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EFFECTS OF GUIDING CHAMBER ON WELDING PRESSURE IN HOLLOW EXTRUSION DIE DESIGN OF AA7075

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ABSTRACT

Porthole die extrusion has a great advantage in the forming of hollow section of aluminum alloy tube. This paper aims at the development of an extruding seam square tube of AA7075 high strength aluminum alloy. In order to increase the welding pressure of the hollow AA7075 tube in extrusion process, a special die feature has been created. Several different proportions of chamber structure in outlet of extrusion die have been designed. The finite element analysis software DEFORM 3D to analyze various design parameters on the load – displacement and the welding pressure have been studied. In this study, a different high proportion in material guiding chamber has been defined. The results showed that if a suitable material guiding chamber has been built then welding pressure can be increased rapidly. When the ratio of chamber height and length is 2:1 the increased welding pressure is the best.

Keywords: extrusion, aluminum, welding pressure, die design.

1. INTRODUCTION

Porthole, bridge or spider die are currently used in the seamless hot extrusion of hollow or complex profiles of aluminum and light alloys. The metal flowing through these die has to split and then rejoin around the mandrel supports (webs) thus creating in the profile a longitudinal extrusion weld (seam) corresponding to the location of each web. The quality of the obtained roles is strictly affected by the effectiveness of the material joining inside the welding chamber. Welding occurs at the solid state if proper temperature and pressure values are reached, resulting in longitudinal bonding lines in the extruded parts. The solid state welding of the seams represents a major manufacturing problem. It affects the productivity of the process, the resistance of the prole and the aspect of the surface.

Extruded aluminum is a unique method to produce products with high precision and complex cross-sections. A special billet, cylinder is heated and put in cavity molding, then use the thrust of hydraulic presses to push billet plastic deformation through a system of mold.

Therefore, products with varied cross sections such as rods, wires, sheets, tubes, hollow or non-hollow parts can be fabricated which are suitable for application in aerospace, construction, automobile, machinery, heat exchanger [1]. In aluminum extrusion process, die design plays an important role by which products' qualities are directly affected [2]. If die characteristics such as geometries, accuracy, properties failed to produce sound products, die change or replacement will cause a time delay and cost increase. Other important process parameters such as billet and die pre-heat, extrusion speed are also needed to decide based on produce good product and obtain good service life for die.

In recent years, there are many researches analyzing plastic deformations by finite element analysis (FEA) increase because the developments of FEA and advances in computer simulation technologies [1-4]. For example, finite element analysis is used to predict the engineering design and simulate parameters of forming. Several engineering analysis software is developed based on finite element method (FEM). Kim et al. [5] studied the methods to increase welding pressure for seam hollow tube extrusion of AA3003 and found that by elongating welding chamber and increasing bearing length. H.H. Jo et al. [6] studied seam hollow tube extrusion of AA7003 by numerical analysis and experiments and found that the maximum welding pressure in the welding plane is approximately 3.5~5.8 times the average flow stress.

Since less paper studying AA7075 high strength aluminum alloy, this paper reports the using of FEM-based software DEFORM 3D [7] to simulate the hollow extrusion process, analyze die stress and measure welding pressure. Three kinds of inclined ratio designs at guiding chambers for extruding Al7075 are simulated and compared which can provide the design guide for obtaining larger welding strength.

2. MATERIALS AND EXPERIMENTAL METHODS

There is a complicated relationship between the flow modes and extruding variations of different extrusion methods. Therefore, different alloys and products require different extrusion modes. This study uses direct extrusion or forward extrusion, as shown in Fig. 1.

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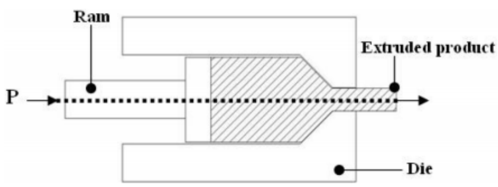

Figure 1. Scheme of direct extrusion.

The high strength aluminum alloy 7075 used in this study has good fatigue strength and workability. The alloy composition and mechanical properties are shown in Table 1 and Table 2.

