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Improvement of die filling by prevention of temperature drop in gas forming of aluminium alloy tube using air filled into sealed tube and resistance heating

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Abstract

A gas forming process of an aluminium alloy tube using air filled into a sealed tube and resistance heating was developed. In this process, the sealed tube is bulged by resistance heating without controlling internal pressure. The deformation behaviour of the tube inside the die was observed through a heatproof glass plate attached to the side wall of the die. The temperature drop of the tube during forming was prevented to improve the die filling by a ceramic die with a small thermal conductivity and optimisation of the current density path.

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Keywords: Tube forming; Gas forming; Aluminium alloy; Temperature; Bulging; Resistance heating

1. Introduction

To improve the fuel consumption of automobiles, the reduction in weight of automobile parts becomes more demanding. Not only strength but also rigidity is required for suspension parts, and thus hollow structures are advantageous to the rigidity. The hydroforming of tubes is attractive in automobile industry as a manufacturing process of hollow products. Koç and Altan (2001) reviewed automotive applications of hydroforming processes of

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tubes. Groche et al. (2005) examined the effects of the deviation of the tube on formability. Mori et al. (2007) examined the mechanism of improvement of formability by the oscillation of internal pressure in a pulsating hydroforming process. In the hydroforming process, the wall thickness of the tube is decreased by the bulging, and thus this brings of the bursting of the tube. Particularly, it is difficult to hydroform aluminium alloy tubes having low ductility.

Warm and hot forming processes are useful for improving the formability of workpieces having low ductility at room temperature. Keigler et al. (2005) heated tubes in the hydroforming. Kim et al. (2007) numerically analysed the warm hydroforming of an AA6061 extruded tube. Yuan et al. (2006) and Manabe et al. (2010) have developed warm hydroforming processes of aluminium and magnesium alloy tubes having small ductility, respectively. However, warm tube hydroforming has limitations of heating temperature because of pressure media such as oil and water, generally below 300 °C.

The limitation of the heating temperature in tube forming can be removed by utilising gas as a pressure medium. Although the gas pressure is much lower that the liquid pressure, gas is available to low flow stress of tubes in hot forming. Fukuchi et al. (2004) have developed a gas forming process of aluminium alloy tubes heated around 400 °C to produce automobile suspension parts. However, it is not easy to simultaneously control the heating temperature and the internal pressure during gas forming (Keigler et al., 2005). Vadillo et al. (2007) have developed the gas forming of the steel tube using resistance heating and the heater installed in the die was omitted. Maeno et al. (2014) have simplified a controlling scheme using resistance heating in gas forming of ultra-high strength steel hollow part by means of air filled into a sealed tube. In this scheme, the tube was formed without buckling and was die-quenched by rapid cooling by reaction force generated by internal pressure of air without control of internal pressure during forming.

In the present study, a gas forming process for an aluminium alloy tube using air filled into a sealed tube and resistance heating was developed. The deformation behaviour and temperature distribution of the tube inside the die were observed. To improve the filling into the die corner, a prevention of the temperature drop by low thermal conductivity die was investigated. In addition, path of the current density was optimised.

2. Gas forming of aluminium alloy tube using air filled into sealed tube and resistance heating

The sequence of gas forming of an aluminium alloy tube using air filled into a sealed tube and resistance heating is illustrated in Fig. 1. In Fig. (a), the air is sealed in the tube, and the tube is rapidly resistance-heated to increase the formability and to decrease the flow stress as shown in Fig. (b). In Fig. (c), the tube is expanded by decrease in flow stress of the heated tube. To prevent the bursting, the tube was compressed by axial feeding of both ends during the heating.

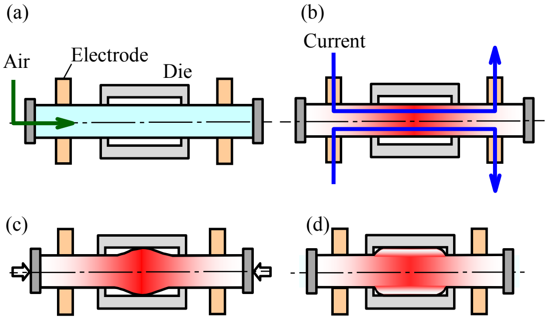

Fig. 1. Sequence of gas forming of aluminium alloy tube using air filled into sealed tube and resistance heating. (a) Filling air pressure, (b) start of heating, (c) start of axial feeding and (d) ends of heating and axial feeding.

