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Effect of pass-set shape on formability in synchronous multipass spinning

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Abstract

Synchronous multi pass spinning is a metal spinning method that can form asymmetric shapes with a noncircular bottom and vertical walls from a metal sheet. In this method, the tool trajectory is calculated by linear interpolation between the mandrel shape and the blank disk shape along a pass set. Here, the pass set corresponds to the tool trajectory in conventional spinning. The aim of this study is to examine the effect of a pass set on the formability of a circular cup shape and a rectangular box shape. We have experimentally examined the formability using various pass sets made by simple rule. The angle growth of the rotational pass set, the incremental movement of the translational pass set, and the nominal product height are varied for comparison in the experiments.

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Keywords: Metal spinning; Tool trajectory; Forming limit; Aluminum sheet;

1. Introduction

Metal spinning is a forming method for shapes with rotational symmetry (Music, Allwood and Kawai, 2010). In this method, a sheet metal blank attached to a rotating mandrel is subjected to a force by a roller tool and formed

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into a mandrel shape. In former studies, spinning methods for asymmetric shapes were developed by controlling the roller position while rotating the mandrel.

(1) Synchronous spinning: The roller is synchronized with the rotation of the mandrel to follow an asymmetric cross-sectional shape (Amano and Tamura,1984; Arai et al., 2005).
(2) Force-controlled spinning: The pushing force of the roller is controlled in the radial direction of the mandrel while the roller moved in the axial direction of the mandrel (Awiszus and Meyer, 2005; Arai, 2005).
(3) Simple spinning using preformed hollow part: It was demonstrated that the preformed blank enabled large deformation by a single pass (Härtel and Awiszus, 2010).

However, it was not possible to form shapes such as rectangular boxes. Thus Sugita and Arai (2012) developed a method named synchronous multipass spinning. In this method, the tool trajectory is calculated from the mandrel shape, the blank disk shape, and pass set. The pass set corresponds to the tool trajectory in conventional spinning, which is described in the normalized two-dimensional space. In this study, we investigate the forming limits of the synchronous multipass spinning based on experiments on the formation of circular cup and rectangular box shapes using pass sets determined from various parameters.

2. Synchronous multipass spinning

2.1. Description of synchronous multipass spinning

In synchronous multipass spinning, the tool trajectory is calculated by the interpolation between the mandrel shape and the blank shape along a pass set. Here, “pass” means the tool trajectory in the normalized two-dimensional plane defined by the radial and axial directions of the mandrel. A “pass set” is the combination of passes used in the entire forming process from the blank to the final shape. The following procedure is the outline of the calculation of the tool trajectory.

(1) The cross-sectional shape of the mandrel is measured at several positions by pushing the force-controlled roller onto the mandrel.
(2) The x coordinate of the axial position corresponding to a point on a pass is calculated. Moreover, the cross sectional shape at the x coordinate is obtained by interpolating the shapes of the two neighboring cross sectional shapes.
(3) The y coordinate is calculated by linear interpolation between the blank shape and the cross-sectional shape at the x coordinate calculated in step 2.
(4) Step 2 and 3 are repeated along the pass set to calculate the whole of the tool trajectory.

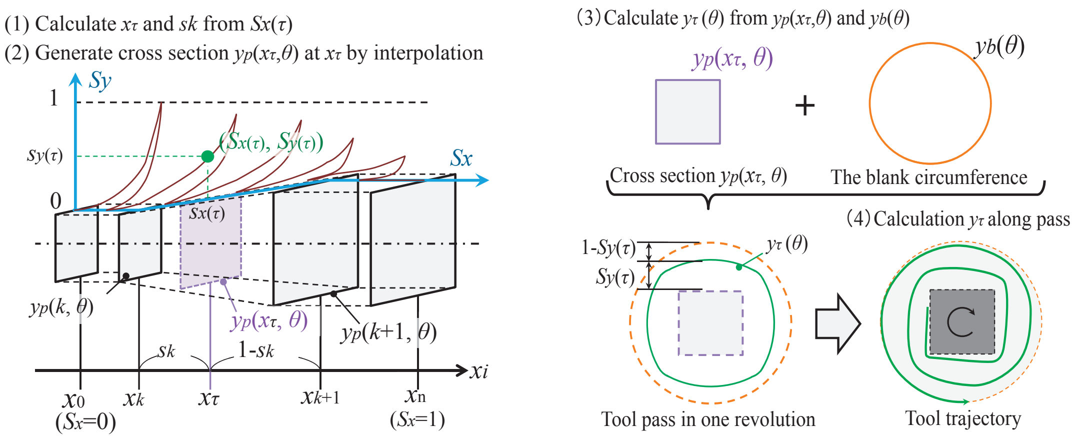

Fig. 1. Calculation of tool trajectory in synchronous multipass spinning.

