

Research on the Cross Section Precision of High-strength Steel Tube with Rectangular Section in Rotary Draw Bending

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Abstract. For the demand of energy conservation and security improvement, high-strength steel (HSS) is increasingly being used to produce safety related automotive components. However, cross-section distortion occurs easily in bending of HSS tube with rectangular section (RS), affecting the forming precision. HSS BR1500HS tube by rotary draw bending is taken as the study object and a description method of cross-section distortion is proposed in this paper. The influence on cross-section precision of geometric parameters including cross-section position, thickness of tube, bend radius etc. are studied by experiment. Besides, simulation of the rotary draw bending of HSS tube with rectangular section by ABAQUS are carried out and compared to the experiment. The results by simulation agree well with the experiment and show that the cross-section is approximately trapezoidal after distortion; the maximum of distortion exists at 45~60° of the bending direction; and the absolute and relative distortion values increase with the decreasing of tube thickness or bending radius. Therefore, the results can provide a reference for the design of geometric parameters of HSS tube with rectangular section in rotary draw bending.

1. Introduction

In recent years, for the demand of energy conservation and security improvement, HSS is increasingly being used to produce safety related automotive components. HSS tubes with rectangular section (RS) process many advantages such as light weight, high strength, material saving, energy efficiency and environmental protection. Therefore, they are the key components in the frame structures, with a wide range of applications in fields of construction, automotive, marine and aerospace. The tensile strength of HSS BR1500HS can reach up to 1500 MPa after strengthening by heat treatment, which can improve the structural strength and reduce structural weight greatly.

However, cross-section distortion occurs easily in bending of HSS tube with rectangular section, affecting the forming precision. Some studies on sectional distortion of RS tubes in bending process have been carried out by domestic and foreign scientists. Corona established a theoretical model of sectional distortion and the model was verified by experiment [1]. Paulsen and Welo have studied the influence law of cross-sectional shape on the cross-sectional distortion of RS tubes in bending process [2]. Mandrel was used by Utsumi for reducing the cross-sectional distortion in rotary draw bending of RS tubes [3]. Liu established a three-dimensional FE model to study the influence of process parameters on distortion of thin-walled RS tubes in bending process [4]. Peng et al. have compared and analyzed the sectional distortion of overall bending and multi-point bending for the RS tubes, and studied the influence of friction coefficient, wall thickness, bend radius on the cross-section distortion in multi-point bending [5]. The previous research objects are mostly ordinary steel or aluminum alloy, however, less studies focus on the bending of high-strength steel RS tubes. Compared with the ordinary steel, HSS has some characteristics such as poorer plasticity, larger forming resistance and bigger springback, etc. In this paper, the combination of pulling and rotary drawing bending of high-strength



steel RS tubes is carried out for studying the influence law of geometric parameters on the cross-sectional distortion.

2. Experimental device and FE model

According to the principle of rotary drawing bending, the bending molds consist of rotary draw bending die, gap clamp block, clamp block, boosting block, mandrel and other components. The geometric model, the corresponding numerical model and the experimental device of the molds are respectively shown in figure 1 A, B and C.

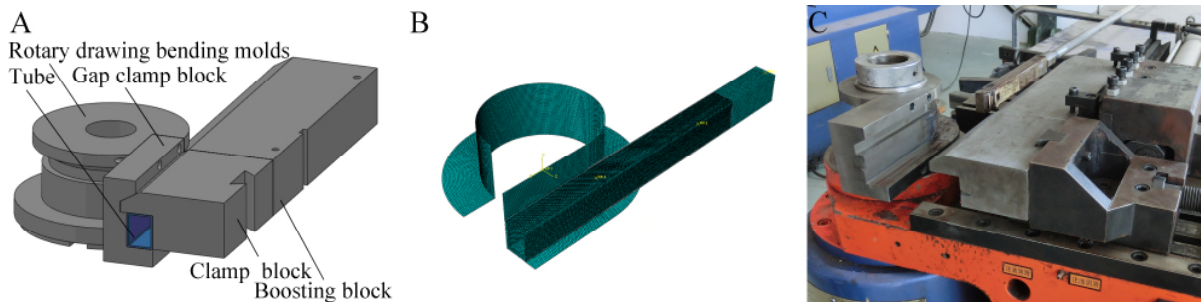


Figure 1. Rotary drawing bending molds:

A) geometry model, B) FE model and C) experimental device..

40Cr was taken as the material of molds while high-strength boron steel BR1500HS of which the stress-strain curve before strengthened (as-delivered) is shown in figure 2 was used for the RS tubes. In FE simulation, the molds were treated as discrete bodies and meshed by four nodes curved shell elements S4R; the RS tube was defined as deformable body and meshed by eight nodes linear hexahedral element C3D8R.

