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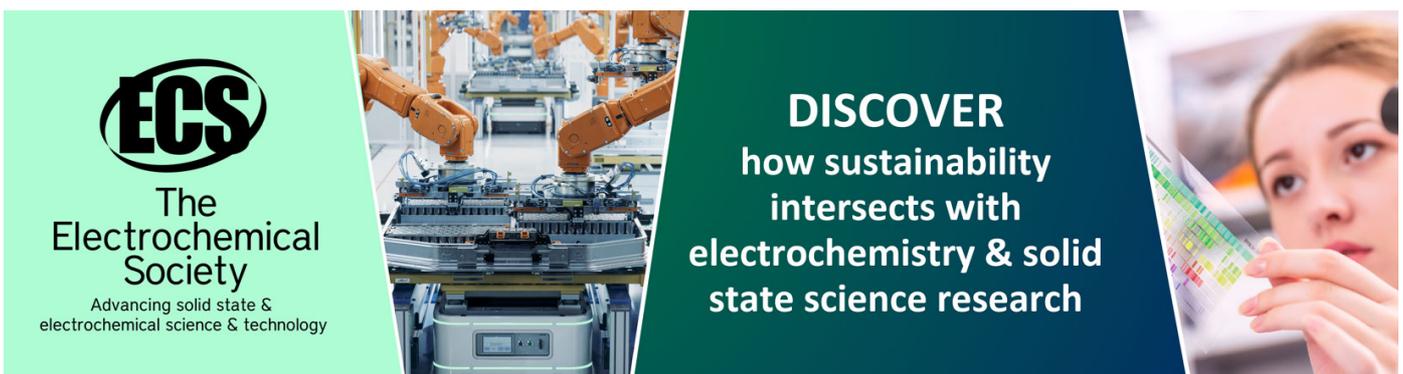
## Study on Distribution and Evolution of Deformation Domain of Tailor Rolled Blank in Variable Speed Stamping Process

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# Study on Distribution and Evolution of Deformation Domain of Tailor Rolled Blank in Variable Speed Stamping Process

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**Abstract.** In this paper, in order to research the formability of TRB (Tailor Rolled Blank) in variable speed deep drawing, the numerical model of deep drawing was established. The distribution of deformation domain and the variation of deformation zone with deep drawing depth under constant speed and variable speed were analyzed. The results show that the deformation domain distribution and its evolution at different drawing speeds are similar, but the difference is that a reasonable speed can reduce the strain of key deformation domain effectively, and improve formability and production efficiency. The turning point of the forming speed in variable speed stamping process was determined by analyzing the variation of the node strain in the key deformation domain with drawing depth, the drawing depth at the reasonable speed turning point is the sum of the radius of the punch, the radius of the die and the thickness of the blank. And simulation results were compared to experimental results to verify the correctness of the simulation.

## 1. Introduction

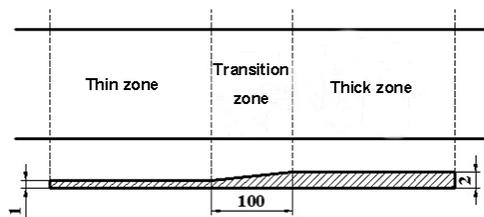
TRB[1,2,3] has become the most promising lightweight structural material in the automotive industry [4,5,6]. Due to the existence of thin zone, thick zone and transitional zone, the main deformation area has obvious regional deformation characteristics. According to the mechanics of deformation, the same deformation point is composed of the deformation domain. The plastic deformation in any one deformation domain reaches a destabilized state, stamping defects were occurred. The key deformation domain where are most likely to cause rupture, wrinkling or other deformation defects play a important role for the whole deformation. However, due to the change of strain state during the process of deformation accumulation, the key deformation domain and instability state are constantly changed. Therefore, variable forming speed suitable for the deformation of each deformation stage can improve the formability of the TRB. At present, the research on the forming of TRB mainly focuses on the influence of sheet metal geometry, process parameters and mold structure on the stamping properties [7,8]. Zhang et al.[9]conducted stamping test and numerical, the influence of the position and length of transition zone on the forming performance of TRB was studied. By using a blank holder and related adapter plate, Kopp et al. [10] conducted TRB drawing experiments and found that by increasing the length of transition zone could prevent wrinkling effectively. Meyer et al. [11] conducted numerical and experimental analyses and claimed that with an optimized sheet thickness distribution of a TRB the maximum draw depth can be increased. In this paper, the finite element numerical simulation technique was used to analyze the distribution of deformation zone and its variation with the drawing stroke at constant speed and different speed, the speed variation affects the distribution of the deformation zone and the evolution mechanism of the key deformation field during



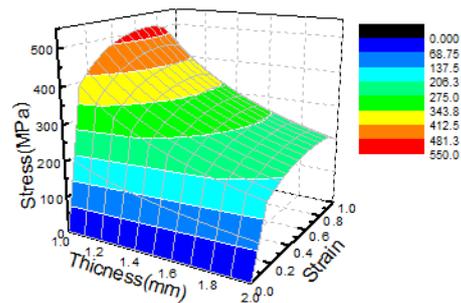
the stamping process were researched, and the forming rule of variable speed process in the sheet metal was obtained.

