Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 589-594

Deformation Behavior of Joining Tube and Holed Rib by Extrusion

Tsutomu Moroi[1], Takashi Kuboki[1] and Makoto Murata[1]

[1]Department of Mechanical Engineering and Intelligent Systems, The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu city, Tokyo 182-8585, Japan

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. Existence of some holes at internal ribs enhances the function and value of the tubes. A new extrusion method is proposed here for the forming of this shape by extrusion with joining. 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 with the inner surface of extrude tube. It was revealed that guide position h has a significant influence on extruded shape. Moreover, the effect of temperature on joining condition and rib deformation was clarified. The gap between tube and rib is able to be suppressed small and joining condition becomes satisfactory when guide position rose or tube wall was thin. When the guide position rose further, or the tube wall thickness was excessively thinner, the amount of the deformation of the rib increases, and it causes defects.

Keywords: *Extrusion, Joining, Guide position, Extrusion temperature, Tube wall thickness*

1. Introduction

Extrusion has been used as a forming method for the long product with the same cross section so far. Many of aluminum tubes, used as structural section are made by extrusion (Fig.1(a)). Most of the aluminum tubes with complex section shape are manufactured by extrusion. Especially, the tubes that have internal rib are used as car parts, such as structural components, radiators and impact absorbers (Fig.1(b)) [1]. Recently, cars are requested to be lighter considering environmental issues. Employment of these tubes can reduce car weight. If these tubes with the holed rib are used as structural components, the following effects can be expected (Fig.1(c)).

(1) If holes are appropriately located inside the 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.

While tubes with uniform cross section as in Fig.s 1(a) and (b) can be formed by conventional extrusion, the tube, which has variable cross section in longitudinal direction, cannot be formed conventionally. Although a method was proposed for changing the inside diameter of circular tube axial direction[2], the method can not form the shape like Fig.1(c) where tube has holes inside the rib. Then, the authors have proposed a method that extrudes tube joining 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. Steel wire reinforced aluminum tube is also a kind of joining extrusion[3]. This research focuses upon a joining extrusion whereby a holed sheet is joined with the inner surface of extrude tube.

The authors checked the validity of the new extrusion using lead as parent material in a prototype experimental set-up [4]. Aluminum is used for parent billet in extrusion at an industrial scale. Hence, verification using aluminum is needed if industrial application is considered. Consequently, 1050 aluminum is used as parent billet and holed rib.

Because aluminum extrusion product is formed by hot extrusion, an experiment was carried out to clarify the effect of temperature on the joining condition between the tube and rib. Then, another experiment was conducted for clarifying the guide position on rib deforming an each temperature.

The applicability of the new extrusion method should be examined for the wider range of tube wall thickness. Because components for transportation vehicles are demanded to be lighter considering environmental issues and reduce costs, thinner walled tubes would be preferable in some parts of industry. On the other hand, thicker walled tube would also be needed as some structural components in other areas.

In this research, results of experiment which showed satisfactory state of joining would be realized under appropriate working conditions corresponding to the tube wall thickness.

2. Experiment condition and method

2.1 Principle of extrusion

Fig.2 shows the principle of the extrusion process. The billet is hollow because we used the mandrel to extrude the tube. The mandrel has a slit to insert the holed sheet. Two guides cover the sheet and control the metal flow which joins the sheet and tube. The billet is extruded from the die exit and joined with the sheet. The billet enters into the die exit and connects with the sheet. Guide position *h*, which is the distance from the guide top to die surface, is one of the important factors for the control of metal flow, as shown in fig.2(b). Fig.3 shows schematic illustration of metal flow. When the guide position is higher, metal flow under the guide changes. And the cross section of the extruded tube changes. Fig.4(a) shows cross section of X-X section of fig.2. Fig.4(b), (c) and (d) shows variation of extruded tube cross section that does not supply the sheet. Fig.4(b), (c) and (d) show the area denoted by the dashed line of fig.3(a), (b) and (c). The cross section of the tube would be classified into one of the following three states:

(1) A state in the same position between the guide position and the die surface (fig.4(b)).

