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Development of a multi-container extrusion method for extruding lightweight wide plates and sheets

To cite this article: W Li *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1270** 012061

Development of a multi-container extrusion method for extruding lightweight wide plates and sheets

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Abstract. Extrusion of wide plates and sheets of light alloys has been studied over a long period of time, yet the extrudable width of the material is still limited due to high extrusion force requirement. To overcome this drawback, a new multi-container extrusion process is proposed in the research, which allows the production of lightweight plates and sheets with less force compared to that of existing extrusion methods. A lab scale feasibility study system with three containers has been designed and built and tested for AA1060 billets. Experimental work has been carried out with the extrusion temperature of 450℃ and extrusion speed of 0.5 mm/s. Optical microscopy observation and tensile tests have been performed for the extruded materials at different positions to investigate the extrusion welding quality between the three extrusion billets. The test results show that the welding quality improves as extrusion progresses and the overall welding quality is stable. This study demonstrates the feasibility of the new multi-container extrusion method.
Keywords. extrusion; multi-container; aluminium alloy; wide sheet; welding quality

1. Introduction

Wide sheets and profiles of lightweight alloys such as aluminium and magnesium alloys have wide applications in many fields, especially in automobile and aerospace industries [1-3]. Conventional technology to manufacture wide aluminium sheets for automobile is rolling, which requires repeatedly rolling process and costly plant. To overcome these drawbacks, extrusion, as a single step manufacturing method, is a possible substitution to produce thin wide aluminium sheets economically. Additionally, the compressive stress of extrusion is in three directions, which generally means larger deformation compared to rolling and leads to finer microstructure and mechanical properties [4,5]. The critical problem of extruding thin wide sheet is the control of extrusion ratio to achieve acceptable load requirement. There has been plenty research on extrusion process, but so far there is no adequate solution to address this problem. The traditional extrusion with single large container is not capable for extruding product wider than the billet diameter and usually leads to large extrusion ratio and load and requires enormous plant for manufacturing wide sheets and profiles; The use of expansion die could widen the product compared to original billet in certain extent [6], but the expansion is limited by expansion die angle and not suitable for producing wide panels for automobiles; Shang *et al* has proposed a method to fabricate wide plate through extruding curved material followed by rolling for flattening, but the mechanical quality at curves and plant cost are hard to control [7]; Quan *et al* used heteromorphic extrusion container to reduce the extrusion ratio, but it leads to high friction and maintenance [8]

A new process called multi-container extrusion method has been developed to produce lightweight wide sheet with low extrusion ratio. Multiple small containers have been used to replace conventional large container to control the extrusion ratio, hence force requirement. To evaluate the feasibility of this method, a lab scale experiment system with three containers has been designed and built. AA 1060 billets are used to produce sheet material. The weld seam between the billets at different positions of the extrudate has been observed and analysed. Tensile tests have been carried out to acquire mechanical properties of extrudate.

2. Process principle

The multi-container extrusion system consists of a container block with multiple containers, a die set and multiple rams with the same number of containers as shown in figure 1. For the beginning, the billets of raw material, with same number of containers, are preheated to elevated temperature, placing into the containers on heated container block. The rams are then moved simultaneously into the containers, push the heated billets into die set to be welded in the welding chamber and finally deformed by the exit die into wide sheet and plate material.

Compared to conventional extrusion process, multi-container extrusion method uses multiple containers with suitable arrangement instead of single large container. This could significantly reduce the cross-sectional area of billets and therefore result in lower extrusion ratio, hence force requirement. In this method, the extrusion ratio is controlled by changing the number of containers. The extrusion force required for manufacture is calculated using empirical formula as follows [9]:

$$\lambda = \frac{A_b}{A_e} \tag{1}$$

$$D = n \times d \tag{2}$$

$$\varepsilon = ln\lambda \tag{3}$$

$$P = ab\overline{Y_f}\left(\varepsilon + \mu\frac{4L}{D}\right) = ab\overline{Y_f}(ln\lambda + \mu\frac{4L}{D}) \tag{4}$$

