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New Extrusion Method for Changing Wall Thickness of Circular Tube

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Abstract

Changing wall thicknesses of tubes for the optimal stiffness distribution is an effective way to reduce the weight of industrial parts. However, wall thicknesses of extruded tubes are constant in the axial direction produced by a conventional extrusion process. Therefore, authors proposed a new extrusion method to change the wall thicknesses of the tubes. The axial position of the tapered mandrel is controlled at the same time of extrusion; therefore, the inside diameter of the extruded tube is continuously changed. Numerical analysis is carried out with the finite element software ELFEN. Basic characteristics of the extrusion method are made clear by this investigation.

1. Introduction

Aluminum tubes are applied to structural parts to reduce the weight because tubes have high flexural rigidity and torsional rigidity compared with solid bars in the same cross-sectional area as well as aluminum is a material with high specific strength. One of the examples of the application is a space frame structure for cars and railway vehicles. The space frame structure can reduce the body weight without reducing the body rigidity [1, 2]. Energy and resource saving is an important issue in the manufacturing field, and further reduction of the weight is required for the issue [3]. Changing wall thicknesses of the tubes for the optimal stiffness distribution is an effective way to reduce the weight.

Extrusion is a common process to produce aluminum tubes. Wall thicknesses of extruded tubes are constant in the axial direction produced by a conventional extrusion method. In order to change wall thicknesses of tubes, extra forming process is applied after extrusion, such as, rotary swaging, spinning, hydro forming and drawing [4–7]. The costs of the tubes are higher because of the process; therefore, applications of these parts are limited in the manufacturing field. Changing wall thicknesses of tubes at the same time of extrusion is a solution of reducing the costs and increasing the applications.

In order to change the wall thicknesses of tubes only by extrusion, authors proposed a new extrusion method [8]. The mandrel for the method is tapered, and the axial position of the mandrel is controlled at the same time of extrusion. Therefore, the inside diameter of the extruded tube is continuously changed. In our previous paper, the validity of the extrusion method was experimentally demonstrated with the prototype CNC (computer numerical control) extrusion machine developed by authors [8, 9].

Purpose of this investigation is to numerically analyze the basic characteristics of the extrusion method with the finite element method.

2. Principle of New Extrusion Method

Principle of the extrusion method, which can optionally change the wall thicknesses of tubes in the axial direction, is illustrated in Figure 1. Wall thicknesses of extruded tubes depend on the axial position of the tapered mandrel; therefore, wall thicknesses of extruded tubes are changed in the axial direction when the axial motion of the tapered mandrel is controlled at the same time of extrusion. Motions of the mandrel are classified into three categories depending on the shapes of extruded tubes as follows:

1. When the tapered mandrel does not move in the axial direction, the wall thickness of the extruded tube is constant, and the wall thickness of the tube is decided by the axial position of the tapered mandrel as shown in Figure 1 (a), (b), (c).
2. When the tapered mandrel moves in the same direction of the extrusion, the wall thickness of the extruded tube continuously decreases with motion of the tapered mandrel as shown in Figure 1 (d).
3. When the tapered mandrel moves in the opposite direction of the extrusion, the wall thickness of the extruded tube continuously increases with motion of the tapered mandrel as shown in Figure 1 (e).

