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Prediction of Welding Pressure in the Non Steady State Porthole Die Extrusion of Al7003 Tubes

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ABSTRACT

This paper describes a numerical analysis of a non-steady state porthole die extrusion, which is useful for manufacturing long tubes with a hollow section. Materials divided through several portholes are gathered within a chamber and are then welded under high pressure. This weldability classifies the quality of tube products and is affected by process variables and die shapes. However, porthole die extrusion has been executed based on the experience of experts, due to the complicated die assembly and the complexity of metal flow. In order to better assist the design of die and to obtain improvement of productivity, non-steady state 3D FE simulation of porthole die extrusion is required. Therefore, the objective of this study is to analyze the behavior of metal flow and to determine the welding pressure of hot extrusion products under various billet temperatures, bearing length, and tube thickness by FE analysis. The results of FE analysis are compared with those of experiments.

Key Words : Hot extrusion, Porthole die, Welding pressure, Expanding ratio, Punch expanding test

1. Introduction

Recently, the use of lightweight parts has been increasing with the development of automobile techniques and the aerospace industry. The automobile industry has gradually studied lightweight materials such as Al alloys, due to an increase in the restriction of exhaust gas and the improvement of the combustion ratio[1]. As a component in lightweight aerospace and automobile parts, the production of Al tubes with high strength and extrudability, such as those needed for door impact beams, seat side rails, and hood support, is in demand. The extrusion process, which is called a welding chamber type with a bridge, porthole die broadly, has great advantage in the production of hollow sections, which are difficult to produce by conventional extrusion with a mandrel on the stem. Using the porthole die extrusion, long tubes can be produced without respect to the length of the mandrel[2]. Due to the complicated die assembly and the complexity of metal flow, this porthole die extrusion has been conducted based on the experience of experts. In the porthole die extrusion, it is very important to calculate the welding pressure that affects the welding strength, which classifies the quality of tube products that are made when divided neighboring materials are welded in the welding chamber. Welding pressure is affected by many process variables, such as the extrusion ratio, the extrusion speed, die shape, bearing length, billet and container temperature, etc[3-8]. However, there are few studies about the relationship between the welding pressure and the process variables.

Therefore, the welding pressure in the welding chamber of hot extrusion products according to billet temperature, bearing length, product thickness, and extrusion ratio was investigated by FE simulations for the Al7003 alloys with 0.6%wt and 1.0%wt. The flow

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stress was obtained by using hot compression test. To verify the result of FE analysis, experiments of the porthole die extrusion and punch expanding tests for extruded tubes were performed to evaluate the welding strength of the material.

2. FE analysis of porthole die extrusion

2.1 Material flow in the porthole die extrusion

Fig. 1 shows the tool assembly of porthole die. The assembly consists of a container, porthole, a mandrel, and a welding chamber. Fig. 2 is a 3D shape of the material flow in the porthole die.

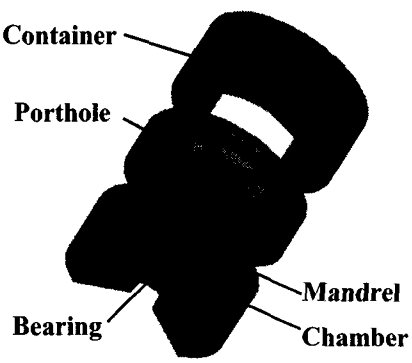


Fig. 1 Split tool assembly used in porthole die extrusion

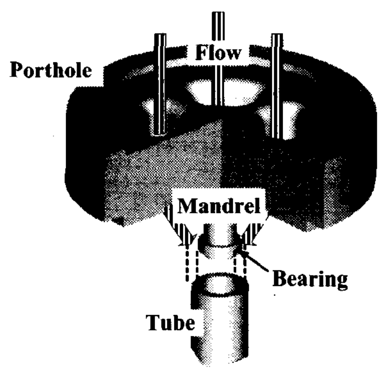
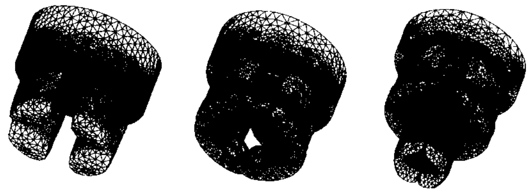


Fig. 2 Schematic diagram of material flow in the porthole die

Fig. 3(a) is the dividing stage in which the billet is divided into several strands at the bridges of the die. Fig. 3(b) is the welding stage in which strands flow into the welding chamber through the portholes, and shows the forming stage in which metal flows to form a required hollow section, then flows out through the die land to the die exit.