Table 1. Compositions (wt%) of improved AA7075 alloy.

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Improved design	0.4	0.5	1.2	0.3	2.1	0.18	5.1	0.2	balance

Table 2. Compositions (wt%) of improved AA7075 alloy.

	Temper	Thickness in. (mm)	Tensile strength ksi (MPa)	Yield strength ksi (MPa)	Elongation %
AA 7075	0 Sheet & plate	0.015~2.00 (0.38~50.80)	40 (max) (276)	21 (max) (145)	9~10
	T6 Sheet	0.008~0.249 (0.203~6.32)	74~78 (510~538)	63~69 (462~476)	5~8

Figure 2 shows the flow stress of AA7075 which are used in DEFORM 3D to represent the true stress and true strain relationship at 440 °C and three different strain rates (40, 5, 0.1).

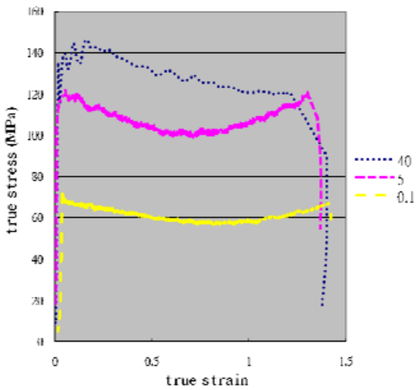

Figure 2. Flow stress of AA7075 at 440 ℃.

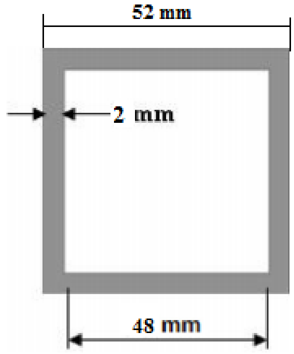

Figure 3. The shape square hollow tube.

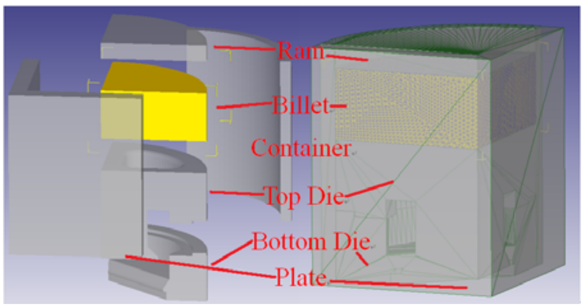

Figure 4. Simulation model (1/4 model).

Figure 3 shows the product shape of simulation result in this study. The product is a square hollow tube whose outer dimension is 52×52 mm and inner dimension is 48×48 mm. The thickness is 2 mm. Figure 4 is the exploded diagram of all the components in this study. The components are billet, bottom die, top die, container, plate, and ram. Figure 5 is the shape product simulated by Deform 3D. Table 3 shows the setting of simulation parameters in DEFORM 3D Pre-Processor.

Table 3. Setting of simulation parameters in DEFORM 3D.

Setting of nature (Ram, Container, Top Die, Bottom Die, Plate)	Rigid Body
Workpiece material data	Aluminum Alloy 7075
Mesh	60,000 approx.
Min Element size	1 mm
Size ratio	2
Temperature	440 ℃
Bcc type	Plate
Friction type	shear friction (m)
Shear friction factor (m)	Billet to billet 1 Billet to die 0.7
Stroke per step	0.34 mm/step
Plate velocity	0.5 mm/Sec