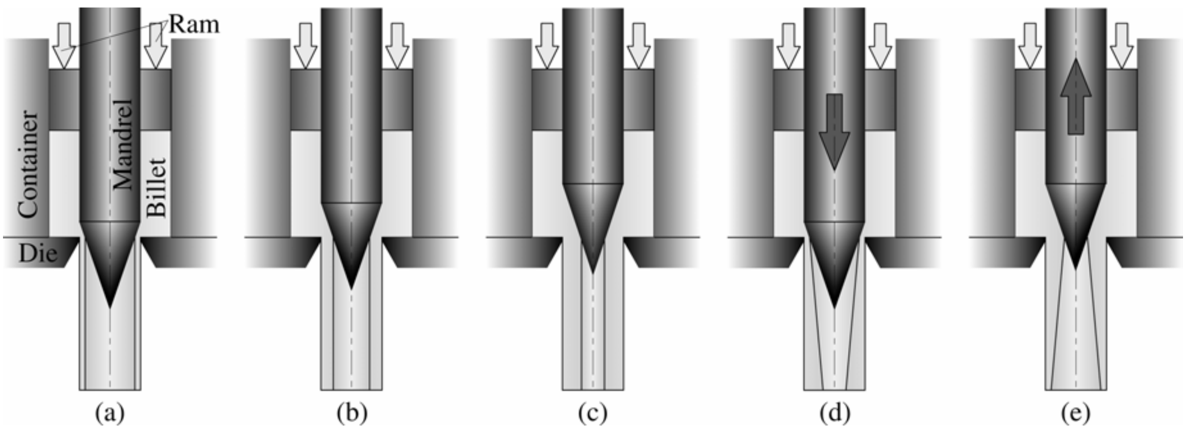

Figure 1: Principle of new extrusion method.

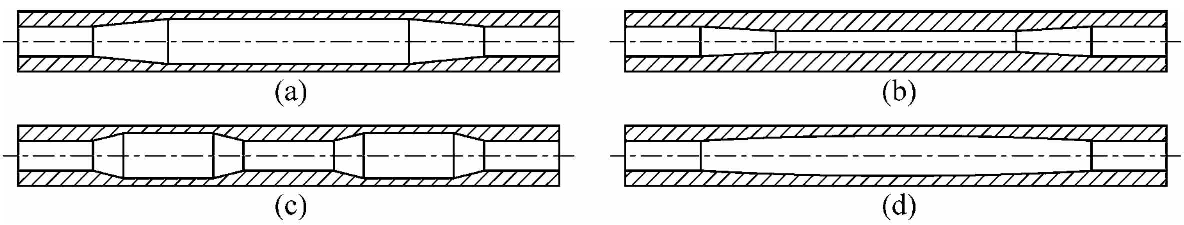

Figure 2: Various Shapes of tubes with changing wall thickness.

Various shapes of tubes with changing wall thickness are illustrated in Figure 2. Those various shapes of tubes are flexibly produced just by controlling the motion of the tapered mandrel. For example, when the motion of the tapered mandrel is controlled as shown in Figure 1 (c) → (d) → (a) → (e) → (c), the extruded tube is formed as shown in Figure 2 (a).

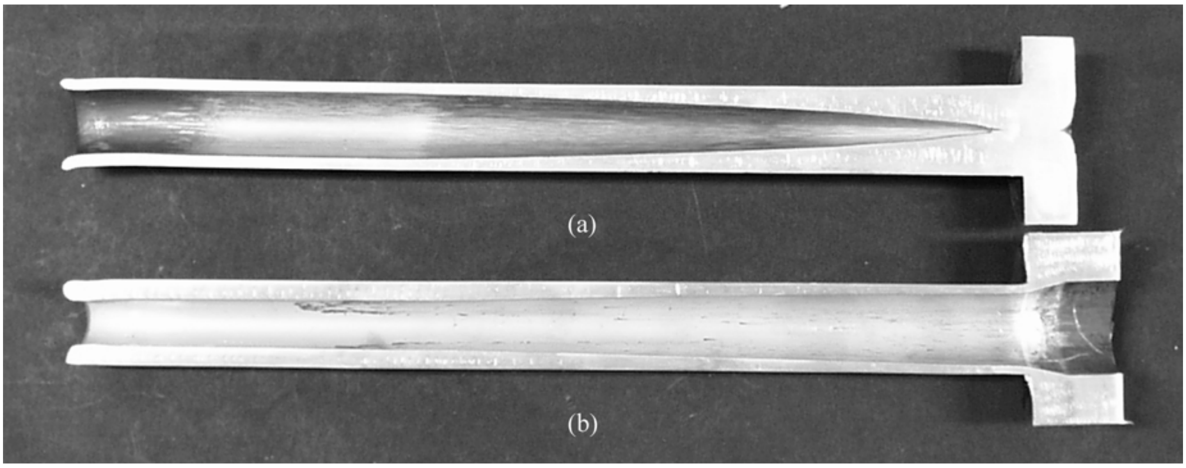

Figure 3: Extruded tubes in a half-section cut by vertical plane.

