Effect of layered polyurethane elastic cushion on quality of surface part in multi-point forming

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Abstract. Multi-point forming (MPF) is a dieless forming method. The upper and lower dies of MPF are composed of discrete height-adjustable punches. However, defect will be generated as some particular dimples crease on the smooth surface parts. Therefore, the addition of elastic cushion between the sheet metal and multi-point die is needed to improve the forming quality of surface parts. In this paper, we investigate the forming quality changes of workpiece through dividing polyurethane elastic cushion of the same thickness into different layers. Besides, spherical parts are selected as the study objects. The dynamic explicit algorithm is used to simulate the MPF process and static implicit algorithm is used to simulate springback. The results demonstrate that the values of the strain, stress and residual stress are smaller in process of multi-layers than that of one layer, and the distributions of the stress and strain are more uniform. Based on the results, it was also found that the layered polyurethane elastic cushion can effectively improve the quality of forming parts in MPF.

1. Introduction

Under the influence of economic and social development, the personal pursuits become more and more diverse, resulting in faster product updates and small batch production. In the production of sheet forming, the traditional die forming method has been unable to achieve the diverse requirement of people. Experts from all over the world have conducted a lot of researches on MPF technology. Hardt et al. from Massachusetts Institute of Technology, developed a reconfigurable die through in-depth research [1, 2]. Professor Li of Jilin University developed a series of sheet metal forming techniques based on the MPF theory and applied successfully to hull outer panels, head covers of high-speed train, medical skull repairing [3] and nest construction of structural parts [4-6]. MPF is composed of series of basic units which are ruled by arrangement [7]. The height of the unit can be controlled by computer to form a curved surface [8]. Compared with the traditional set of die, which can only produce parts of certain sizes and shapes, MPF uses the height-adjustable features of punches to realize the idea that a set of devices can form various parts. The punch of the multi-point mold directly contacted with the sheet will produce stress concentration, and sheet surface will appear indentation defects [9, 10]. As a elastic cushion, Polyurethane with good elasticity can effectively solve the indentation defects, which has been successfully applied in the MPF [10] and multi-point stretch forming [12, 13]. Hardness of the whole polyurethane elastic cushion is larger than the multi-layer polyurethane elastic. Forming a large workpiece will need to match the corresponding large polyurethane elastic cushion, and the placement process is not easy. The multi-layer elastic cushion is more flexible than the whole elastic cushion and the placement process before MPF is easy. Although the forming of the sheet under the condition of the whole polyurethane elastic cushion has been
studied [14], the forming of the sheet under the condition of multi-layer polyurethane elastic cushion has not been studied.

In this paper, phe rical objects as the object of study, the MPF of the sheet under the condition of the whole polyurethane elastic cushion and the multi-layer polyurethane elastic cushion have been studied by the finite element software. The effects of different elastic cushion conditions on the forming quality of sheet were studied. At the same time, the stress distribution, strain distribution and residual stress of the forming sheet are studied.

2. Finite element model.

The simulation experiments were carried out by dividing 20mm thick polyurethane elastic cushion into different layers and forming the sphere with radius 900mm. The sheet size is 500mm×700mm×5mm, and the material is 08Al. The modulus of elasticity is 207GPa. The Poisson's ratio of sheet is 0.3, and the yield limit of sheet is 91.3MPa. Besides, the density of sheet is 7800kg/m³ and the elastic cushion is regarded as super-elasticity material. The density of polyurethane elastic cushion is 1260 kg/m³. The dimension of the die surface is 500mm×700mm. The cross section size of the multi-point die is 10mm×10mm, and the punch radius is 8mm.

A finite element model with two layers elastic cushion is shown in Figure.1, which consists of multi-point upper die, lower die, polyurethane elastic cushions and metal sheet. Due to the symmetry of the spherical structure and symmetrical boundary conditions, a quarter model was built to save computational time. In addition, 20mm thick polyurethane was chosen as the elastic cushion, and the friction coefficient between the elastic cushion and sheet is set to 0.3. In numerical simulation, it is assumed that the sheet is isotropic. During the simulation, the lower die is fixed and the upper die is descended until the thickness direction of the elastic cushion is compressed by 1/3. The vertical degree of freedom of the upper die is free while the remaining freedom degrees are restricted. Moreover, the pressing process of the upper die is controlled according to time and displacement curve during the downward movement. In this simulation, the dynamic explicit and static implicit algorithms are selected. Forming sheet is set to the hexahedral structure with 2mm size, which is C3D8R unit type and the unit cell of elastic cushion selected hexahedron structure grid with 2mm size, as well as C3D8R unit type. The upper and lower multi-point modules are set as discrete rigid bodies, and quadrilateral-based neutral axis algorithm free mesh with 2mm size and R3D4 unit type are selected.

Figure.1 Finite element model (1/4)

3. Multi-point forming experiment

Experimental equipment selected the YAM-200 MPF press developed by Jilin University (Figure.2). Test material is 08Al. Besides, sheet size and swing head unit is the same as the numerical simulation.

Figure.3 is simulated experimental light pictures and experimental specimen pictures. According to Figure.3, Figure.3a and Figure.3c are the light picture and the forming part under the condition of the overall polyurethane elastic cushion, b and d are the results under the condition of two layers polyurethane elastic cushion. Obviously, the workpiece’s surface quality is good both under the whole
elastic cushion and layered elastic cushion conditions. Despite the good surface quality of the formed parts obtained under the conditions of the overall and layered elastic cushion, the in-depth study on stress and strain of the forming parts and residual stress is practically significant and necessary to get the higher quality forming parts of longer life span.

Figure 2 YAM-200 MPF press

Figure 3 Simulated light figure and forming results

4. Results and discussions

The finite element software Abaqus/Explicit is used to simulate the sheet processing in MPF by respectively dividing 20mm thick polyurethane elastic cushion into different layers, and the forming results were compared and analyzed.

