Springback simulation study for air-bending forming of sheet metal

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In this paper, the influencing factors of springback for air-bending of sheet metal are introduced. The bending springback in various process parameters is simulated with a ABAQUS FEA software. The influence of different parameters on bending springback is investigated and some effective methods for predicting and restricting springback are put forward.

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Keywords: Sheet metal forming, Air-bending, Springback, Finite-element method, Numerical simulation

1. Introduction

In a quest to achieve low-mass hydraulic mobile crane, the crane industry has been actively investigating the use of lightweight materials for a wide range of structural parts of crane telescopic boom. Boom is a large workpiece, its processing with the multichannel time by gradual bending forming method, and the intensity of every bending of plate high involves serious springback problem. Obviously, the existence of the rebound will reduce the geometric accuracy of parts, influence subsequent assembly, therefore, the research of springback has important significance. For sheet metal bending forming, springback would result in sheet metal bending radius, bending angle change. The bending radius of a sheet metal after unloading is called springback radius (R), the unloaded bend angle is referred as springback angle (α).The difference between springback radius and punch radius is defined as springback quantity of bending radius ($\Delta\rho = R - r$); the difference between springback angle and bending angle is referred as springback quantity of bending angle ($\Delta\beta = \alpha - \theta$) (see Fig. 1).We note that many methods have been proposed to control springback angle. In which type of convex die surface modification is a widely used method to compensate the springback [1]. However, springback is not only associated with punch structure, but relevant to plate property, geometric shape, die structure, punch displacement, friction, etc. Therefore, this research intends to study different process parameters influencing on springback by numerical simulation.

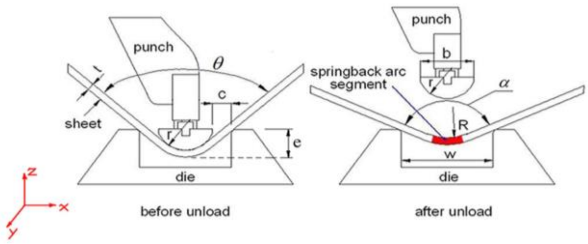

Fig. 1. Geometric model of sheet metal bending

Where R is springback radius, α is the springback Angle, r as the punch radius, t is thickness, c for mold clearance, w for die openings, b for punch width.

2. Sheet metal air-bending and springback analysis

The sheet metal air-bending forming is a very complex physical process involving geometric nonlinearity, material nonlinearity and boundary nonlinearity. Contact between the mold surface and the sheet metal was in the non-steady state due to the flow of sheet, and the forming process often associated with the instability phenomenon of tension and compression. It is required to be effectively set the loading and boundary conditions in the simulation.

Sheet metal produced springback after bending has two main reasons [2]: in the sheet metal forming process, when the surface fibers of sheet metal come into the plastic state, and the fibers in the sheet metal center is still in elastic state, sheet metal produce the elastic recovery after removing the load. In addition, the metal forming is always accompanied by elastic deformation, during the sheet metal bending, even all the inner and outer fibers come into the plastic state, after removing the external forces, the elastic deformation disappears, and there will be springback too. Geometry shape changes of the sheet before and after the springback are shown in Fig. 1.

3. The numerical simulation theory

3.1 Algorithm

The time integral method mainly used in finite element numerical simulation to solve equations of motion, integral method has two kinds: static implicit and dynamic explicit. Dynamic explicit algorithm in each incremental step are not need for matrix inversion, there are no problem of the convergence, so the dynamic explicit algorithm is suitable for large-scale strongly nonlinear analysis of the problem. Static implicit algorithm used the static equilibrium equation, is suitable for a class of quasi static problems as the springback. According to the springback definition, Springback is a process that the internal stress redistribution. Therefore, we can assume that the springback process without mould, can not considering the nonlinear contact between mold and sheet metal, the springback deformation of the process of is much smaller than the forming process. Caused by large displacement, large rotation and large deformation of the geometric nonlinear also decreased significantly, all of these conditions provides the necessary conditions for the application of implicit algorithm in springback. So we use ABAQUS/Explicit Explicit module to simulate the sheet metal forming process, and ABAQUS/Standard implicit module to simulate springback process of sheet metal.

Due to the result of any time during the ABAQUS/Standard module running could be treated as initial condition run in the ABAQUS/Explicit module for further calculating and analyzing, and vice versa. Therefore, ABAQUS software function is very suitable for multiple-step air bending process. We integrated ABAQUS/Explicit and ABAQUS/Standard to carry out the mixed operations. This method can make the non-linear behavior of each step in multiple-step air bending forming be solved with higher precision and faster convergence, compared with algorithms of other FEM softwares [3].