Figure 3 shows the extruded tubes, some of the results of the previous investigation, in a half-section cut by a vertical plane. Direction of the extrusion in this photograph is from right to left. When the motion of the mandrel is controlled in the opposite direction of the extrusion, the wall thickness becomes thicker as shown in Figure 3 (a). When the motion of the mandrel is controlled in the same direction of the extrusion, the wall thickness becomes thinner as shown in Figure 3 (b). From the results, validity of the extrusion method was experimentally demonstrated.

3. Numerical Analysis

Numerical analysis is carried out with the finite element method. The finite element software is ELFEN developed by Rockfield Software Limited at the University of Wales Swansea. In order to investigate basic characteristics of the extrusion method, the model of the numerical analysis is simplified in this simulation. Therefore, a two-dimensional axisymmetric model is applied, and thermal coupling is not considered. Geometrical dimensions of the extrusion tools are shown in Figure 4. The taper angle θ is defined as an angle between axis of the mandrel and surface of the taper. The mandrel diameter D_M is defined as the cross-sectional diameter of the mandrel in the die face. The die diameter D_D is defined as the outside diameter of the die opening. Dimensions of the billet are 40mm in outside diameter, 20mm in inside diameter and 100mm in length. The material property for the billet is applied as A6063 at 470°C. Adaptive remeshing is performed because of large deformation of the billet.

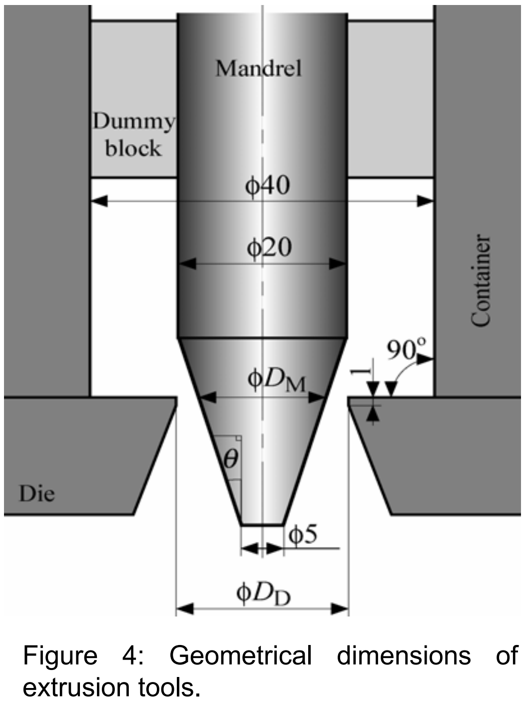

Figure 4: Geometrical dimensions of extrusion tools.

Conditions for the analysis are summarized in Table 1. The taper of the mandrel is the unique point of this extrusion method, and the shape of extrusion tools is a factor of extrusion properties.

The numerical analysis is carried out in different taper angles. In order to investigate the effect of taper angle itself, numerical analysis is carried out on a straight mandrel ($\theta = 0^o$) as well. In this analysis, the tapered mandrel does not move in the axial direction.

Table 1: Conditions for analysis

Ram velocity V_R (mm/s)	0.6
Taper angle θ (°)	7.50, 11.25, 15.00, 22.50, 30.00
Die diameter D_D (mm)	20.0
Mandrel Diameter D_M (mm)	16.0

4. Results

Figure 5 shows the extrusion force F_E and the mandrel force F_M with the ram stroke S when the taper angle θ is 15.00°. The extrusion force decreases with increasing ram stroke because contact surface area between the billet and the extrusion tools decreases. The mandrel force F_M is defined as axial mandrel force and compressive force is positive. Tensile force is acting on the mandrel because of friction between the mandrel and the billet. The tensile mandrel force slightly decreases with increasing ram stroke because the contact surface area between the billet and the mandrel decreases.

