A Novel Method for Reducing Springback of Hot Stretch Bending Parts

Fengchao Cao¹,²,³*, Yuansong Zeng¹,²,³, Baosheng Liu¹,²,³ and WeiWu¹,²,³

¹Metal forming department, AVIC manufacture technology institute, Beijing, 100024, China
²Aeronautical key laboratory for plastic forming technologies, Beijing, 100024, China
³Beijing key laboratory of digital plastic forming technology and equipment, Beijing, 100024, China

*Corresponding author’s e-mail: fengchaocao@126.com

Abstract. Due to the impact of temperature on springback in hot stretch bending (HSB) process, this paper proposed a modified hot stretch bending (MHSB) process in which a reheating process was added before post stretching. The reheating process was realized by controlling the current distribution in the straight region and the bent region of titanium extrusion. Prior to HSB tests, uniaxial tensile tests were carried out to determine the deformation behavior of extrusion under the temperature condition similar to the HSB processes investigated. The results of the tensile tests provided supporting evidence for that the temperature of post stretching strongly affected the forming accuracy of hot stretch bending parts. Particularly, much more joule heat generated in the bent region than in the straight region successfully reheated it to initial forming temperature by increasing current before post stretching. Accordingly, the springback was significantly reduced via the novel method compared to conventional hot stretch bending (HSB) process. This method is proved to be an efficient and lower cost solution for reducing springback in HSB.

1. Introduction

Hot stretch bending (HSB) is a feasible method for bending titanium extrusions which are widely applied in aerospace industry[1,2]. As a major defect associated with HSB process, springback is influenced by plenty of factors wherein temperature plays an important role[3,4]. In conventional hot stretch bending (HSB) process, the temperature of the bent region of extrusion decreases rapidly due to the conductive thermal loss as the workpiece is warped around work surface. At the same time, however, the temperature of the straight region basically still maintains at initial forming temperature. Post stretching can't be conducted until the temperature difference between the straight region and the bent region is small which leads to large springback[5]. Up to now, efforts made on temperature control of workpiece have proved that springback in HSB can be effectively reduced by increasing the initial temperature of mould[6] or providing enclosure which includes radiant heaters for surrounding the mould and the bent region of workpiece to maintain a substantially constant forming temperature throughout the process[7,8]. The latter method has been used to hot stretch bending and creep forming of titanium sheets and profiles to obtain components with small springback[9,10].

Regarding to the impact of temperature on springback, this work proposed a novel method, i.e. add a reheating process before post stretching by controlling the current distribution in the bent region and
the straight region of workpiece to reduce springback. Also, stretch bending model was developed and the deformation behavior of selected extrusions was studied by performing uniaxial tensile tests under the temperature condition similar to the HSB processes investigated.

2. Stretch bending analysis
The stretch bending process was analyzed based on bilinear kinematic hardening material model. The basic hypotheses are as follows: Any cross-section remains planar throughout deformation; The stress state is uniaxial; Homogeneous, isotropic material behavior is adopted; The Bauschinger effect is taken into account while reverse loading and unloading. The stretch bending method in this work is conducted in three steps, as follows.

- Pre stretching, the extrusion is pre-stretched to yield stress(along path “OSA” in Figure 1).
- Bending, the clamps move to accomplish an increasing contact between the mould and the extrusion until bending process is completed(along path “AB” for outer surface, along path “ADE” for inner surface in Figure 1).
- Post stretching, an additional post-stretch displacement is applied with the clamps after bending process(along path “BC” for outer surface, along path “EFA” for inner surface in Figure 1).

Figure 1. Variation of stress during stretch bending process
Figure 2. Stress distribution of “L” cross section

Calculating formula for springback\(^{[11]}\) is shown as follows:

$$\Delta k = \frac{1}{R} - \frac{1}{r} = \frac{M}{EI} \quad (1)$$

where $\Delta k$ is the change of curvature, $R$ and $r$ stand for the curvature radius before and after the force is unloaded, respectively, $M$ is the moment, $E$ indicates the Young’s modulus of unloading, $I$ is the moment of inertia of the cross section. The stress distribution of “L” cross section during stretch bending process corresponding to Figure 1 is exhibited in Figure 2. According to the formula above, it can be concluded that the springback of hot stretch bending parts is strongly associated with temperature in HSB process due to the effect of temperature on the stress-strain relationship of material. Hence, higher accuracy can be achieved by controlling the forming temperature reasonably in HSB.

