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Non-symmetric hollow extrusion of high strength 7075 aluminum alloy

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Abstract

A hollow extrusion process by varying pocket geometry in welding chamber and bearing length to obtain a uniform material flow is studied. Finite element analysis and Taguchi method are used to obtain a better porthole type extrusion die design. The research results show that the billet has the best uniform material flow and minimum dead metal zone in Double arc type, and the ramp load shows that R of 40 mm is smaller than 45mm. In addition, unequal bearing length makes metal flow more uniform. Finally, extrusion die with port-hole die structure has been manufactured and a successful extruding process has been conducted which proves the better design using the double arc pocket and unequal bearing length.

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keywords: AA7075; Porthole die; Hollow extrusion; Die design; Material flow

1. Introduction

Porthole die extrusion has a great advantage in the forming of hollow section tubes that are difficult to produce by conventional extrusion with a mandrel on the bridge. Because of the complicated structure of the die assembly, the extrusion of hollow section tubes has been investigated experimentally. Analytic approaches that are useful in profitable die design and in the improvement of productivity are inevitably demanded. Kim et al. (2002) have conducted finite element analysis on aluminum tube extrusion for AA3003 to obtain larger welding pressure than

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that of conventional porthole dies, and the effect of the improved porthole die on welding pressure has been investigated.

Design parameters such as billet temperature, bearing length and product thickness, are examined by Jo et al. (2003). The welding pressures are examined through 3D simulation of the non-steady state and compared with experimental results for AA7003 as billet material. The extrusion process of an aluminum AA1100 rectangular hollow pipe was simulated using finite volume method based software Msc/SuperForge by Wu et al. (2006). The simulation results indicate that the extruded work-piece has an uneven forepart, non-uniform deformation distribution and high load peak if using the original die design.

In order to investigate the effects of pockets in the porthole die on the metal flow, temperature at the die bearing exit and the extrusion load were contrasted with the traditional die design without the pockets in the lower die, two different multi-hole porthole dies with and without pockets in lower die for H-type solid extrusion of AA6061 were designed by He et al. (2010). The simulation results show that the pockets could be used to effectively adjust the metal flow and especially benefit to the metal flow under the bridges.

Multi-hole pocket dies are a type of extrusion tooling setup commonly used across the aluminum extrusion industry for efficient production of solid aluminum profiles. Fang et al. (2009) did the multi-hole pocket dies FEM simulation and extrusion experiments for AA6063 as the billet material, and found that multi-steps in die pocket could be effectively used to regulate the metal flow through multi-hole dies.

Aue-u-lan and Khansai (2012) focuses on the effect of the factors that could be caused of shorten die life, such as flow behavior, extrusion load, flow velocity, and temperature distribution. FEM was employed to simulate and investigate the effect of those factors on die stress for die material of AISI H-13. DEFORM 3D was used to simulate this hot extrusion process of AA6063 with square hollow profile. The simulation result of die stress was predictable and coherent with failure in real die that used to produce aluminum profile.

Low-temperature incipient melting and high deformation resistance of aluminum alloy AA7075 place extraordinary demands on extrusion die design and process optimization, especially when the shape of the extrudate is complex. Fang et al. (2009) studied on die design and process optimization for the alloy to manufacture a complex solid profile with large differences in wall thickness, by means of 3D FEM simulation and experimentation instead of the traditional trial and error approach. The effects of die bearing length and extrusion speed on extrudate temperature and extrusion pressure were predicted. The authors (Hsu et al., 2011 and 2012) have studied solid welding conditions and square tube extrusion process of AA7075. The proposed paper is a continue research extending to hollow extrusion of complex profile for high strength aluminium alloy 7075.

