26

Journal of Manufacturing Engineering, 2006, Vol.1, No.1

FINITE ELEMENT ANALYSIS OF REVERSE SUPERPLASTIC BLOW FORMING OF TI-AL-4V ALLOY FOR OPTIMIZED CONTROL OF THICKNESS VARIATION USING ABAQUS

A. Chennakesava Reddy*

Associate Professor, Department of Mechanical Engineering,
JNTU College of Engineering (Autonomous), Anantapur, India.
***E Mail: dr_acreddy@rediffmail.com**

ABSTRACT

In this paper, reverse superplastic blow forming of a Ti-6Al-4V sheet has been simulated using finite element method in ABAQUS to achieve the optimized control of thickness variations. The deformation process, pressure versus time curve, variation of thickness strain and effect of a change in friction coefficient have been investigated. In addition, simulation of the same structure with non-reverse forming has also been carried out and a detailed comparison has been made between results from different forming processes.

Keywords: Superplastic, Blow Forming, Thickness Variation

1. INTRODUCTION

Superplastic forming (SPF) has been widely accepted as an economical method to produce highly complex, lightweight and integral parts with a single forming operation in modern industry, especially in the aerospace industry. Generally, superplastically formed parts experience a great amount of elongation, thus leading to potentially large thickness variations. As the shape of a component becomes more complicated, thinning will become severe which is normally undesirable. Therefore it is important to investigate the thickness variation to improve the uniformity of thickness distribution of the component [1].

During a superplastic forming process, thinning of components depends on several parameters including the shape of the die, the material properties, and the forming conditions such as pressure and temperature [2]. Reverse blow forming is widely recognized as an effective technique to obtain good thickness distribution control in complex components.

Generally a reverse forming process consists of two operations starting from an initial sheet as shown in Fig. 1. In the first operation, gas pressure is imposed on top of the heated sheet. After producing the performing shape, the forming pressure is reversed forcing the material to flow into the final tool [3].

An optimal shape of the preforming tool should be initially designed in order to obtain a prescribed thickness distribution in the final component. A number of simulations have been performed on the simple shape of a superplastic blow forming component such as a cylindrical cup and a rectangular box [4,5]. However, the main concerns of those studies are to predict the pressure loading cycles and the final thickness distributions, which have led to a basic understanding of the superplastic blow forming process.

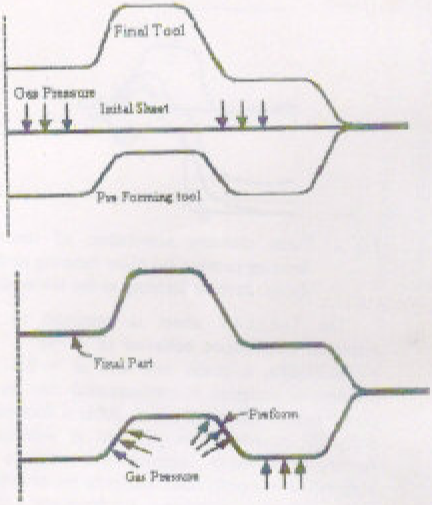

Fig 1. Schematic diagram of reverse blow forming

There is little on the available publications for a reasonable interpretation of the good thickness control in the reverse blow forming process. This study has been initiated and guided by the need to establish a clear understanding of the thickness control mechanism in the reverse forming process.

Finite element analysis (FEA) offers an efficient method to visualize and model the thinning process in a more intuitive way in the analysis of complicated superplastic blow forming components. It provides valuable guidelines on how the parameters in a current process should be modified to meet the requirements of the process and components. In this study, the multi-step reverse forming of a Ti-6Al-4V sheet into a complicated component has been carefully simulated within ABAQUS [6]. The deformed processes at different loading stages and the strain and the stress distribution in the final stage have been fully investigated. For the purpose of comparison, simulation of the same structure under non-and a final forming lower-die. A circular sheet of 3 mm in thickness and 330 mm in diameter, of which the periphery is clamped between the two dies, is subjected to gas pressure. The simulation of reverse blow forming of the sheet studied in this paper can be simplified as a case of 2-D axisymmetric plain strain problem. Because of symmetry, only half of the whole structure is modeled as shown in Fig. 2.

