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ScienceDirect

Procedia Manufacturing 37 (2019) 85–90

Procedia MANUFACTURING

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9th International Conference on Physical and Numerical Simulation of Materials Processing (ICPNS'2019)

The effect of finite element type on the results of superplastic forming simulation

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Abstract

Superplastic Forming is an industrial process to produce thin-walled products of complex shape. At the same time this process allows one to obtain the products with close to uniform thickness distribution. The process exploits the abilities of some polycrystalline materials to large elongations before failure. The best formability can be achieved only under very specific conditions of temperature and strain rate. In order to calculate the pressure regime to sustain target strain rate in critical arias it is necessary to use finite element simulation. The pressure regime calculation lasts for a day's especially while 3 dimensional elements are use. To reduce the time of calculation it is possible to use elements from membrane theory. The main idea of this approach is to use planar elements instead of tetrahedronal for 3D tasks or 2 nodes elements instead of triangular ones for axisymmetric tasks. This reduction doesn't take in account share stress accruing into material. The main aim of this paper is to study the effect of elements type on the accuracy of thickness distribution prognosis.

Keywords: Computer simulation, superplastic forming, titanium alloy, FEM, thickness distribution

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10.1016/j.promfg.2019.12.017

1. Main text

Supreplastic forming is an industrial technology allowing one to produce a thin sheet parts of complex shape. Such parts are widely used in different industrial fields but mainly in aeronautical industries. Superplasticity is the ability of polycrystalline material to exhibit in a generally isotropic manner, very high tensile elongations prior the failure. When a material deforms under superplastic conditions, the strain rate sensitivity is exceeding 0.5 [1]. The most popular materials with this ability are the alloys of titanium and aluminum [2,3]. The elongation of some superplastic materials could exceed almost 2000% [4]. The implementation of superplastic materials allows one to obtain parts with a more uniform distribution of thickness than usual. Despite this it was shown [5,6] that thickness value in different areas of the product may vary significantly.

The most popular way for superplastic material processing is the gas forming. The workpiece is clamping between the die and the blank holder and then the sheet is blown into the die with the negative shape of the manufacturing part. The superplastic behavior of the material occurs in a narrow ranges of strain rates and temperatures. During the manufacturing it is extremely important to sustain the optimum conditions of forming. For this purpose, it is necessary to calculate the suitable parameters of SPF process.

Numerical simulation of superplastic forming (SPF) procedure plays an important role during the design phase of manufacturing [3]. The analysis of simulations result instead of the results of actual experimental trials allows one to avoid the expenses of the technological experiments. The simulations can be used for pressure regime calculation [7], material characterization, or prediction of final sheet thickness distribution in order to detect extreme thinning before the actual product manufacturing. The finite element method is the most reliable method of for computer simulations of SPF processes. Since the simulation reliability strongly depends on the accuracy of the material characterization border condition and simulation technic while the time of calculation depends on product geometry complexity and the level of discretization of the workpiece. The tensile testing is the most common technic to identify the constitutive behavior of the material. Material superplastic behavior in commonly characterizing by Backofen power law [8]:

$$\sigma_\epsilon = K\dot{\varepsilon}_\epsilon^m \tag{1}$$

Where σ_ϵ - effective flow stress, $\dot{\varepsilon}_\epsilon$ - effective strain rate, K - stress amplitude, m – strain rate sensitivity, responsible for the localization of the material flow [9]. Since the superplastic materials are highly sensitive to the strain rate rather than to effective strain it is make sense to use modification of tensile test – a tensile test with a stepped strain rate change (tensile jump test).

Forming processes of the parts with complex geometry are usually simulated using shell elements in order to reduce the time of calculation. The shell elements from the membrane theory doesn't take into account the effect of share stress. This effect can be the reason of inaccuracies in thickness prediction, and as a consequence lead to unreliable calculation of pressure regime for maintaining target strain rate.

In the present work two technics of finite element simulation were used to predict the final thickness distribution of axisymmetric blow forming task. The information about the blow forming procedure was taken from the literature [10]. To assess the inaccuracies caused by the implementation of shell finite elements instead of volume ones the results were compared with the experimental data described in [10].

Nomenclature

σ_ϵ	effective flow stress
$\dot{\varepsilon}_\epsilon$	effective strain rate
K	stress amplitude
m	strain rate sensitivity

2. Experimental data

The study presented in [10] is devoted to all-embracing analysis of VT6(Ti-6Al-4V) alloy and its formability in a wide range of temperatures and strain rates. It's its chemical composition is presented on the table1.

Table 1. Chemical composition of VT6 alloy.

