Available online at www.sciencedirect.com
SCIENCE DIRECT®
Trans. Nonferrous Met. Soc. China 17(2007) 581−585
Transactions of Nonferrous Metals Society of China
www.csu.edu.cn/ysxb/

Numerical analysis of dimension precision of U-shaped aluminium profile rotary stretch bending

YU Zhong-qi(于忠奇), LIN Zhong-qin(林忠钦)

School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

Received 14 September 2006; accepted 22 January 2007

Abstract: In order to enhance the dimension precision of bent part, advanced bending technologies is requested recently. Rotary stretch bending(RSB) is a suitable technology to realize high precision of bent part. The effect of processing parameters, namely the side pressure and the stretching force, on the dimension precision of aluminium profile RSB part was studied by finite element method. The numerical simulation of the U-shaped aluminium profile RSB was carried out, and the validity of the simulation was checked. Parametric analysis shows that the section distortion of the U-shaped profile LY12M bent part decreases with the increasing of the side pressure, whereas the springback of curvature increases, and that both of the section distortion and the springback of curvature decrease with the increasing of the stretching force, moreover, the uniformity of curvature of the bent part is clearly enhanced with the increasing of the stretching force. The results above prove that RSB technology can better improve the dimension precision of aluminium profile bent part.

Key words: rotary stretch bending; aluminium profile; springback; section distortion; numerical simulation

1 Introduction

The demand of aluminium profile has increased considerably in recent years. A major part of this growth is initiated by the transportation industry. Especially, in the automotive industry, the manufacturers are facing a demand for lighter vehicles in order to reduce fuel consumption[1]. This requirement can be met by use of aluminium components. Another reason for choosing aluminium is recycling. Rotary draw bending(RDB) is one of the primary technologies of bending process for aluminium profile. For RDB of profile, springback of curvature and section distortion that influence the dimension precision of bent part are the main quality problems. At present, in order to improve the dimension precision of bent part, the multi-pass RDB process that is very low efficiency is used in industrial production. Due to the weakness above, rotary stretch bending(RSB) has been developed based on conventional RDB and stretch bending[2]. The principle of RSB is shown in Fig.1. In RSB, one end of profile is fixed at the bend die, and the other end is guided by the guide die, whilst is loaded a longitudinal stretching force at the guide die. As the bending die turns, the profile is continuously bended. The deformation zone of profile is in the region where contacts between the profile and the bending die, and an appropriate longitudinal stretching force is acted on the deformation zone.

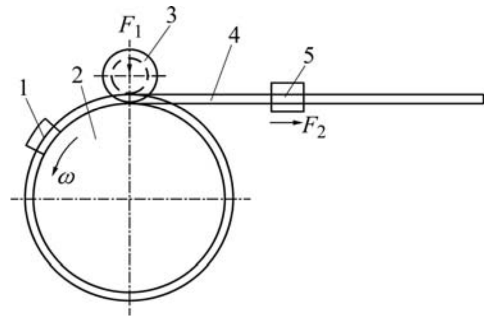

Fig.1 Sketch of RSB of U-shaped profile: 1 Clamp die; 2 Bend die; 3 Pressure die; 4 U-shaped profile; 5 Guide die and stretching force

Only a few of the scholars experimentally studied the RDB of aluminium profile. DONG et al[3] discussed the effect of the bending pass on the dimension precision

Foundation item: Project(2005CB724100) supported by the National Basic Research Program of China; Project(50605043) supported by the National Natural Science Foundation of China
Corresponding author: YU Zhong-qi; Tel: +86-21-34206785; E-mail: yuzhq@sjtu.edu.cn

of conventional RDB. To improve the dimension precision of bent part, LOU and KIM[4] have developed an online measure technology and used it in conventional RDB. LI et al[5] and UTSUMI and SAKAKI[6] studied the effect of processing parameters on the section distortion of bent part in RSB. The finite element method(FEM) is a viable tool for optimizing the process layout in metal forming. Numerical simulation helps designers to estimate metal formability and improve process layout. PAULSEN and WELO[7] earlier simulated bending of profile by means of the finite element code MARC. YANG et al[8] and LEE et al[9] numerically analyzed tube pre-bending in tube hydroforming. CLAUSEN et al[10] and JIN et al[11] studied springback behavior of aluminium profile stretch bending by numerical simulation, whilst ZHAN et al[12] and GU et al[13] numerically investigated the forming and springback behavior of stainless steel tube NC bending. Otherwise, SUN et al[14] and BAUDIN et al[15] carried out push-bending simulation of profile and tube, respectively, by finite element method.