2.2. Pass – parts of pass set

A pass set is a combination of curved and force-controlled passes. As shown in Fig. 2, a curved pass is part of an ellipse between start point and end point. A force-controlled pass is a pass in which force applied by the roller in the radial direction of the mandrel is regulated while the roller position in the axial direction of the mandrel is controlled simultaneously.

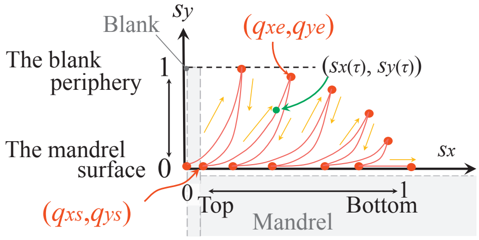

Fig. 2. Curved passes for part of ellipse between start point and end point.

3. Method of calculating pass set

3.1. Combining passes

The tool trajectory has been conventionally determined by the experience and intuition of artisans, with some forming trials necessary when a shape is deformed for the first time. Predicating how the blank will deform is more difficult in the forming asymmetric shapes than in the forming of circular shapes, and hence it is difficult to find a formable pass set. Therefore, we referred to Hayama's research (1970) and examined the formability of the two type pass sets, rotational pass set and translational pass set (Fig. 3). In the rotational pass set, the pass rotates around the same point. This pass set is composed of passes in which the angle of the end point relative to the start point is decreased by $\Delta\theta$. The start point does not move. In the translational pass set, the passes move along the axial direction of the mandrel without the angle decreases. The pass set is composed of passes in which the angle remains at its initial value θ_0, and the start point moves by $\Delta\alpha$.

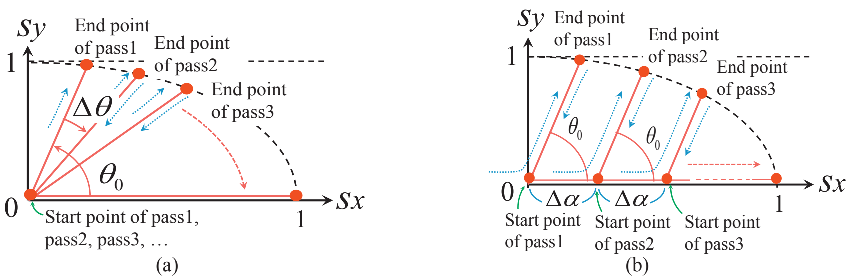

Fig. 3. Two type of pass set: (a) Rotational pass set; (b) translational pass set.

3.2. Calculation of outer circumference points of passes

The outer circumference point of each pass was calculated to define the pass set. The outer circumference of the blank before forming is represented as $(Sx, Sy) = (1, 0)$ and the end point of the forming process is represented as $(Sx, Sy) = (0, 1)$. However, it is difficult to exactly predict the locus of the outer circumference of the blank during the forming process because it depends on the shapes of the mandrel and blank, and the pass set. Therefore, we intuitively assumed that the locus can be approximated as a circular arc here (Fig. 4). A straight line is drawn that passes through the point $(a, 0)$ with angle θ to the arc. The point of intersection of the straight line and the arc is defined as the end point of the pass.

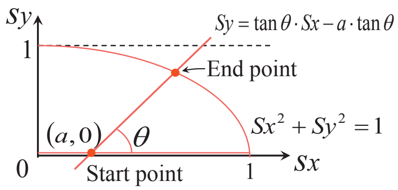

Fig. 4. Calculation of end point of passes on circumference.

4. Forming experiments

4.1. Experimental setup

The roller is moved by an XY table driven by 400 W AC servomotors and 5-mm-pitch ball screw. The spindle motor is a 400 W AC servomotor with a planetary gear box having a reduction ratio of 21. A six-axis force sensor is installed at the base of the roller holder. The direction of the roller is arranged to be inclined at 45 degrees to the spindle axis. The roller has a diameter of 70 mm and a corner of 8 mm and is made from AISI D2 tool steel.

We used the cylindrical mandrel and prismatic mandrel in forming experiments. The cylindrical mandrel used in experiments on the forming of circular cup shape had a circular base with a diameter of 85 mm and a height of 90 mm. Its corners were rounded to a radius of R2. The prismatic mandrel used in experiments on the forming of rectangular box shape had a square base of dimensions 60 x 60 mm and a height of 90 mm. Its corners were rounded to a radius of R1. These mandrels were made of AISI1045 carbon steel.

The blank used in the experiments was a circular disk of thickness 1 mm and diameter 150 mm for circular cup shape and 120 mm for rectangular box shape. The blank was made of pure aluminium.