3.2 Material model

The accuracy of the finite element simulation depends largely on the material constitutive relation can truly reflect the real properties of materials. Therefore, the use of appropriate material model and the real material mechanics parameters is an important factor of springback simulation accuracy.

Due to the sheet metal used to form large workpiece has a distinct planar anisotropy and normal anisotropy, the traditional isotropic plasticity theory is difficult to derive the linear incremental relationship between stress and strain in a complex stress state according to Mises yield criterion and plastic flow equation. At the moment studying the deformation of metal can only use anisotropy plastic theory to describe the physical constitutive relation between stress (stress rate) and strain (strain rate) of the elastic-plastic deformation body. The research results of Hill [4] and Barlat [5] are most representative in this field. Currently, finite element numerical simulation generally uses the Hill48 and the Barlat89 anisotropic yield criterions. Hill48 anisotropic yield criterion is more accurate in the description of the anisotropic behavior of the metal plate when $\bar{L}$ (anisotropy coefficient) is large ($\bar{L} > 1$) [4], and Barlat anisotropic yield criterion can accurately describe the yield behavior of aluminum alloy sheet while $\bar{L}$ is small($\bar{L} < 1$) [6]. So, the numerical simulation in this paper follow Hill yield criterion, the Hill of anisotropic material model. The model function as shown below.

$$f(\sigma_{ij}) = F(\sigma_y - \sigma_z)^2 + G(\sigma_z - \sigma_x)^2 + H(\sigma_x - \sigma_y)^2$$
$$2L\tau_{yz}^2 + 2M\tau_{zx}^2 + 2N\tau_{xy}^2 = 2\bar{\sigma}_e^{\ 2} \tag{1}$$

Type F, G, H, L, M and N as the transient characteristics of the anisotropic parameters; σ_x, σ_y, σ_z respectively orthogonal symmetric stress axis (x, y, z) on the uniaxial tensile yield stress; τ_{yz}, τ_{zx}, τ_{xy} respectively yz-, zx- and xy- coordinates in the plane of shear yield stress; $\bar{\sigma}_e$ is the equivalent stress.

Leave out high price and ignore the shear effect, (1) with (2) type simplified

$$\psi^2(\sigma_{ij}, \varepsilon_{ij}) = \sigma_x^2 + \sigma_y^2 - \frac{2\bar{L}}{1+\bar{L}}\sigma_x\sigma_y + \frac{2}{1+\bar{L}}(\sigma_z^2 - \sigma_x\sigma_z - \sigma_y\sigma_z) - \bar{\sigma}_e^{\ 2} = 0 \tag{2}$$

In the Type, q for anisotropy coefficient; W for the yield function.

For sheet metal bending forming, adopt plane strain assumption. Namely, $\varepsilon_y = 0$, make $d\varepsilon_y = d\lambda \frac{\partial \psi(\sigma_{ij}, \varepsilon_{ij})}{\partial \sigma_y} = 0$ ($d\lambda$ is a factor). And (2) type combination get $\bar{\sigma}_e$, It said:

$$\bar{\sigma}_e = \sqrt{1+2\bar{L}}\left|\sigma_x - \sigma_y\right| \tag{3}$$

$$\overline{\sigma}_e = \frac{\sqrt{1+2\overline{L}}}{1+\overline{L}}\left|\sigma_x - \sigma_z\right| \tag{4}$$

According to the formula of plastic work, equivalent strain can be represented by the type:

$$\overline{\varepsilon}_e = \frac{1+\overline{L}}{\sqrt{1+2\overline{L}}}\left|\varepsilon_x\right| \tag{5}$$

According to the law of strain hardening, equivalent stress and equivalent strain relationship is expressed as:

$$\overline{\sigma}_e = K\ (\overline{\varepsilon}_0 + \overline{\varepsilon}_e)^n \tag{6}$$

In the type, $\overline{\varepsilon}_0$ for initial strain, $\overline{\varepsilon}_e$ as the equivalent strain.

Put (5) and (6) into (3) and (4), and can solve σ_y , σ_z , $\overline{\sigma}_e$ and $\overline{\varepsilon}_e$ .This is the theoretical basis of numerical simulation of sheet metal bending forming process.