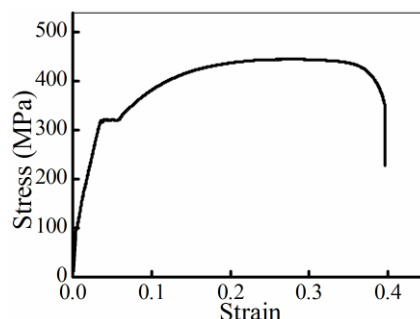


Figure 2. The stress-strain relationship of BR1500HS as-delivered.

The process parameters for bending were as follows, bending angle (α) was 90° , bending speed (ω) was 1.576 rad/s, mandrel gap was 0.3 mm, friction coefficient was 0.1, the elasticity modulus was 2.11×10^5 MPa and Poisson's ratio was 0.284.

3. The defining method of cross-section distortion

The outer wall of the RS tube is under tensile stress in the tangential direction, compressive stress in the radial direction and tensile stress in the width direction during the bending process. However, the inner wall is under compressive stress in the three directions. Under the combined action of the tangential stresses on both inner and outer wall, distortion occurs in the cross-section. As a consequence, the normal size will reduce, the size of inner wall in the width direction will increase. Besides, the size of outer wall will reduce because of the sunken appears in the central portion.

The position of cross-section on the tube after bending is shown in figure 3, the position of the bent portion tangent to the straight edge is defined as 0 cross section, and the other sections are 15° from one to the next. The size distribution is shown in figure 4, in which the original width and height of the tube is B_0 and H_0 ; after bending, the minimum width of outer wall, intermediate width, maximum width of inner wall, side height and central height are B_1 , B_2 , B_3 , H_1 and H_2 , respectively.

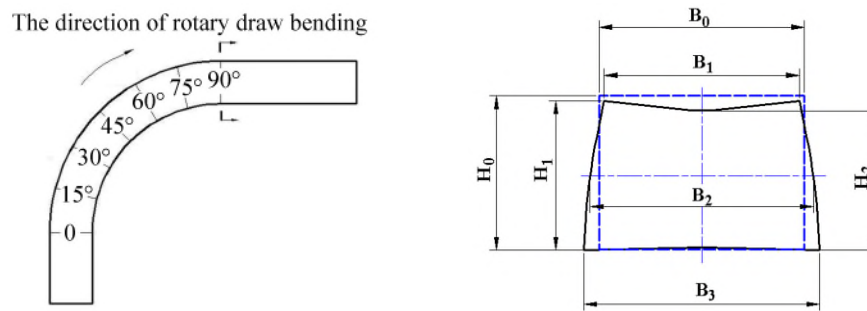


Figure 3. Distribution of measure position. **Figure 4.** The definition of cross-section size.

The amount of absolute distortion of height and width after bending can be expressed as:

$$\Delta H_i = H_0 - H_i \quad (i = 1, 2). \quad (1)$$

$$\Delta B_j = B_0 - B_j \quad (j = 1, 2, 3). \quad (2)$$

The maximum amount of relative distortion of height and width after bending can be expressed as:

$$\Delta H = H_1 - H_2 \quad \text{and} \quad \Delta B = B_3 - B_1. \quad (3)$$

The amount of absolute distortion represents the sectional deformation of RS tube after bending, in which ΔB_2 is close to 0 and thus not concerned. The amount of relative distortion represents the size difference produced by distortion in the same direction after bending and offers better reflection for the degree of sectional distortion.

4. Analysis of experimental and simulated results

4.1. Analysis of experimental results

First is the influence of thickness on the absolute distortion. Figure 5 shows different cross-sectional shapes of 0~ 90° with the aspect ratio $B/H = 40/30$, bending radius $R = 90$ mm and wall thickness $t = 2$ mm. The cross-sectional shapes can match up with the shape that defined in figure 4, and they are approximately trapezoidal. The outer wall has inward deflection, the inner wall remains substantially straight, and the side wall is not obviously convex. The values of sectional distortion at all positions change with the thickness of wall, as shown in figure 6. Obviously, the maximum cross-sectional distortion occurs at the position between 45~ 60°. The distortion values along the directions of height and width increase with the decrease of the wall thickness, and the value ΔH_1 along the height direction is greater than ΔH_2 . In the width direction, the size of outer wall reduces while the inner wall increases. Besides, the position of section has little influence on the size of outer wall.

