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Influence of Punch Servo Path on Elliptical Hole Flange Forming

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Abstract**—**This study investigated the process of forming an elliptical hole flange by using a SPFC780Y high-strength steel sheet with a material thickness of 1 mm. Three servo motion paths on a servo press were compared with a traditional crank motion path on a conventional press. Four punch motion paths were analyzed, namely a crank motion path on a conventional press (type T), a servo motion path with a 3-mm downward motion followed by a 0.5-mm upward motion (type S3), a servo motion path with a 2-mm downward motion followed by a 0.5-mm upward motion (type S2), and a servo motion path with a 1-mm downward motion followed by a 0.5-mm upward motion (type S1). The finished products of an elliptical hole flanging process were evaluated in terms of thickness, force-displacement, stress, strain, and springback. The results reveal that the products produced using the evaluated servo motion paths were superior to those produced using the evaluated crank motion path.

Index Terms—*Elliptical hole flanging, servo press, punch servo path.*

Introduction

Traditional presses can be mechanical or hydraulic. Although mechanical presses operate quickly, their speed is fixed. Hydraulic presses allow for speed adjustments, but they offer limited options and lower production efficiency. With the introduction of servo presses, new processing methods have been used in sheet metal forming. Servo press motion path models include a crank mode, toggle mode, holding mode, vibration mode, pendulum mode, and free mode, all of which are depicted in Figure 1 [1]. These models provide diverse options and variations in terms of punch speed and paths, enabling the most efficient mode to be selected for a servo press on the basis of product characteristics. Thus, they address the limitations associated with traditional presses.

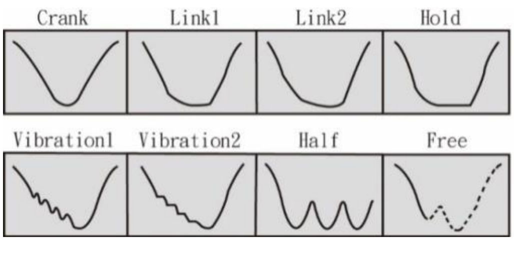

Figure 1. Punch motion paths [1].

Literature Review

In 2004, Chen et al. [2] studied the association between punch load and stroke in the direct piercing and repiercing processes for forming a circular flange. Through an analysis and experimental comparison, they discovered that repiercing forming loads were smaller than direct piercing forming loads. For a given punch fillet radius, repiercing forming exhibited superior formability relative to direct piercing forming, as evidenced by an increase in the forming limit ratio from 2.70 to 2.97.

In 2012, Huang et al. [3] used the unique pulse process path of a servo press to improve lubrication conditions and enhance the formability of workpieces. They conducted a simulation involving adjusting the friction coefficient on the basis of punch travel and compared the results of their proposed press with those of a conventional press. They reported that the formability of the proposed pulse process path was superior to that of a conventional press path.

In 2011, Wang et al. [4] used Dynaform analysis software to simulate elliptical cup drawing and elliptical hole flanging to investigate the associations among punch load and stroke, deformation, thickness variation, and formability limits. Experimental tests were also conducted using a 50-ton hydraulic forming machine. Their analysis revealed that the maximum stress and minimum thickness of an elliptical hole flange were in the region where a workpiece came into contact with the major axis of a punch. This result was primarily due to this region being the location of the maximum tensile stress experienced by the workpiece along the major axis of the ellipse, with this stress leading to a considerable reduction in sheet thickness. Their study also defined the ratio of the circumference of an elliptical cylindrical punch to the initial circumference of the smallest elliptical hole in a blank as the limiting drawing ratio. They revealed that for an elliptical hole flange workpiece, the limiting drawing ratio that can be achieved without causing fractures is 1.463.

SHEET MATERIAL AND SIMULATION PLANNING

Sheet Material Parameters

A SPFC780Y high-strength steel sheet with a thickness of 1 mm was used in the present study; its parameters were based on those applied in Huang and Lu [3]. The three angle tensile test specimens used in the present study are depicted in Figure 2 [2], and the parameters of the tensile tests are presented in Figure 3 [2].

Simulation Planning

The present study used the Dynaform computer analysis software for simulation analysis. First, a mold was designed per the dimensions depicted in Figure 4. To reduce simulation time, a 1/4 model of the mold and sheet material was used for analysis (Figure 5). The total punch stroke was set to 15.5 mm. On the basis of the results of a material analysis, the formed product was predicted to have an elliptical inner hole with a 68.5-mm major axis and a 33.5-mm minor axis. Four punch motion paths were simulated and analyzed (Table 1).

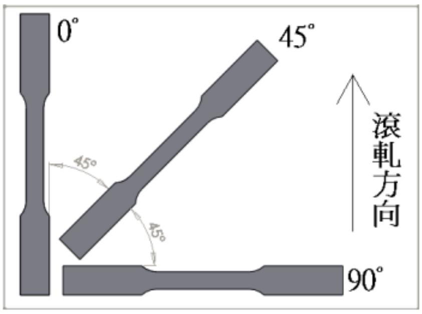

Figure 2. Configuration of tensile test specimens [2].

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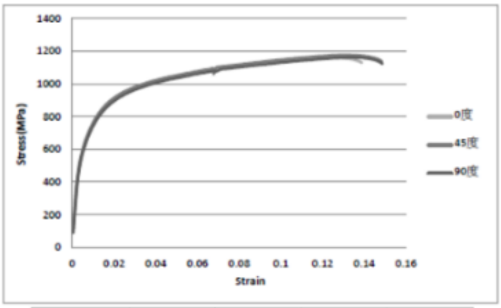

SPFC780Y	E（GPa）	v	YS（MPa）	TS（MPa）
0°	207	0.3	429	1023
45°	207	0.3	402	1031
90°	207	0.3	418	997

Figure 3. Material properties of SPFC780Y [2].

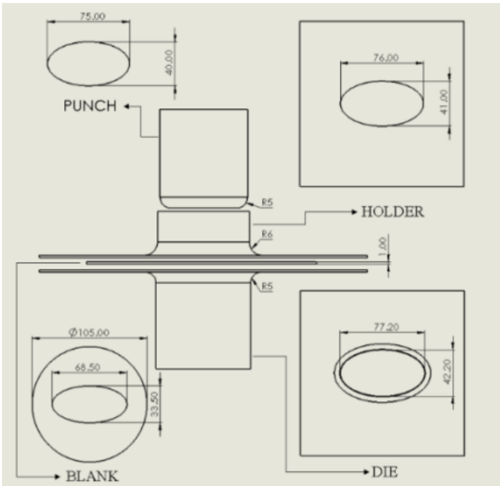

Figure 4. Dimensions of mold and sheet material.

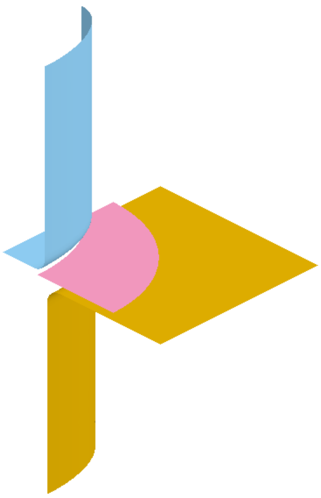

Figure 5. Schematic of 1/4 elliptical hole stretching process.

Table 1. Four punch motion paths (total stroke: 15.5 mm).

	Paths	Decline (mm)	Rise (mm)
T	Traditional	15.5	0.0
S3	Servo	03.0	0.5
S2	Servo	02.0	0.5
S1	Servo	01.0	0.5

Results and Discussion

Analysis of Sheet Material Shape and Forming Limit

In the present study, a simulation analysis was conducted with varying dimensions of elliptical inner holes in sheet metal. First, the flange height of each simulated elliptical hole was determined (Figure 6). Subsequently, an analysis was performed to determine the flange height limit on the basis of the difference between the dimensions of the major and minor axes. Through the analysis, the oval hole was determined to have a major axis of 68.5 mm and a minor axis of 33.5 mm (Figure 7).

Analysis of Velocity and Blank Holding Force

The traditional punch velocity was adjusted to 2, 5, 10, 15, and 20 spm, and the results indicated minimal variations in thickness across these speeds. Therefore, the velocity of 10 spm was selected (Table 2). The blank holding force was subsequently analyzed using the Dynaform software and was determined to be 2348.42 N (Figure 8).

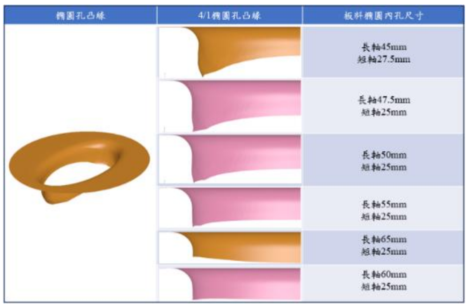

Figure 6. Flange height and major and minor axis dimensions.

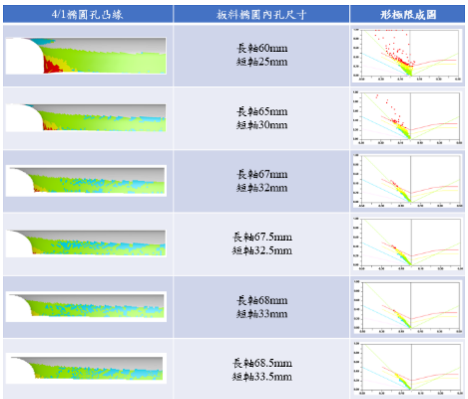

Figure 7. Forming limit diagram depicting elliptical hole flanging.

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Table 2. Thickness variations at different speeds (unit: mm).

	minimum thickness	maximum thickness
2spm	0.830	1
5spm	0.830	1
10spm	0.831	1
15spm	0.831	1
20spm	0.830	1

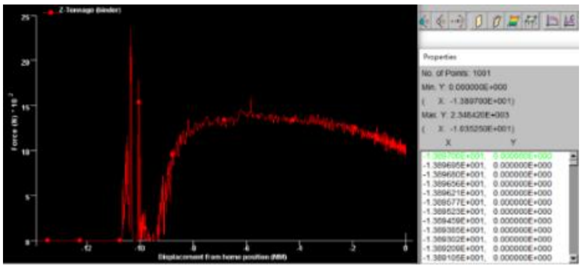


Figure 8. Blank holding force–displacement diagram

Tensile Force–Displacement Diagrams for Elliptical Hole Flanging

A simulation analysis was conducted to obtain tensile force–displacement diagrams for three servo paths (Figures 9–12). These diagrams reveal that all three servo paths released tensile force on the evaluated sheet metal, with the S1 path releasing stress most frequently and therefore releasing the lowest tensile force. The maximum tensile forces released through the S1, S2, and S3 paths were 3027.33, 3095.1, and 3099.35 N, respectively; by comparison, the T path, which did not release stress, released the highest force of 3224.49 N. Because the simulation analysis was performed on a 1/4 model, the calculated tensile forces were multiplied by 4 to obtain the actual values for the mold and sheet material.

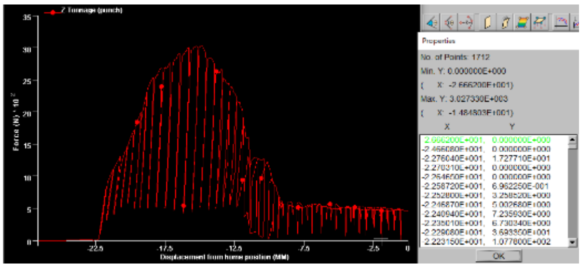


Figure 9. Tensile force–displacement diagram for S1 path.

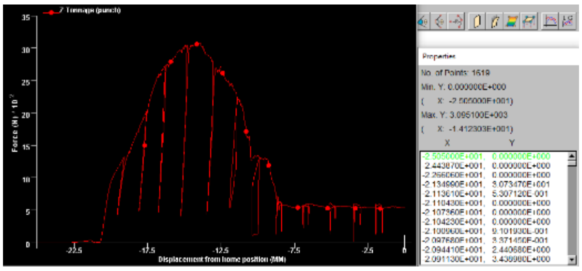


Figure 10. Tensile force–displacement diagram for S2 path.

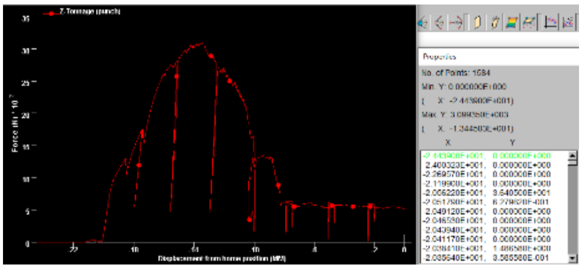


Figure 11. Tensile force–displacement diagram for S3 path.

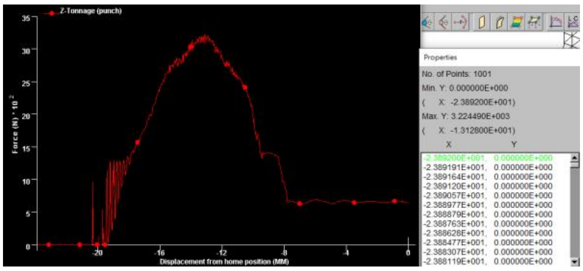


Figure 12. Tensile force–displacement diagram for T path.

A. Thickness Distribution of Elliptical Hole Flange

For thickness distribution, the evaluated workpiece was thinnest at the rounded corners of the major axis of the ellipse (Figures 13–16). When the T path was used, the thickness of the workpiece could be reduced to a minimum of 0.827 mm before fracturing; by comparison the minimum points for the S3, S2, and S1 paths were 0.806, 0.805, and 0.792 mm, respectively. Furthermore, the thickness distribution graph indicates that the use of the S1 and T paths led to the most and least even thickness distributions, respectively.

Stress and Strain Distribution of Elliptical Hole Flange

The stress and strain distributions for the elliptical hole flange are depicted in Figures 17–20, which reveal that using the S1 path led to the most favorable stress and strain distributions, whereas using the T path led to the least favorable distributions. This finding can mainly be attributed to the stress release along the servo paths.

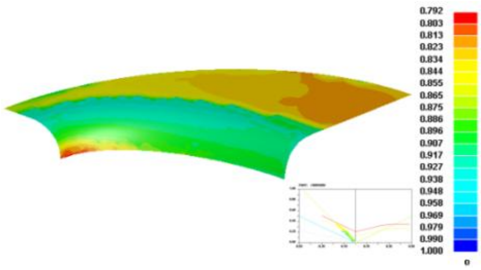


Figure 13. Thickness distribution for S1 path.

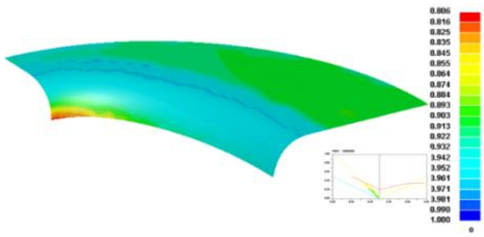


Figure 14. Thickness distribution for S2 path.

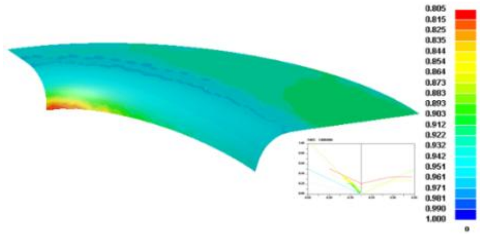


Figure 15. Thickness distribution for S3 path.

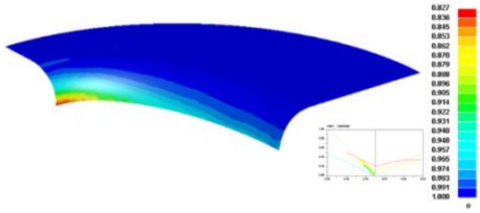
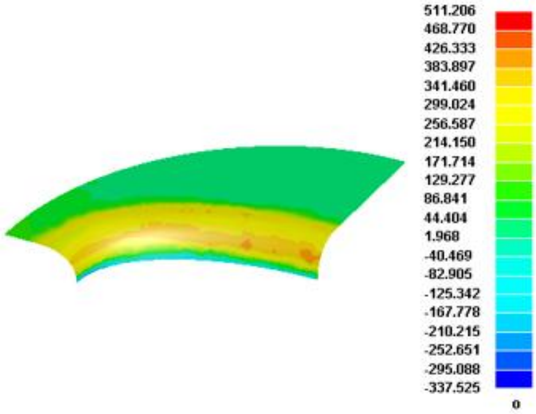
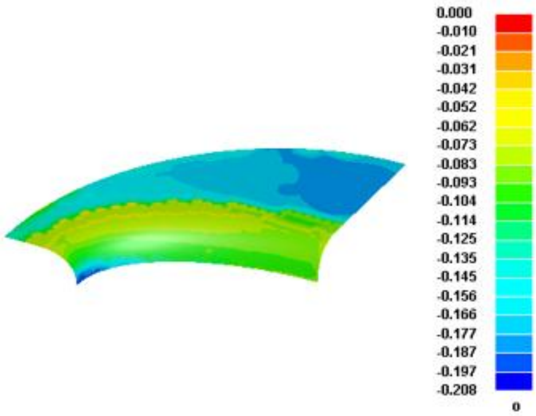


Figure 16. Thickness distribution for T path.



