Study on the Influence of Transition Zone Position on Bending Spring back of TRBs

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Abstract. In this paper, the crystal plastic finite element method is used to study the influence of the transition zone position of Tailor Rolled Blank (TRB) on the bending deformation behavior and spring-back from the mesoscale. The polycrystalline plastic finite element bending model of TRB is established and the bending forming process was simulated. The results show that the B-shaped blank (the blank consists of thick zone and transition zone) has a uniform plastic deformation and a smaller spring-back value than the A-shaped blank (the blank consists of thin zone and transition zone). The stress-strain zone of the B-shaped blank is uniform spread from the bend zone to both sides, but the stress-strain area of the A-shaped blank is transferred to the transition zone, which makes the blank exhibit poor forming properties. And this deformation ununiformity makes the spring-back angle of the A-shaped blank larger than that of the B-shaped blank.

1. Introduction
Tailor Rolled Blank (TRB) has different thicknesses after rolling process, which has the advantages of high surface quality, good formability and strong load carrying capacity. In recent years, scholars have done a lot of research on the stamping formability of TRB and have achieved good results in the world. Meyer et al. [1] used finite element software to analyze the drawing process of the box parts, and the result show that Optimizing the thickness distribution of TRB can effectively reduce the weight and increase the depth of drawing. Abratis et al. [2] designed a new flexible mold system in studying the free bending process of TRB, in which the punch can be adjusted according to the thickness and mechanical property of the steel. Bao [3] used the uniaxial tension to test the mechanical property of different thickness plates and studied the stress-strain relationship of the transition zone by interpolation method, which made him obtain the spring-back law in bending forming of TRB. Zhang Huawei et al. [4] applied the theoretical analysis, numerical simulation and stamping experiment to study the spring-back law of TRB, and obtained the optimal mold clearance, friction coefficient and transition length of the thick zone in the U-bending forming process of TRB. At present, most of these studies are at a macroscopic point, which is not enough to reveal the physical nature of plastic deformation. Through researching on the micro-deformation mechanism of TRB, it can not only obtain the law of microstructure deformation in each thickness zone and guide the rolling process of TRB, but also combine the macroscopic performance with the microscopic performance to effectively predict the quality of TRB. The different thickness zones of TRB are subjected to different pressures during the rolling process, which lead to non-uniform microstructure. Because of ununiformity of the section thickness and the microstructure and interaction between the transition zone and equal thickness zone, its bending deformation behavior is different from that of the equal thick blank. In this paper, the crystal plastic finite element method is used to establish the...
polycrystalline plastic finite element model of the differential plate and study the influence of the transition zone position of Tailor Rolled Blank (TRB) on the bending deformation behavior and spring-back from the mesoscale.

2. Establishment of Polycrystalline Plastic Bending Model

2.1. Taylor Polycrystalline Model

The Taylor polymorphic model determines the slip system of the material according to the principle of minimum shear stress. It can achieve any specified strain by combinations of slip systems and slip amounts, resulting in different orientation changes. The anisotropy of material’s local plastic response depends mainly on the grain orientation. Therefore, in this paper based on the Taylor polycrystal theory, the multi-crystal plastic bending model is established by the hardening formula of Hutchinson [5]. According to the description of the elastic potential by Hill and Rice, assumed that the slip has no effect on the elastic properties of the crystal, the single crystal elastic constitutive equation can be expressed as:

\[ \tau^* = C^* : D^* \]

The polymorphic constitutive relationship can be obtained from the stress formula of the polycrystalline polymer proposed by Taylor:

\[ \overline{T} = \sum_{a=1}^{n} v^n T^a \]

2.2. Establishment of Polycrystalline Geometric Model

Polycrystalline geometry model of A-shaped blank (the blank consists of thin zone and transition zone) and B-shaped blank (the blank consists of thick zone and transition zone) is established by using the voronoi [6] package in neper. The location of the transition zone is shown in Figure 1.

Figure 1. The location of the transition zone

Figure 2a shows a polycrystalline model built by using a voronoi diagram. The blank size is 80mm×20mm, and the mesh type is C3D20R (Three-dimensional twenty-node reduced integral hexahedral solid element), and the number of mesh element is 400. Both the die and the V-shaped punch are rigid and are discrete by using R3D4 (three-dimensional quadrilateral rigid body element). Each module is set to face-to-face contact with 0.1 coefficient friction. In the load module, the die adopts a full fixed constraint; the translation and rotation of the y and z directions are fixed at 10 mm from the end of the blank; the punches are fully constrained except for the translation in the y direction. And polycrystalline bending geometric model is shown in Figure 2b.
2.3. Material Parameters Settings
The specific microstructure of TRB, such as the texture and grain size of each zone, is based on the data in [7]. The values of other material parameters are shown in Table 1.