Fe	C	Si	V	N	Al	Zr	O	H	Impurity	Ti
0.6%	0.1%	0.1%	4%	0.05%	6%	0.3%	0.2%	0.015%	0.3%	Balanced

In [10] the stress-strain rate curves were obtained from tensile jump test. These curves were analyzed and the models of the VT6 superplastic behavior were formulated. The models were verified by the experiments on forming of VT6 sheets to the die with a geometry presented in figure 1

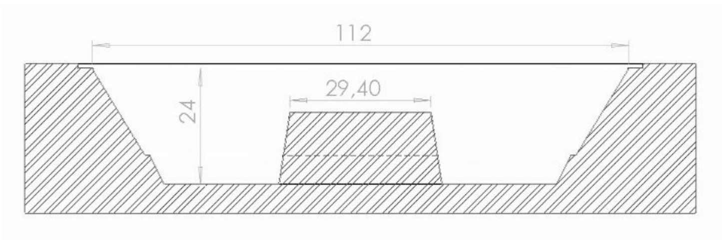

Fig. 1. The drawing of the die

Pressure regime which was applied for the forming was calculated in order to control maximum strain rate at the level of 10^{-1}[10]. This strain rate was considered as the optimal one for this alloy at the temperature of 825 ℃ based on the analysis of jump tensile test. The pressure regime is presented on figure 2a. The experimental data(red circles) obtained from tensile jump test for Vt6 titanium alloy at 825 ℃ are presented on the figure 2b as well as its approximation(blue line). The approximation was made by linear regression the constants of Backofen equation were found as $K = 2044$ $m = 0.56$

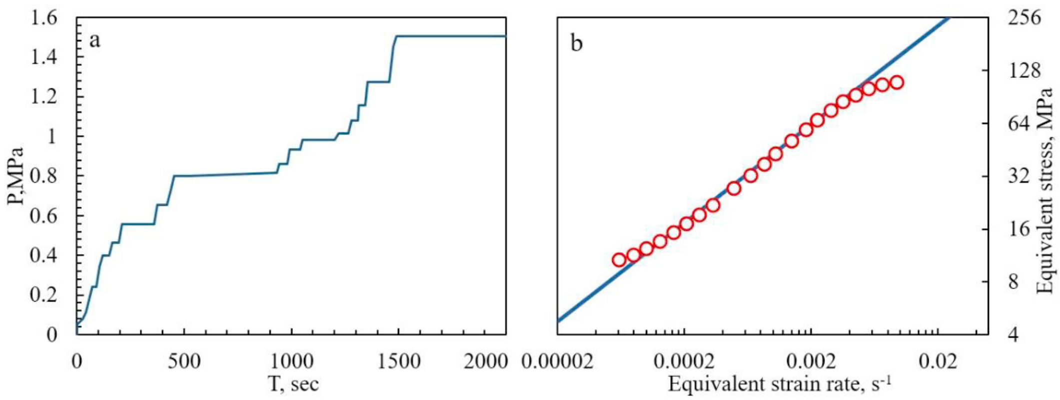

Fig. 2. (a) Pressure regime; (b) Stress- Strain rate curve for Ti-6Al-4V at 825 ℃

3. Results and discussion

The present study is based on the experimental results described in [10]. The forming process was simulated using of both 2-nodes and 4 nodes axisymmetric finite elements. The simulation parameters such as die geometry, material properties, pressure regime were taken from [10] for VT6 titanium alloy at 825 °C. In order to compare the results of simulation with the experimental ones the thickness of the formed part was measured in different points. The positions of this points, and an obtained thickness values are presented on the figure 3.

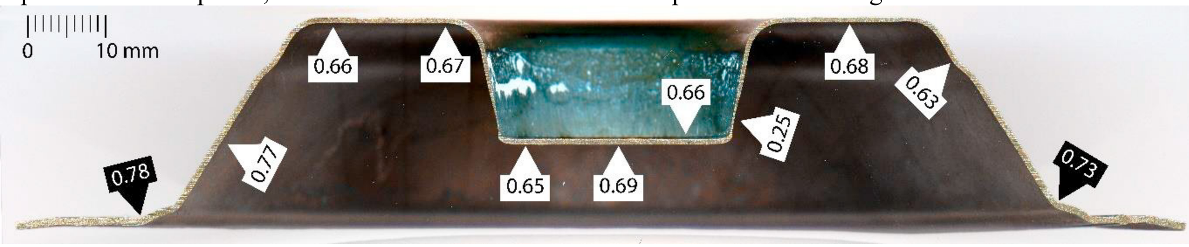

Fig. 3. The formed part with thickness measurement.

The length of 4 nodal and 2 nodal elements were equal. In the simulation with 4 node elements the specimen was divided on 1000 elements (200-by length and 5- by height). The number of elements for the second simulation utilizing the membrane theory was 200. The pressure regime corresponding to the one applied in the experiment was used in both simulations. The temperature was considered to be constant and equal to 825 °C. As the boron nitride was used as a lubricant the friction coefficient between specimen and the die was consider equal 0.1 [11]. The evolution of specimen during the simulation with 4-nodes elements presented on figure 4.