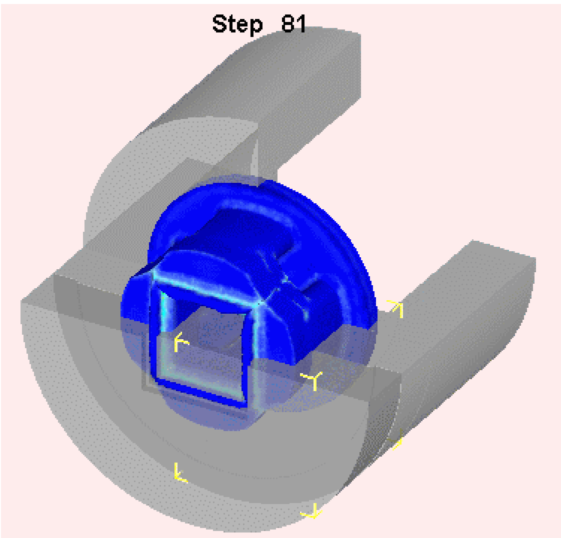

Figure 5. Square hollow tubes formed during extrusion by simulation.

Figure 6(a) is the traditional outlet structural design of 6XXX series extrusion die. The material welds easily when extruding seam hollow tube by using 6XXX series aluminum alloy, so the pressure of welding surface and die geometry are not considered seriously when designing the dies. The design concept is usually on rapid material flow, high efficiency, and high productivity. For this reason, draft angle is usually adopted at outlet region to assist material flow. Figure 6(b) is the design of this study. In order to increase the welding pressure and help the welding condition, the geometric design of outlet is much complicated, which can block the material flow. The mandrel is reduced to increase the area of welding, and the welding pressure is improved significantly and effectively. This design is hard to manufacture, and is suggested to be a reference of simulation. Figure 6(c) is the die design of this study based on die design principle, measurement of welding pressure and outlet. The draft angle is not adopted at mandrel so the flow velocity is increased. The welding surface is designed as a rectangular section and the welding area is lessened to increase the welding pressure. Figure 6(d) is the improved design of that in Fig. 6(c). Inclined material guiding chambers are adopted at the outlet of bottom die and the bearing of top die. Welding surface is also modified as a rectangular section with an inclined angle. In this design, the advantages of that in Fig. 6(c) are kept and the welding pressure is increased efficiently.

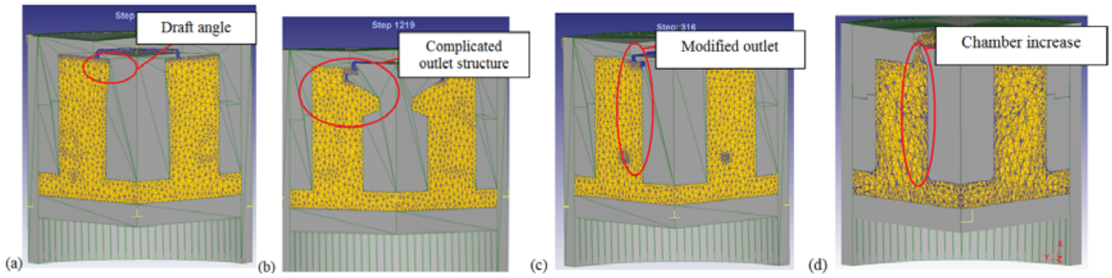

Figure 6. Various die design of extrusion: (a) traditional die design with a draft angle;(b) modified die whose outlet structure is complicated;(c) modified die whose outlet structure is amend; (d) modified die based on the design of Fig. 6(c).

Figure 7 is the structural design diagram of material guiding chamber. In this study, the ratio of height to length in the material guiding chamber is the reference of the inclined angle in the guiding chamber. The inclined ratio in the simulation designs are (1:2), (1:1), and (2:1) respectively. Figure 7 depicts the design with inclined ratio of (2:1).

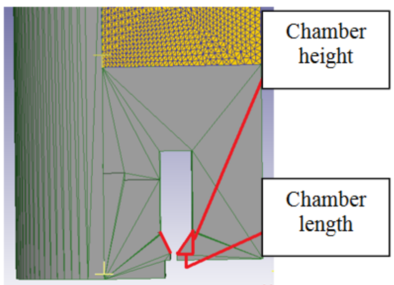

Figure 7. The relationship between material guiding chamber height and length.

3. RESULTS AND DISCUSSION

All the simulation results of various die designs are completed by using DEFORM 3D simulation software. In the post-processor, the steps which the billets are completely fill with the chambers and flow out of the outlets, so called steady stage, are used to observe the normal welding pressure of welding surface and the load-stroke curve.