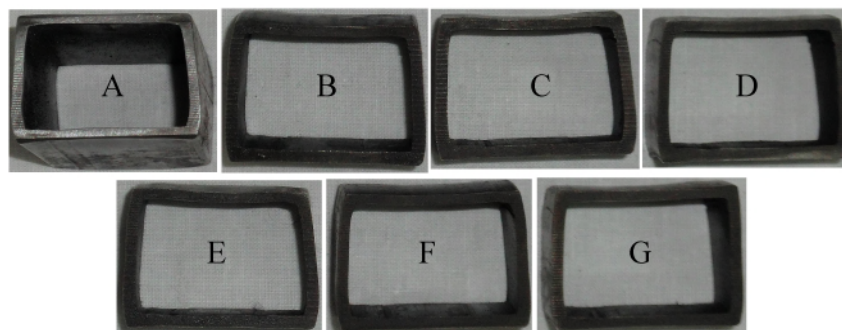


Figure 5. Cross-sectional shapes of the RS tube: A) 0°, B) 15°, C) 30°, D) 45°, E) 60°, F) 75° and G) 90°.

Then is the influence of the bending radius on the absolute distortion. Figure 7 shows the RS tubes after bending with the aspect ratio $B/H = 40/30$, wall thickness $t = 2$ mm and the bending radius $R = 75, 90, 105$ and 120 mm. The influence of bending radius on the cross-sectional distortion is shown in figure 8.

The maximum cross-sectional distortion occurs at the position between 45~ 60° along the bending direction. Besides, the distortion value decreases with the increasing of bending radius.

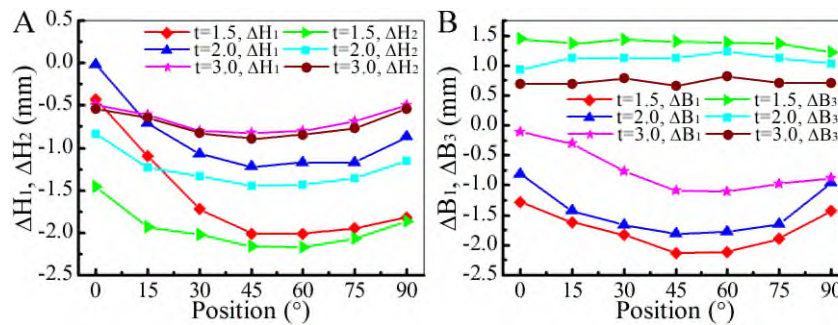


Figure 6. Influence of the thickness on the absolute distortion:
A) height variation and B) width variation.

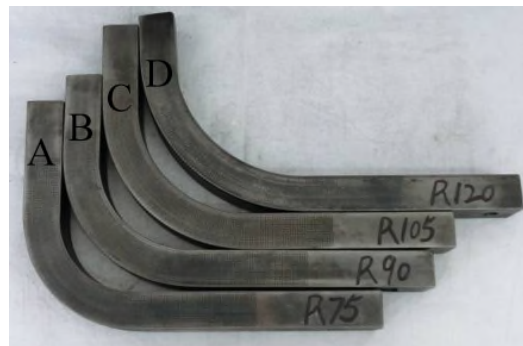


Figure 7. Test samples with different bending radius: A) 75°, B) 90°, C) 105°, D) 120°.

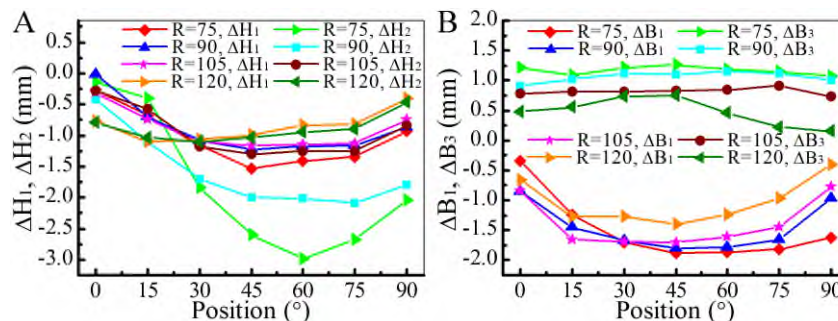


Figure 8. Influence of the bending radius on the absolute distortion:
A) height variation and B) width variation.

Last is the influence of thickness on the relative distortion. Figure 9 (A) shows the values of relative distortion at each section with aspect ratio $B/H=40/30$, bending radius $R=90$ mm and wall thickness $t=1.5, 2, 3$ mm; and figure 9 (B) shows the values with aspect ratio $B/H=40/30$, wall thickness $t=2$ mm, bending radius $R=90, 105, 120$ mm. Similarly, the maximum value of the relative distortion appears mostly at the position between 45~ 60°. The values of relative distortion along the directions of width and height decrease mainly with the increasing of thickness or bending radius. However, the distortion value in the height direction changes a little when the wall thickness varies from 1.5 to 2 mm, and meanwhile the values with the wall thickness 2 mm are larger. This phenomenon appears due to the side wall is too thin, and it is difficult for the edges to maintain a straight state in distorting process.

