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A new extrusion method joining tube and sheet with holed rib

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Abstract

Wall thickness is constant in the axial direction when aluminum tubes are formed by conventional extrusion process. Tubes with internal ribs have high strength in comparison with those without ribs. These tubes can be used, for example, as structural parts, heat sinks, and impact absorbers. The existence of some holes at ribs enhances the function and value of the tubes. The appropriate positioning of holes at ribs reduces the weight of structural parts without strength reduction. In the case of heat sinks, holes change the fluid flow and would realize effective heat transfer. In this research, a new extrusion method is proposed by authors for manufacturing tubes with holed ribs. A new extrusion method is applied by FEM analysis. Model experiment was carried out based on the results. The method involves the use of a unique mandrel that has a slit along its axis and two guides at the slit exit. A holed sheet is fed through the slit and joined to the inner surface of the tube. In particular, the effect of the guide height is clarified in this study.

Keywords: Extrusion; Joining; Metal flow; Rib with holes

1. Introduction

Extrusion has been used as a forming method for the long product with the same cross section so far. Aluminum tubes as structural section are made by extrusion. Most of the aluminum tubes with complex section shape are manufactured by extrusion. Especially, the tubes that have the rib internally in the tube are used as car parts, for example, structural component, radiator, and impact absorbers [1], and so on. Recently, car is requested to be lighter considering environmental problems. Using these materials can reduce car weight. If these tubes with the holed rib are used as structural components, the following effects can be expected.

(1) If there are holes at the appropriate position of ribs, structural component could be lighter without reducing strength.

(2) Installation of such tubes into shock absorption units could stabilize buckling behavior.

(3) Installation in a radiator would improve its heat exchange performance.

Tube with holed rib can not be formed by usual extrusion. Then, the authors propose a method that extrudes with a ready made rib. The rib is a machined sheet metal with holes. While the tube is extruded, the rib is fed through a slit of mandrel. Tube and sheet are joined at the same time of extrusion. A numerical simulation was carried out to verify the practicality of the proposed processing method. Moreover, a series of experiments was carried out for verification of the numerical results.

2. Principle of extrusion

Fig. 1 shows the principle of the extrusion processing. The billet is hollow because we used the mandrel to extrude the tube. Mandrel has slit to insert the holed sheet. The metal of billet enters into the die

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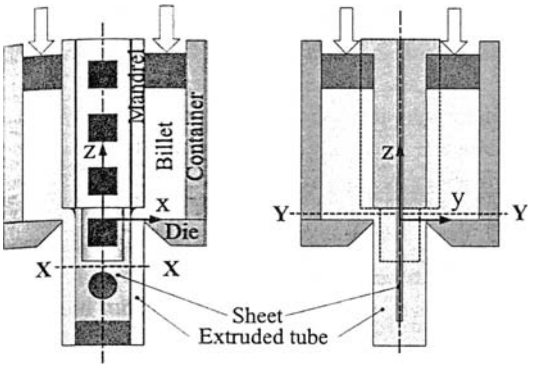


(a) Front view A-A (b) Side view B-B

Fig. 1. Principle of the proposed extrusion process for tubes with holed rib.

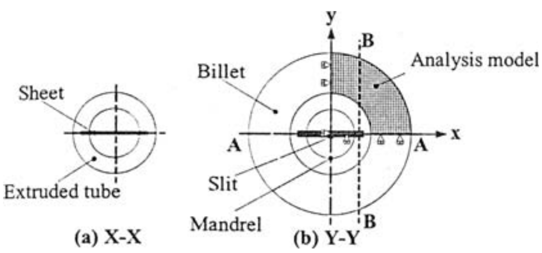


Fig. 2. Cross section of extruded tube and billet.

exit and connects with the sheet

Fig. 2 (a) and (b) shows the cross-section of tube and tools at the plane denoted by X-X and Y-Y in Fig.1 (a) and (b) respectively.

3. Analysis

Finite element analysis was conducted using the commercial code ELFEN, which was developed by Rockfield Software Limited. Analysis model is 1/4 considering symmetry. Billet and sheet are elasto-plastic material and they obey Von Mises yield criterion with stress-strain curve in Fig. 3 obtained by compression test. Yield stress of the billet is 5.8 MPa, Young's modulus is 17.2 GPa and Poisson's ratio is 0.44. Container and die are defined as rigid body. Mesh is divided by tetrahedral solid element.

3.1. Analysis model

Analysis model is shown in Fig. 4. Mandrel top diameter is 10 mm and die hole diameter is 20 mm. Billet dimension is that inside diameter, outside diameter, and length are 20 mm, 40 mm, and 20 mm respectively.