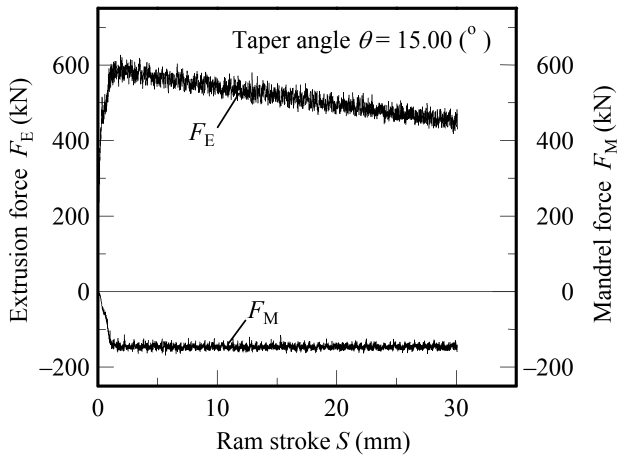

Figure 5: Extrusion force and mandrel force with ram stroke.

Figure 6 shows the influence of the taper angle θ on the extrusion force F_E and the mandrel force F_M when the ram stoke S is 25mm. The extrusion force increases with increasing taper angle, and the mandrel force is independent of the taper angle.

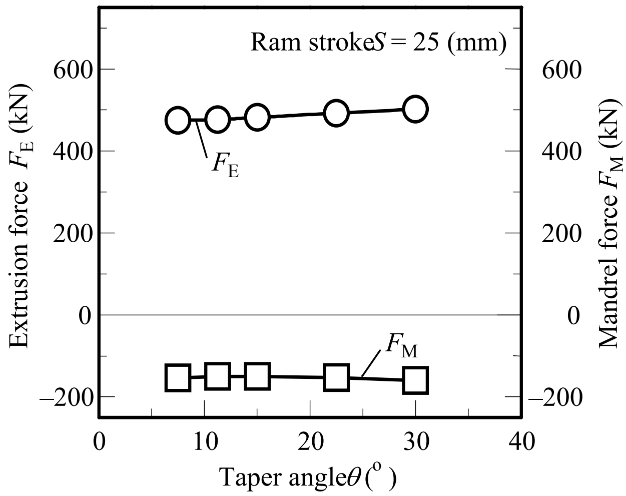

Figure 6: Influence of taper angle on extrusion force and mandrel force.

Figure 7 shows the distribution of the velocity at the tip of the die. The outside diameter and the inside diameter are almost the same as the die diameter and the mandrel diameter respectively on the straight mandrel. However, the metal flows toward the center in a radial direction along the surface of the taper, and the outside diameter and the inside diameter are formed smaller than the die diameter and the mandrel diameter respectively on the tapered mandrels. The metal flows along the taper of the mandrel; therefore, radial component displacement becomes larger when the taper angle is large.