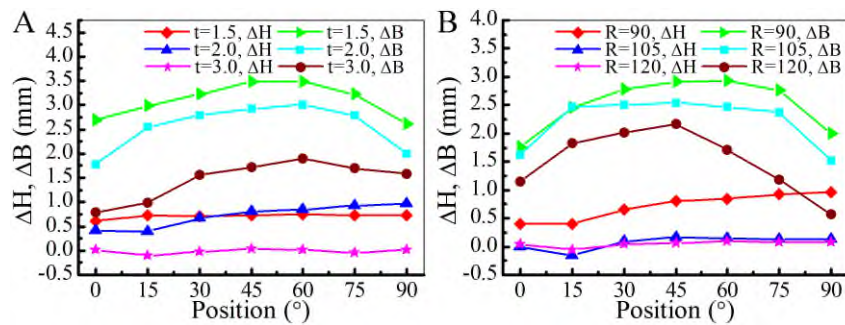


Figure 9. The values of relative distortion change under the influence of:
A) thickness and B) bending radius.

Besides, erratically fluctuation appears in the data at the position between 0~30°, as shown in figure 5, 7 and 8. This phenomenon appears because the wrinkling trend appears at that position, which would affect the sectional size of distortion.

4.2. Comparison between simulated and experimental results

Figure 10 shows the simulated cross-sectional shapes at different sections according to figure 3 with the aspect ratio $B/H = 40/30$, $t = 2$ mm, $R = 90$ mm. Obviously, the cross-sectional shapes have the same variation trend with the experiments as shown in figure 5.

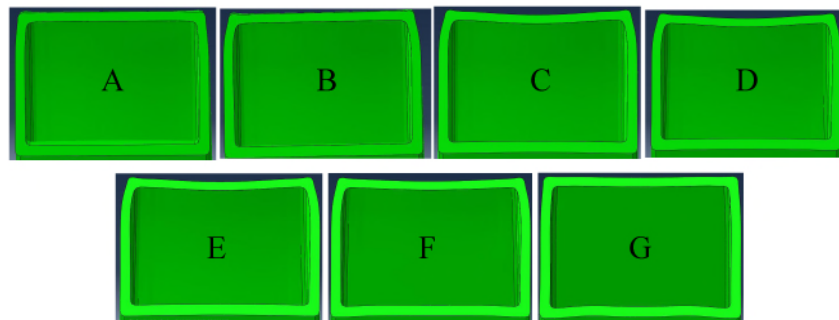


Figure 10. Cross-sectional shapes of the simulated RS tube:
A) 0°, B) 15°, C) 30°, D) 45°, E) 60°, F) 75° and G) 90°.

The comparison of each sectional size between experimental and simulated values is shown in figure 11. The absolute distortion amount of height and width after bending by experiments (ΔH_1 , ΔH_2 , ΔB_1 , ΔB_3) are compared with the corresponding simulated values $\Delta H_1'$, $\Delta H_2'$, $\Delta B_1'$, $\Delta B_3'$, with the consistent trend and the average error of 13.2%. Therefore, the FE model can predict and analyse the cross-sectional distortion of RS tubes in the bending process with good accuracy and reliability.

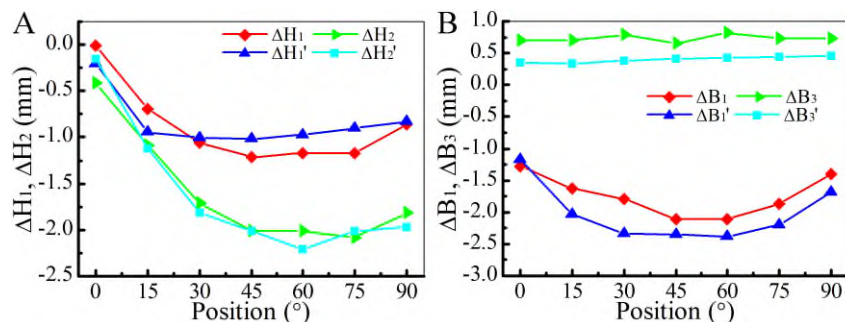


Figure 11. Comparison between the experimental and simulated data of:
A) height variation and B) width variation.

5. Conclusion

After bending, the cross-sectional distortion of high strength steel RS tube is approximately trapezoidal and different with the drum cross-section distortion of the ordinary steel or aluminium alloy RS tube.

The maximum values of absolute and relative cross-sectional distortion appear at the position between 45~ 60° along the bending direction. The inner wall appears wrinkling tendency at the position between 0~ 30°, which would affect the shape and size of the section distortion.

Increasing the wall thickness can enhance the ability of anti-sectional distortion, and the value of distortion decreases with the increasing of thickness or bending radius.

The FE model can predict and analyse the cross-sectional distortion of RS tubes in the bending process with good accuracy and reliability. Besides, the result of this study provides a reference for the geometric parameters selection for the bending process of high-strength steel RS tubes.

6. References

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