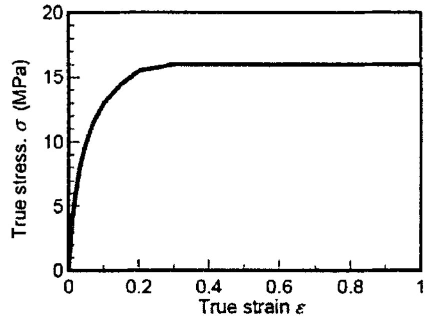


Fig. 3. Stress - strain curve for material property of billet.

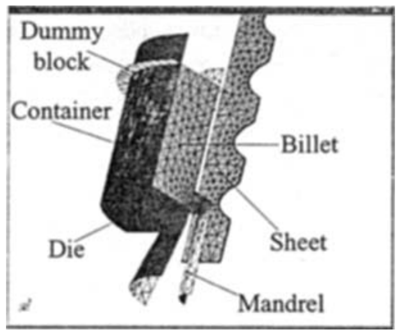
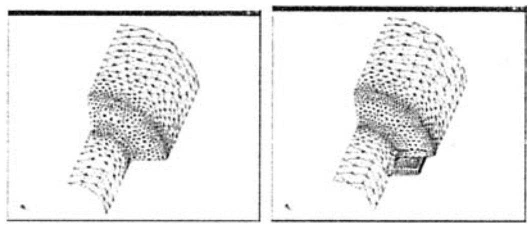


Fig. 4. Cut model of extrusion.



(a) Default mandrel (b) Mandrel with guide

Fig. 5. Variation of mandrel.

Sheet dimension of rib is that sheet thickness, sheet width, sheet hole diameter and distance between hole centers are 1.0 mm, 15 mm, 6 mm and 10 mm.

The sheet is fed through the slit inside the mandrel. Two types of mandrels are used as shown in Fig. 5. Mandrel (a) is axisymmetric. Mandrel (b) has a rectangle guide that covers the sheet.

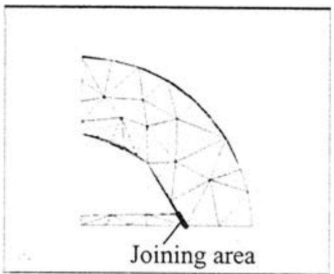
3.2. Analytical results

Fig. 6(a) shows cross section of tube extruded without guide. Fig. 6(b) shows cross section of tube extruded with guide. In the case of mandrel without guide, sheet is pressed in the width direction. Sheet can not be joined with tube because joining area is too small. In the case of mandrel with guide, sheet is compressed in thickness direction. Sheet can be joined with tube because joining area is wide.

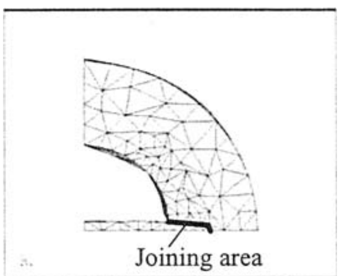
As a result of analysis, it is revealed that applying guide to mandrel is useful for this extrusion. The metal flow controlled by the guide can join the sheet and the tube in tube extrusion. Then, the control of metal flow is important for joining sheet and tube. Besides the guide cross-section, guide position h, which is the distance from the guide top to die surface, is out of important factor for the control of metal flow. The definition of guide position is shown in Fig. 7. A series of numerical analysis were carried out in order to clarify the influence of the guide position h or the metal flow. The results are shown in Fig. 8. In the case of h=0 mm, the metal flow does not occur below the guide top, i.e. the shape of cross section is constant below the guide top. Therefore, the sheet and tube are not joined because gap between sheet and tube is large. In the case of h=1, 2 mm, the gap between the tube and sheet is still observed. In the case of satisfactory large guide position h=3, 4 mm, the gap is not observed.

Besides joining condition, the deformation of rib hole should be examined for industrial use._Fig. 9 shows shape of rib's hole after extrusion.

In the case of guide position h=0 mm, sheet does not deform because the tube does not contact the



(a) Use default mandrel



(b) Use mandrel with guide

Fig. 6. Cross section of extruded tube.

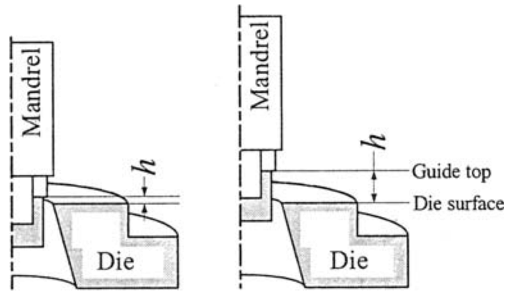


Fig. 7. Explain of guide position.

sheet. In the case of h=1, 2 mm, the sheet deforms little. In the case of h=3 mm, sheet hole is compressed in the width direction. In the case of h=4 mm, the sheet deforms considerably and the sheet hole is elongated along the extrusion direction.