$$F = P \times A \tag{5}$$

$$k_F = \frac{F_m}{F_s} = \frac{ab\overline{Y_f}(ln\lambda_d + \mu\frac{4L_d}{d}) * \frac{n\pi d^2}{4}}{ab\overline{Y_f}(ln\lambda_D + \mu\frac{4L_D}{D}) * \frac{\pi D^2}{4}} = \frac{ln\lambda_d + \mu\frac{4L_d}{d}}{(ln\lambda_D + \mu\frac{4L_D}{D}) * n} \tag{6}$$

where λ is the extrusion ratio; A_b and A_e are the cross-sectional area of original billet and extrudate respectively; ε is the true strain; *D* is the diameter of large container; *n* is the number of small containers; *d* is the diameter of small containers; *P* is the extrusion pressure required; $\overline{Y_f}$ is the yield strength; *a* is the material factor, usually *a* = 1~1.35, for hard alloy *a* =1.35, and for soft alloy, *a* = 1.0; *b* is the production cross section factor, for round cross section *b* = 1, and for complex profile, *b* = 1.1~1.6 according to the complexity; μ is the friction factor; *L* is the length of container; *F* is the force required for extrusion [9]; k_F is the ratio between the force requirement of *n* small containers and a single large container; F_m, λ_d, L_d are the values for *n* small containers; F_s, λ_D, L_D are the values for a single large container.

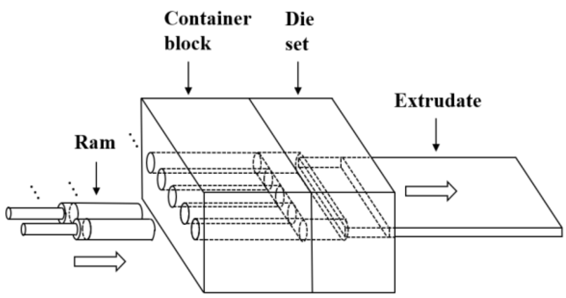

Figure 1. Schematic of multi-container extrusion system.

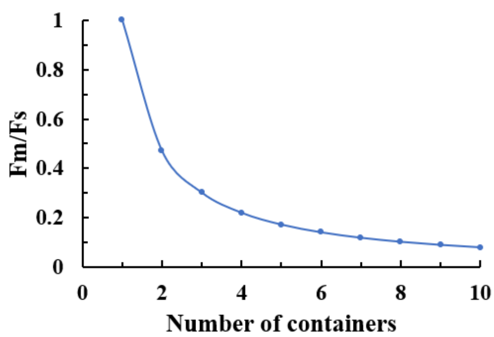

Figure 2. Calculated force requirement versus number of containers.

Take AA6061 sheet with 800 mm in width and 5 mm in thickness as an example, figure 2 shows the relationship between the calculated force requirement and number of containers for extrusion, where F_m is the extrusion force required for multi-container extrusion method and F_s is the force required for a single large container using the conventional extrusion method. As is seen, the force required is halved when using two containers, and continually decreases with increasing the number of containers used.

3. Experiment

In this research, a container block with three containers and a die set are designed and manufactured for the experimental investigation of multi-container extrusion method. As shown in figure 3, the die set consists of a deflector to control the material flow and a forming die for extrusion. Three containers are paralleled to one another. Pure aluminium alloy AA1060 round billets in O temper are used as the raw material, with 38 mm in diameter and 185 mm in length. The tool set is installed on an extrusion machine with a load capacity of 300 tonne. The tool set and raw billets are heated to 450 °C separately before extrusion. Then the billets are placed into each container. During the extrusion process, the billets ae pushed simultaneously by rams with a speed of 0.5 mm/s and extruded into sheet material with the dimensions of 3 mm in thickness and 177 mm in width. During the extrusion process, the highest force reaches 81 tonnes.

The extrusion force for the single container and 3 small containers has been calculated using equation (1) to (5). Take a = 1, b = 1.4, $\overline{Y_f}$ = 22 MPa, d = 38 mm, D = 114 mm, L/D = 5, μ = 0.325, the extrusion force requirement is calculated as follows,

$$F_m = P \times A = ab\overline{Y}_f \left(ln\lambda_d + \mu \frac{4L_d}{d} \right) * \frac{n\pi d^2}{4} = 89 \text{ tonne} \quad (7)$$

$$F_s = P \times A = ab\overline{Y}_f \left(ln\lambda_D + \mu \frac{4L_D}{D} \right) * \frac{\pi D^2}{4} = 303 \text{ tonne} \quad (8)$$

Therefore, 70% of calculated force reduction has been achieved.