3.3 Unit type

Unit of sheet metal forming numerical simulation technology has experienced film unit, Cauchy Hoff (Kirchhoff) shell element, Medellin (Mindlin) shell unit and entity unit, degenerate shell element, relative freedom shell element this development process[7].At present, the main numerical simulation of sheet metal stamping are three units: shell membrane unit, unit and entity unit. In comparison, the thin shell element with the most, It makes up for the film unit can't realize the springback phenomenon such as wrinkle simulation faults, the calculation speed and precision of result is better than that of the three-dimensional entity unit. This article uses the finite element software ABAQUS ,and it use shell element technology, sheet metal bending simulation reduced order integral quadrilateral shell element with eight nodes.

3.4 Friction model

In the process of sheet metal forming, friction phenomenon has been found to be important, sometimes need to strengthen the friction effect, sometimes need to reduce. The main purpose is to control the material flow in the mold. Accurate calculation of friction in sheet metal forming is very important. The applicable law of friction still is coulomb's law.

4. Forming simulation

4.1 Material and process parameters

Select the size of the metal sheet 320mm×80mm. The thickness (t) were respectively taken 5, 6, 7, 8 and 9mm, the punch radius were taken 50, 70, 100, 142 and 193mm, die gap were taken 20, 25, 30 , 35 and 40mm, the mount of punch press were 30, 35, 40, 45 and 50mm. Material characteristics are in Table1. Punch speed was set to 8mm/s. Quality amplification factor was set to 10. The sheet is deformable body, and the punch and die are analytical rigid body. Contact condition between metal plates and the punch and die follows the contact surface weighting search algorithm, penalty function algorithm for contact force and coulomb friction law. The sheet metal forming uses Hill anisotropic yield criteria. To compare the size of springback under different bending conditions of forming workpiece, this paper measures springback using $\Delta\rho$, $\Delta\beta$ as a indictors.

Table 1. Material characteristics of sheet metal using for simulating

Material	E(Mpa)	σ (Mpa)	Poisson's Ratio	Density(kg/m3)	σ /E
WELDOX700-1	217069.7	776.287	0.266	7830	0.00358
WELDOX700-2	178846.6	699.842	0.243	7830	0.00391
WELDOX900-1	205856.3	950.812	0.284	7830	0.00466
WELDOX900-2	200405.4	956.009	0.276	7830	0.00477
OPTIM 960	204620	1257.59	0.276	7830	0.00615

4.2 Simulation results and analysis

Simulation results of the bending springback were solved by ABAQUS. The impacts of process parameters on the springback were analyzed as follows:

1) The influence of punch radius on springback

The influence of different punch radius on simulation springback results is shown in Fig. 2. It can be seen from the figure, the springback radius increases with the radius of the punch changing larger, and the springback angle decreases with the radius of the punch increases.

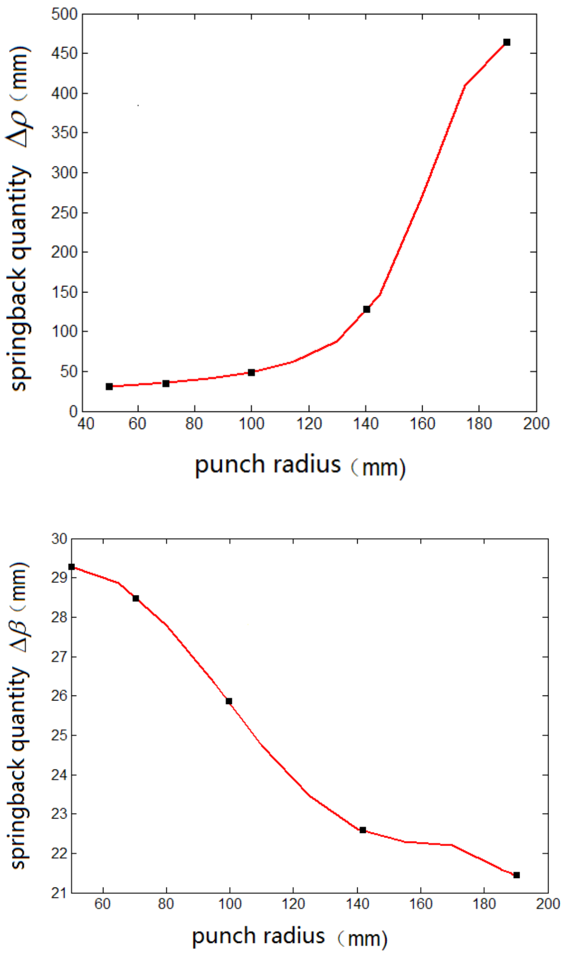

Fig. 2. The influence of punch radius on springback

2) The influence of plate thickness on the springback

The influence of different thickness on simulation springback results is shown in Fig. 3. It can be seen that with the thickness of sheet increasing the springback decreases because of the material in plastic deformation increased with the thickness.