Figure 8(a) shows the normal welding pressure of traditional 6XXX series aluminum alloy extrusion die design. The maximum pressure value of scale bar is 500 MPa. There is a zero pressure zone at lower left corner of welding surface. The pressure of the periphery of this zero pressure zone is higher than 500 MPa. It is because the meshes of the welding surfaces penetrate each other. When a section is set to observe the welding pressure, the section and mesh overlap, causes the zero pressure zone occurs at the central part, and the high pressure distribution occurs at the periphery. The original welding pressure should be about 300 MPa. Figure 8(b) shows the normal welding pressure of the complicated outlet feature die design used to increase the welding pressure of this study. The maximum pressure value of scale bar is 600 MPa. The maximum pressure at welding surface is about 500 MPa, but the distribution is not uniform. The more the observed zone closes to the outlet, the more the pressure decreases. Besides, this design is hard for the die makers to manufacture. Figure 8(c) is the pressure distribution of the die design of this study based on die design principle, measurement of welding pressure and outlet. No draft angle is adopted at the mandrel and the profile of welding surface is a regular rectangle. The maximum pressure value of scale bar is 500 MPa, and the actual welding pressure is closed to 400 MPa.

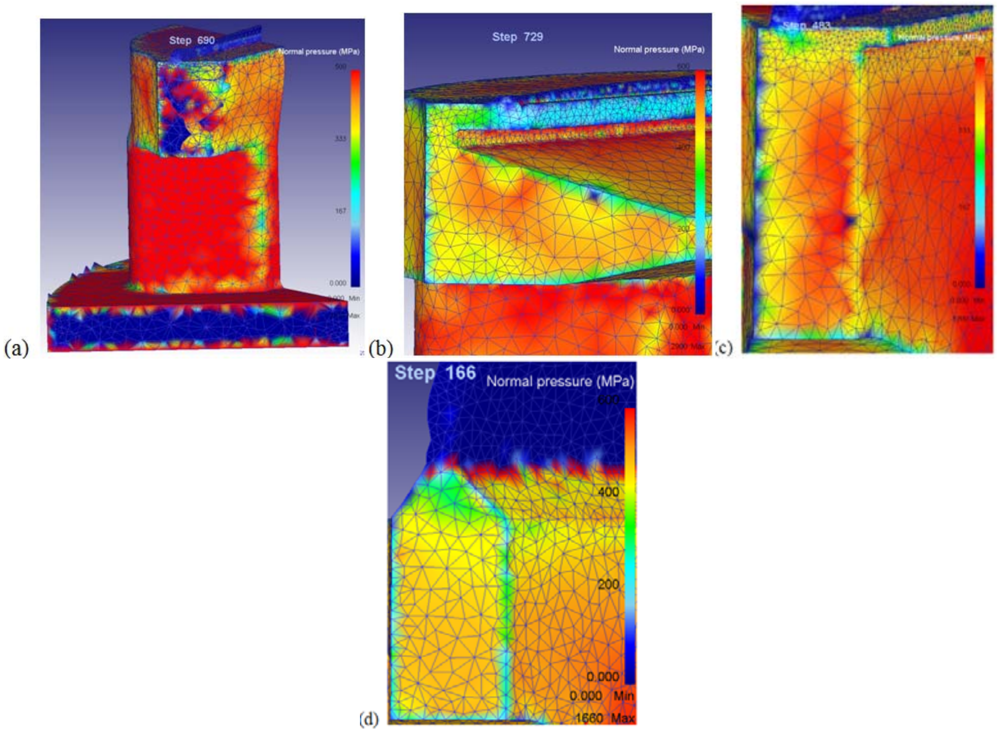

Figure 8. Pressure distributions of various die design of extrusion: (a) normal welding pressure of traditional 6XXX series aluminum alloy extrusion die design;(b) normal welding pressure of the complicated outlet feature die design; (c) pressure distribution of the die design of this study based on die design principle, measurement of welding pressure and outlet; (d) pressure distribution of the improved design based on that of Fig 8(c).