(a) Dividing (b) Welding (c) Forming

Fig. 3 Tool assembly used in porthole die extrusion

2.2 FE model of the porthole extrusion process

In the present study, the welding pressure in the welding plane can be affected by many process variables. The study also examines extrusion loads, welding pressure, and material flow from a container to the die exit, according to various billet temperatures, bearing lengths, and tube thickness. Porthole die extrusions using improved Al7003 are performed on a square die with a container that is 75mm in diameter.

Table 1 Conditions of the extrusion process

Conditions	Values
Billet Diameter(mm)	74.0
Bridge Height(mm)	38.5
Chamber Height(mm)	20.2
Product Thickness(mm)	1.5, 1.7 at the same extrusion ratio 43
Extrusion Ratio	57
Extrusion Speed(mm/s)	1.0
Billet Temperature(℃)	400, 430, 460
Container/Die Temperature(℃)	400
Friction factor	0.7

For FE simulations and experiments, the initial billet temperatures are 40, 430, and 460℃, the bearing lengths are 3, 4.5, and 6mm, the product thicknesses are 1.5 and 1.7mm for the same extrusion ratio 43. Table 1 presents the process variables used in the FE analysis. It used DEFORM 3-D S/W[9] for the analysis, and a 1/8-section is applied, considering the symmetry of the porthole die.' Fig. 4 shows a schematic illustration applied in the process analysis of the porthole die extrusion.

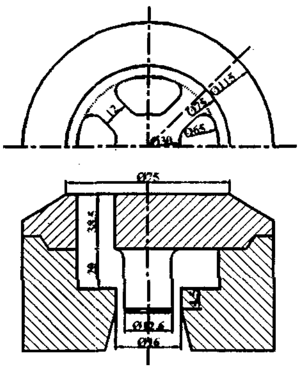


Fig. 4 Die geometry for process analysis

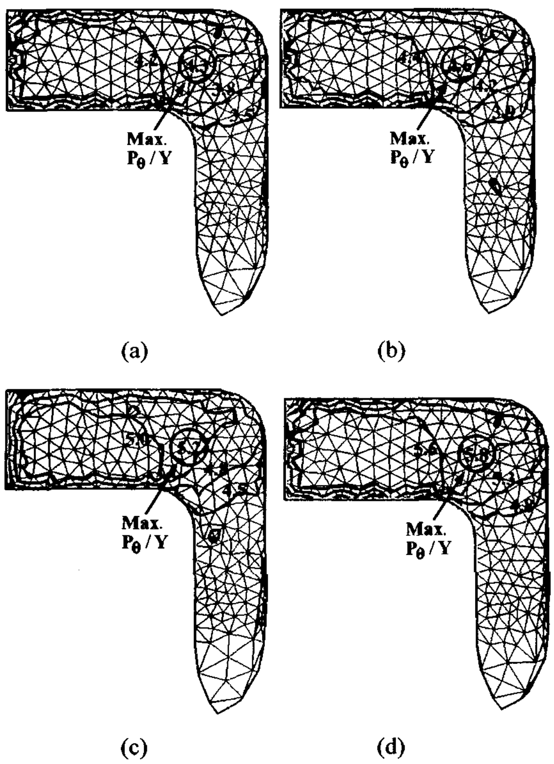


Fig. 5 Distribution of normal pressure in the welding plane

(a)~(c) When billet temperature is respectively 400℃, 430℃, 460℃, bearing length is 4.5mm and tube thickness is 1.7mm

(d) When billet temperature is 400℃, bearing length is 6mm and tube thickness is 1.7mm

3. Determination of welding pressure

Fig. 5 shows the distribution of normal pressure in the welding plane. In Fig. 5, *P* and *Y* are the normal pressure in the welding plane and the average flow stress respectively. It can be seen from Fig. 5(a), (b) and (c) that the normal pressure increases according to the increase of initial billet temperature when the tube thickness and bearing are 1.7mm and 4.5mm respectively. Fig. 5(d) shows that the welding pressure obviously increases when the initial billet temperature 400℃ and the bearing length is 6mm. The divided materials at the bridges are welded in the welding chamber at the high pressure, which then flows out through the die land to the die exit. When the materials are welded, the maximum welding pressure occurs at the narrow area near the bearing. The welding state of the tubes was examined by an expanding test using conical punch according to the process variables.

4. Experiment and the result of analysis

Table 2 shows the chemical composition of the improved Al7003 alloy. The hot compression test was performed to obtain the flow stress according to the temperature and the strain rate by using 25ton MTS(material test system) along with the diameter and the height of used specimen. In order to prevent the oxidation of specimen surface, the B-N spray are used.

