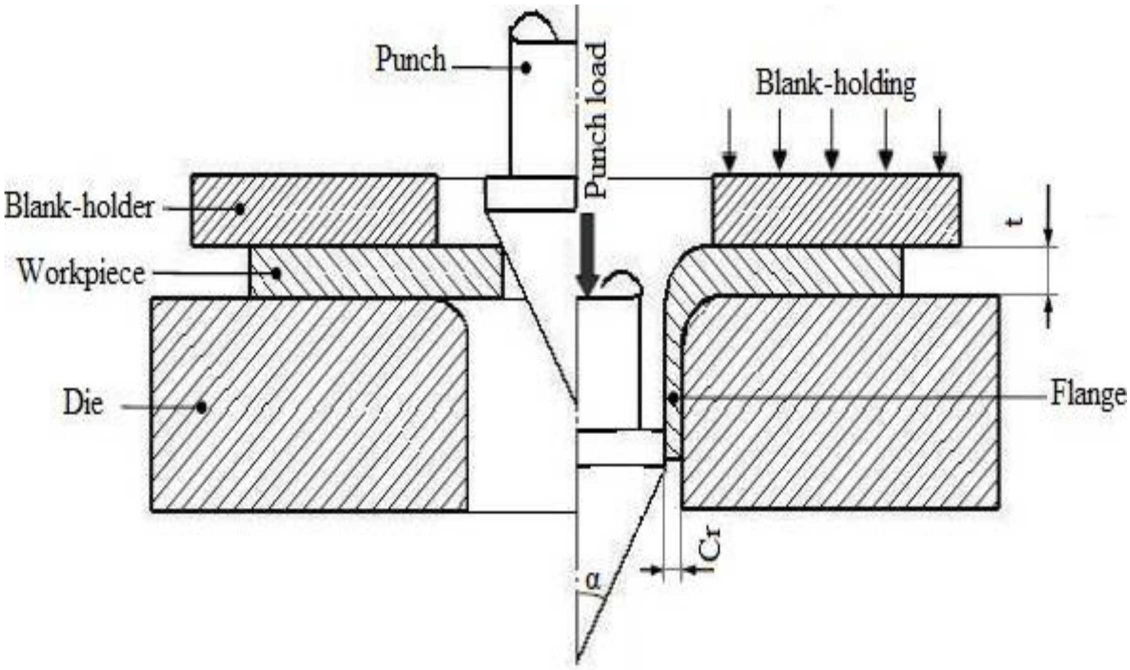


Figure 1.Hole-flanging process

A. FE modelling

The simulations are performed using the FE software ABAQUS, the complexities of the hole-flanging process and the large number of interacting factors is investigated taking into account the elastoplastic behavior of the metal sheet by the mean of an appropriate model. Some experiments were performed to verify the efficiency of the FE models.

The unloading procedure is executed by assuming that the nodes on the outer boundary are fixed in the directions and all elements are reset to be elastic. The force of the nodes that come in contact with the tools is reversed to be become the prescribed force boundary condition on the sheet. A typical FE mesh is shown in Figure.2. The workpiece was modelled as deformable bodies, whereas the tools (die, punch and blank-holder) were modelled as rigid surfaces since they are much stiffer

B. Material behaviour

A commercial sheet of aluminum with a thickness of (*t = 2mm*) was considered for this work. Uniaxial tensile test was used to describe the stress-strain relationship.

The material data for the aluminum sheet were

- Yield stress: $\overline{\sigma}_y = 52MPa$
- Stress-strain relation: $\overline{\sigma} = 52 + 160(1 - e^{-18\varepsilon_p})$
- Poisson's ratio: ν = 0.35
- Elastic modulus : E = 70MPa

C. Experimental work

The experimental procedure was as follows:

- The die set was assembled on the hydraulic press
- The blank holder force was set to 1450N to prevent slipping in the contact region between the blank and the die
- The velocity was selected for the punch to draw the blank into die, the speed of punch being kept very low to eliminate the effect of speed on the experimental results

- The relationships between punch load and punch travel were recorded using the data acquisition equipment.