In RSB of profile, the side pressure and the stretching force that influence the dimension precision of bent part are important processing parameters. In this study, therefore, RSB of a U-shaped aluminium profile was simulated by FEM, and the effect of the side pressure and the stretching force on the curvature springback and the section distortion was analyzed.

2 Finite element model

The finite element software, ETA/Dynaform, was used to simulate the U-shaped profile RSB. Fig.2 shows the finite element model of the RSB. The tools and the profile were modeled with the half geometry due to symmetry. In numerical simulation of RSB, the dynamic explicit algorithm and the static implicit algorithm were used to calculate forming and springback, respectively. To truly simulate springback behavior of bent part, it is necessary to adopt appropriate parameters such as bending velocity, mesh size and integral point in forming simulation[16]. In the FE simulation, the following boundary conditions were used: bending velocity of 12 rad/s, and total bend-angle of $\pi/2$, friction coefficient of interfaces between the profile and the tools (the bending die and the guide die) was assumed to be 0.3, and friction coefficient of interfaces between the profile and the pressure die was assumed to be 0. Before the bending die turns, a given clamp force was acted at the clamp die, then the side pressure and the stretching force were loaded. In this study, to make the results more universal, the side pressure was expressed by side pressure per unit contact length, namely N/mm, and the stretching force was expressed by stretching force per unit area, namely MPa.

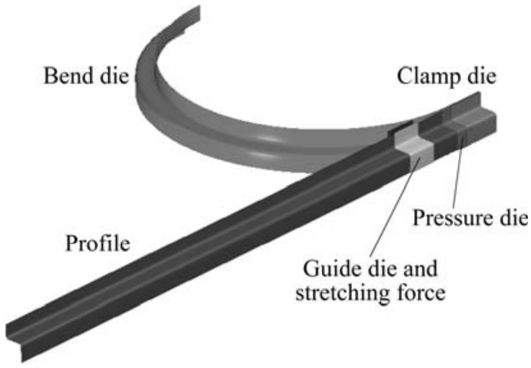

Fig.2 Finite element model of RSB

The test material was a U-shaped aluminium alloy profile LY12M with thickness of 2 mm and length of 800 mm. Table 1 lists the properties of LY12M material obtained from uniaxial tension test. In the FE simulation, an anisotropic, elastic-plastic material following the Barlat’1989 yield criterion, with isotropic work hardening, was the material model. Four-node Belytschko-Tsay(B-T) shell elements with seven layers of integral point and mesh size of 3 mm×3 mm at the plane zone and 3 mm×0.5 mm at the corner zones comprised the profile LY12M.

Table 1 Material properties of LY12M

Property	Value
Elastic moduls, E/GPa	69
Poisson ratio, v	0.33
Yield stress, σ_s/MPa	90
Strength coefficient ($\sigma=K\varepsilon^n$), K/MPa	363
Hardening exponent, n	0.21
Normal anisotropy coefficient, r	0.7

The springback simulation based on the forming simulation results was calculated. The constraint type 3-2-1 was used, and the three constraint points were placed at the one end of profile which contacts with the clamp die.

3 Results and discussion

3.1 Numerical simulation results and verification

To verify the reliability of FEM for RSB, the comparison between the simulation results and the experimental data of the U-shaped profile LY12M RSB was performed. The model for the experimental bending, reported in Ref.[2], is conventional RDB that only includes the side pressure with 490 N/mm without stretching force. Fig.3 shows the thickness distribution of the bent part in Dynaform. It is found from Fig.3 that the thickness at the outer side of the part decreases, and increases at the inner side. For RSB of U-shaped profile, warp of the wing and springback of curvature, as shown Fig.4, are the two main quality defects. Fig.4 shows the radius of curvature and the warp angle α of the unloaded bent part in Dynaform. It is calculated from Fig.4(a) that the average radius is 240.6 mm. The average radius of the experimental bent part is approximately 243 mm[2]. It is seen from Fig.4(b) that the warp angle α is 18°−13°. The warp angle α of the experimental bent part is 16°−12°[2]. In addition, the distribution tendency of the warp angle α in the simulation is consistent with that in the experiment.