The distribution is much uniform than that of Fig. 8(b), but when we observe the distribution of welding pressure by using the outlet as a centerline, the welding pressures of right and left sides are not symmetric. In this case, the welding surface is modified as a regular rectangle to reduce the welding area. The welding pressure of this simulation is higher and the transverse pressure distribution is much uniform than those of Fig 8(a). But the vertical pressure distribution is still not uniform. Figure 8(d) is the pressure distribution of the improved design of that in Fig. 8(c). The maximum pressure value of scale bar is 600 MPa, and the actual maximum welding pressure is closed to 500 MPa. The transverse pressure and vertical pressure distributions are much uniform, the more the pressure and decline when the more the observed zone closes to the outlet. Comparing among the designs of (a), (b) and(c), the design of (d) increases the welding pressure, has uniform distribution of welding pressure, and the die is able to be manufactured easily.

In this study, 3 different kinds of inclined angle are designed. The ratio of material guiding chamber height and length in the simulation designs are (1:2), (1:1), and (2:1) respectively. The comparisons are done based on the same extrusion conditions and pre-processor settings. Figure 8 shows the load-stroke curves of these structural designs and Figure 9 shows the pressure distributions of the welding surfaces of these designs. When the stroke for the case (2:1) is 12.5 mm, the material flows into the merging region because the inclined angle is the largest, cause the material flows contact and flow into the merging region early while flowing into the chamber; when the stroke of ratio (1:2) is 15 mm, the material flows into the merging region because the angle is the smallest; and the stroke of ratio (1:1) is somewhere in between those of ratio (2:1) and ratio (1:2), as shown in Fig. 9. The predicted load of ratio (2:1) rises faster than the other cases, but when we observe the predicted loads of merging region, the gradients and trends of these load curves are almost identical. The predicted load of ratio (2:1), which is the highest, is about 262 tons; that of ratio (1:2), which is the lowest, is about 196 tons; that of ratio (1:1) is about 243 tons. These researches show that the larger the inclined angle is, the higher the welding pressure is obtained. Of course, the extrusion load increases simultaneously.

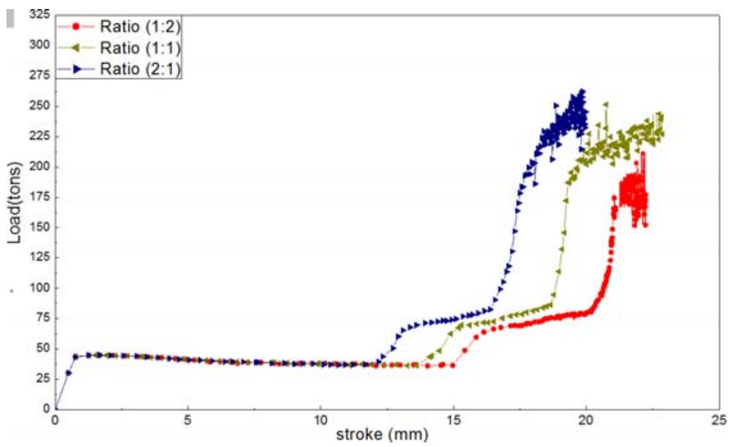

Figure 9. Load-stroke curves of various inclined ratio designs at guiding chambers.

Figure 10(a) shows the pressure distribution at welding surface of ratio (2:1). The maximum pressure value of scale bar is 600 MPa, and the maximum predicted welding pressure is about 550 MPa. The larger the inclined angle is, the more obvious welding pressure is observed along extrusion direction. The pressure at outlet drops rapidly. Fig 10(b) shows the pressure distribution at welding surface of ratio (1:1). The maximum pressure value of scale bar is 600 MPa, and the maximum predicted welding pressure is about 500 MPa. The inclined angle is smaller than that of ratio (2:1), and the welding pressure distribution observed along extrusion direction is more uniform. Besides, the pressure at outlet drops less. Fig 10(c) shows the pressure distribution at welding surface of ratio (1:2). The maximum pressure value of scale bar is 600 MPa, and the maximum predicted welding pressure is about 350 MPa. The inclined angle is the smallest, and the welding pressure distribution observed along extrusion direction is the most uniform. The trend of pressure drop at outlet is not obvious, and the welding pressure distribution at welding surface is quite uniform.