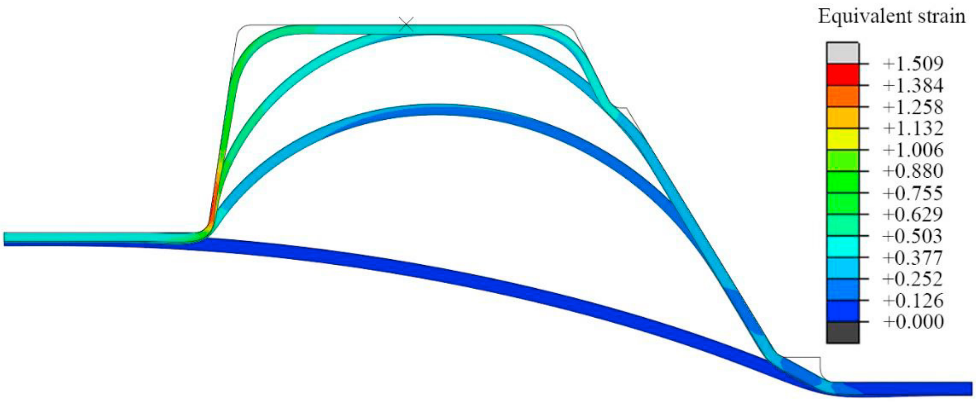

Fig. 4. Stages of FE simulation

The comparison between the results of FE simulations with the measured thickness is presented on figure 5a. The solid curves illustrate thickness distribution obtained by FE simulation. The blue curve corresponds to the simulation with 4-nodes elements, the red one corresponds to 2- nodes elements. The green circles correspond to the experimental data presented on figure 3. It can be seen that the utilization of membrane theory for the given case leads to underestimation of thickness in the center of the part. At the same time the overestimation of the minimal thickness in the most critical area of maximum thinning can be observed.

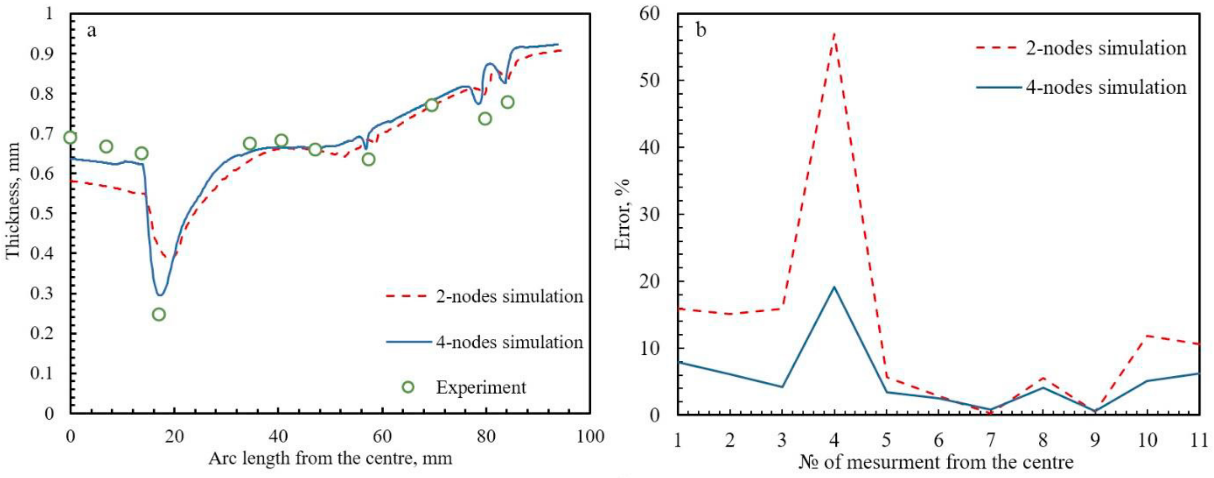

Fig. 5. (a) The thickness distribution at the final forming state; (b) The relative error between simulations and the experimental data.

The relative deviations between numerical predictions and the measured values are illustrated on figure 5b. The value of maximum variation between experimental data and the results of the simulation utilizing solid elements is 20% while for the simulation based on membrane theory this value is much higher and exceeds 56%. The point corresponding to the maximum deviations is the same for both simulations and located in the area of maximum thinning.

4. Conclusions

The numerical simulations of supereplastic forming procedure were carried out both using 2 nodes elements and 4-nodes elements. The results of simulations were compared with the experimental data.

The simulation results of superplastic forming process manifest that implementation of shell elements leads to a more uniform thickness distribution than the observed experiment and obtained by using volume elements. The most significant errors are observed in the central part of the workpiece while in its peripheral area predictions are more similar to each other and are in better agreement with the experiment. The results show that the implementation of shell finite elements for complex part forming simulation can leads to significant errors.

Acknowledgements

The author is grateful to professor Chumachenko and professor Portnoi who provided the experimental data used in this paper.

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