Fig.3 Thinning of bent part in Dynaform

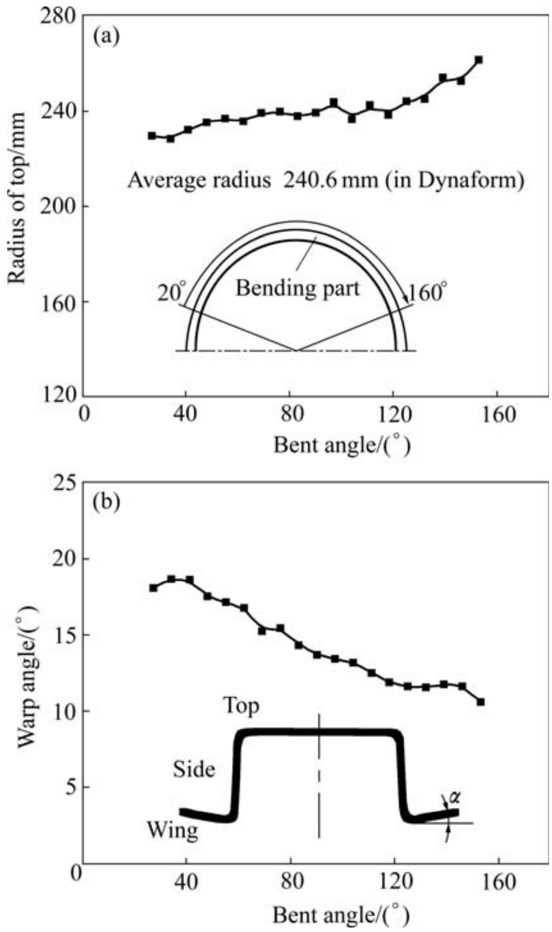

Fig.4 Dimension of bent part in Dynaform: (a) Radius of top; (b) Warp angle of wing

The overall comparison of the FEM results with the experimental results provides evidence that the present FEM bending model is valid for simulations of the RSB of the U-shaped profile LY12M.

3.2 Effect of side pressure on dimension precision

Side pressure is one of the main factors that influence the dimension precision of part in RSB. Fig.5 shows the side pressure effects on the warp angle α and the radius of curvature in the U-shaped profile LY12M rotary stretching bending with the stretching force 10 MPa. It is obtained from Fig.5 that, with the increasing of the side pressure, the average warp angle α decreases whereas the average radius of the top increases, but the change of these values above is very small when the side pressure reaches a bigger value. The conclusion can be drawn that the increasing of the side pressure can not roundly improve the dimension precision of the U-shaped profile LY12M bent part.

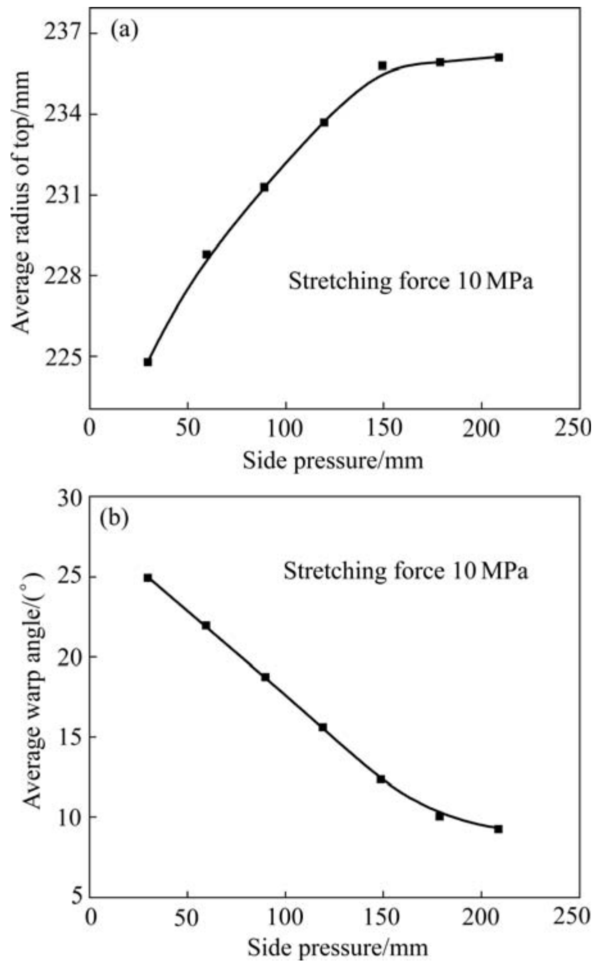

Fig.5 Effect of side pressure on dimension

3.3 Effect of stretching force on dimension precision

Stretching force is the other main factors that influence the dimension precision of part in RSB. Fig.6 shows the stretching force effects on the warp angle α

and the radius of curvature in the U-shaped profile LY12M rotary stretching bending with the side pressure of 149 N/mm. It is seen from Fig.6 that both of the average warp angle α and the average radius decrease with the increasing of stretching force. And the comparison between Fig.5 and Fig.6 finds that the ability of the stretching force which improves the dimension precision is better than that of the side pressure.