We conducted forming experiments to determine the formability for various rotational pass sets and translational pass sets. The spindle speed was 30 rpm and the pitch of the roller, i.e., the roller feed per spindle rotation, was 1 mm/rev in each experiment. However, the spindle speed of the force-controlled passes was 15 rpm for the rectangular box shapes since there was contact between the mandrel and the roller. In the force-controlled passes, the desired value of the pushing force was 500 N.

4.2. Circular cup shapes and rotational pass set

The experiments on the forming of the circular cup shapes using the rotational pass sets were carried out with the following parameters. Initial angle was 80 deg, angle growth were from 6 deg to 12 deg, forming height were from 45 mm to 65 mm. An example of the formed product, plots of the formability and wall thickness distribution are shown in Fig. 5. The plots show whether or not the forming was successful, and if not, how it failed. When the forming height was set to less than 60 mm, forming was possible up to an angle growth of 10 deg. When the forming height was set to 60 mm or above, the maximum angle growth was 8 deg. The wall thickness distributions were measured by a micrometer. Fig. 5(c) shows the wall thickness distribution of a product when the angle growth was 10 deg. The graph has a bathtub shape. The thickness is not affected by the forming height near the open side.

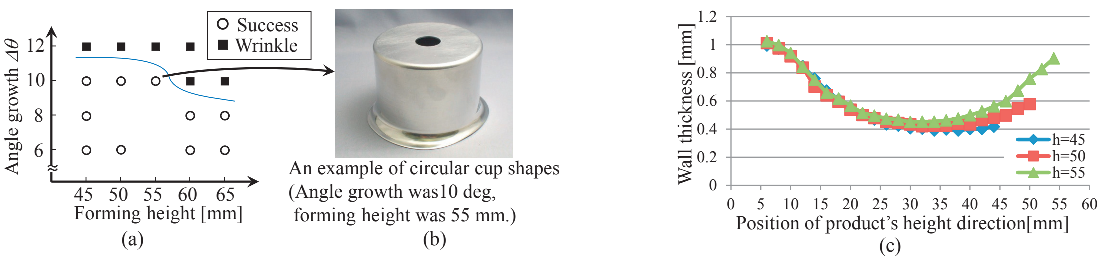

Fig. 5. Results of experiments on forming of circular cup shapes using rotational pass sets: (a) plots of formability; (b) product formed by a rotational pass set ; (c) wall thickness distributions formed by pass sets with angle growth of 10 deg.

4.3. Circular cup shapes and translational pass set

The experiments on the forming of the circular cup shapes using the translational pass sets were carried out with the following parameters. Initial angle was 62 deg, incremental movement was from 0.08 to 0.15, forming height was from 45 to 60 mm. An example of the formed product, plots of the formability and wall thickness distribution are shown in Fig. 6. For this initial angle, we found that it was possible to increase the incremental movement by increasing the forming height. Fig. 6(c) shows the wall thickness distribution of a product formed by a pass set with incremental movement of 0.1. The graph has the shape of bathtub and the minimum thickness is 0.4 mm. The thickness is not affected by the forming height near the open side, similarly to the case of the rotational pass sets.

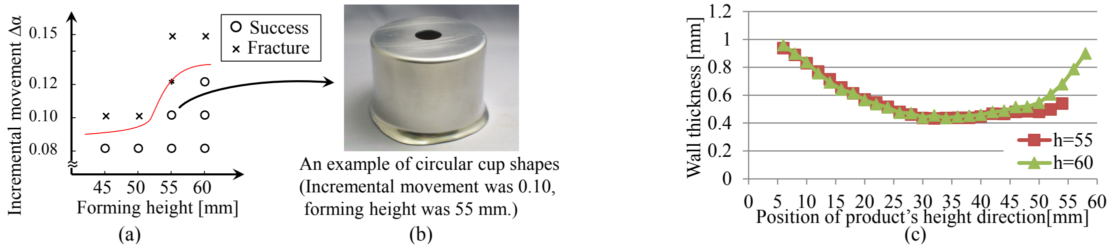

Fig. 6. Results of experiments on forming of circular cup shapes using translational pass sets: (a) plots of formability; (b) product formed by a translational pass set; (c) wall thickness distributions formed by pass sets with incremental movement of 0.10.