The experimental apparatus and the electrode for gas forming of the aluminium alloy tube using air filled into the sealed tube and resistance heating are shown in Fig. 2. An A6063 aluminium alloy seamless drawing tube having 22.0 mm in outer diameter and 1 mm in wall thickness was used in the experiment. Both ends of the tube having 150 mm in length were clamped by the copper electrodes. The contacting length of the electrodes in the hoop direction was 90%, and the electrodes were in contact with the tube by the springs having 600 N in load. The distance between the electrodes was 100 mm. A constant direct current power supply was used for the resistance heating. The resistance heating was controlled by the current density $J = 76 - 106\text{A/mm}^2$ and the heating time $t_e = 3.5 - 8.0$ s. The pressure of sealed air was 1.5MPa, and the axial feeding was not performed in this experiment.

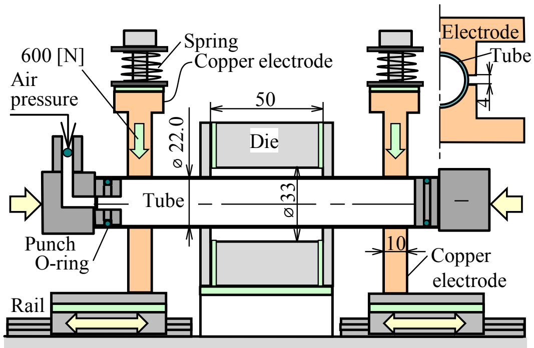

Fig. 2. Experimental apparatus for gas forming of aluminium alloy tube using air filled into sealed tube and resistance heating.

To measure the temperature of the tube inside the die, small holes are drilled in the die as shown in Fig. 3(a). Although the measuring points are in no contact with the die, the measured temperature is almost accurate due to the cooling from the periphery. The diameter and intervals of the small holes in the die were 3 mm and 5 mm, respectively. The obtained infrared thermography image is shown in Fig. 3 (b). The temperature drop in middle portion of the tube was observed through the small hall

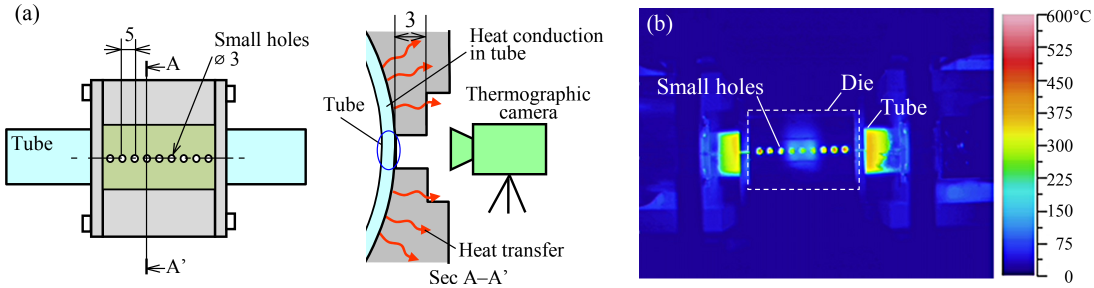

Fig. 3. (a) Measurement of temperature of tube inside die using small holes and (b) obtained infrared thermography image.

To observe the deforming behaviour of the tube inside the die, the heatproof glass plate was inserted into the die as shown in Fig.4 (a). The tube inside the die was observed by the video camera as shown in Fig4 (b).

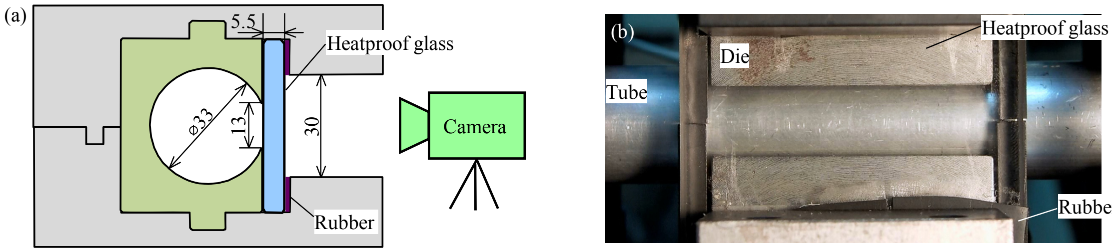

Fig. 4. (a) Die having heatproof glass plate for observing deformation behaviour of tube inside die and (b) observed image.

3. Improvement of corner filling by prevention of temperature drop

3.1. Deformation behaviour of tube in gas forming

The deforming tube inside the die in the hot gas bulging without axial feeding is shown in Fig. 5. Owing to the heating, the tube is expanded by decreasing the flow stress of the tube and by increasing the internal pressure due to the thermal expansion of air sealed in the tube. From t = 2.5 s, the bulging of the tube starts due to thermal expansion of the air without control of the internal pressure, and most of the outer surface is in contact with the inner surface of the heat proof glass for t = 2.9 s. The forming time after the start of the bulging is short.