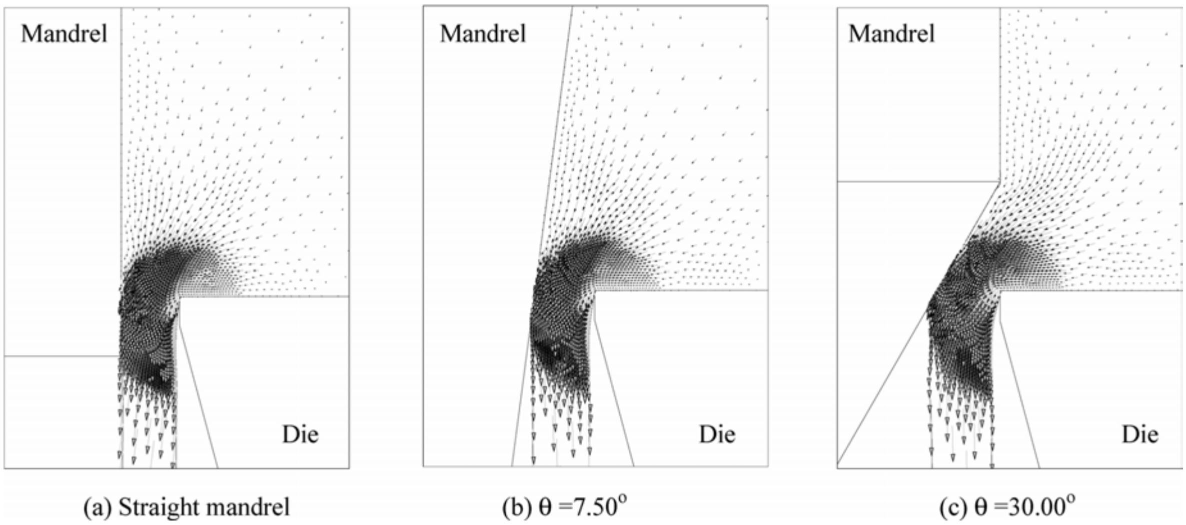

Figure 7: Distribution of velocity at tip of die.

Figure 8 shows the influence of the taper angel θ on the outside diameter D_O. The outside diameter is almost the same as the die diameter that constrains the metal flow toward outside in the radius direction on the straight mandrel. However, the outside diameters are smaller than the die diameter on tapered mandrel, and the outside diameter decreases with increasing taper angle because the metal flows toward the center of the tube along the taper of the mandrel as shown in Figure 7.

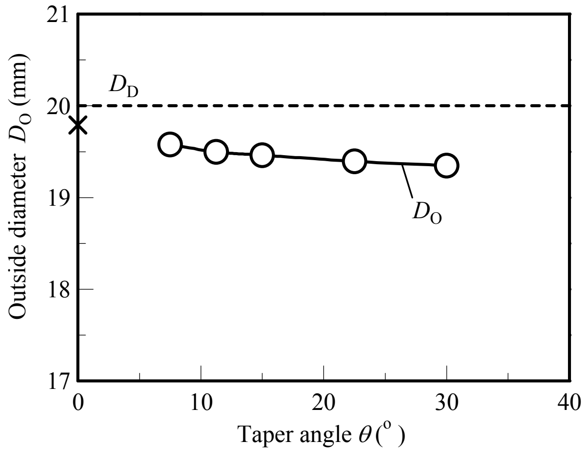

Figure 8: Influence of taper angle on outside diameter.

Figure 9 shows the influence of the taper angle θ on the inside diameter D_I. The inside diameter is almost the same as the mandrel diameter that constrains the metal flow toward the center of the tube on the straight mandrel. However, the inside diameters are smaller than the mandrel diameter on tapered mandrel, and the outside diameter decreases with increasing taper angle because the metal flows toward the center of the tube along the taper of the mandrel as shown in Figure 7.

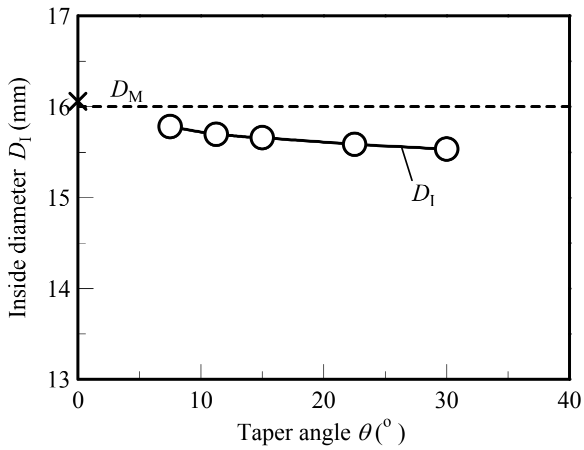

Figure 9: Influence of taper angle on inside diameter.

5. Conclusions

The new extrusion method to change the wall thicknesses of the tubes with the tapered mandrel was proposed. Numerical analysis is performed to investigate the basic characteristics of the new extrusion method with the finite element software ELFEN. Characteristics of this extrusion method are summarized as follows:

1. The extrusion force increases with increasing taper angle.

2. The mandrel force is independent of the taper angle.
3. The outside diameter is formed smaller than the die diameter, and decreases with increasing taper angle.
4. The inside diameter is formed smaller than the mandrel diameter, and decreases with increasing taper angle.

Acknowledgements

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