4.4. Rectangular box shapes and rotational pass set

The experiments on the forming of the rectangular box shapes using the rotational pass sets were carried out with the following parameters. Initial angle was 80 deg, angle growth was from 3 to 6 deg, forming height was from 25 to 40 mm. An example of the formed product, plots of the formability and wall thickness distribution are shown in Fig. 7. The thickness is measured at the middle point of the side wall. The maximum product heights were about 30 mm regardless of the parameters of the pass set. When the angle growth was small, it was possible to successfully form the products. However, the forming became more difficult as the angle growth increased. According to the the wall thickness distribution of products formed by the pass set of 3 deg (Fig. 7(c)), the wall thickness was constant. As for the circumferential direction, we found that the material tends to gather to the corners and the thickness at the corners is increased (Sugita and Arai 2012).

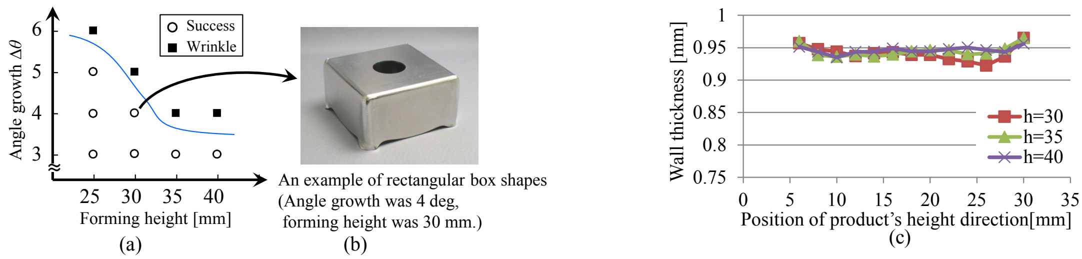

Fig. 7. Results of experiments on forming of rectangular box shapes using rotational pass sets: (a) plots of formability; (b) product formed by a rotational pass set; (c) wall thickness distributions formed by pass sets with angle growth of 3 deg.

4.5. Rectangular box shapes and translational pass set

The experiments on the forming of the rectangular box shapes using the translational pass sets were carried out with the following parameters. Initial angle was 62 deg, incremental movement was from 0.06 to 0.12 deg, forming height was from 25 to 40 mm. An example of the formed product, plots of the formability and wall thickness distribution are shown in Fig. 8. The walls of the products were under much greater strain than those of products formed using the rotational pass sets. Some products have wrinkles in their flange. The maximum incremental movement was achieved when the forming height was set to 25 mm.

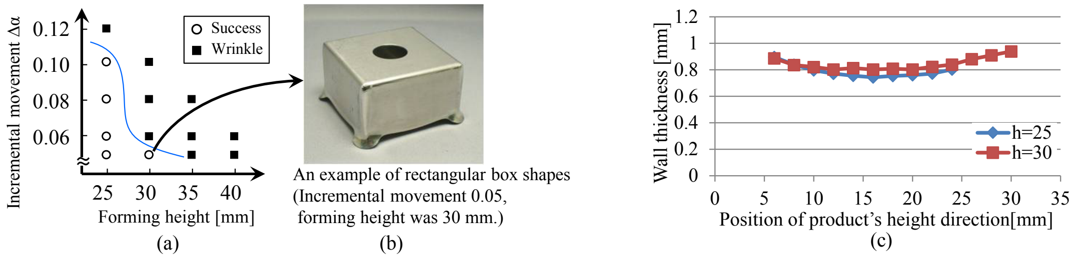

Fig. 8. Results of experiments on forming of rectangular box shapes using rotational pass sets: (a) plots of formability; (b) product formed by a translational pass set; (c) wall thickness distributions formed by pass sets with incremental movement of 0.05.

The wall thickness distribution shown in Fig. 8(c) has a bathtub shape. The wall thickness tends to be maintained when the pass set has a sufficiently large forming height. In contrast, the thickness is excessively reduced when the forming height is too small. This is assumed to be because the tool cannot reach the edge of the blank disk at the circumference end of the pass since the tool trajectory is shorter than the flange, and the material is expanded in a similar way to that observed in shear spinning.

5. Conclusion

We presented the results of forming experiments in which circular cup and rectangular box were formed by synchronous multipass spinning with rotational pass sets or translational pass sets. In the forming of the circular cup shapes using rotational pass sets, it was found that wrinkle occurred when the angle growth was too large.

When rectangular box shapes were formed using rotational pass sets, wrinkles similarly occurred to those in the circular cup shapes. In the forming of rectangular box shapes with translational pass sets, wrinkles or fracture was observed for excessive incremental movement. The wall thickness distributions of the rectangular box shapes formed using the rotational pass sets did not decrease markedly from the original thickness, whereas the wall thickness distributions in other cases had a bathtub shapes.

In future research, we will investigate the forming limit of rotational and translational pass sets that is combinations of the rotational pass set and translational pass set. We will then aim to improve the automatic calculation algorithm for the pass set considering the characteristics of the forming limit.

Acknowledgements

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