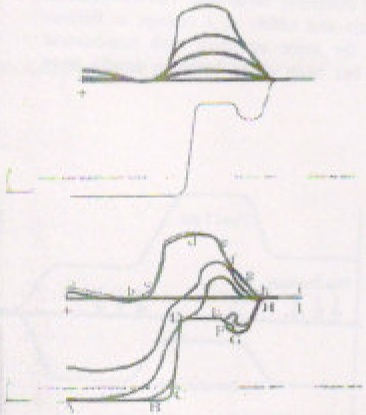

Fig 2. Finite element simulation of reverse blow forming process (a) blow forming to the upper-die (b) reverse forming to the lower-die

The Ti-6Al-4V sheet is assumed to have an empirical constitutive behavior of $\sigma = \kappa\dot{\varepsilon}^m$ where, κ =1030.78MPa, $\dot{\varepsilon}$ strain rate and m = 0.61305. The constitutive equation is implemented into an isotropic creep model within ABAQUS. After a detailed element study [8], a continuum element is selected reverse forming has been carried out and a detailed comparison has been made between the reverse forming and non-reverse forming. Furthermore, the effect of friction coefficients has been studied reverse forming has been carried out and a detailed comparison has been made between the reverse forming and non-reverse forming. Furthermore, the effect of friction coefficients has been studied.

2. FEA OF REVERSE BLOW FORMING

Simulation of a reverse blow forming process is characterized by large deformation and material non-linearity involved. The complicated contacts between the sheet and the dies are generally presented in the forming process, thus adding difficulty for the simulations. The reverse forming tools simulated in the current study include a pre-forming upper-die to achieve an accurate modeling of the blow forming process. In addition, the regions where stress concentrations are significant are constructed with fine meshes. To obtain an accurate modeling of the superplastic deformation, an iterative Newton-Raphson solution technique is employed to solve the governing nonlinear equations. The imposed gas pressure is controlled by a special solution dependent magnitude scheme [6] to maintain an approximately constant strain rate (the target value) in the simulation.

The problem of friction associated with the contacts between the sheet and the dies is very important for a superplastic reverse blow forming process. An important factor in accurate modeling of the process is how to simulate the friction effect due to contact. In this paper, the two dies are treated as rigid and the contact interactions between the dies and the sheet are modeled as rigid surfaces and a deformable surface. The penalty Coulomb friction formulation [7] is used to model the friction effect associated with the contact pairs by specifying a friction coefficient. A reasonable penetration of the deformable surface into the rigid surfaces has been assigned to monitor the contact interaction.

A reverse forming process is different from customary blow forming methods in that a performing process is necessary before the final shape is produced. The whole process can be accurately modeled using multiple loading steps. Pressure has to be applied underneath the sheet to make it inflate into the upper-die first. As the initial application of the pressure is assumed to occur so quickly, a purely elastic response is performed in the first step. The inflation process of the sheet into the upper-die is then carried out in the second step. The third step is to remove all contact pairs of the upper-die and the sheet, and the target creep stain rate defined in the second step. Finally the reversed pressure is imposed on the top of the sheet to force the sheet to flow into the lower-die. The above procedures enable the FEA program to accurately model the reverse forming process.

3. RESULTS AND DISCUSSION

It is important that a good FEA model is capable of predicting the reverse forming behavior. Typical deformation configurations in the reverse forming process have been predicted and shown in Fig. 2. In particular, Fig. 2 (a) shows the processes of the sheet bulged into the upper-die whilst Fig. 2 (b) is the reverse process into the final tool. For the convenience of description, points a to i represent the deformation instants to the upper-die whilst points A to I represent the corresponding instants where the material flow into the lower-die.