Microstructure of cross section of extruded sheet is examined using optical microscopy to observe the weld seams formed between billets at different positions. The specimens are cut from the extrudate, mounted in Bakelite resin, grinded and polished to 1 μm, followed by etching using Keller's reagent for 40 s [10].

Tensile tests are performed on an Instron machine to obtain the mechanical properties of the final product. The extruded sheet is heated at 300 °C for 2 hours and pressed with a force of 10 tonne for flattening, then cooled in furnace to room temperature. Tensile test specimens are cut from the extrudate at different distances, i.e. 30, 50, 130, 150 mm, from the front end. The specimens are tested at room temperature with an initial strain rate of 0.00025 s^{-1}, then changed into 0.0067 s^{-1} when reaches 0.3 % of gauge length to acquire accurate yield and tensile strength.

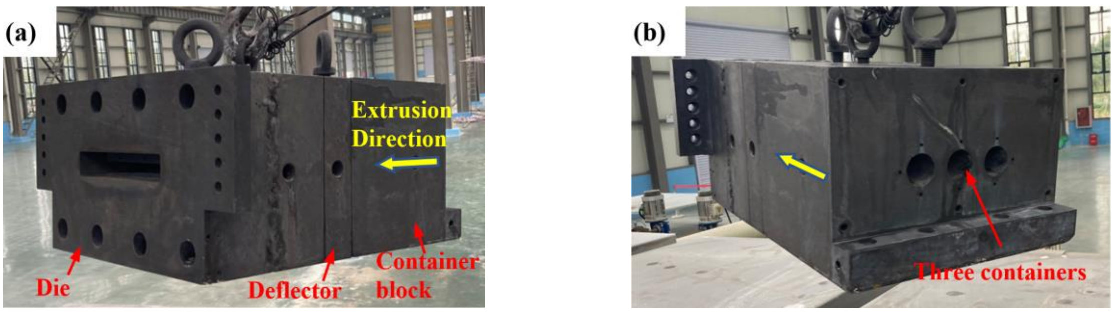

Figure 3. Extrusion system for experiment with three containers showing (a) front view and (b) back view.

4. Results and discussion

4.1. Microstructure

The OM results of AA1060 sheet after extrusion are shown in figure 4. The specimens are taken at

IOP Conf. Series: Materials Science and Engineering 1270 (2022) 012061 doi:10.1088/1757-899X/1270/1/012061

distances of 0, 90 and 180 mm from front head to observe the evolution of weld seam as extrusion progresses as shown in figure 4(a). The two welding lines between three billets are symmetrical. The position of welding line gradually moves from 50 mm from side to one third of width. This is due to the unstable material flow and exit velocity difference between middle billet and side billets at the beginning of extrusion. It also results in the semi-circular projection of billet in the middle at the front head. A clear arciform weld seam is observed at 0 mm position as seen in figure 4(b). The arciform welding line is due to the higher flowing velocity of material in middle billet and hence uneven horizontal expansion compared to billets at both sides. The black dots along the welding seam are the voids aroused by insufficient welding time. As extrusion progressed, there is no clear sign of voids at position of 90 mm from the front head as shown in figure 4(c). At this point, the middle billet is furtherly pressed vertically, and partially enfolded by the billets at both sides. The boundary of different billets could still be distinguished, but the width of welding seam is decreased compared to figure 4(b), suggesting better weldment between billets compared to 0 mm position. Figure 4(d) indicates the microstructure at 180 mm from front head where no clear sign of welding line is observed. This suggests the weldment of billets has been furtherly improved.