The variations of the temperature of the die corner and die centre for during forming are shown in Fig. 6. The temperature of the tube rapidly drops after touching with the die.

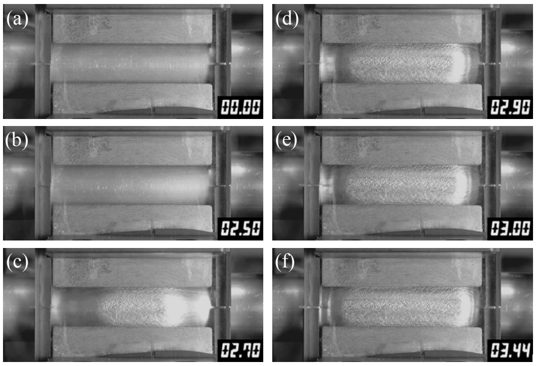

Fig. 5. Deforming tube inside dies in gas forming without axial feeding for $J = 106$ A/mm^2 and $t_e = 8$ s.

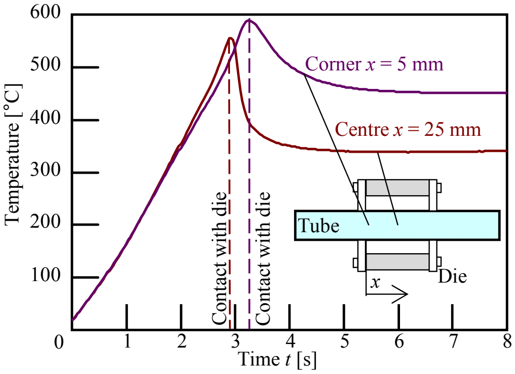

Fig. 6. Variations of temperature of die corner and die centre during forming for $J = 106$ A/mm^2 and $t_e = 8$ s.

3.2. Prevention of temperature drop by low thermal conductivity dies

The temperature of the tube rapidly drops after touching with the die, and the deformation of the tube stops because of the increase in flow stress, i.e. filling into the die corner becomes small. To improve corner filling, the temperature drop during forming was prevented by using low thermal conductivity dies shown in Table 1. The stainless steel having low thermal conductivity and the machinable ceramic die made of SiO_2 and Al_2O_3 were employed. The current density for the ceramic die having low thermal conductivity was reduced to prevent melting of the tube.

Table 1. Thermal conductivity of die and used heating conditions

Die material	Thermal conductivity of die [W/m·K]	Heating condition	
		Current density J [A/mm^2]	Resistance heating time t_e [s]
Mild steel: SS400	51.6	106	8.0
Stainless steel: SUS304	16.3	106	7.5
Ceramic: Photoveel	1.7	76	8.0

The bulged tubes with the mild steel, stainless steel and ceramic dies and the cross-section in the vicinity of the corner are shown in Fig. 7. In the ceramic die, lines are appeared on the bulged surface of the tube by transferring of the cutting mark on the inside the ceramic die. Corner filling for the ceramic die is remarkably improved by the prevention of temperature drop.

The variations of temperature of the die corner using the mild steel, stainless steel and ceramic dies are shown in Fig. 8. The temperature drop after the touch with the die for the ceramic die is small.

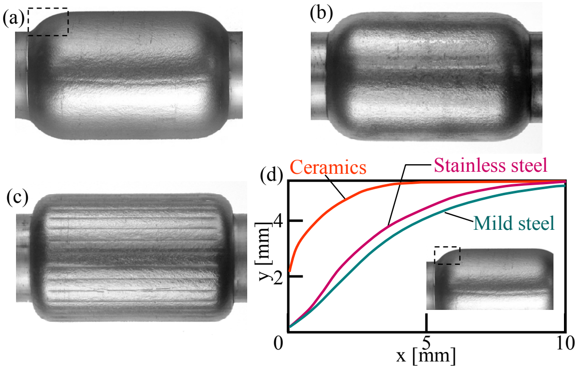

Fig. 7. Bulged tubes with (a) mild steel, (b) stainless steel and (c) ceramic dies and (d) cross-section in vicinity of corner.

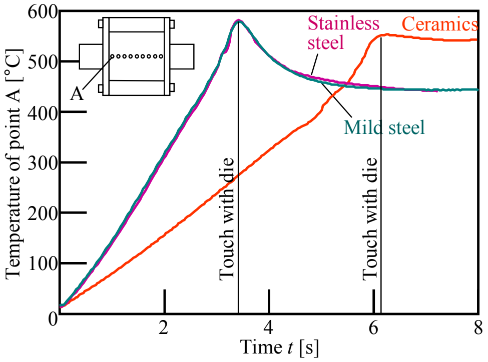

Fig. 8. Variations of temperature of die corner using mild steel, stainless steel and ceramic dies.