It can be clearly seen that the large deformation is concentrated around the bubble area (region c to h) in the preforming process, resulting in a thickness profile in which the centre and the clamped area is thicker than the bubble area. After filling the upper-die, the sheet flows downward gradually to the bottom AB, region DE and the bottom corner BC respectively. The outside small corner FG is the last filled area.

The predicted pressure versus time curves of the sheet inflated into the upper-die and the lower-die in the reverse forming process are shown in Fig. 3, in which both initially rise rapidly, followed by a comparable stable region, then increasing again sharply. It is easily seen that a higher pressure is needed in the preforming stage to the upper-die. The distribution of equivalent Von Mises stress on the deformed component is illustrated in Fig. 4. It is noted that "true" stress is used in the simulation within ABAQUS. It can be clearly observed that the maximum stress occurs at the small corner, which is the last formed area in the reverse forming process.

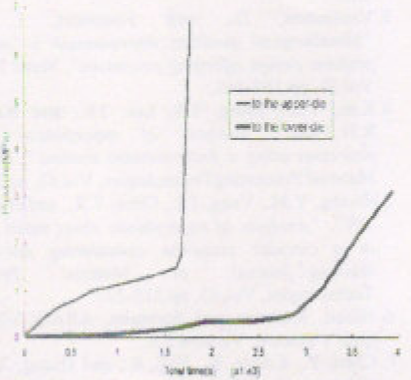

Fig 3. Pressurization curves in the reverse forming process

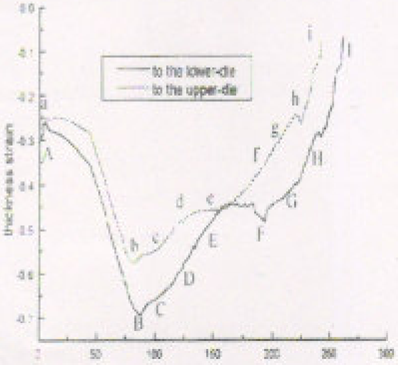

Fig 4. Pressurization curves in the reverse forming process.

The thickness distribution along the component is essential to assess whether the formed component is successful or not. To investigate the thickness variation in the preforming and final forming stages, the thickness strain is evaluated in this study. Figure 5 shows the thickness strain distribution of the sheet inflated into the upper-die in comparison with that into the lower-die. It is evident that in both cases the sheet is thinned, but the degree of thinning is greater for the sheet bulged into the lower-die. It is noted that the greatest thinning strain occurs around the bottom corner (region BC). The effect of friction on the thinning of a component in the reverse blow forming process has been studied, in which the friction coefficient is assumed to be uniform along the contact surface, varying from 0.1 to 0.5 in this paper. The distributions of thickness strain under different friction coefficients are illustrated in Fig. 6. Again, greater thinning occurs around the bottom corner of the lower-die for all values of the friction coefficient studied. The lower the friction coefficient, the more uniform thickness distribution along the component. It should be noted that when the friction coefficient is greater than 0.4, the thickness strain sharply changes around the outside corner (region FG) as illustrated in Fig. 6. This is mainly because a higher friction coefficient tends to resist further deformation of the sheet on contact and thus results in sharp thickness variations in the simulation and an unsuccessful formed component in practice.

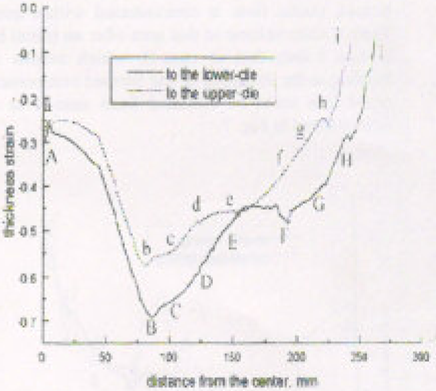

Fig 5. Thickness strain of the sheet into the upper-die in comparison with that of into the lower-die