3. Materials and methods

3.1. Material
The extruded profiles used in the experiment are OT4M titanium extrusions with “L” cross section which length are 1800 mm. The specimens applied in uniaxial tensile tests were prepared by wire electrode cutting from the extrusions along longitudinal direction.
3.2. Uniaxial tensile tests
The stretch bending model in section 2 states that the springback of hot stretch bending parts is strongly affected by temperature for certain cross-section dimension in HSB. Then, uniaxial tensile tests were initiated specifically to reveal the changing law of the deformation behavior of extrusion with temperature on Gleeble-3500 simulator and further to determine the impact of temperature on springback in HSB. The detailed test scheme is displayed in Figure 3. Specimens 1 and 2 were designed to investigate the influence of the temperature of last deformation on final stress level. The process of stretching specimens from L1 to L2 can be regarded as post stretching process. As for specimen 3, it was conducted at constant temperature for comparison. Furthermore, unloading process was added to each tensile test for comparing the elastic recovery under the three different conditions, the tensile velocity of the tensile tests is 0.1mm/s.

![Figure 3. Schematic of uniaxial tensile tests](image)

3.3. Stretch bending tests
A comparison test between CHSB and MHSB was performed using displacement control electrically assisted stretch bending machine. Same stretch bending parameters(initial forming temperature of 923 K, pre stretching strain of 0.005, bending velocity of 0.5°/s, post stretching strain of 0.01) were adopted. Unlike the processes of power off and cooling before post stretching in CHSB, a reheating process was applied in MHSB as shown in Figure 4. The reheating process is accomplished by controlling the current distribution in the bent region and the straight region of extrusion. The details is described as follows: A layer of ceramic coating(0.5mm) formed on the work surface of the mould(R=1000mm, α=70°), as in Figure 5, electrically insulates the bent region of titanium extrusion from the metal of the mould to prevent shunting therebetween. A pair of copper plates(RCu≈0.05RS, Rs stands for the resistance of the straight region) attached to the straight regions, as shown in Figure 6, makes them connected in parallel to create shunting therebetween. Theoretically, the current flowing through the bent region is approximately twenty times the value of the straight region. Accordingly, much more joule heat generated in the bent region than in the straight region can reheat it to elevated temperature before post stretching in spite of the additional conductive thermal loss.
4. Results and discussion
The results of tensile tests are displayed in Figure 7. Comparing with the stress-strain curves in Figure 7(a), it is found that the final stress level and the subsequent elastic recovery of specimen 2 are much lower than those of specimen 1. Clearly, the stress-time curve of specimen 2 in Figure 7(c) shows the stress drop from point A to point B resulting from the softening effect of material caused by the reheating process at the length of $L_1$ contributes to the phenomenon above. Thus, the results indicate that the temperature of last deformation strongly affects the elastic recovery after unloading. Besides, it should be noted that due to the integrated affection of stress relaxation and hardening effect, the stresses of specimens 1-3 decrease at first and then increase during cooling process as presented in Figure 7(c). In Figure 7(b) the plot of stress vs. strain shows that the Young’s modulus of unloading($E$) and the final stress level which is directly related to the moment($M$) of specimens 2 and 3 are approximately equal. It is reasonable to infer, therefore, that the forming accuracy achieved in HSB process with constant forming temperature can be duplicated by using the proposed MHSB in which the temperature of post stretching process is equal to initial forming temperature according to the formula for springback in section 2.

The results of stretch bending tests are summarized in Figure 8. As anticipated before, Figure 8 shows that the final stretching force of MHSB is much lower than that of CHSB and the variation
tendencies of stretching force with temperature and deformation during two HSB processes are consistent with the findings on tensile tests above. The temperature-time curves of the bent region(Point 1) and the straight region(Point 2) of extrusion during MHSB process, as in Figure 8, show that the bent region was as expected reheated to initial forming temperature after bending by increasing current while it was in contact with the mould, and meanwhile the temperature of the straight region was lower than that of the bent region which is advantageous for post stretching. Clearly, the bent region was reheated to elevated temperature as shown in Figure 9. Figure 10 exhibits the stretch bending parts of OT4M extrusions. The springback magnitude of MHSB was reduced 54.7% in comparison with that of CHSB. The reduction of springback is mainly attributed to the reduced flow stresses in different layers of extrusion after the reheating process. To a certain extent, the internal stresses can also be released by increasing the temperature of extrusion before post stretching. In addition, the effect of stress relaxation can become notable for further improving the accuracy of hot stretch bending parts by maintaining the temperature of extrusion for a dwell time after post stretching. Thus, the results have revealed that the proposed novel method can effectively increase the temperature of the bent region of extrusion to initial forming temperature by controlling the current distribution in extrusion for reducing springback.

Figure 8. Force-time curves and temperature-time curves of stretch bending tests.

Figure 9. Reheated bent region of extrusion.  

Figure 10. Stretch bending parts

5. Conclusions
In summary, the results of tensile tests support that the reheating process before last deformation is effective to reduce the elastic recovery after unloading. Moreover, the forming accuracy achieved in HSB process with constant forming temperature is possibly to be duplicated by using the proposed MHSB in which the temperature of post stretching process is equal to initial forming temperature. The springback of hot stretch bending parts is significantly reduced by controlling the generation of joule heat in different regions of extrusion to increase the temperature of the bent region to elevated temperature before post stretching. This study provides an efficient and lower cost solution into HSB for reducing springback.

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