4. Experiment

Although rising guide position is effective for joining, rib's hole is distorted at the same time. Extrusion products are requested to have both enough joining strength and least rib deformation.

Based on the analysis, we investigated effect of the guide position by model experiment. Trial joining extrusion of sheet and tube was carried out actually. We estimated joining condition by observing tube cross section in order to verify adequate value of guide position.

4.1. Extrusion condition

In order to adjust the guide position h correctly, the CNC extrusion machine was used for this experiment [2]. AC servo motors were installed into the prototype machine for the independent control of the ram and mandrel.

Fig. 10 shows the dimension of extrusion tools. The material of the extrusion die, the container and the dummy block is made of SKD11. That of the mandrel is S45C. The billet is lead which is suitable as model test of hot extrusion [3]. However, it would be necessary to consider influence of surface oxide film, temperature distribution etc. when this joining process is adapted practically for other metals. W_G is 4.0 mm. Guide position h is set every 0.5 mm from 2.5 to 4.0 mm.

4.2. Result (experiment)

Fig. 11 shows photo of cross section after extrusion.

Joining condition is not satisfactory because gap is seen between sheet and tube at h=2.5 mm. At h=3.5 and 4.0 mm the gap is not seen between sheet and tube. When guide position rises, joining condition becomes satisfactory. Instead, the sheet is curved at h=4.0 mm because the sheet is pressed by the metal flow in width direction with increase of the guide position h.

Fig. 12 shows photo of tube extruded by joining sheet and tube in extrusion. At guide position h=2.5, 3.0 mm, the diameter of the hole in extrusion direction and that in sheet width direction are almost the same. When guide position h is 3.5 mm or larger, the diameter of the hole in extrusion direction becomes larger, and the diameter of the hole in sheet width direction becomes smaller as h gets higher.

The reason why the diameter of the hole in the extrusion direction becomes larger is as follows. Metal flow in guide width direction increases as the guide position is larger as clarified in **3.2**. The sheet

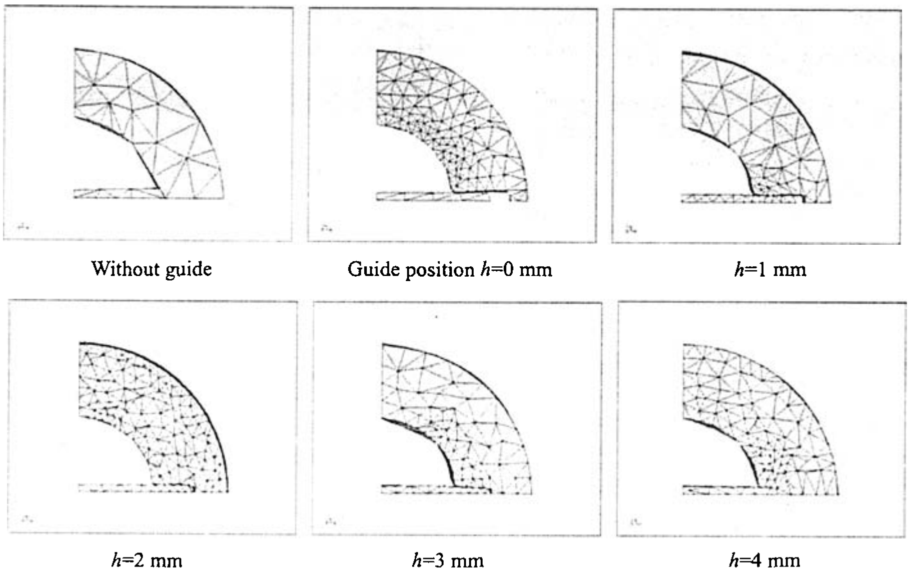


Fig. 8. Cross section of extruded tube by analysis.