3.3. Prevention of temperature drop by increase in current density after touch with die

Although the temperature drop by the touch with the die was prevented by using ceramic die, it is difficult to use the ceramic die having low toughness in gas forming of complex aluminium alloy hollow parts. To prevent the temperature drop even in the stainless steel die, the current density after the touch with the die was increased. Paths of current density with and without the increase after the touch with the die are shown in Fig. 9.

The effect of the increase in current density after the touch with the die on the deforming shape of the tube using the stainless steel die is shown in Fig. 10. The corner filling for with the increase in current density is remarkably improved.

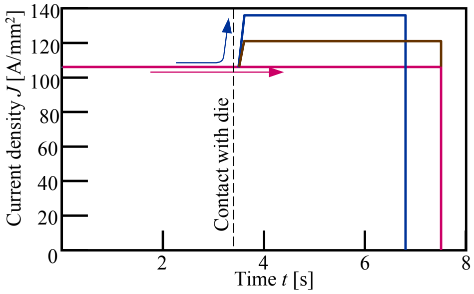

Fig. 9. Path of current density with and without increase after touch with die.

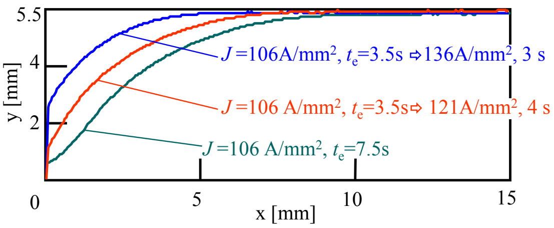

Fig. 10. Effect of increase in current density after touch with die on deforming shape of tube using stainless steel die.

The variations of the temperature of the die corner using the stainless steel die with and without the increase in current density after the touch with the die are shown in Fig. 11. The temperature drop for with the increase in the current density was slightly delayed, however even then the corner filling was remarkably improved because of the short forming time as shown in Fig. 5.

The filling ratios of the die corner and the electrical energy used for resistance heating are shown in Fig. 12. The filling ratio for using the stainless steel die with the increase in current density is much the same as that for using ceramic die, whereas the electrical energy was doubled.

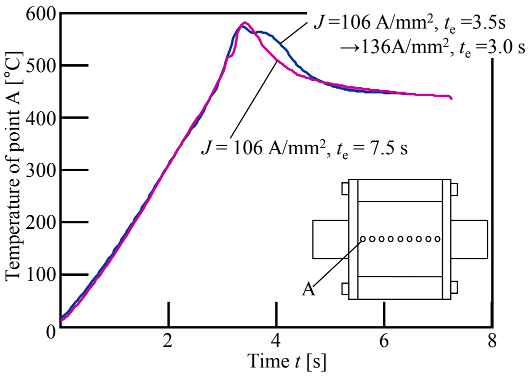

Fig. 11. Variations of temperature of die corner using stainless steel die with and without increase in current density after touch with die.

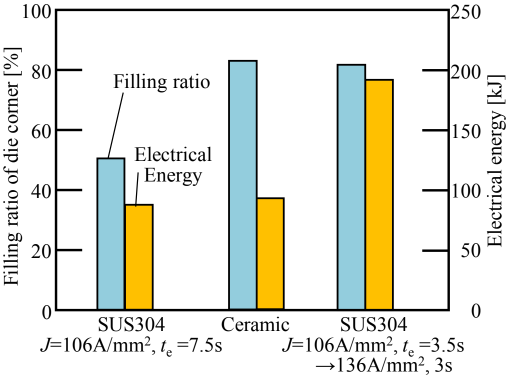

Fig. 12. Filling ratios of die corner and electrical energy.

4. Conclusion

A gas forming process for an aluminium alloy tube using air filled into a sealed tube and resistance heating was developed to produce an aluminium alloy hollow parts. The deformation behaviour and temperature distribution of the tube inside the die were observed. In addition, to improve the filling into the die corner, a prevention of the temperature drop by low thermal conductivity die was investigated.

(1) The expansion speed is rapid and the forming time after the start of the bulging is short.
(2) The corner filling was remarkably improved by using low thermal conductivity dies made of ceramic.
(3) Just to reduce the temperature drop after the touch with the die just a little, the corner filling can be improved because of the short forming time of the gas forming.

Aluminium alloy hollow parts are increasingly demanded for the reduction in weight with high rigidity of automobiles. Conventional tube hydroforming processes are difficult to produce these aluminium alloy parts because of the low ductility of the aluminium alloy tubes. The present gas forming process using air filled into sealed tubes and resistance heating is one of the most useful processes for producing aluminium alloy hollow parts. Heating approaches of tubes, forming approaches for complicated shapes of products, proper tube properties, controlling approaches of internal pressure, etc. should be still studied.

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