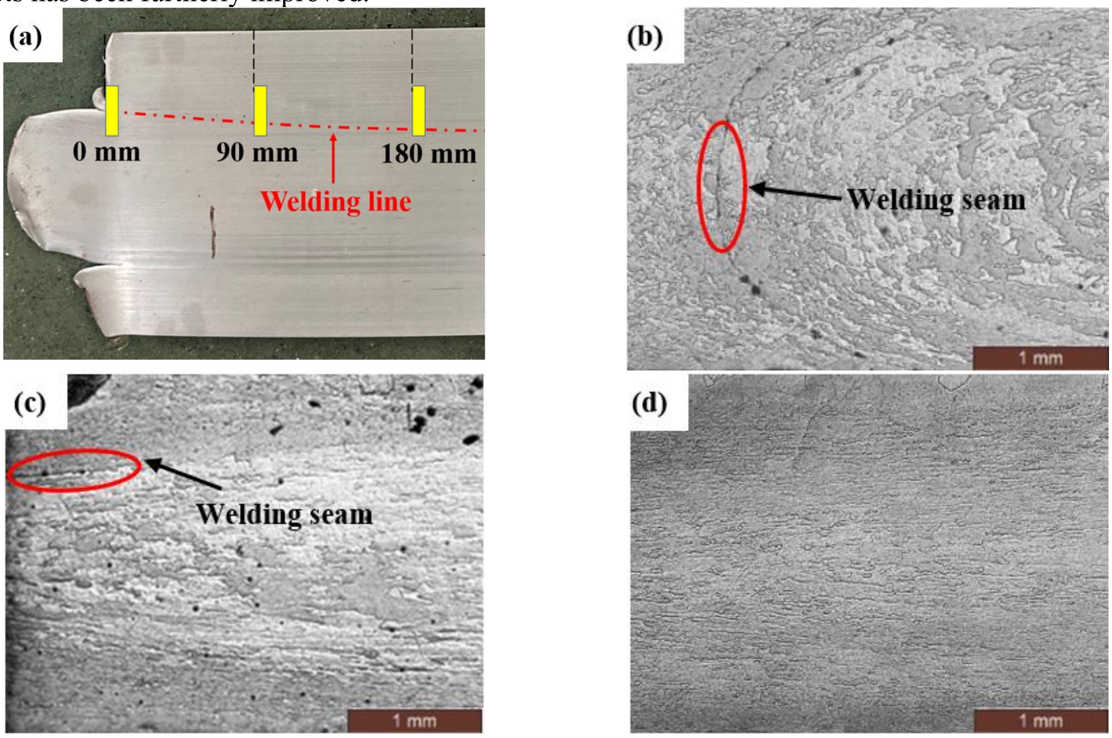

Figure 4. Micrographs at different sampling positions, showing (a) the welding seams formed between billets gradually disappearing from the front end 0 mm (b) to 90 mm (c) to 180mm (d) of AA1060 extruded under 450°C, 0.5 mm/s.

4.2. Tensile behaviour

The true stress-strain curve during tensile test of AA1060 at different locations of extrudate are obtained to show the tensile behaviour of extruded AA1060 sheet. The specimens are taken at distance of 30 mm, 50 mm, 130 mm, and 150 mm from the front head respectively as shown in figure 5(a). The positions of welding seam are pointed out in red lines. The detailed dimension of specimen is illustrated in figure 5(b). As the mechanical properties are strongly related to the microstructure, hence the tensile results are used to analyse the welding quality of extruded AA1060 sheet. As seen in figure 5(c) is the stress-strain curve of the 4 specimens stretched under same testing procedure and temperature. It is clear to be seen that the tendency of 30 mm and 50 mm specimens and the tendency of 130 mm and 150 mm specimens are similar respectively. The ultimate tensile strength of 50 mm specimen is slightly higher than the other specimens, which is possibly due to experimental error. The strains at ultimate tensile stress point of 4 specimens are also similar. The elongation of 30 mm and 50 mm specimens is close to 30%, while for 130 mm and 150 mm, it is close to 20%. As for the yield strength, it is obvious that the yield strength of 130 mm and 150 mm specimens of 43 MPa is higher than that of 30 mm and 50 mm specimens of 35 MPa. The reduction of elongation along with the increase of yield strength from 30 mm to 180 mm may be due to the difference of thermal history at each position. As shown in figure 5(d) is the fractured specimens. The positions of fracture of specimens show randomness and there is no clear sign of fracture and welding seam taking place at the same position. This indicates that all 4 specimens have high quality welding seams. Although the welding seam are clear to be observed between 0 mm to 180 mm as shown in figure 4(b)-(c), but it is possibly due to the effect of etching and not necessarily related to the mechanical properties.