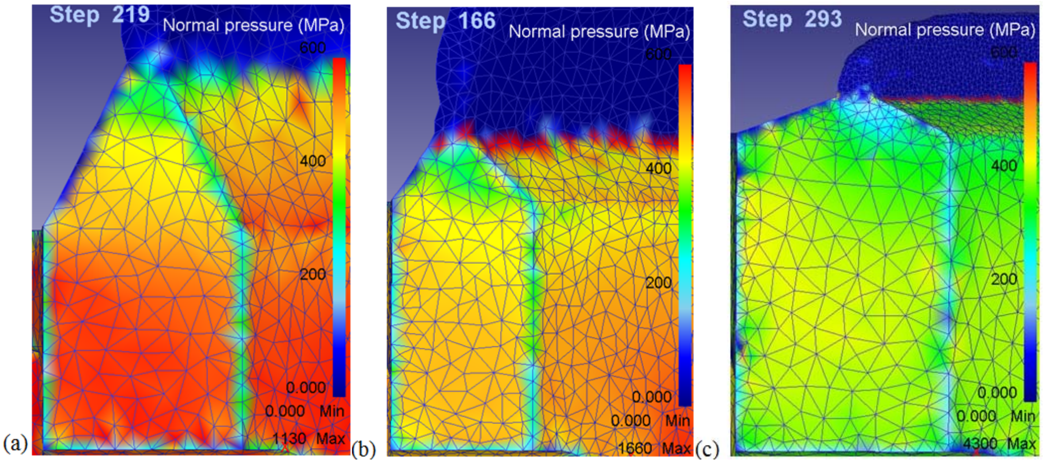

Figure 10. Welding pressure distributions of various inclined ratio designs at guiding chambers: (a) pressure distribution of ratio (2:1); (b) pressure distribution of ratio (1:1); (c) pressure distribution of ratio (1:2).

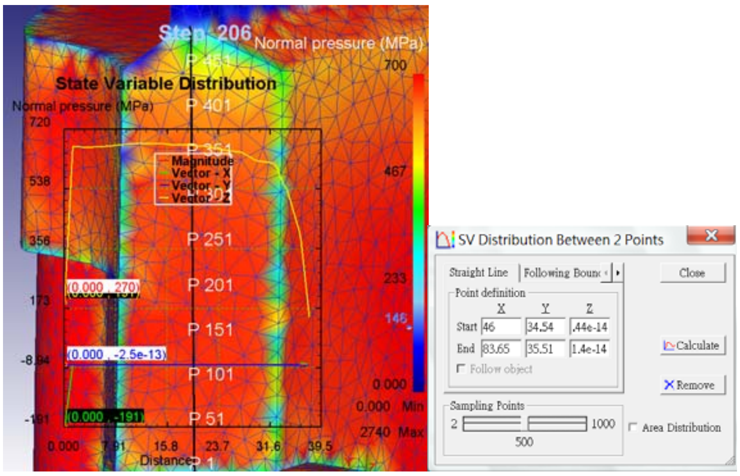

Figure 11. Point tracking of welding pressure at welding surface in DEFORM 3D Post-Processor.

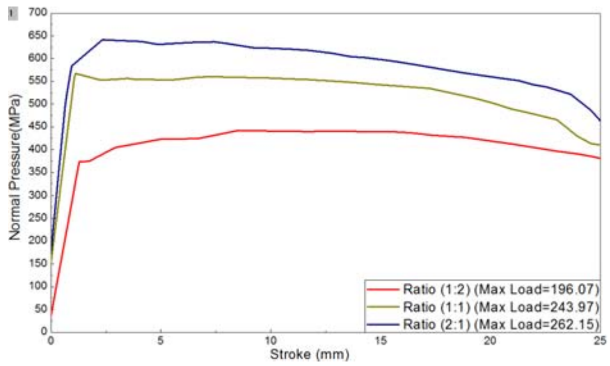

Figure 12. Pressure curves observed at welding surfaces of various inclined ratio designs at guiding chambers.