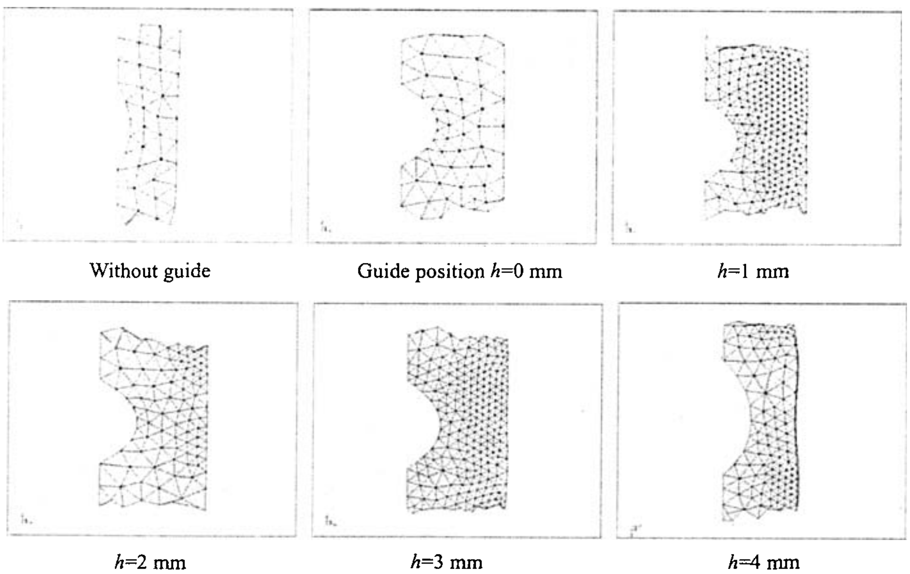


Fig. 9. Influence of guide position on sheet hole diameter after extrusion.

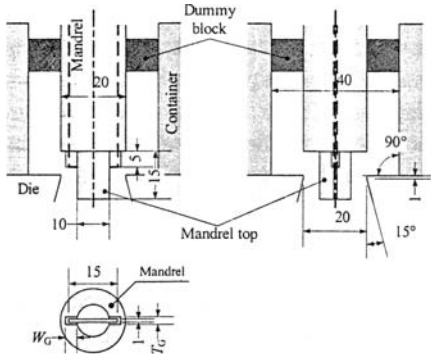


Fig. 10. Dimension of extrusion tools.

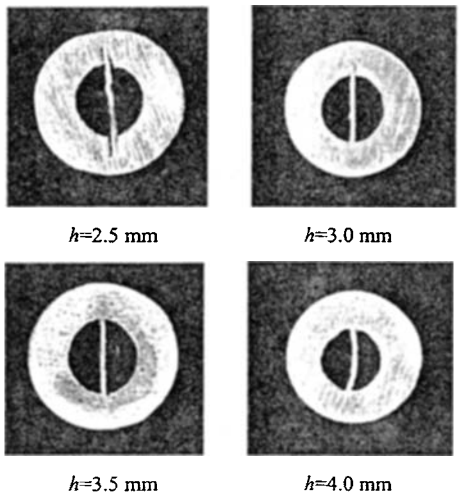


Fig. 11. Cross section of extruded tube by experiment.

has been compressed in guide width direction by the metal flow in guide width direction.

The reason why diameter of hole to sheet width direction becomes smaller is as follows. When the guide position gets higher, the metal flow velocity tends to be higher toward the die exit in extrusion direction. This tendency causes the velocity difference of metal flow between the vicinity of the guide and the die exit. The higher the guide position, gets the larger the velocity difference is [4]. If there is no slipping between the sheet and metal flow, the sheet is elongated in longitudinal direction according to the velocity difference.

5. Conclusions

To investigate adequacy of the proposed processing,

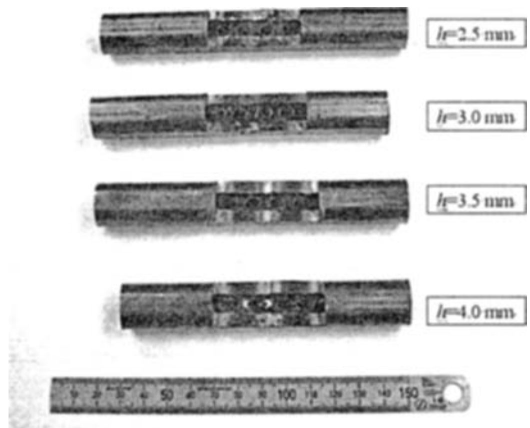


Fig. 12. Shape of holes after extrusion.

numerical analysis and model test are carried out. In this processing method, guide position *h* that is an important parameter is shown below.

1) Joining condition between sheet and tube is improved by rising the guide position *h*.

2) Deformation of the rib hole grows by rising the guide position *h*.

3) Compatible satisfactory joining condition *h* exists.

As a result of experiment based above, sheet and tube can successfully be joined. We indicated effectivity of industry of the processing method.

Acknowledgements

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