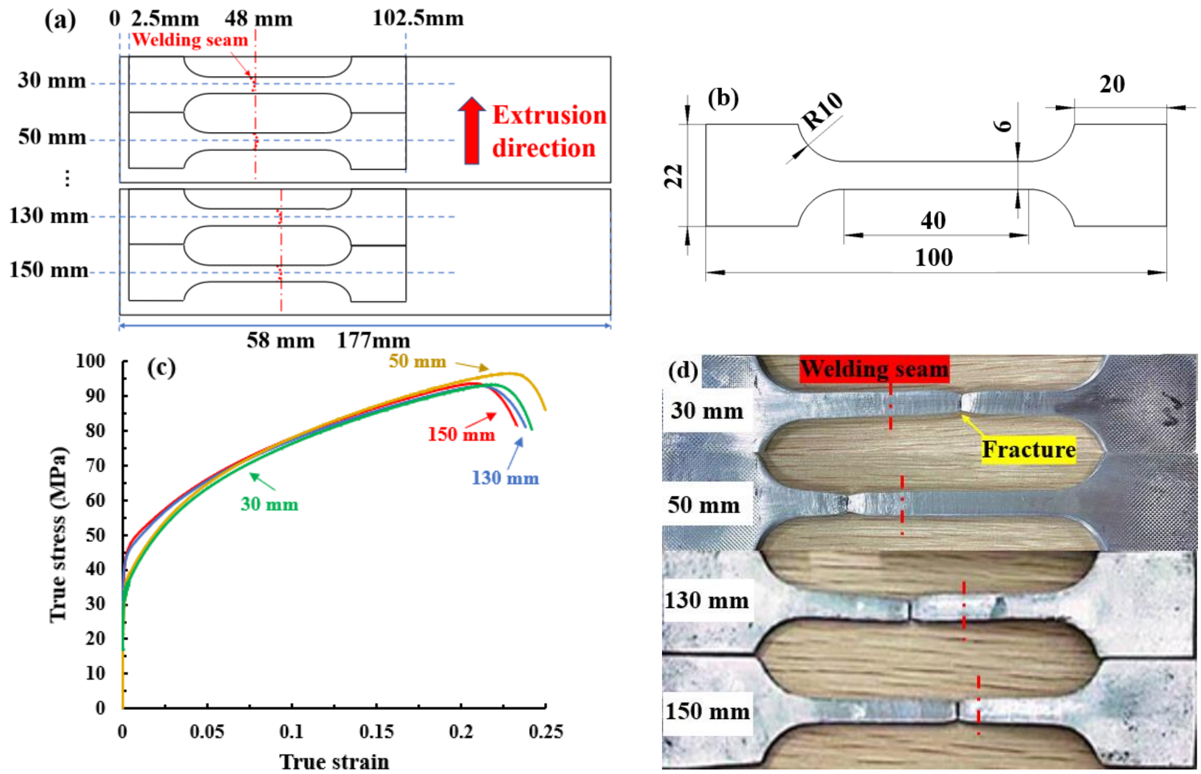

Figure 5. Tensile testing specimens and testing results of AA1060, showing (a) sampling positions taken from 30, 50, 130 and 150 mm to the front end, (b) geometry and dimensions, (c) good mechanical properties and (d) tested specimens.

5. Conclusions

A lab scale experimenting system with three containers has been developed and used to test the feasibility of the multi-container extrusion system for producing wide-thin plate with reduced force. The extrusion force could be reduced by about 70% using the developed extrusion system compared with that of the traditional extrusion process. The welding seam between the three billets completely disappears at about 180mm from the front end for AA1060 extruded under the extrusion temperature of 450°C and extrusion speed of 0.5 mm/s, high-quality extrusion welding seams have been obtained.

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