2. Porthole die design for non-symmetric hollow extrusion

A hollow extruded AA7075 product with complex cross section as shown in Fig.1(a), which can be used as structure part, is an industrial case for current study. The minimum thickness is about 3mm in rib and 5mm in web. A port-hole die configuration is needed to conduct the hollow extrusion process, where the upper die is to provide the divided flow of source material and restrict the inner geometry of product, and the lower die is to provide the welding chamfer and restrict the outer shape of product. The mandrel of upper die and orifice of lower die can be used to regulate the material flow.

Fig. 1(b) depicts the schematic configuration of porthole die for hollow extrusion including ram, container, billet, upper die and lower die. Fig. 1(c) depicts the upper die (10) and lower die (20) where the former includes billet flow in port (11), connect bridge (12), welding chamber (13), mandrel (14), and the latter includes welding chamber pocket (21), hole (22) and simple support beam (23).

The welding chamber pocket geometry is an important design for non-symmetric extrusion part. There are three different types (Original type, Cut edge type and Double arc type) of pocket are designed, as shown in Fig. 2(a)-(c). The original type pocket is a circle with diameter of 110mm. The cut edge type pocket has a cutting plane with a distance of 40mm to central point. The double arc pocket has another small arc labelled as *R* besides the original diameter of 110mm. There are two types of die bearing, namely: all 4mm equal type and unequal type of 4mm & 12mm considered in the present study for welding chamber with double arc type pocket, as shown in Fig. 2(d). For current study, the four port holes in upper die have the same cross sections and areas. The central axis of hole in lower die and the central axis of mandrel in upper die are coincided.

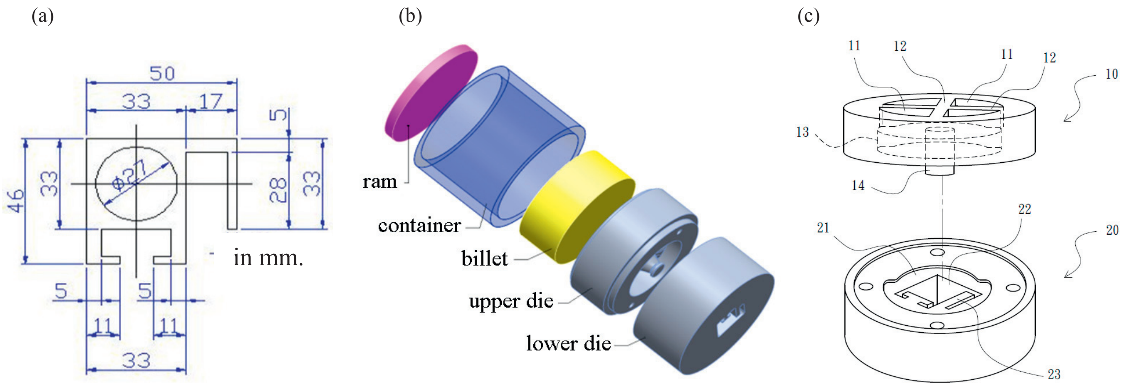

Fig. 1. (a) Hollow extruded product with complex profile; (b) die configuration for porthole extrusion; (c) upper die and lower die.

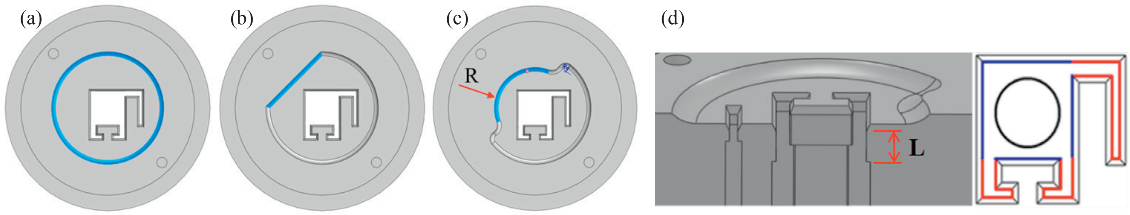

Fig. 2. Three different types of welding chamber pocket: (a) Original type, (b) cut edge type and (c) double arc type; (d) equal type or unequal type of die bearing length.