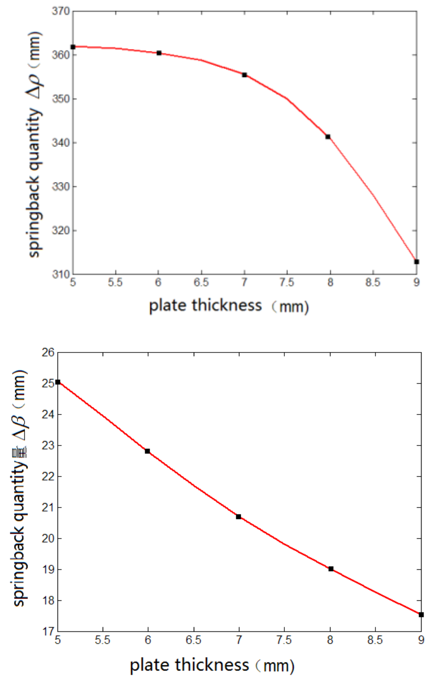

Fig. 3. The influence of plate thickness on the springback

3) The influence of die gap on springback

The influence of different die clearance on simulation springback results is shown in Fig. 4. It can be seen from the figure that springback increase with the mold clearance.

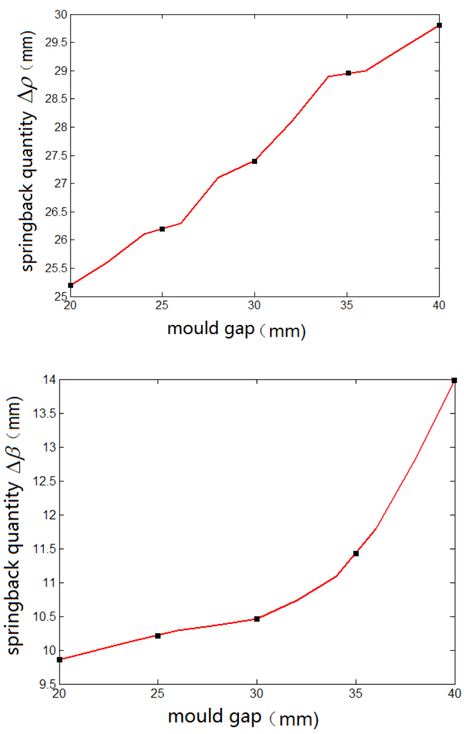

Fig. 4. The influence of die gap on springback

4) The influence of press amount of punch on springback

The influence of different press amount on simulation springback results is shown in Fig. 5. It can be seen that the springback decreases with the press amount increases.