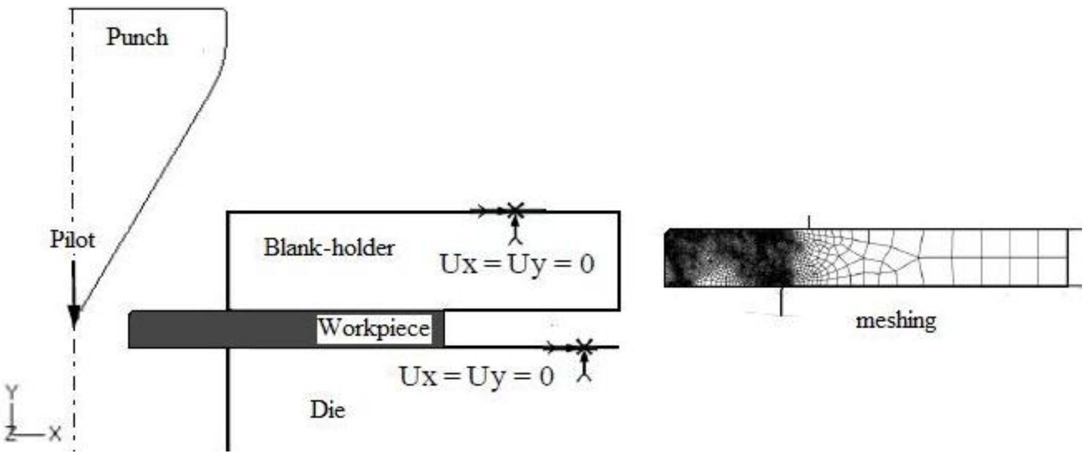


Figure 2.FE model of hole-flanging process

III. RESULTS AND DISCUSSION

A. Comparing the punch load for different initial hole diameters at the blank centre

The comparison of punch load of experiment, with that finite-element simulation, with initial diameter assumed to be 5.8, 6.0, 6.2, 6.4 and 6.6 are shown in Figure. 3. Used in the simulation of the hole-flanging process. The punch load increased progressively with punch travel until about half of travel. This is bent twice, around the profile of the die and then of the conical punch. After maximum punch load was obtained, the load decreased progressively for expanded holes and thinning of the flange.

The finished products are obtained free from necking or fracture. Atypical example is shown in Figure.4. After unloading, the final shape reveals a loss of flatness in the outer edge of the finished product, as shown in Figure .4.b To illustrate the shape of the flange, a sectional view of each finished product is plotted in Figure .4.c.

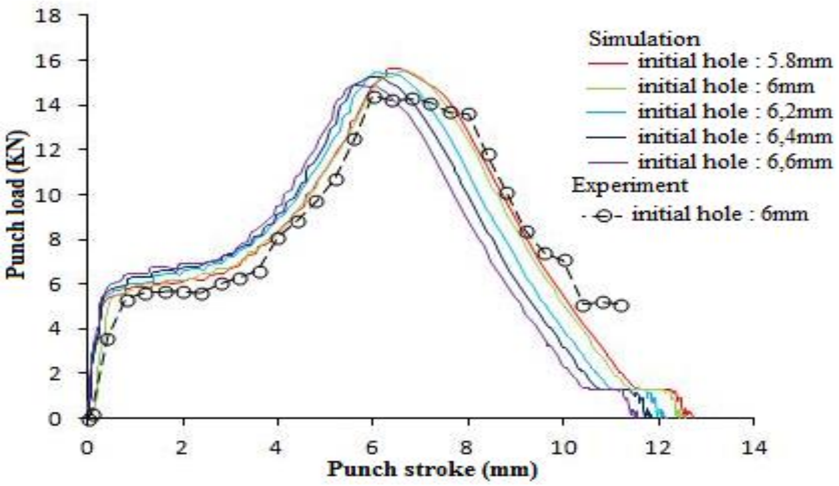
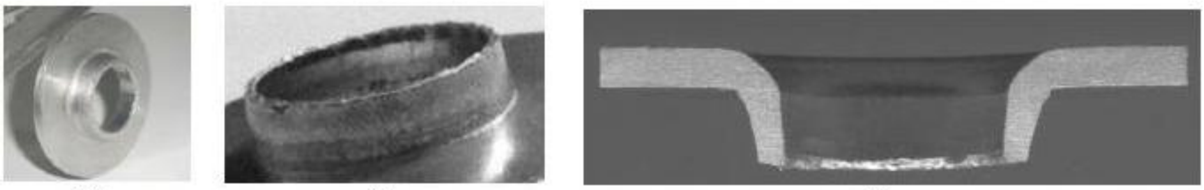