Fig. 6 Experiment apparatus for porthole extrusion

Table 2 Composition of improved Al7003 alloy[wt%]

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Zr	Al
Improved Al7003	0.3	0.1	0.15	0.2	0.6 1.0	0.1	6.0	0.15	Rem.

Fig. 6 is the die set for the porthole die extrusion. The ram velocity is 1.0mm/s. The used material contains Mg 0.6wt% and 1.0wt% respectively. No lubricant was applied to prevent the effect on the welding stage.

The length of porthole is 38.5mm and the height of the welding chamber is 20mm. The diameter of the welding chamber is 65mm. The diameter of welding chamber is equal to the outer diameter of the porthole is 65mm.

4.1 The extrusion load according to the process variables

The Al7003 alloy with Mg 1.0wt% was used to perform the FE analysis. The extrusion experiment was carried out for the Al7003 alloys with Mg 0.6wt% and 1.0wt%.

Table 3 shows the process conditions and the maximum extrusion load at each process condition. The extrusion loads decrease in proportion to an increase in the initial billet temperature. However the extrusion loads only increase slightly are with the increase of the bearing length. The extrusion loads make little difference with regard to tube thickness for the same extrusion ratio.

Table 3 Appearance of tubes after expanding test

Billet Temp. (℃)	Bearing Length (mm)	Tube Thick. (mm)	Max. Extrusion Load(ton) Experiment Mg0.6	Experiment Mg1.0	FE Mg1.0
400	4.5	1.7	510	510	530
430	4.5	1.7	500	506	520
460	4.5	1.7	429	457	480
400	3	1.7	507	508	512
400	4.5	1.7	510	511	515
400	6	1.7	511	513	516
400	4.5	1.5	500	502	510
400	4.5	1.7	500	501	508

4.2 The comparison of tube expanding test and FE analysis

Fig. 7 shows a schematic illustration for evaluating the welding state of welding planes. The welding strength is evaluated by the expanding ratio (Ψ). The expanding ratio(Ψ) is defined as d_{max}/d_o, where d_{max} is the maximum diameter when a fracture occurs just after expanding, and do is the initial outer diameter of the tubes[10-11].

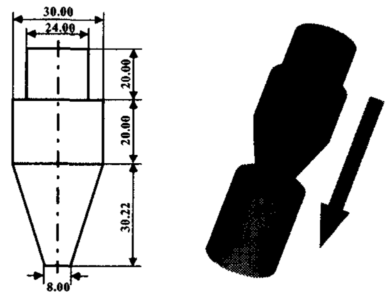


Fig. 7 Expanding test for extruded tubes

Table 4 Appearance of tubes after expanding test

Tube Thick. (mm)	Billet Temp. (℃)	Bearing Length (mm)	Extruded specimen Mg0.6	Extruded specimen Mg1.0	Expanding ratio(Ψ) 0.6	Expanding ratio(Ψ) 1.0	P_θ/Y 1.0
1.5	400	4.5	Fig.8(a)	(b)	1.062	1.022	4.5
1.7	400	4.5	(c)	(d)	1.056	1.018	4.3
1.7	430	4.5	(e)	(f)	1.069	1.025	4.6
1.7	460	4.5	(g)	(h)	1.075	1.050	5.2
1.7	400	3	(i)	(j)	1.019	1.019	3.5
1.7	400	6	(k)	(l)	1.075	1.050	5.8

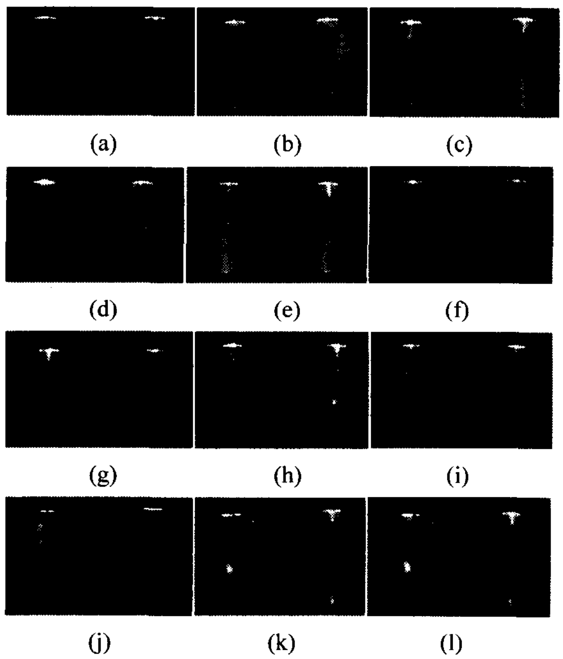


Fig. 8 Extruded tubes by expanding test

Table 4 shows the value of P/Y at the vicinity of bearing and the expanding ratio through the tube expanding test. The expanding ratio increases with the increase of billet temperature. When the bearing length is 3mm, the expanding ratio is relatively low. The reason is due to the welded tube coming out of the bearing before the welding part is stabilized. The tube thickness made little difference in the expanding ratio because of the same extrusion ratio.