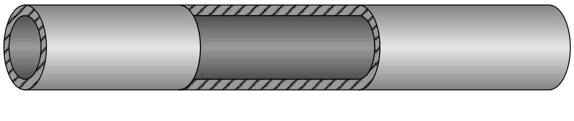
A metal flow at the lower part of the guide does not contact with the sheet. A guide mark becomes the same shape of the guide.

(2) The guide position is in the upper part from the die surface (fig.4(c)).

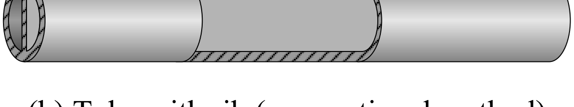
Guide mark's width and its deepness become smaller than the state (1).

(3) The guide position is the upper part from the state (2) (fig.4(d)).

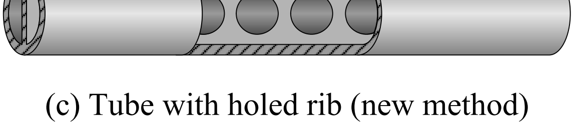
Before metal flow is carried to the die bearing, the width of the guide mark vanishes. In the state (1), joining is impossible because dimension of guide mark become larger than the sheet. In the state (2) and (3), tube and sheet can be joined.



(a) Tube (conventional method)

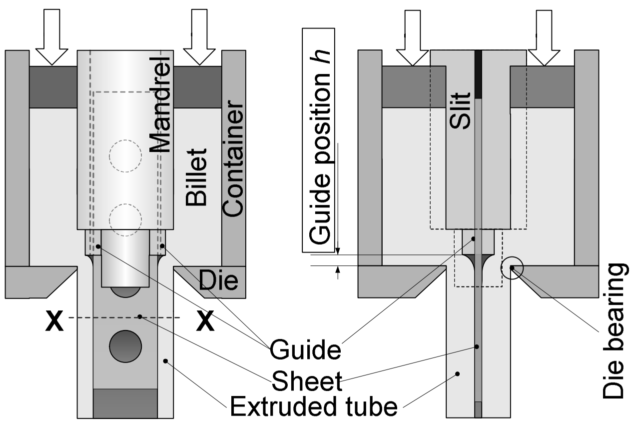


(b) Tube with rib (conventional method)



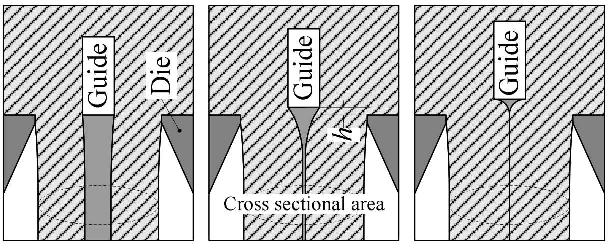
(c) Tube with holed rib (new method)

Fig.1 Variable of extruded tube.



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

Fig.2 Principle of extrusion joining.



. (a)h=0mm. (b)h=2.0mm. (c)h=3.0mm.

Fig.3 Illustration of metal flow.
(section of side view B-B)

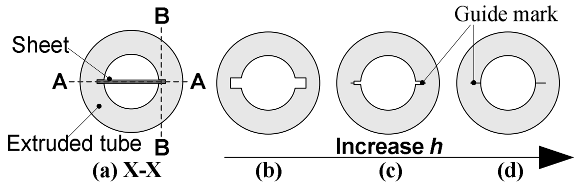


Fig.4 Cross section of extruded tube.