Table 1. Material parameters.

| C11  | C12  | C44  | $\dot{\gamma}_0$ | n   | $h_0$ | $\tau_s$ | $\tau_0$ | q |
|------|------|------|-------------------|-----|-------|----------|----------|---|
| 230GPa | 130GPa | 117GPa | 0.001s$^{-1}$   | 4   | 240MPa | 68MPa    | 60MPa    | 1 |

3. Finite Element Analysis of Polycrystalline Plastic Bending Model

3.1. Influence of the Transition Zone Position on Stress
The stress cloud diagram of the A-shaped blank and the B-shaped blank with a bending under 20mm is shown in Figure 3. As can be seen from the figure, the stress is mainly concentrated on the bend area and the die corner radius area. In Figure 3a, the maximum stress in the transition zone of the A-shaped blank is significantly higher than that in the thin zone. It reaches 206.6 MPa in the transition zone, and is only 143.5 MPa in the thin zone. But in Figure 3b, the stress distribution on the bend area of the B-shaped blank is relatively uniform, and the stress values are all around 175 MPa.

Two kinds of grains with the highest stress were selected in the bend area of the A-shaped blank and the B-shaped blank, and the stress-time curve of the two grains is shown in Figure 4.
In Figure 4, the trend of Stress-time curves of the grain N is smooth and gradually rising, indicating that its plastic formability is good. But the stress of grain P increases sharply after the smooth rising in the deformation process, and the maximum stress value of grain P is 25 MPa more than that of grain N. It can be seen that the grains of the A-shaped blank are not easily deformed, and the plastic formability is poor.

3.2. Influence of the Transition Zone Position on Strain

The strain cloud diagram of the A-shaped blank and the B-shaped blank with a bending under 20mm is shown in Figure 5. As can be seen from the figure, strain is also mainly concentrated on the bend area. In Figure 5a, the strain near the punch corner radius area is more obvious, and the maximum strain value reaches 0.1543. And Figure 5b shows that the strain of the B-shaped blank is uniform distributed at the bend area and the maximum strain value is 0.1295. At the same time, strain concentration area of the A-shaped blank is more widely distributed than that of the A-shaped blank.

![Figure 4. Stress-time curves of grain P and grain N](image)

![Figure 5. The strain cloud diagram (a) the A-shaped blank; (b) the B-shaped blank.](image)
Comparing strain-time curves of the grain M and grain N from Figure 6, it can be seen that when the bending punch descends, the deformation of the grain M appears earlier than the grain N, and the change is more severe. In the late bending stage, the strain appears to be stagnant, and then gradually changes, indicating that the grain M has non-uniform deformation during the bending process, and it is prone to forming defects such as cracking. The strain of the grain N gradually increases with time, indicating that the grain deformation of the B-shaped blank is uniformly spread on the bend area.

The above analysis shows that the distribution of the strain concentration zone of the A-shaped blank is very non-uniform, and the maximum strain region is not the maximum stress region, the grain deformation is severe, the deformation is large, and the formability is poor. The distribution of the strain concentration zone of the B-type plate relatively uniform, the grain deformation tends to be gentle, the deformation is small, and the formability is better.

3.3. Influence of Transition Zone Position on Spring-back

The spring-back angle can be calculated according to the calculation formula: \( \Delta \alpha = \alpha' - \alpha \). Table 2 shows the spring-back angle of the A and B-shaped blank. The spring-back angle of the A-type plate is 1.7°, it shows that the microstructure of the A-shaped blank is non-uniform, and it occurs severe asymmetric bending deformation when the punch is descending, and the straight wall section of the V-shaped parts is bent too far to the inside. The spring-back angle of the B-shaped blank is -1.2°, indicating that the deformation is relatively uniform, which is the result of the spring-back mutual restraint between the thick zone and the transition zone.

| blank types               | blank types |
|---------------------------|-------------|
| the A-shaped blank        | 1.7°        |
| the B-shaped blank        | -1.2°       |

![Figure 6. Strain-time curves of grain M and grain N](image)
4. Conclusion

From the mesoscopic point of view, the crystal plastic finite element method is used to simulate the bending process of TRB and study the influence of the transition zone position on the bending deformation behavior and spring-back. The conclusion is as follows: Due to the non-uniformity of the microstructure of the A-shaped blank, the deformation is non-uniform during the bending process, and the deformation zone is transferred to the transition zone, which exhibits poor formability. The change of the stress value first increases steadily and then increases sharply, and the strain value changes sharply and then rises steadily, and the maximum stress and strain are larger than the B-shaped blank. The bending deformation of the B-shaped blank is relatively uniform, and the deformation region is uniformly spread from the bend area to both sides, and the formability is higher. At the same time, the ununiformity of the bending deformation makes the spring-back angle of the A-shaped blank larger than that of the B-shaped blank.

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6. References

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