3. Results and discussion

3.1. Pocket shape effect on product front and ram load

Finite element analysis of hollow extrusion processes for three different kinds of pocket geometry are conducted by using DEFORM-3D. Some simulation conditions are set as follows: billet diameter of 170 mm, billet length of 70mm, billet temperature maintained constant at 480 °C, constant shear friction factor between die and billet is set 0.7 and ram velocity is 0.5 mm/sec. Among them the outlet product geometry for case of double-arc pocket is more uniform than the two other cases (original and cut-edge pocket). Therefore, the double-arc pocket design is adopted for further study. The ram load and stroke relation for two different radiuses, i.e. R40 and 45 mm, where the maximum extrusion loads are 1.19×10^7 N and 1.21×10^7 N, respectively. Therefore, R40 mm of pocket geometry is adopted for further die design.

3.2. Pocket shape and die bearing effect on material flow near welding plane

The dividing flow of billet in extrusion process along the ram direction especially at welding plane, after billet flowing through upper die and contact together, is studied to understand pocket shape and die bearing length effect. Fig. 3(a) depicts the sampling cross-section just after chamfer angle of lower die and Fig. 3(b) depicts the velocity distribution of material flow along the ram direction where four marked regions showing four welding planes. Twelve sampling lines are selected to understand the flow status, as shown in Fig. 3(c). Label **D** - **G** represent four divided flows of billet due to four ports in upper die. Label **1** - **4** represent four welding planes. Therefore, **D1** means the sampling line near welding plane **1** where the material coming from divided flow **D**. Each sampling line consists of 300 sampling points. The velocity of each sampling line is the average velocity of 300 sampling points.

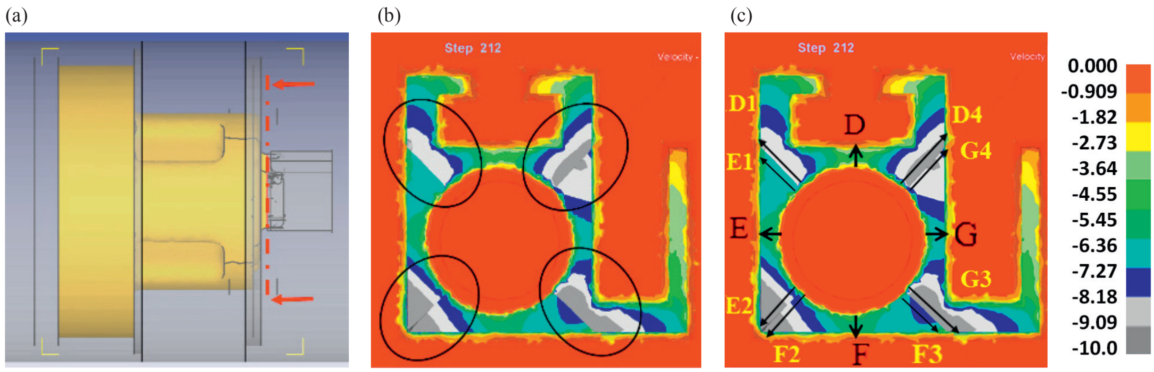

Fig. 3. (a) Cross section to obtain material flow velocity, (b) velocity distribution, (c) twelve sampling lines to calculate flow velocity where Label D - G represent four divided flows of billet and Label 1 - 4 represent four welding planes.

3.3. Taguchi method and numerical simulation assisting in die design

Taguchi method is one of the efficient problems solving tools to upgrade the performance of products and processes with a significant reduction in cost and time involved. Besides pocket contour, there are several die features will affect extrusion process, namely: bridge shape in upper die, pocket corner radius and chamfer angel in lower die, as shown in Fig. 4. The selected die feature parameters are given in Table 1. The experimental layout plan with three factors and three levels using L9 orthogonal array, 9 experiments were carried out to study the effects of simulation where the output parameters including maximum ram load, maximum die stress in upper die and lower die and the objective is to seek their minimum values.