Figure 3.Comparison of punch load for different initial hole



(a) (b) (c)

Figure 4.Example of a typical finished product and Sectional vie

B. Deformation history in simulation

Figure.5 shows deformed nodal velocity distributions of the hole-flanging process. The calculated geometries shown are compared with those of the experimental results. At the flange of the sheet, the phenomena of expansion of the inner hole are clearly observed in both calculation and experiment. The reduction of the thickness of the sheet is clearly observed along the direction of the length of the sheet, especially at the hole periphery of the flange, and increasing its degree as the process proceeds. In figure the nodal velocity distributions show the correct deformation procedures of the flanging process.

C. Limitation of formability

Engineers desire that the finished lip will yield without any fracture or necking in the hole-flanging process. They also know that the size of the punch profile where the fracture occurs on blanks, and that the size of the initial hole of blanks is the cause of fracture occurrence.

Figure 6 shows the simulated relation between thickness distributions and diameter of initial hole. However, the velocity of wall thinning is increased with the initial hole of the blank holder load.

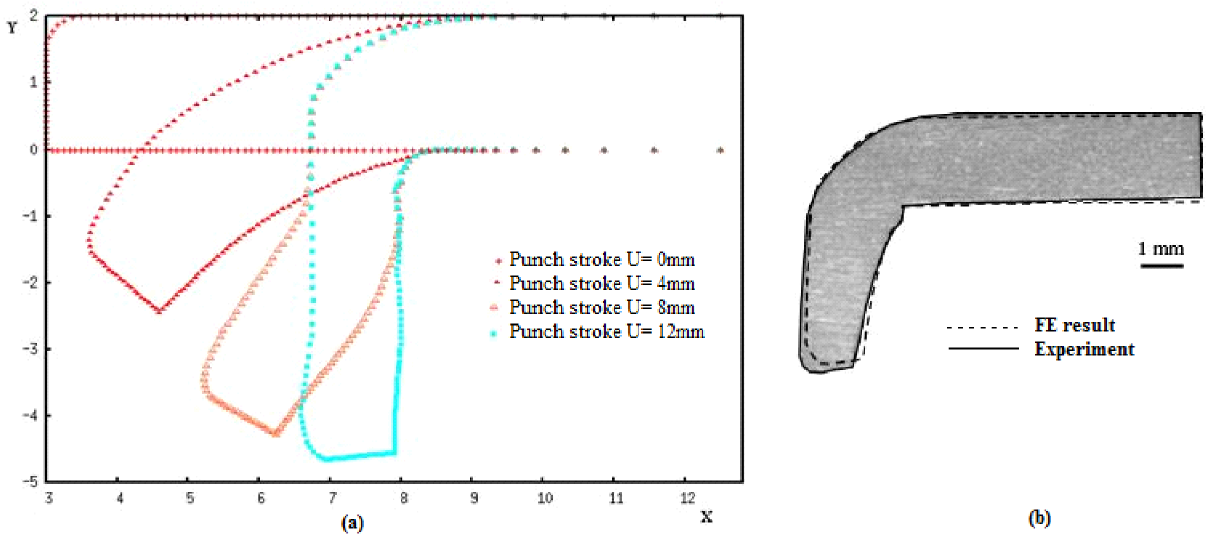


Figure 5. (a) The deformed geometrical configuration of the flange at different punch travels (b)Sectional view and FE deformed shape

