The Favourable Choice of the Shape of Billet's Contact Surface to Quality of Extruded Aluminium Profiles

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Summary

The theoretical and experimental method of optimization the aluminium billet’s contact surface during extrusion have been presented in this paper. The theoretical assumption, based on welding criteria, have been confirmed by experimental researches. The technique of measurement has been shown as well. Experiments are made using plasticine as a substitute material. Some kind of different variants have been investigated. The theory and experiments have been provided to optimize the modeling shape and may help in design and technology. The theory has been tested experimentally using a plasticine as a substitute material and a plexiglass die such that the velocity fields at the surfaces could be observed and measured during plastic flow, allowing the empirical coefficients in the mathematical formulation to be estimated. On the basis of the theory and experiments an optimal billet’s contact surface was proposed.

Keywords: innovative materials and foundry technologies, extrusion of aluminium alloys, experimental modelling, optimal shape of billet

1. Introduction

An aluminum extrusion is a process in which the metal is heat-treated and pushed through a die to create a form with design parameters desired by the manufacturer [8, 9, 10]. This manufacturing requires tight tolerances to ensure accurate interfacing with other parts. Along with this quality, the shape can be engineered to distribute material at optimal locations along the piece in order to produce stronger parts. The manufacturing of an aluminum product using the extrusion process helps produce the most cost-effective and accurate shapes needed by manufacturers.

In general, four basic approaches have been used for analysis of the complex phenomena occurring in the zones of material welding during hot extrusion of aluminium alloys [1, 2, 3, 4, 5, 6].

The earliest efforts concentrated on criteria of purely empirical character based on the accumulated industrial experience. As a rule, such criteria have been formulated in terms of technological guidelines concerning the die shape and dimensions, billet temperature and ram velocity. The technological criteria are still in practical value and are being continually developed. Proper insight into the physical nature of the process occurring along the contact zone of the two material surfaces being weld together comes from metallurgical hypotheses [4, 5, 6]. One can mention interpretations based on recrystalization, diffusion and adhesion phenomena, dislocation mechanics and energetic approach. The metallurgical hypotheses emphasise the role of the numerous factors concerned with the contact conditions such as the surface conditions, structure and texture of the surface layers, material temperature, properties of the oxide film, presence and properties of contaminants and conditions facilitating creation of interatomic bonds [7, 15].

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metallurgical hypotheses are of great importance for better understanding of the welding phenomena but are of limited value from the point of view of hot extrusion optimisation because of their qualitative and often non-formal descriptive character.

Adhesion bonding of two contacting surfaces requires certain amount of energy to be supplied into the contact zone. The energy necessary for a permanent bond to be created is assumed to be proportional to the active contact area. Thus, it is postulated that a permanent bonding is created once the intensity of the deformation energy obtains some critical value. It can be written as follows:

\[ \int_{t_0}^{t} 1(T, \sigma_i) \sigma_n v_n dt + \int_{t_0}^{t} F_2(S) \sigma_f v_f dt \geq E_{kr} \quad (1) \]

where:
- \( \sigma_n \) - normal stress,
- \( v_n \) - normal velocity,
- \( \sigma_f \) - tangential stress,
- \( v_f \) - tangential velocity on contact surface during welding process, in time from \( t_0 \) to \( t \).

Values: \( F_1(T, \sigma_i) \) and \( F_2(S) \) are the functions depend on temperature \( T \), yield stress \( \sigma_i \) and quality of the contact surface \( S \). Value \( E_{kr} \) means the smallest, necessary energy, which guarantee the best quality of weld. The time of welding (from \( t_0 \) to \( t \)) depends on shape of the contact surface, yield stress distribution and temperatures.

From theoretical analysis is possibly to obtain approximate, favourable shape of billet’s end-parts.

2. Shape of contact surface analysis

The criterion (1) gives direct information to optimize shape of billets. Fig. 1. show the scheme of extrusion process with billets, which have flat (upper II) and rounded (bottom I) end–pieces. Fig. 1b. presented qualitative the distribution of normal stress \( \sigma_n \) during extrusion.

![Fig. 1. The first (I) variant of extrusion](image)

![Fig. 2. The second (II) variant of extrusion](image)

The average value of \( \sigma_{na} \) (Fig. 2.) is as follows:

\[ \sigma_{na} = \frac{4P}{\pi h^2} \quad (2) \]

where:
- \( P \) – extrusion force,
- \( h \) – actual diameter of contact.

The hatch area XOY is variable. Tangential stress on contact surface amount to \( \sigma_f \). Material is carrying out into this space with average speed \( v_f \). Time of the contact is determined by section OB. Next, an assumption was made, that both of billets have the identical temperature distribution and yield stress. The same scenario, but for mutually rounded shape of contact is shown on Fig. 2. In conclusion, from comparison of variant I and II, bigger velocity \( v_f \) in hatch area XOY will appear in presented Fig. 1. In this case area XOY is smaller almost two times.

So, with assumption about similarity distribution of average normal stress \( \sigma_n \), the second segment in criterion (1) will increase to a bigger value. Thus preferable, optimal shape of contact surface now is scheme presented in Fig. 1.

3. Optimisation of contact surface

Proposed optimal shape of contact means here rounded end-part of billet I and flat of billet II. Shapes of contact is presented in Fig. 3.