The expanding ratio increases slightly with the decrease of Mg wt% because the brittleness of material decreases according to the decrease of Mg wt%. Also, the welding pressure on the welding plane through the FE analysis showed the same tendency as the tube expanding test. Fig. 8 shows the expanded tubes after the tube expanding test. All things considering, in order to produce tubes with superior welding strength, it is necessary to select optimal process variables from the expanding ratio through the tube expanding test and the welding pressure from the FE analysis[12].

5. Observation of the welding line

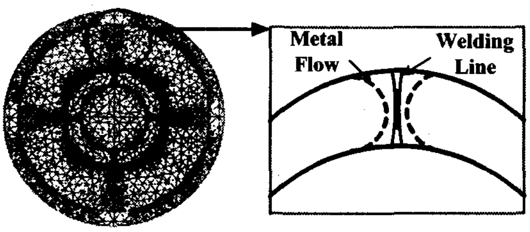
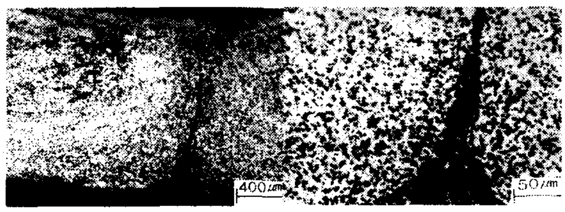


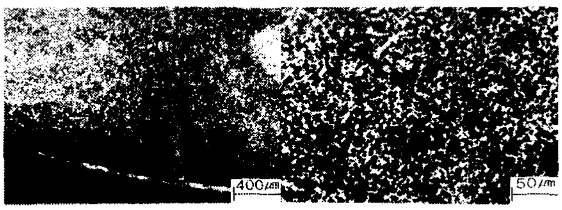
Fig. 9 Observation part for extruded tubes

Fig. 10 Formation of welding line in transverse view of extruded tube

The material flow in the vicinity of welding line was observed through the observation of microstructure of welded tube. Fig. 9 is the observed location of the extruded tube. Fig. 10 shows the formation angle of the welding line in a transverse view of the extruded tube. The formation angle was always 90° for every process variables. Fig. 11(a) shows the microstructure when the welding line was generated at the initial billet temperature 430℃, the bearing length of 3mm, and the tube thickness of 1.7mm. Fig. 11(b) shows the microstructure when the welding line was not generated at the initial billet temperature 400℃, the bearing length of 6mm, and the tube thickness of 1.7mm. As the initial billet temperature increases, the possibility of the formation of a welding line shows a tendency to decrease. The longer the bearing length, the likeness the flow defects like welding lines being generated decreases.



(a) When billet temperature is 430℃, bearing length is 3mm and tube thickness is 1.7mm



(b) When billet temperature is 400℃, bearing length is 6mm and tube thickness is 1.7mm

Fig. 11 Microstructure of welding line

(a) A case where welding line is appeared

(b) A case where welding line is not appeared

6. Conclusion

This study investigated the extrusion pressure and the material flow of porthole die extrusions for the production of tubes according to the process parameters; the billet temperature, the bearing length and the tube thickness through the FE analysis and the extrusion experiment. By using the tube expanding text, the optimal condition was obtained for each process conditions. Also, the welding line was observed as the microstructure for the transverse view of extruded tubes. Based on the results of the study, the following conclusions had been made:

(1) The welding pressure on the welding plane is the greatest when the initial billet temperature is 460 ℃ and the bearing length is 6mm. The maximum welding pressure is approximately 3.5~5.8 times that of mean flow stress.

(2) The welding pressure gradually increase with the increase of the initial billet temperature. The expanding ratio decrease with decreases of bearing length.

(3) The initial billet temperature and the tube thickness have little influence on the welding pressure. However, the welding pressure increases according to the increase of bearing length.

(4) From the result of the observation of microstructure, the thickness of welding line slightly increase with the increases of initial billet temperature. Especially, according to the increase of bearing length, it is possible to obtain the sound product without welding lines.

(5) It is possible to obtain the appropriate process variables for production of a sound tube with good welding strength through the FE analysis and the tube expanding test. The normal pressure through FE analysis and the expanding ration through the tube expanding test.

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