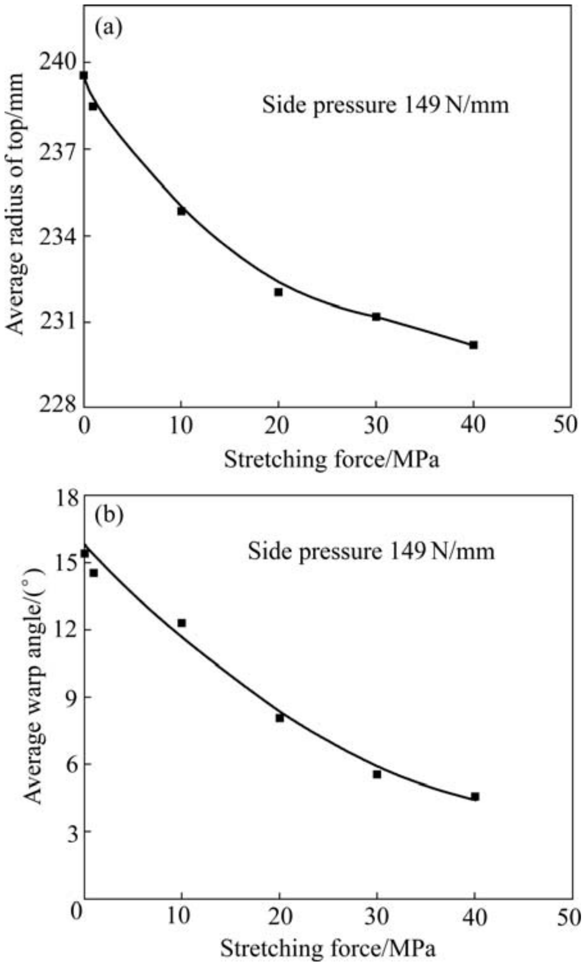

Fig.6 Effect of stretching force on dimension

Fig.7 shows the stretching force effects on the longitudinal stress in deformation zone. The longitudinal stress and the ratio of tension stress in the side zone of section increase with the increasing of the stretching force, which results in the increasing of the plastic strain and the motion of the strain central layer to the inner side. Thus the springback of curvature of the RSB part clearly decreases. And it can be seen from Fig.7 that the consistency of the stress in deformation zone of the wing is enhanced with the increasing of the stretching force. This phenomenon indicates that the blank in the wing is better closed to the bend die during bending. This is a main reason for decreasing of the warp angle α obviously in RSB technology. As shown in Fig.8, otherwise, the increasing of the stretching force can clearly improve the uniformity of curvature of the RSB part.