The stress distribution of forming sheet with the elastic cushion in one layer, two layers, four layers and eight layers can be found in Figure 4. It can be seen that the maximal Mises stress of forming sheet with one layer is 358.1MPa and the stress range is 344.22MPa. The stress and strain distribution are not uniform when the polyurethane elastic cushion is not layered. When the elastic cushion of the same thickness was equally divided into two layers, four layers and eight layers, Mises stress maximums are 299.1MPa, 300.4MPa, 302.5MPa. However, the stress ranges are 273.17MPa, 288.91MPa and 293.183MPa respectively. The stress and strain distribution become uniform. This is because the elastic cushion of the sheet’s lower surface contacts only with lower die at the center point at the beginning of forming. However the elastic cushion of the sheet’s upper surface contacts only with upper die at the four corner points. During the forming process, the upper die goes down and the elastic cushion is squeezed to the central area, resulting in different thickness of the elastic cushion around the surface of the sheet, so there is dispersion of stress concentration. When the elastic cushion is layered, the mutual friction between the layers will inhibit the flow of the elastic medium material contacting with sheet. Throughout the surface of the sheet, the elastic medium thickness is uniform, thus avoiding the occurrence of stress concentration.

The equivalent strain distribution of forming sheet with the elastic cushion in one layer, two layers, four layers and eight layers are presented in Figure 5. When the elastic cushion is not layered, the equivalent strain distribution is in the range of 0 to 0.2228 on the whole sheet, and the obvious large strain region appears near the middle of the sheet. However, when the elastic cushion of the same thickness were equally divided into two, four, and eight, the strain distribution of the whole sheet surface is more uniform. During the forming process of the spherical parts, the material flows from the center to the periphery. Therefore, the equivalent strain gradually decreases from the center to the periphery. The equivalent strain distribution ranges from 0 to 0.0899, 0 to 0.9303, and 0 to 0.9527, which are reduced by 59.65%, 58.25% and 57.23% respectively in comparison with the maximum equivalent strain of forming sheet with one layer elastic cushion. Because the mutual friction between the layers suppresses the problem that the elastic cushion is extruded inwardly by the die and the elastic cushion is unevenly distributed after the remove of the polyurethane elastic cushion. As a result, the layered polyurethane elastic cushion has better flexibility and is favorable for the flow in the sheet.
forming process. The results of stress and equivalent strain distribution demonstrate the effectiveness of polyurethane elastic cushion stratification on forming quality sheet during MPF.

![Stress distribution clouds of forming sheets](image1)

**Figure 4** The stress distribution clouds of forming sheets

![Strain distribution pattern](image2)

**Figure 5** The strain distribution pattern

The stress and strain distribution in the diagonal OA direction of the forming part is presented in Figure 6. Obviously, the stress and strain distribution along OA of integral polyurethane elastic cushion have a large fluctuation and un-uniform. The stress and strain values are obvious in the curve along the diagonal OA direction of about 100mm. The stress in fluctuation area is small whereas strain is large due to the fact that only four corners of the upper surface of the elastic cushion are in contact.
with the upper die. However, the upper die is just in contact with the elastic cushion. As the upper die continues to push down, the elastic cushion is squeezed to the middle, causing excess elastic cushion and a large bulge in the middle, while the central bump squeeze is transferred to around and turn into a lot smaller bump in the process of further clamping. As these smaller protrusions have less or no frictional force with the sheet surface and the pressure of the machine is dispersed by the elastic cushion, the sheet below the raised portion of the polyurethane have better fluidity and ultimately have less stress and greater strain. When the elastic cushion is layered, only the elastic cushion layer in direct contact with the die is greatly affected by the extrusion. The rest of the elastic cushion exists as a decentralized machine load pressure, thus the plate surface and elastic cushion fit better. Therefore, the same thickness of the elastic cushion from two to eight layers can obtain the continuous transition stress and strain curve along OA. In addition, with the increase number of layers, the values of stress and strain increase slightly, and the distribution tends to be the same. These findings further demonstrate that the effectiveness of layered elastic cushion can enhance the quality of the forming sheet in MPF.

![Stress distribution curve](image1)

**Figure 6** Stress and strain curve along the direction of OA

![Residual stress distribution](image2)

**Figure 7** Residual stress distribution

The residual stress distribution nephogram after unloading is shown in Figure.7. Compared with the maximum residual stress of one layer, the residual stresses of the sheet are reduced by 38.34%, 38.68%, 39.55% respectively and the workpiece has a more uniform stress distribution. Figure.7a shows that the residual stress distribution curve of neutral layer is at the center of the diagonal
direction to the corner after springback, indicating that the central region of the springback part with overall polyurethane elastomeric medium is larger in stress, and it fluctuates significantly and transits nonuniformly. Figure.7b is the residual stress curve of the springpack parts on the thickness direction of the center. It can be seen that the residual stress decreases with the polyurethane elastomer layer number increase. Residual stress will not only shorten the life of the workpiece, but also change the product size and shape. This scenario leads to a decrease in the deformation resistance, plasticity, impact toughness and anti-fatigue strength. As a result, the advantages of using stratified polyurethane elastomers will be more significant in MPF.

5. Conclusion
1 In the process of MPF, polyurethane elastic cushion can suppress the occurrence of indentation defects in MPF. Under the whole and layered polyurethane elastic cushion conditions, the good surface quality of the forming parts can be obtained.
2 Compared with the non-layered polyurethane elastic cushion, layered elastic cushion can obtain more uniform stress and strain distribution after loading and springback. Furthermore, with the increase of the number of elastic cushion layers, the residual stress of the springback parts accordingly decrease.

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