Fig. 3a. shows optimal shape of line OY. Her equation may be approximated by:

\[ y^2_{(OY)} = \alpha \lambda^2 x_{(OY)} \quad (3) \]

where:
- \( \lambda \) - reduction ratio, described as:

\[ \lambda = \frac{D^2}{d^2} \quad (4) \]
Coordinates of optimal profile line is $y_{(XY)}$ and $x_{(XY)}$. It is mostly recommended to fix value $e$ from modelling experiments using real materials.

Value $e$ means the transformation of line (YOY) into line of billet’s head on die opening area. Fig. 3b. shows the final configuration of the two penetrated billets.

4. Influence of temperature and yield stress distribution

Fig. 4 shows the diagram of deformation in while of contact two billets: „hard“ I and „soft“ II. This kind of contact ensures bigger surface of joint. That means better quality of welding process as well.

Another configuration of contact is shown on Fig. 5. Additionally outside part of upper billet is hard, inside part – soft. The bottom billet is hard. Soft and hard means upper and lower yield stress $\sigma_i$ respectively. It is shown on Fig. 4b i 5b.

5. Experimental modelling and substitute material

A special modelling experiments using substitutive material have been designed and carried out. After several tests with a number of modelling materials plasticine with or without rape oil has been selected due to similarity of its characteristics at room temperature to that of aluminium at extrusion temperatures as well as its transparency that enables analysis of three-dimensional flows using modern visualisation techniques. For hot aluminium alloys the constitutive relation, i.e. the relation between the equivalent stress $\sigma_i$ and the equivalent strain rate $\dot{\varepsilon}_i$ can be approximated by:

$$\sigma_i = C \cdot \dot{\varepsilon}_i^m$$

where:

$\sigma_i$ – actual yield stress [MPa],
$\dot{\varepsilon}_i$ – strain rate [1/s].

Criterion of similarity has been assumed, that exponent $m$ of real and modelling material must be equal. The values of constant C may be different. Additionally, the plastic flow kinematics of substitute material must be according to real material. Accordance of flow kinematics, using plasticine as a substitute material has been confirmed in several experiments [11, 12, 14].

The samples have been prepared in a shape of a parallelepiped made out of homogeneous plasticine, the outer dimensions of the samples being 200mm×80mm×20mm as length, width and thickness respectively. End – pieces of samples were made as rounded, where radius $R = 50$ mm. For simulation of billets reheated, the plasticine samples were mixed with rape oil. Addition of oil was not bigger than 10 % all volume of sample.
Square grid on the face of the samples is very useful for kinematics of plastic flow analysis. Displacements of nodes allow to develop vector map of velocity.

6. Experimental stand

A special test stand has been set up to simulate joining of the material streams. The stand is equipped with a computerised data recording and image processing system. It enables recording of the displacements and velocities of the grid nodes.

Special samples with dimensions 200x80x20 mm have been prepared using plasticine with contrast grid. Like a grid have been inserted on the faces of the samples with spaces 5x5 mm. The samples have been extruded through different variants of contact surface with ram velocity \( v_o = 5 \) mm/s. The deformation of the grid has been recorded with a camera and then processed on a computer to obtain distribution of the flow velocities. Experimental stand is shown on Fig.6.

![Experimental stand](image)

**Fig. 6. Experimental stand: 1- ram, 2 - container, 3,4 - brackets, 5 - die, 6 - M10x120 bolts**

7. Experimental results

Results of experimental researches are presented as a several steps of plastic deformation during longitudinal extrusion process. There are shown on Fig. 7 ÷ 9. The most important information is influence on kinematics of different shape of end-part (flat and rounded). It is significant clue to choice the favourable configuration, which guarantee the best quality of the weld. On the front surface of samples the deformed grid is observed.

The samples have been extruded with different configuration of end-part contact shape with ram velocity \( v_o = 5 \) mm/s. The deformation of the grid has been recorded with a camera and then processed on a computer to obtain distribution of the flow velocities.

![Experimental results](image)

**Fig. 7. Welding process of billets. Kinematics of plastic flow: end – parts of billets: upper - radius of curvature R=50 mm, bottom - flat**

![Experimental results](image)
8. Discussion of the test results

The results, which are presented below, allow recognize the influence of shape of billet’s contact surface on quality of welding process. Quality of weld depends on material flow kinematics. The results of experimental tests using plasticine as a substitute materials are made for all analysed variants of end-parts of billets. Properly designed experiments can give valuable insight into the flow field within the contact zone. The above information can be used to verify theoretical analysis. Theoretical assumption, such as geometrical condition and criterion (1) recommends technology of extrusion from Fig. 1. (flat II and rounded I).

Optimal shape is determined by equation (3). Optimal distribution of yield stress and temperatures can be taken from diagrams on Fig. 4. or Fig. 5.

Recommended configuration of shape of billet’s end - parts has been resulted from analysis of plastic flow kinematics (Fig. 8.) and from theoretical description (Fig. 5.). This configuration allows to remove pollutions and gas pockets. Variant, in which the end–part of upper billet is flat and bottom billet is rounded, is beneficially technological as well. If the solitary area between two billets has been closed, the analysis of deformed grid indicates, that in this case quality assurance of the weld should be preserved.
References:


