Numerical simulation and experiment of dimple for flexible clamp multi-point stretch forming of spherical part

Heli Peng1,a,*, Haijian Liu1,b, Xu Chen1,c, Xing Han1,d

1Research and Development Centre, Shanghai Spaceflight Precision Machinery Institute, Shanghai, China

a,* Corresponding author:phl12616040811@126.com, b623513470@qq.com, cchenxu1412@163.com, dhanxing_mc106@163.com

Abstract—The structural character of flexible clamp stretch forming machine is introduced. The real stress and strain curve of Aluminium alloy 2024-O is tested by uniaxial tensile. Numerical simulation of dimple for spherical part with flexible clamp multi-point stretch forming (FCMPSF) is carried out by ABAQUS, and the generated result of dimple is elaborated. The effects of transitional length, sheet thickness and spherical radius on dimple are investigated by lots of numerical simulations, and the thickness strain of spherical part along the objective line ef with different forming suituation is extracted. Then polyurethane sheet is chosen as elastic cushion to depress dimple, and series of numerical simulations are put forward for spherical part of FCMPSF with different thicknesses of polyurethane sheet. Finally, FCMPSF experiment is done and forming precision is measured. Consequently, the spherical part has good forming shape and surface accuracy, which illustrates that the FCMPSF technology is feasible and practional to forming three-dimensional surface part.

1. INTRODUCTION

Stretch forming is an important forming method of sheet metal. With the wide use of three-dimensional sheet metal in the fields of aeronautics and astronautics, high-speed train, it urgent needs the flexibility of forming die and clamp to reduce production costs and improve material utilization.

In order to decrease the fabricating cost and time of stretching die, flexible reconfigurable dies have been developed to form different parts without traditional rigid die. Hardt[1] and Walczyk[2] proposed the concept of flexible fabricating method using reconfigurable die. Papazian[3] developed a reconfigurable die consists of 2688 punch elelemnts. Li[4] proposed the concept of multi-point forming(MPF), and the core idea of MPF is a pair of oppsed matrices of punch elements replace the tradidional matched-dies. Which has been used successfully to form three-dimensional metal such as the skins of high-speed train, the ship hull plate and large crankle part, et.al. Then, Zhou[5] proposed the concept of multi-point stretch forming(MPSF) based on MPF, which is used to form aircraft outskin part. Cai and Wang[6,7] investigated the influencing factors of processing parameters on the forming accuracy during MPSF. However, the clamp of MPSF is rigid.

In order to improve material utilization, flexible clamp stretch forming[8] was proposed, and then flexible clamp multi-point stretch forming(FCMPSF)[9] was studied based on multi-point die and flexible clamp stretch forming. The purpose of this paper is to investigate dimple of FCMPSF.
2. **THE CHARACTER OF FLEXIBLE CLAMP STRETCH FORMING MACHINE**

The structural diagram of flexible clamp stretch forming machine is shown as Fig.1. The notable feature of the flexible clamp stretch forming machine is that the stretching forces are provided by several clamping units, and each clamping unit is consist of three is hydraulic cylinders with different stretching orientation, which are horizontal direction, vertical direction and leaning direction. The biggest difference between flexible clamp stretch forming machine and traditional clamp stretch forming machine is that traditional rigid clamp is the flexible rotating clamp replace the rigid fixed clamp, which lead to the curve outline of discrete clamp units can be changed arbitrarily by rotation of different clamping units.

Fig.2 is the schematic diagram of flexible clamp stretch forming progress, we can find that the all sub-clamps are arranged into a horizontal line state when stretching begin, then the all sub-clamps make real-time position in according with the shape of stretching die during the stretching process, and the all sub-clamps come to a curve similar to the edge line of stretching die when stretching end.

![Flexible clamp stretch forming machine](image)

**Figure 1. Flexible clamp stretch forming machine**

![Flexible clamp outline diagram](image)

**Figure 2. The clamp outline of flexible clamp stretch forming**

3. **FINITE ELEMENT MODEL**

Aluminium alloy 2024-O has played a dominant role in aircraft structures since it offer good mechanical properties with low weight, which is selected as the sheet material in this paper. The real stress and strain curve of 2024-O obtained by uniaxial tensile test is shown in Fig.3.
Figure 3. Real stress-strain of 2024-O

Numerical simulation for FCMPSF process will be performed by Abaqus. Fig.3 presents a quarter of finite element model for FCMPSF process of spherical part, which is composed of 30×30 punch elements. The clamping area of a sub-clamp is 100×110mm, and the clearance of adjacent sub-clamp is 10mm.

Figure 4. A quarter of the finite element model

When the spherical radius is 2000mm, the sheet thickness is 2mm, and the transitional length is 100mm. The illuminated diagram of spherical part formed by FCMPSF method is shown in Fig.5(a), it can be found that dimples appear at the points where the spherical part contact with multi-point stretching die clearly. The thickness strain of spherical part formed by FCMPSF method is shown in Fig.5(b), it can be found that the thickness strain has distribution rule and consistent with illuminated diagram, which illustrate that the dimple can be described by thickness strain.

Figure 5. Numerical simulation of dimple for spherical part

4. NUMERICAL SIMULATION OF DIMPLE FOR SPHERICAL PART WITH FCMPSF

4.1 Influencing factors of dimple
When the spherical radius is 2000mm and sheet thickness is 2mm, four kinds of transitional lengths are investigated. The thickness strain of spherical part with different transitional lengths along the line ef is shown in Fig.6. When the transitional length is 60mm, the maximum value of thickness strain
fluctuation range is 0.025. With the transitional length increasing to 80mm, the maximum value of thickness strain fluctuation range decreases to 0.023. When the transitional length increases to 120mm, the maximum value of thickness strain fluctuation range is 0.02. The result shows that the longer the transitional length is, the smaller the thickness strain fluctuation range will be. The reason is that a longer transitional length has more uniform deformation.

Figure 6. Thickness strain of spherical parts with different transitional lengths

When the spherical radius is 2000mm, the transitional length is 100mm, the sheet thicknesses are 1mm, 2mm, 3mm and 4mm respectively. The thickness strain of spherical part with different thicknesses along the line ef is shown in Fig.7. It can be found that the change trend of thickness strain is consistent for different thickness. The thicker the sheet thickness is, the smaller the thickness strain fluctuation range will be. The reason is that a thicker sheet has stronger capability to resist deformation, which lead to a slighter dimple.

Figure 7. Thickness strain of spherical parts with different sheet thicknesses

When the transitional length is 100mm, the sheet thickness is 2mm, the spherical radii are 1500mm, 2000mm, 2500mm and 3000mm, respectively. The thickness strain of spherical parts with different with four kinds of radii is shown in Fig.8. It can be found that the smaller the spherical radius is, the smaller the thickness strain fluctuation range will be, but the difference of thickness strain fluctuating value for different radius is very large. The reason is that a larger radius has smaller deformation, which lead to a slighter dimple.
4.2 Depressing of dimple

In order to depress the dimple, the polyurethane sheet is chosen as elastic cushion during FCMPSF. The thickness strain of spherical part with different thickness of elastic cushion are shown in Fig.6. It can be found that the thickness strain of spherical part is discontinuous during FCMPSF without elastic cushion, and the thickness strain of contacting zone between the sheet and MPSD is larger than surrounding zone, as shown in Fig.9(a). When the thickness of elastic cushion is 10mm, the thickness strain decreasing obviously, as shown in Fig.9(b). With the elastic cushion increasing to 30mm, the dimple is suppressed, as shown in Fig.9(c).

Figure 8. Thickness strain of spherical parts with different spherical radii

Figure 9. Thickness strain of spherical parts with different elastic cushion
5. FCMPSF EXPERIMENT OF SPHERICAL PART

FCMPSF experiment of spherical part has been done to verify the numerical results. The spherical radius is 2000mm, and the size of effect forming zone is 1200×1200mm. The size of sheet metal is 1200×1200×2mm, and the thickness of elastic cushion is 30mm. Fig.10 shows the experimental result of spherical part, it can be found that spherical part has good surface quality.

![FCMPSF experiment of spherical part](image)

(a) forming experiment (b) forming part

Figure 10. The MPFCSF experiment of spherical part

Three-Dimensional Sensing System (3DSS) is used to measure the forming precision of spherical part, as shown in Fig.11, it shows that the forming error is less than 1mm. Which indicates the experimental part has good forming precision.

![Error diagram of spherical part](image)

Figure 11. The error diagram of spherical part

6. CONCLUSIONS

The character of FCMPSF is elaborated, and FEM of FCMPSF is set up. The dimple of spherical part formed by with FCMPSF is studied, and its generating result, influencing factors and depressing method are studied. The effects of transitional length, sheet thickness and spherical radius on dimple are investigated by lots of numerical simulations. The results show that the longer the transitional length is, the smaller the thickness strain fluctuation range will be. The thicker the sheet thickness is, the smaller the thickness strain fluctuation range will be. The larger the spherical radius is, the smaller the thickness strain fluctuation range will be. Then polyurethane sheet is chosen as elastic cushion to depress dimple, and the effects of different thickness of polyurethane elastic cushion on dimple of spherical part with FCMPSF are investigated. The results show that the dimple can be decreased when the thickness of polyurethane elastic cushion is 30mm. Based on the numerical results, the suitable forming parameters are obtained, the FCMPSF experiment of spherical part is done, and three dimensional sensing system is used to measure the shape accuracy. The results show that the spherical part has good surface quality and forming outline, which illustrate that the results obtained by numerical simulation are sensible to depress dimple, and FCMPSF technology used to form three-dimensional suraface part is feasible and practional.
REFERENCES

[1] D.E. Hardt, M.C. Boyce, and D.F. Walczky, “A flexible forming system for rapid response production of sheet metal parts,” Proceedings of IBEC’93, Detroit, Mi’chigan, USA, 1993, pp. 61-69.

[2] D.F. Walczyk, and D.E. Hardt, “Design and analysis of reconfigurable discrete dies for sheet metal forming,” Journal of Manufacturing System. vol.17, pp. 436-454, 1998.

[3] J.M. Papazian, “Tools of change: reconfigurable forming dies raise the efficiency of small-lot production,” Mechanical Engineering vol. 124, pp. 52-55, 2002.

[4] M.Z. Li, K. Nakamura, S. Watanabe, et al, “Study of the basic principles (1st report: research on multi-point forming for sheet metal),” In: Proceedings of the Japanese Spring conference for Technology of Plasticity, Yokohama, Japan, 1992, pp. 519-522 (in Japanese).

[5] Z.H. Zhou, Z.Y. Cai and M.Z. Li, “Stretching process based on multi-point die and its numerical simulation.” Journal of Jilin University (Engineering and Technology Edition.) vol.35, pp. 287-291, 2005 (in Chinese).

[6] Z.Y. Cai, S.H. Wang, D.X. Xu, et.al, “Numerical simulation for the multi-point stretch forming process of sheet metal,” Journal of Material Processing Technology, vol.20, pp. 396-407, 2009.

[7] S.H. Wang, Z.Y. Cai and M.Z. Li, “Numerical investigation of the influence of punch element in multi-point stretch forming process,” The International Journal of Advanced Manufacturing Technology, vol.49, pp. 475-483, 2010.

[8] X. Chen, M.Z. Li, W.Z. Fu, et al, “Research on multi-head stretch forming technology of sheet metal,” 2010 International Conference on Electrical and Control Engineering, 2010, vol.720, pp. 2952-2955.

[9] H.L. Peng, C.G. Liu, M.Z. Li, “Multi-point Stretch Forming Experiment and Numerical Simulation of Saddle Part with Flexible Clamp,” Journal of Xi’an Jiaotong University, vol.46, pp. 109-113, 2012. (in Chinese).