(a)應力



(b)應變

Figure 17. Stress and strain distributions for S1 path.

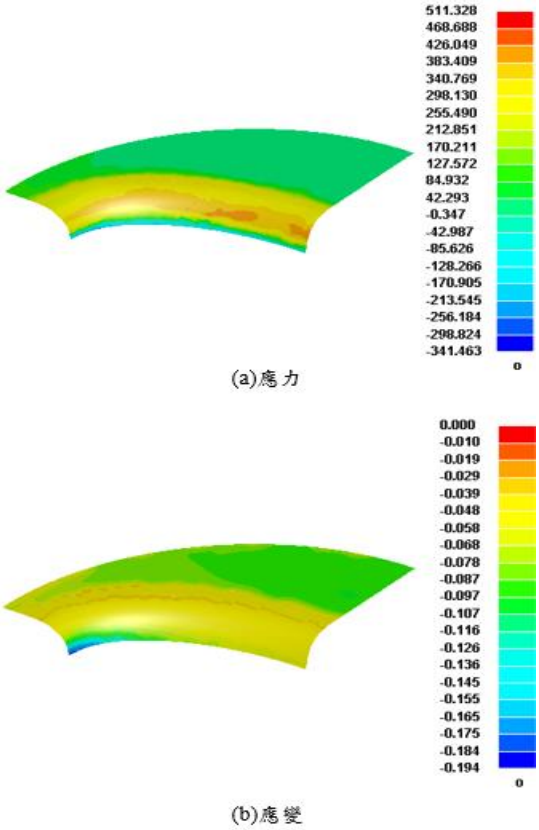


Figure 18. Stress and strain distributions for S2 path.

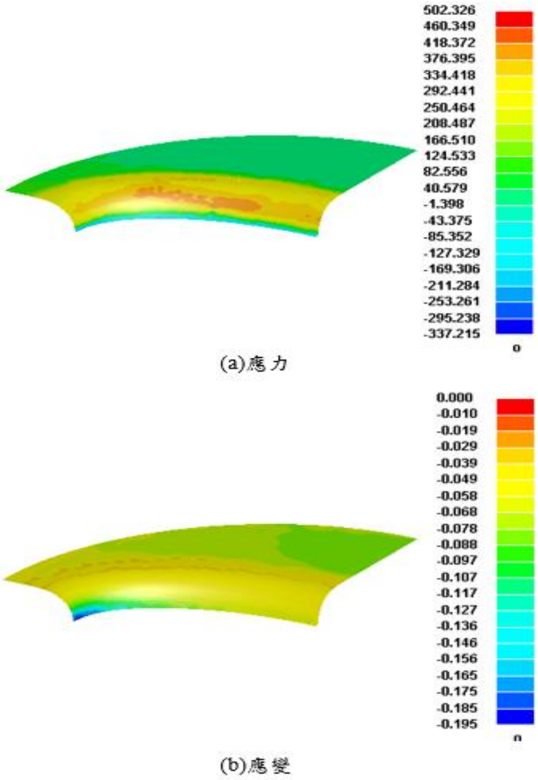


Figure 19. Stress and strain distributions for S3 path.

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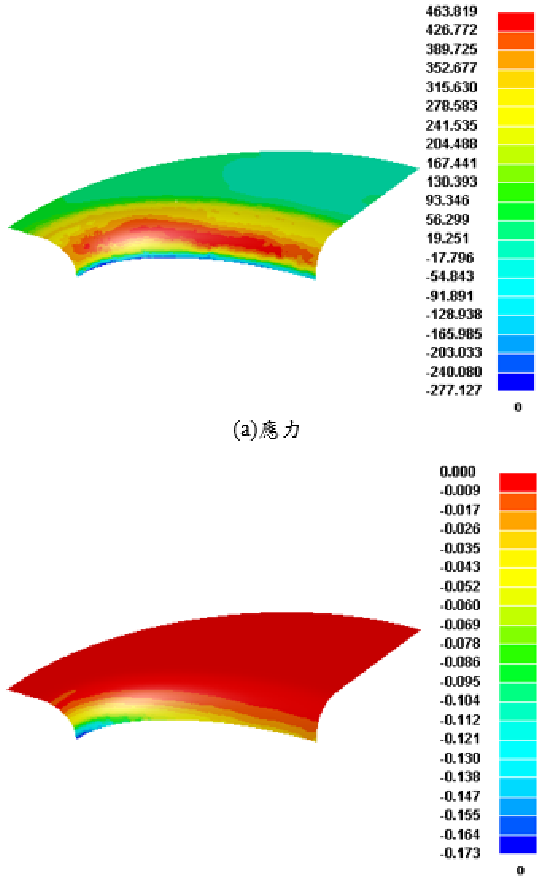

(b)應變

Figure 20. Stress and strain distributions for T path.