2.2 Extrusion equipment

Fig.6 shows the extrusion tools. The material of mandrel, extrusion die, container and dummy block was SKD61. Mandrel top diameter d_0 is 10mm and die hole diameter is from 16 to 20mm. The tube wall thickness is set by adjusting the die hole diameter. Consequently, extruded tube had inside diameter d_0 mm and outside diameter D_0 mm, tube wall thickness t is calculated by $(D_0-d_0)/2$. A1050 rolled sheet was employed as rib. The dimensions were 0.5 mm thickness, 12 mm width, and 130 mm length. The diameter of the hole rib was 6 mm, the distance between the center was 10 mm. The billet had 20.5 mm inside the diameter, 39.5 mm outside the diameter, and 50 mm height. The billet was heated by heaters installed in the container. One ring heater with the capacity of 1,100 W and six straight heaters of 200 W were employed. Extrusion temperature was measured by thermocouples placed inside the container. The temperature was kept constant at the set value for 10 minutes before the extrusion started. Table 1 shows tested extrusion conditions.

Table 1 Each part of appellation and dimensions

Extrusion temperature T / K	623, 673, 723, 773, 823
Gude position h / mm	1.0 to 4.5
Tube wall thickness t / mm	2, 3, 4, 5
Ram velocity V_R / mms^{-1}	0.1

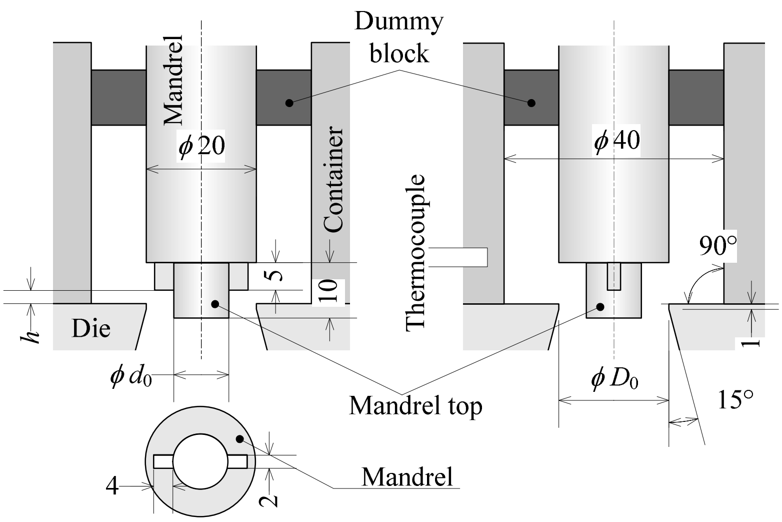


Fig.6 Dimension of extrusion tool.

3. Results and discussion

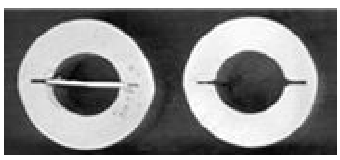
3.1 Effect of guide potion on joining condition and rib deformation

The cross sections of tube were observed. Extrusion was conducted with and without rib. Fig.7 (a) to (e) shows the effect of guide position on formed product cross section. In each figure, the left side shows a tube with rib, and the right side shows the tube without rib. In the case of *h*=2.0 mm, the sheet and tube are not joined because gap between sheet and tube is large. In the case of *h*=2.5, 3.0 mm, the gap between the tube and sheet still exists. In the case of *h*=3.5, 4.0, tube inside the wall protruded out toward inside. This is a result from a metal flow which comes toward the center in radial direction and reaches into the slit of mandrel top when guide position ascends. Joining condition becomes satisfactory by rising guide position. As guide position h rises, the gap between rib and tube becomes small and the joining state becomes satisfactory. But a buckling is observed at *h*=4.0 mm.

3.2 Effect of extrusion temperature on extrusion joining

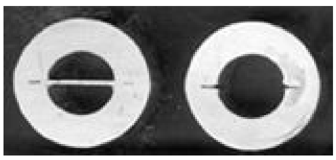
Although rising guide position is effective for joining, it also causes the distortion of the rib hole. Extrusion products are requested to have both enough joining strength and rib deformation as small as possible. Fig.8(a) to (d) shows the deformation of rib hole by removing tube side wall. In each figure, the left side shows the result of holed rib, the right side shows non-holed rib. Fig.8(a) to (c) shows results of extrusion at the same temperature but different guide position. Figure 12(c) and (d) show results at the same guide position but different temperature. In fig.8(a), rib deformation are not observed regardless of hole existence. In fig.8(b), hole deformed severely. On the other hand, non-holed rib showed little distortion. The cause of deformation is the force applied on the sheet in width direction by the metal flow. Holed rib has inferior strength compared to non-holed rib.