## 2. Experiment material

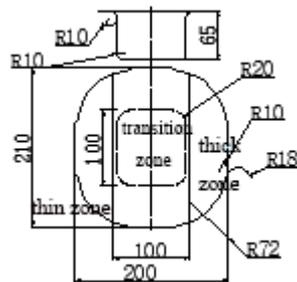
The experimental materials CR340 were annealed after rolling. The geometry of the TRB is displayed in figure 1. The tensile test of thin zone and thick zone was carried out on an AG-100KN testing machine, using the Ludwig equation to fit the test results, the constitutive equation of the transition zone was established based on the interpolation theory. The relation among stress, strain, and thickness of TRB is graphically presented in figure 2.



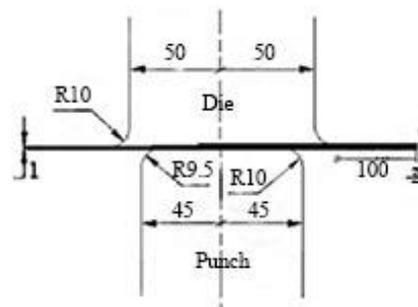
**Figure 1.** Section shape of TRB



**Figure 2.** CR340 TRB stress - strain - thickness curve



**Figure 3.** Blank dimension and stamping part



**Figure 4.** The size of the stamping mold

## 3. Finite element numerical simulation and deep drawing experiment

### 3.1. Box deep drawing numerical model establishment

The initial blank and drawing parts shape and size are shown in figure 3. Drawing die shape and size are shown in figure 4. We use the finite element method to assign material properties for TRB. Using C3D8R for its global meshing, thus eliminating the impact of rigid body movement. Punch, die and blank holder modeling using analytical rigid body which has high efficiency, using R3D4 for meshing.

### 3.2. Forming speed and analysis step settings

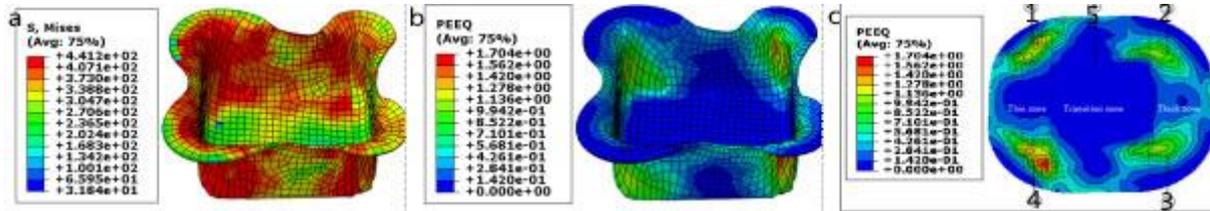
Box deep drawing with the constant speed of 5mm/s and 30mm/s and variable speed of 5(22)50(43) mm/s were analyzed. Drawing depth is 65mm at constant speeds 5mm/s and 30mm/s, and 5(22)50(43) mm/s means first drawing depth is 22mm at 5mm/s, and then with drawing speed of 50mm/s continued to draw to 65mm.

## 4. Simulation results and experimental results analysis

### 4.1. Characteristics of Box part for TRB deep drawing and distribution of deformation

The stress and equivalent strain distribution of TRB when it is drawn at a constant speed of 5mm/s are shown in figure 5. As we can know from figure 5, stress and strain are mainly concentrated at the four corners of the part. The deformation of the fillet section is similar to the cylinder drawing and

deformation is more intense, straight edge similar to bending deformation. The corners of the box part are subjected to a large tensile stress, the thickness is severely reduced, and the side walls are easily cracked at the tangent to the bottom.