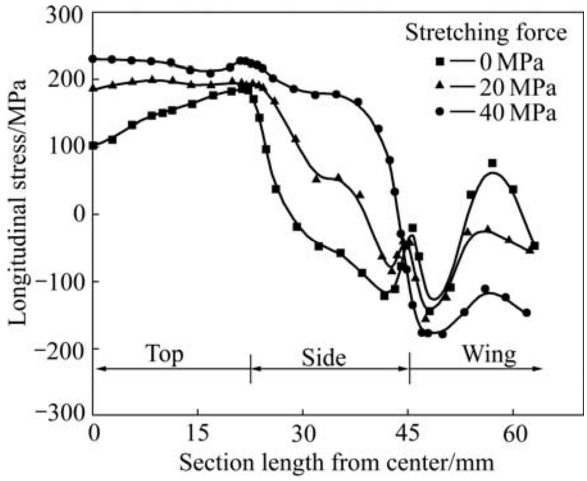

Fig.7 Effect of stretching force on longitudinal stress in deformation zone

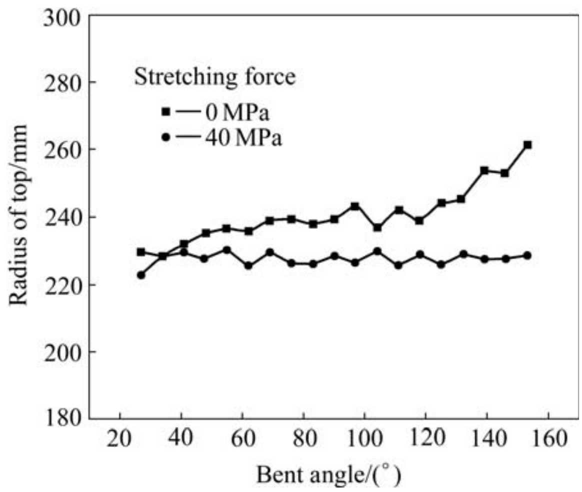

Fig.8 Effect of stretching force on uniformity of radius

4 Conclusions

A finite element model of RSB was built, and the simulation of the RSB of the U-shaped profile LY12M was carried out. The comparison of the simulation with the experiment proves that the present bending simulation model is reliable. Parametric analysis shows that the side pressure and the stretching force significantly influence the dimension precision of the RSB part of the U-shaped profile LY12M. For the two main factors above, both of the springback of curvature and the section distortion decrease with the increasing of the stretching force, whereas the two can not decrease simultaneously with the increasing of the side pressure.

References

[1] CHEN P, LIN Z Q, CHEN G L, MUAMMER K. Parametric analysis of warm forming of aluminum blanks with FEA and DOE [J]. Trans Nonferrous Met Soc China, 2006, 16(2): 267−273.

[2] VOLLERTSEN F, SPRENGER A. Extrusion, channel and profile bending: A review [J]. Journal of Materials Processing Technology, 1999, 87: 1−27.

[3] DONG Y, YANG Y Y, ZHAO L H. Research on the relationship between the number of rotary draw bending and the shape precision of a bent hat-section profile [J]. Journal of Materials Processing Technology, 2004, 151: 307−311.

[4] LOU H Z, KIM A S. Three-dimensional tube geometry control for rotary draw tube bending (part 1): Bend angle and overall tube geometry control [J]. ASME Journal of Manufacturing Science and Engineering, 2001, 123: 258−265.

[5] LI C F, YANG Y Y, GAO G F, XU W L. Research on the section distortion of hat-section profiles in rotary draw bending with stretching force [J]. Journal of Materials Processing Technology, 1999, 94: 41−44.

[6] UTSUMI N, SAKAKI S. Countermeasures against undesirable phenomena in the draw-bending process for extruded square tubes [J]. Journal of Materials Processing Technology, 2002, 123: 264−269.

[7] PAULSEN F, WELO T. Application of numerical simulation in the bending of aluminium alloy profiles [J]. Journal of Materials Processing Technology, 1996, 58: 274−285.

[8] YANG J B, JEON B H, OH S I. The tube bending technology of a hydroforming process for an automotive part [J]. Journal of Materials Processing Technology, 2001, 111: 175−181.

[9] LEE H, VAN TYNE C J, FIELD D. Finite element bending analysis of oval tubes using rotary draw bender for hydroforming applications [J]. Journal of Materials Processing Technology, 2005, 168: 327−335.

[10] CLAUSEN A H, HOPPERSTAD O S, LANGSETH M. Sensitivity of model parameters in stretch bending of aluminium extrusions [J]. Inter Journal of Mechanical Sciences, 2001, 43: 427−453.

[11] JIN C H, ZHOU X B. Springback analysis for stretch bending of aluminum profile [J]. Materials Science and Technology, 2004, 12: 394−397. (in Chinese)

[12] ZHAN M, YANG H, LI Z B. A study on a 3D FE simulation method of the NC bending process of thin-walled tube [J]. Journal of Materials Processing Technology, 2002, 129: 273−276.

[13] GU R J, YANG H. Springback of thin-walled tube NC precision bending and its numerical simulation [J]. Trans Nonferrous Met Soc China, 2006, 16(2): 631−638.

[14] SUN Z Z, YANG Y Y. Push-bending process of aluminum profile [J]. The Chinese Journal of Nonferrous Metals, 2004, 14(10): 1677−1682. (in Chinese)

[15] BAUDIU S, RAY P, MACDONALD B J, HASHMI M S J. Development of a novel method of tube bending using finite element simulation [J]. Journal of Materials Processing Technology, 2004, 153/154: 128−133.

[16] XU W L, MA C H, LI C H, FENG W J. Sensitive factors in springback simulation for sheet metal forming [J]. Journal of Materials Processing Technology, 2004, 151: 217−222.

(Edited by YUAN Sai-qian)