Consequently, holed rib displays significantly more distortion than non-holed rib. In fig.8(c), distortion of the rib grows more than fig.8(b). Effect of temperature on rib distort is shown in fig.8(c) and (d). The influence of the temperatures is almost not observed. This is because the billet and the rib become soft regardless of temperature when the temperature is above 673 K. As described above, guide position has influence on rib distortion, while temperature has little influence.

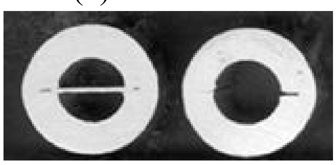


With rib Without rib

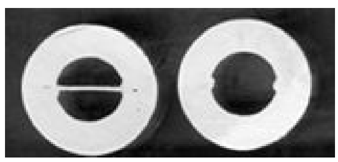
(a) *h*=2.0mm



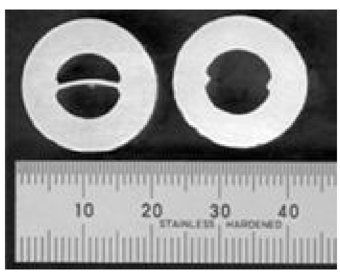
(b) *h*=2.5mm



(c) *h*=3.0mm



(d) *h*=3.5mm



(e) *h*=4.0mm

Fig.7 Cross section observation of extruded tube.

3.3 Effect of tube wall thickness on extrusion joining

Results for each tube wall thickness of t =2, 3, 5 mm were shown in Fig.9. When the guide position is constant, the gaps become small with decrease of tube wall thickness due to the metal flow. This is because thin tube wall raises the extrusion ratio so that a large amount of metal might flow toward the center of cylinder. As a result of these experiments, it was predicted that lower guide position would be suitable for thinner tube wall. To summarize our interpretation of the results, it can be explained that the rib deforms largely with increase of guide position or decrease of tube wall.

4. Conclusion

Proposed new extrusion method is verified to be applicable for 1050 aluminum. The effect of guide position on joining condition and rib distortion is clarified at various temperatures. In the changed wall thickness experiment, the proper forming condition corresponding to the tube wall thickness was clarified. The rib and the tube are joined with the metal that flow through the space between the guide and the die. As a result, control of metal flow is very important. The conclusions are as follows.

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

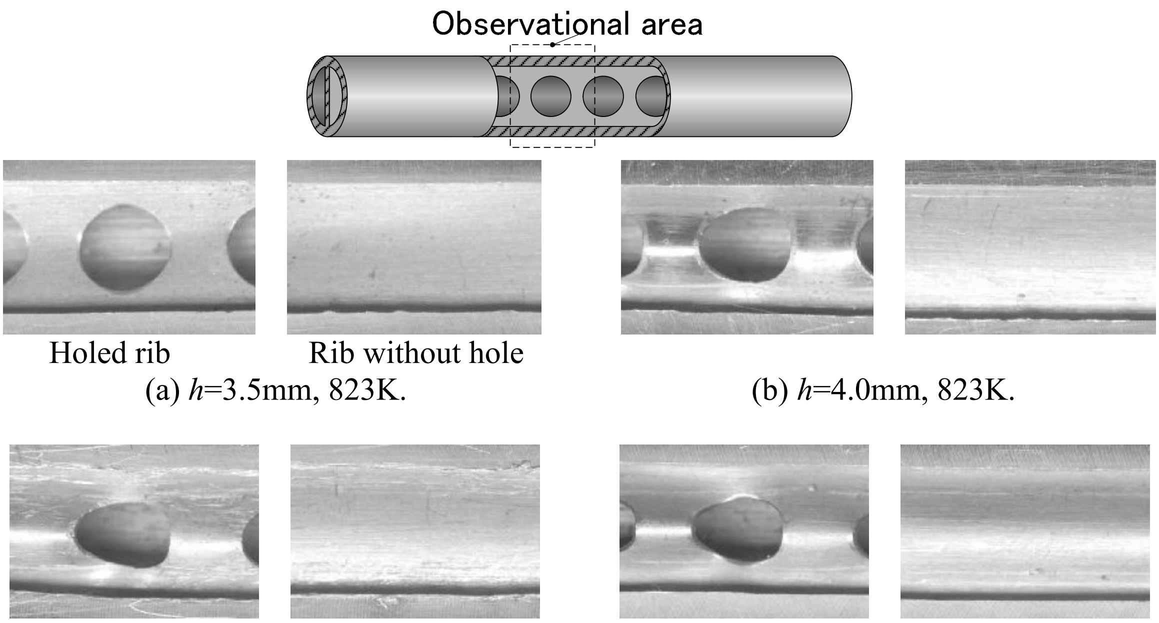
(2) Deformation of the rib hole grows by ascending the guide position h.