In order to assist investigations efficiently, point tracking is used to measure the accurate pressure values in DEFORM 3D Post-Processor, as shown in Figure 11. Approximately 500 nodes are tracked along the contact line of the welding surface and the pressure at each point is measured. Pressure curves, as shown in Figure 11, consist of these pressure values. Figure 12 shows the pressure curves of various inclined ratio designs at guiding chambers. The initial pressure is relatively low. When the material flows reach the welding surface, the pressure values are nearly identical. The pressure drops slightly at outlet. It also shows that the welding pressure of ratio (2:1), about to 600MPa, is the highest; the welding pressure of ratio (1:2), about to 400MPa, is the lowest; the welding pressure of ratio (1:1), about to 550MPa, is somewhere in between those of ratio (2:1) and ratio (1:2). Moreover, the vertical pressure near die outlet of ratio (2:1) decreases most significantly, and that of ratio (1:2) is the most uniform.

4. CONCLUSIONS

The design concept of extrusion dies for 6XXX series aluminum alloy are usually on rapid material flow, high efficiency, and high productivity. It is hard to provide sufficient welding pressure when applying to 7XXX series aluminum alloy extrusion. In this study, a modified extrusion die is developed by lessening the welding area and fixing the sectional geometry. This design increases the welding pressure significantly, which increases from 300 MPa to 400 MPa, and simplifies the die manufacture.

Compared with traditional die design, the design of this study increases the welding pressure significantly because the guiding chamber is optimized. The pressure rises from 300 MPa to 500 MPa. The pressure distribution is much uniform than that of traditional die because the welding surface is designed as a symmetric rectangle. It also helps the material welding significantly.

In this study, 3 kinds of inclined ratio designs at guiding chambers, including (1:2), (1:1), and (2:1), are presented. The predicted welding pressures are 400, 550, and 600 MPa, respectively. The simulation results shows that the ratio (2:1) provides the maximum welding pressure, and the ratio (1:2) has the most uniform pressure distribution. Besides, the outlet pressure of ratio (2:1) drops significantly.

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TÓM TẮT

NGHIÊN CỨU ẢNH HƯỞNG CỦA KÊNH DẪN HƯỚNG ĐẾN ÁP LỰC HÀN TRONG THIẾT KẾ KHUÔN ÉP ĐÙN ỐNG RỖNG HỢP KIM NHÔM AA7075

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Khuôn ép đùn có một lợi thế lớn trong việc hình thành các phần rỗng của ống hợp kim nhôm. Mục đích của bài báo là đề xuất nhằm phát triển một khuôn ép đùn đường hàn ống vuông AA7075 hợp kim nhôm có độ bền cao. Để tăng áp lực hàn ống Al7075 rỗng trong quá trình ép đùn, một số thiết kế khuôn đặc biệt đã được tạo ra. Một số tỷ lệ khác nhau của cấu trúc buồng ép trong kênh thoát của khuôn ép đùn đã được thiết kế. Các phân tích phần tử hữu hạn trên phần mềm DEFORM 3D để phân tích các thông số thiết kế khác nhau ảnh hưởng tới tải trọng- chuyển vị và áp lực hàn đã được thực hiện. Trong nghiên cứu này, một tỷ lệ khác nhau trong kênh dẫn vật liệu đã được xác định. Kết quả cho thấy rằng nếu một kênh dẫn vật liệu phù hợp được xây dựng thì áp lực hàn có thể được tăng lên nhanh chóng. Các tỷ lệ của kênh dẫn như chiều cao và chiều dài là 2:1 áp lực hàn tăng là tốt nhất.

Từ khóa: ép đùn, hợp kim nhôm, áp suất hàn, thiết kế khuôn.