The S/N response graph and factor contribution histogram for minimum the objectives are shown in Figs. 5-7 for maximum ram load, maximum die stress in upper die and lower die, respectively. From the combined Taguchi method and numerical simulation results learned that the most contribution for ram load and upper die stress is factor A (bridge type) and for lower die stress is factor B (chamfer angel).

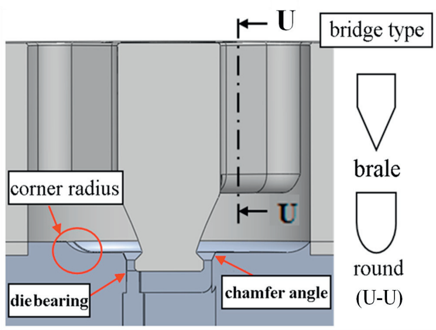

Fig. 4. Control factors for die design used in Taguchi method.

Table 1. Control factors and levels of die design used in Taguchi method.

Control factors		Levels		
		1	2	3
A	bridge type	brale	round	
B	chamfer angel (degree)	25	30	35
C	pocket corner radius (mm)	4	12	24

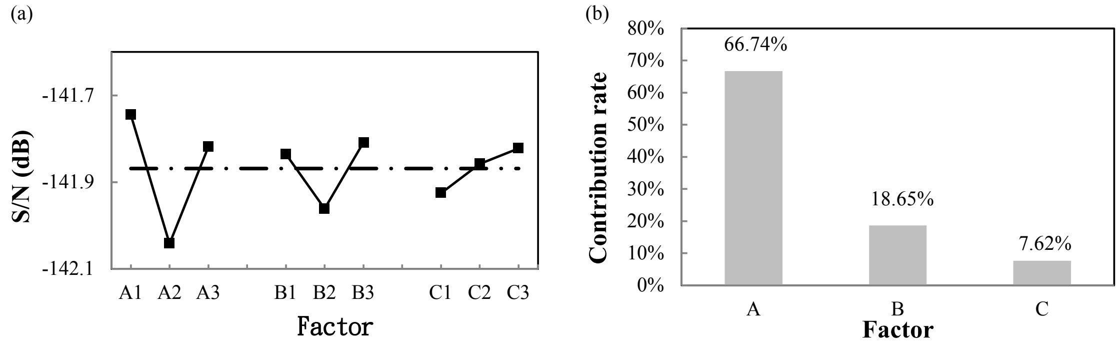

Fig.5. Maximum ram load: (a) S/N response graph; (b) factor contribution histogram.

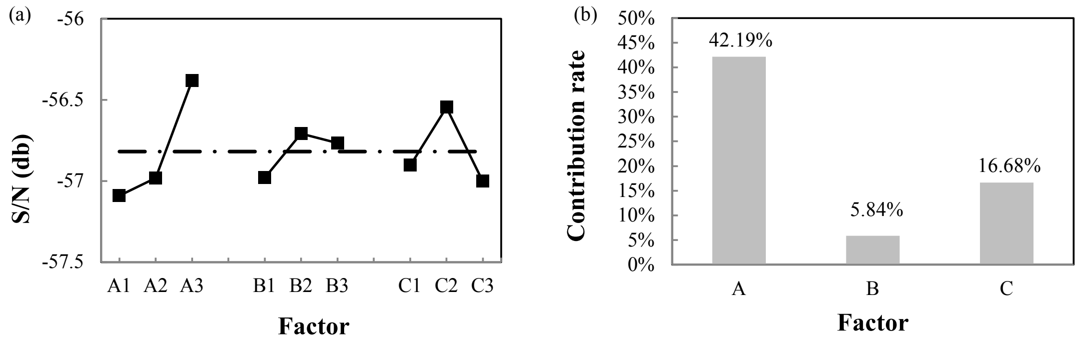

Fig. 6. Maximum die stress of upper die: (a) S/N response graph; (b) factor contribution histogram.