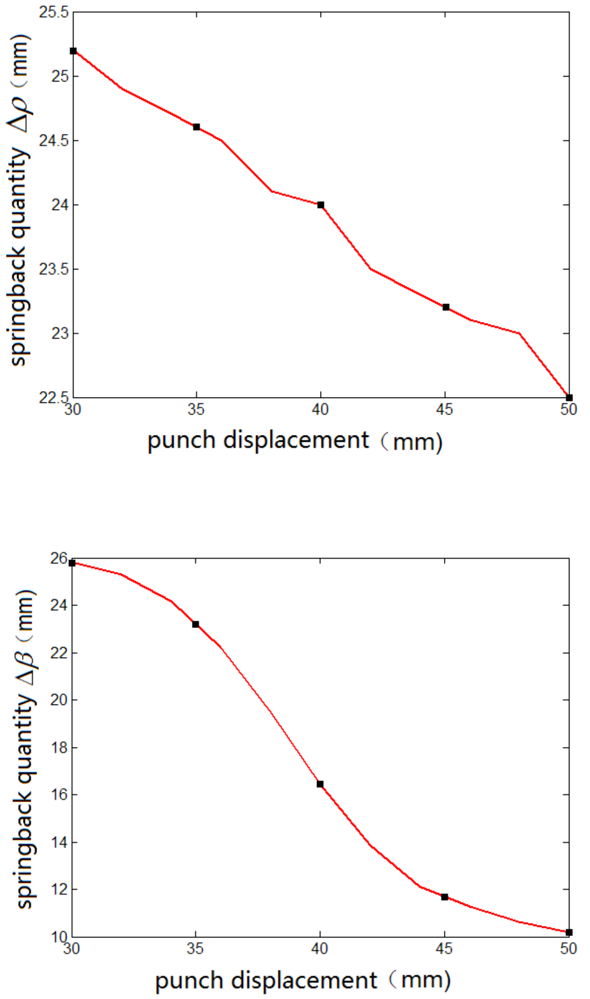

Fig. 5. The influence of press amount of punch on springback

5) The influence of sheet properties on springback

The influence of different sheet properties on simulation springback results is shown in Fig. 6. It can be seen from the figure that with the increase of the yield strength the springback increases, and with the Young's modulus increasing the springback decreases.

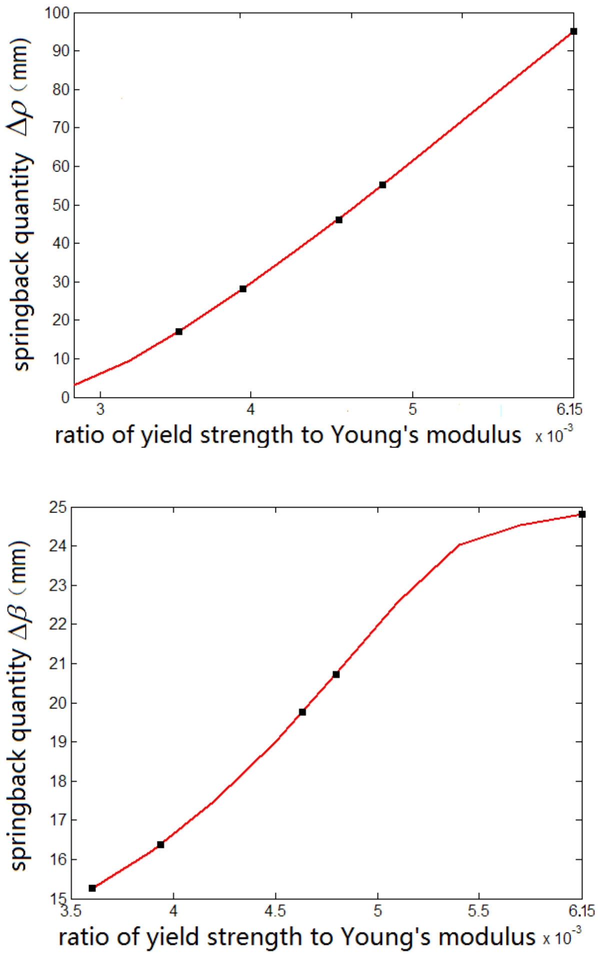

Fig. 6. The influence of sheet properties on springback

5. Method for controlling springback

Influence factor of the springback was analyzed above. The ways to reduce springback are also sought from these aspects in the actual production. The springback control methods are as follows:

1) The material of high elastic modulus, low yield point can reduce the springback effectively.
2) Reduce the amount of die clearance can reduce the springback, but the forming force increases and results in the deformation of the bending machine body increase. If forming the large workpiece, there will be serious warping.
3) The die compensation method. According to the experimental iteration results, constantly revise the mold surface and effectively compensate the springback error.
4) Bending over method. Make the plastic deformation of sheet metal increasing by further press of Punch for effectively reducing the springback after forming.

6. Conclusions

Based on the numerical simulation of sheet metal bending springback, the influence of punch radius, sheet metal properties, sheet thickness, die clearance and convex mold quantity are studied, got here are some useful to control and reduce the bending springback, reference conclusion:

1) In the simulation of springback of bending workpiece, the springback decreases with the thickness of sheet metal increasing. In actual production, it is better to use slightly thicker sheet metal to control and reduce springback if conditions allow.
2) Springback increases with the die gap increases. If the die gap is too small there will be surface indentation, warping phenomenon and if the gap is too large will produce wrinkling, springback and other undesirable phenomenon, so choosing proper die clearance is critical.
3) From the model results, lower springback value could be obtained with the material of smaller yield strength, bigger Young's modulus, thicker sheet metal, and smaller punch radius.

Numerical simulation technology was used to study the influence of the bending forming process parameters on springback, the ultimate goal is to provide scientific data with mold design manufacture and workpiece forming, ensure that the product geometric accuracy.

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