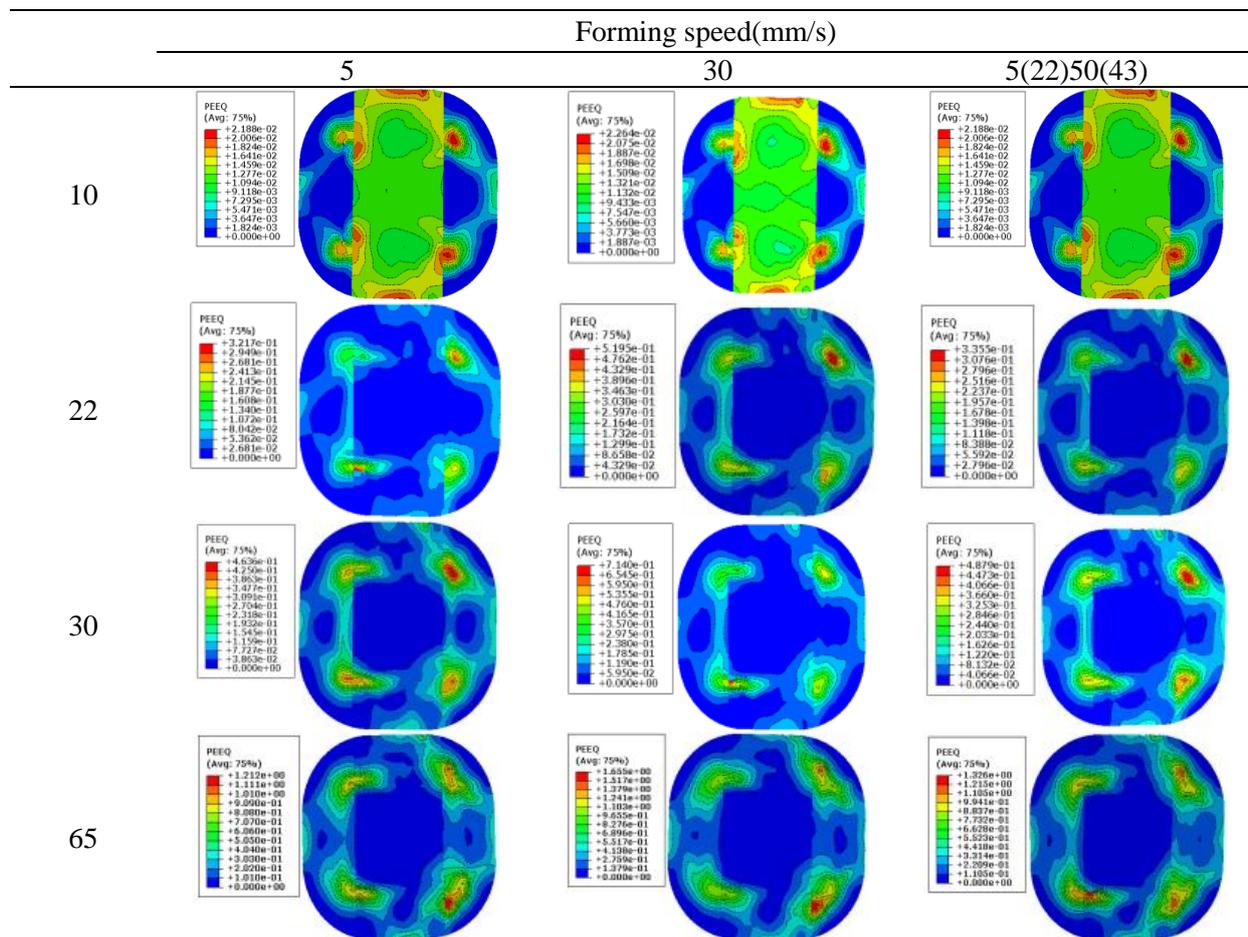


**Figure 5.** *a*-Stress distribution curve for 5mm/s, *b*-Strain distribution curve for 5mm/s, *c*-Strain of contour plot strain of deformation zone

As can be seen from Figure 5, the deformation zones with larger strain are mainly distributed at the four corners of the side wall of the box part, that is, at the critical point of the thin zone and the transition zone, the thick zone and the transition zone, as shown in figure 5(c)1-4. The strain at the center of the bottom and sidewall of the part is small, as shown by the deformation field 5 in figure 5(c). Deformation zone 1-4 plays a decisive role for blank forming, where is the key for the deformation of TRB.

#### 4.2. Effect of drawing speed on distribution and evolution of deformation domain

The deformation distribution and the deformation curve of the deformation zone with the drawing stroke are shown in Table 1. From Table 1, we can see that the distribution law and evolution of deformation domain with depth of stamping under different speed are similar. The only difference is that a reasonable speed and speed mode of drawing can reduce the strain value of the critical deformation domain, which could improve the blank formability.