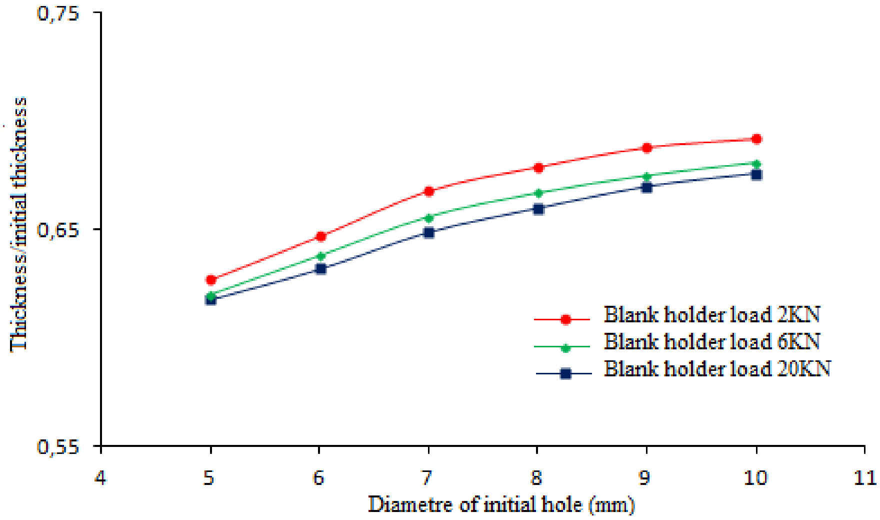


Figure 6.Comparison of sheet thickness for different initial hole

IV. Conclusion

An incremental elasto-plastic FEM based on the updated Lagrangian formulation was adopted to predict of the hole-flanging process. The experimental and simulated results obtained are summarized as follows: The simulated results, such as the variation of thickness and the relationship between punch load and punch travel, agree well with the experimental results. The maximum residual stress occurred on the periphery of the expanded hole. The maximum reduction in wall thickness occurs on the end of major axis of the expanded hole, i.e. the tensile stress in the circumferential direction at the edges of the flanged hole is the main reason for failure due to cracking or tearing.

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REFERENCES

[1] K. Yoshida, Classification and systematization of sheet metal press-forming process. Inst. Phys. Chem. Res. 53, 125 (1959).
[2] W. Johnson, N. R. Chitkara, A. H. Ibrahim and A. K. Dasgupta, Hole flanging and punching of circular plates with conically headed cylindrical punches. J. Strain Analysis 8, 228 (1973).
[3] JOHNSON W, CHITKARA N R, MINH H V. Deformation mode and lip fracture during hole-flanging of circular plates of anisotropic materials [J]. Trans ASME J Eng Jnd, 1977,99: 738-748.
[4] S. C. Tang, Large elasto-plastic strain analysis of flanged hole forming. Comput. Struct. 13, 363 (1981).
[5] LEU D. Finite-element simulation of hole-flanging process of circular sheets of anisotropic materials [J]. Int J Mech Sci, 1996, 38: 917-933.
[6] TAKUDA H, KKUCHI S, HATTA N. Formability of a commercially pure zirconium sheet [J]. J Mater Pro Tech, 1998, 84: 11 7-121.
[7] LEU D, CHEN T, HUANG Y. Influence of punch shapes on the collar-drawing process of sheet metal [J]. J Mater Pro Tech, 1999,84: 134-1 46.
[8] HUANG Y, CHIEN K. Influence of punch profile on the limitation of formability in the hole-flanging process [J] J Mater Pro Tech, 2001, 113: 720-724.
[9] Hyun, D.I., Oak, S.M., Kang, S.S., Moon, Y.H., 2002. Estimation of hole flangeability for high strength steel plates. J. Mater. Process. Technol. 130/131, 9–13.
[10] Li, C.L., Li, C.Y., Chen, J.D., 2002. The analysis on the hole-flanging penetration process of sheet metal with semi-spherical punch. In: Proceedings of the 26th national conference on theoretical and applied mechanics R.O.C., M016.
[11] You-Min Huang, Yi-Wei Tsai, Ching-Lun Li Analysis of forming limits in metal forming processes J. Mater. Process. Tech. (2008), in press
[12] Kacem A., Krichen A, Manach P.Y., “Occurrence and effect of ironing in the hole-flanging process” Journal of Materials Processing Technology, vol.211 (2011) p.1606-16013