Springback of Elliptical Hole Flange

Further analysis was conducted using Dynaform to investigate the springback of the elliptical hole flange. Because the servo paths provided a more even distribution of thickness and stress in the forming process relative to the traditional path, the springback resulting from the use of the servo paths was less pronounced than that resulting from the traditional path (Figures 21–24). The springback resulting from the use of the S1, S2, S3, and T paths was 0.025, 0.029, 0.032, and 0.708 mm, respectively.

Conclusion

In the present study, the effects of three servo paths and the traditional path on the flanging process of elliptical hole workpieces were compared with those of a traditional crank motion path. The following conclusions were drawn:

1) The more frequently a servo path released stress, the smaller were the values of tensile force, thickness, stress, and springback.

2) The more frequently a servo path released stress, the more uniform were the distributions of thickness, stress, strain, and springback.

3) Under extreme conditions, the evaluated servo paths reduced thinning to a greater extent than the evaluated traditional path did.

4) Because of its lack of stress release, the traditional path resulted in higher values for punch force, stress, and springback relative to the servo paths.

5) Without stress release, the traditional path led to poorer distributions of thickness, stress, strain, and

springback relative to the servo paths.

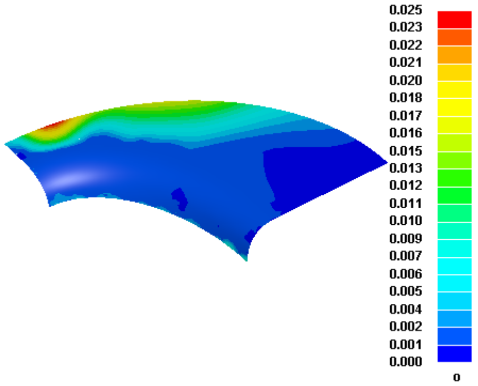

Figure 21. Springback distribution for S1 path.

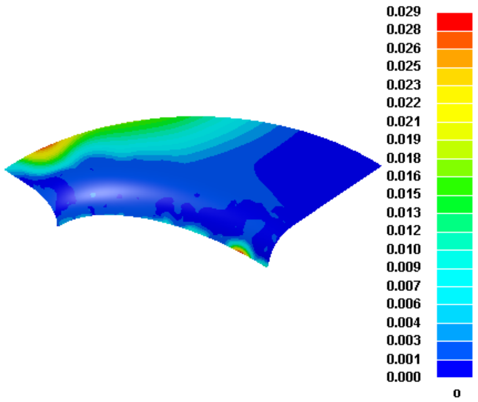

Figure 22. Springback distribution for S2 path.

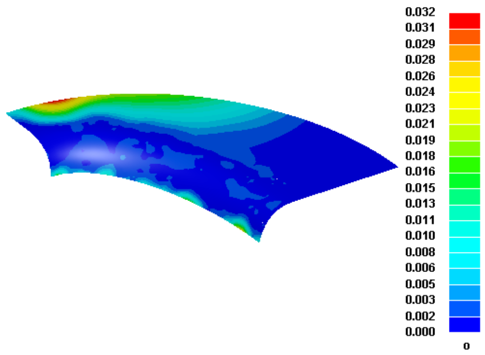

Figure 23. Springback distribution for S3 path.

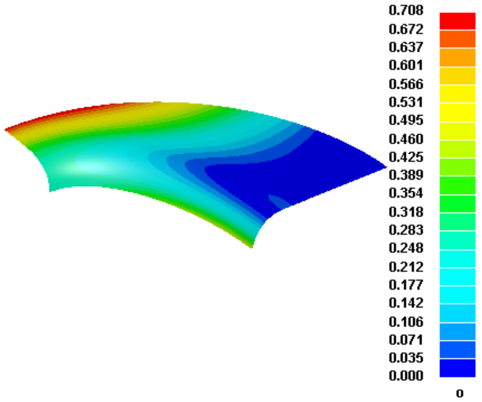

Figure 24. Springback distribution for T path.

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