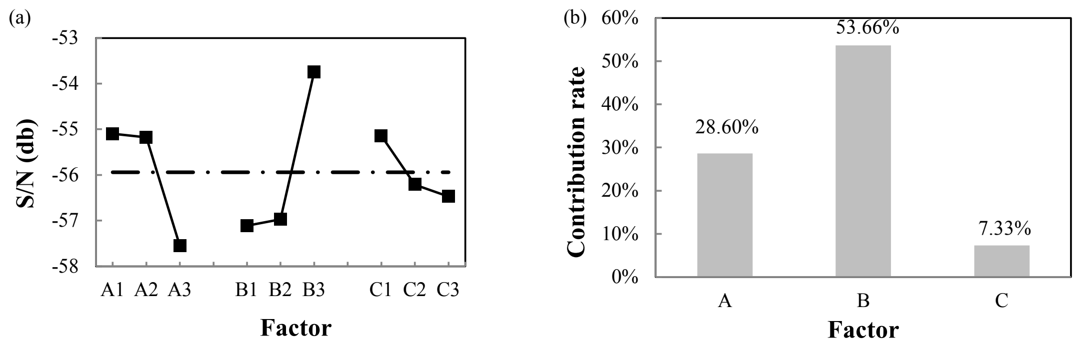

Fig. 7. Maximum die stress of lower die: (a) S/N response graph; (b) factor contribution histogram.

3.4. Die manufacturing and extrusion process

Upper die was made by turning due to its mandrel character and further milling was conducted due to its port feature, as shown in Fig. 8(a). Lower die was made by rough turning and fine milling for pocket geometry and wire

EDM cutting for die bearing feature, as shown in Fig. 8 (b). Die material is SKD-61 and heat treatment operation was conducted to reach hardness of HRC-48. Fig. 8 (c)-(d) depicts the final product after steady state extrusion.

(a) (b) (c) (d)

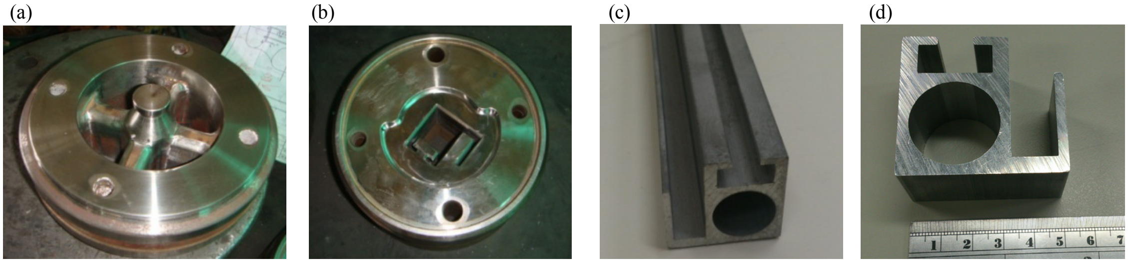

Fig. 8. Die manufacture: (a) top view of upper die; (b) top view of lower die. (c) hollow extrusion product and (d) cross section.

4. Conclusions

This study use DEFORM-3D finite element analysis software to simulation about welding chamber and bearing design which has compared billet velocity, die stress and ramp load. The welding chamber has three different types (Original type, Cut edge type and Double arc type) and two different length of die bearing (all 4 mm equal type and unequal type of 4 and 12mm) have considered studying. Furthermore, we study die stress and ramp load on Double arc type which with different size. The results show that the billet has the best fluidity and minimum dead zone in Double arc type, and the ramp load shows that R of 40 mm is smaller than 45 mm. In addition, unequal bearing length makes billet fluidity better. Finally, design and manufacture the extrusion die of a successful extruding process which has the double arc and unequal bearing length.

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