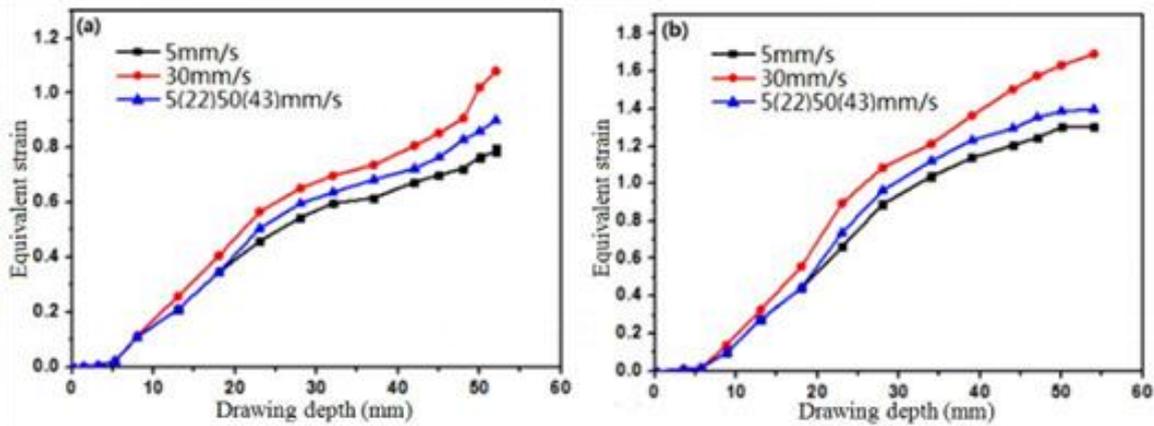
**Table 1.** Strain domains at different depths

#### 4.3 Determination of the turning point in speed

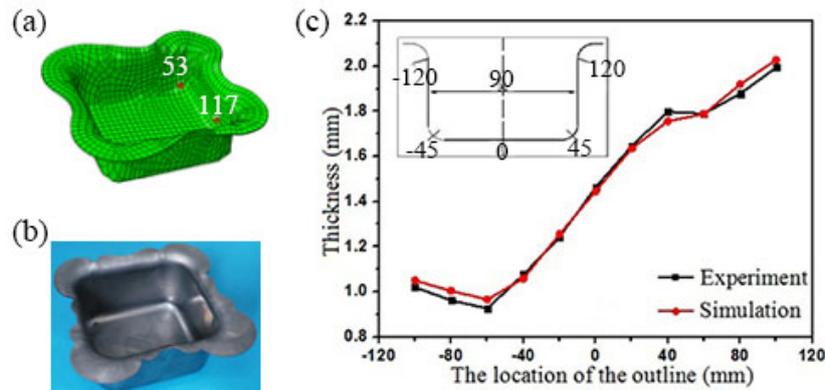
During the drawing process, the four corners of the box part are similar to the cylindrical draw, the four side walls are similar to the bending of the sheet. Bending deformation occurred in the four corners at the blank, and the deformation is more severe. Therefore, using a lower speed is conducive to drawing before the four corners to complete the bend, then using a higher drawing speed to improve production efficiency. According to the drawing characteristics of the cylindrical part, the bending depth of the four rounded parts is corresponding to the drawing depth  $H$ :

$$H = r_p + r_d + t$$

Where,  $r_p$  is the radius of punch,  $r_d$  is the radius of die,  $t$  is the thickness of thickness zone. The parts simulated and experimentally obtained at a drawing speed of 5(22)50(43)mm/s are shown in Figure 6 (a) and (b). From Figure 7(c) we can see that the distribution curve of wall thickness in the simulation and experimental conditions are consistent, therefore, the simulation results are reliable.



**Figure 6.** Strain and depth at different velocity: **a**-Node53 and **b**-Node117



**Figure 7.** Results a-simulation, b-experiment, c-comparison of simulation and experiment

Taking the depth of 22mm as the turning point, the influence of drawing speed on the strain of the key deformation zone was analyzed. According to the symmetry of the box parts, choose a node randomly in the key deformation domain of thin and thick zone, the node selection is shown in Figure 7(a). The strain-drawing depth curves of node 53 and node 117 at different drawing speeds are shown in Figure 6. As can be seen from Figure 6, the strain tends to increase linearly with depth at about 22 mm of the drawing depth, and then the magnitude of the increase of strain becomes slower, so the theoretical analysis of the turning point of the corresponding depth of value H is reasonable. The strain at the speed of 5(22)50(43) mm/s and the strain at 5 mm/s are equally before slipping, After the drawing speed increases, the strain value increases more than the speed of 5mm/s, but the increasing trend is less than the drawing speed of 30mm/s. The result shows that a reasonable speed of change can effectively reduce the strain value of the key deformation field and improve the formability of TRB in the process of stamping.

## 5. Conclusions

- (1) Reasonable drawing speed and its speed change mode can effectively reduce the strain value in the critical deformation domain and improve the formability of TRB.
- (2) The key deformation field is distributed at the four fillets of the side wall of the box part. The deformation at the middle position of side wall and the bottom area is smaller.
- (3) In variable speed deep drawing, the corresponding drawing depth at the reasonable speed turning point is the sum of the fillet radius of the punch, the fillet radius of the die and the thickness of the thickness zone.

## 6. Acknowledgement

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