(3) The gap between tube and rib becomes small and joining condition gets into satisfactory when guide position rises or tube wall is thin.

(4) When the guide position rises further, or the tube wall thickness is excessively thinner, the amount of the deformation of the rib increases, and it causes defects.

(5) The setting of the guide position is difficult for the tube wall thickness to thin. The effect of the guide position is small for the thin wall-tube extrusion.

(6) When the thin-wall tube is extruded, it is necessary to improve device to reduce the extrusion ratio for enhancing the efficiency of guide position control.



(a) h=3.5mm, 823K. (b) h=4.0mm, 823K.

(c) h=4.5mm, 823K. (d) h=4.5mm, 673K.

Fig.8 Photograph of rib deformation at tube inside.

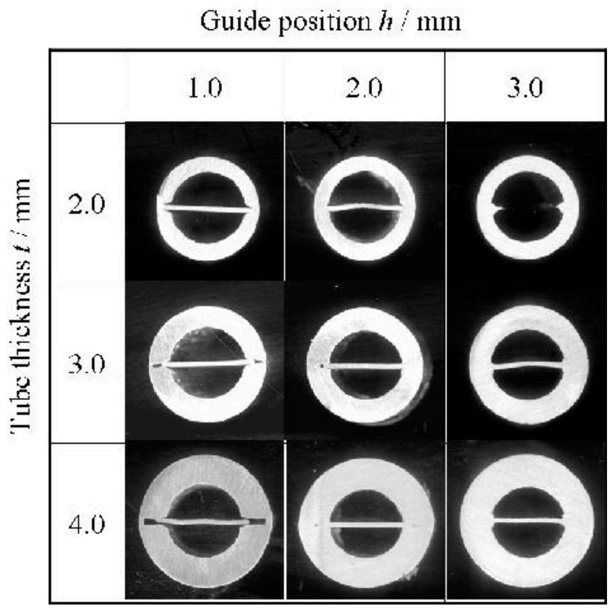


Fig.9 Cross section of tube at various tube thickness and guide position.

References

[1] Murakami S.: *Extrusion Products that Employs New Technology*, Journal of Japan Society for Technology of Plasticity, Vol. 41, No. 472, (2000), pp. 460-461.

[2] Takahiro Makiyama and Makoto Murata: *Controlling Inside Diameter of Circular Tube by Extrusion*, Materials Science Forum, Vol. 396-402, (2002), pp. 513-518.

[3] Katsuyoshi Saito and Katsumi Watanabe: *Co-extruded aluminum composites*, Journal of Japan Institute of Light Metals, Vol. 35, No. 5, (1985), 297-303, pp. 336-342.

[4] T. Moroi, T. Kuboki and M. Murata: *A new extrusion method joining tube and sheet with holed rib*, Journal of Mechanical Science and Technology, Vol.21, No. 10, October 2007, pp. 1548-1552.