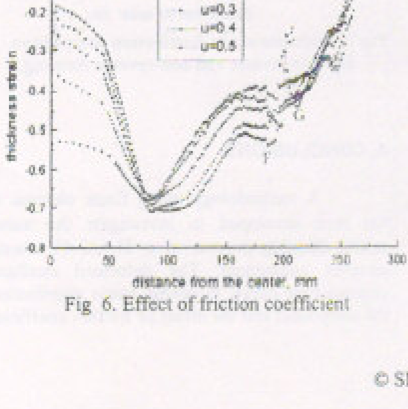

Fig 6. Effect of friction coefficient

To further understand the effect of reverse blow forming, simulation of a non-reverse forming process for the same sheet has also been conducted for a comparison with that of reverse forming. Similar deformation configurations, as shown in Fig. 2(b), are obtained for a non-reverse forming process. Furthermore, thickness strain distributions along the final component for a reverse forming and non-reverse forming process are compared in Fig. 7. For the convenience of description, reverse blow forming is denoted as case-I and non-reverse blow forming as case II. It is evident from Fig. 7 that in both cases the sheet has thinned, but the degree of thinning is less for case I in the bulge area (region AB). However, this trend is different in the middle portion of the lower die (region CD). Although reverse forming causes slightly larger thinning at region CD, it greatly improves the thinning at bottom region AB, which is important in practice. During the initial bulging into the upper-die, deformation is concentrated primarily in the large bubble area (region c to h), i.e. the thickness around the bubble is thinning greatly thus causing more volume flow into the adjacent areas (region ac). When the material is reverse flowed into the lower-die, little additional deformation occurs within the bubble area. Instead, plastic flow is concentrated within zone AB. There is more volume in this area after an initial bulging in case I than that in case-II, which results in less thinning in the thickness of the formed component from case-I than could be obtained from case-II as clearly demonstrated in Fig. 7.

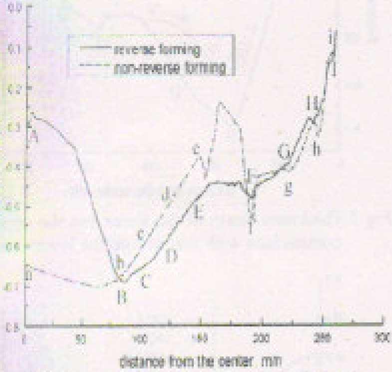

Fig 7. Thickness strain distribution comparison between reverse and non-reverse forming.

4. CONCLUSIONS

A methodology using finite element analysis has been developed to investigate the superplastic reverse forming process of a Ti-6Al-4V sheet into a complex component. The deformed configurations, pressure-time curve, thickness strain distribution along the component and the effect of friction coefficient have been studied carefully. It is found that a lower friction coefficient results in a better uniform thickness strain distribution along the component. Comparisons demonstrate that reverse blow forming results in less thinning in the thickness of the formed component than could be obtained from a non-reverse forming process.

5. REFERENCES

1. Story, J.M., 1990, "*Superplasticity in Aerospace*", The Minerals, and Metals & Materials Society, pp.151-166.
2. Garriga, M.D., and Curtis, R.V., 2001, "*Geometric analysis of thinning during superplastic forming*", Materials Science Forum, Vol.357, pp.213-218.
3. Vieilledent, D., and Fourment, L, 2000, "*Metallurgical qualities improvement by automatic preform design offorging processes*", Metal Forming, Vol.21, pp.157-162.
4. Kim, Y.U., Hong, S.S, Lee, J.S., and Wangoner, R.H.,1996, "*Analysis of superplastic forming processes using a finite-element method*", Journal of Material ProcessingTechnologies, Vol.62, pp.90-99.
5. Hwang, Y.M., Yang, J.S., Chen, T.R., and Huang, J.C 1997, "*Analysis of superplastic sheet metal forming in a circular close-die considering non-uniform thinning*",Journal of Material Processing Technologies, Vol.63, pp.215-227.
6. Hibbit, Karlsson and Sorensen, ABAQUS/Standard User's Manual, Version 5.8.
7. Chen, Y., Kibble, K., Hall, R., and Huang, X., 2001, "*Numerical analysis of superplastic blow forming of Ti-6Al-4V alloys*", Materials and Design, V.22, pp.679-685.