24/18

ARCHIWUM ODLEWNICTWA
Rok 2006, Rocznik 6, Nr 18 (1/2)
ARCHIVES OF FOUNDRY
Year 2006, Volume 6, N^{o} 18 (1/2)
PAN – Katowice PL ISSN 1642-5308

ENERGETISTIC CRITERION OF LONGITUDINAL WELDING IN HOT EXTRUSION OF ALUMINIUM ALLOYS

A. PATEJUK, J. PIWNIK
Technical University, st. Wiejska 45C, Białystok, Poland

ABSTRACT

Theoretical criteria are proposed for the plastic cohesion of aluminum alloys during hot extrusion. It is postulated that the governing influence is the tangential force field at the surfaces in contact. The critical value of the energy liberated at the surfaces by the action of these forces depends on the temperature, the pressure, the yield stress and the physical state and degree of intimacy of the contacting surfaces. A mathematical formulation is proposed, which is a function of the temperature, the yield stress, the normal stress field at the surface, the deformation rate and certain parameters describing the geometry and the physical state of the surface

Key words: longitudinal welding, theoretical criteria, hot extrusion, aluminum alloys

I. INTRODUCTION

To produce a successful extrusion it is necessary to assure stress, flow and temperature conditions such that sound welds can be obtained. In general the weld quality is considerably influenced many factors relating to the die design [1-4], billet material and extrusion conditions (ram velocity, billet and die temperature). The objective of this paper is to present new criteria for longitudinal and transversal welding in hot extrusion processes. The criteria have been formulated by basing on the plastic flow theory. They can be used to evaluate the physical conditions along the contact zone of two material surfaces necessary for a sound weld to be produced as well as optimise the die shape and dimensions.

The third approach to analysis of material welding during hot extrusion consists in utilising phenomenological hypotheses and is generally free from the above limitation [5, 6]. These hypotheses are formulated on the basis of mechanics of plastic deformation and are of either stress, strain, mixed stress-strain or energetic character. The basic material parameter is the flow stress, which depends on the temperature and strain rate [7]. In the following section some new phenomenological energetic hypotheses will be proposed for longitudinal welding.

II. CRITERION OF LONGITUDINAL WELDING

Let us now consider relative motion of two plastic streams as illustrated in Figure 2. The upper stream moves with relative velocity v with respect to the lower one. Along the initial segment AB of the streams' interface, i.e. from x=0 to $x=x^*$ the friction stresses occur that are here assumed to change linearly as shown in Fig. 1:

$$\tau(x) = f_n \sigma_n + (k - f_n \sigma_n)\frac{x}{x^*} \tag{1}$$

where: σ_n is the normal stress at the contacting surfaces, f_n is the friction coefficient ($f_n \in (0,1)$) and k is the material shear yield stress.

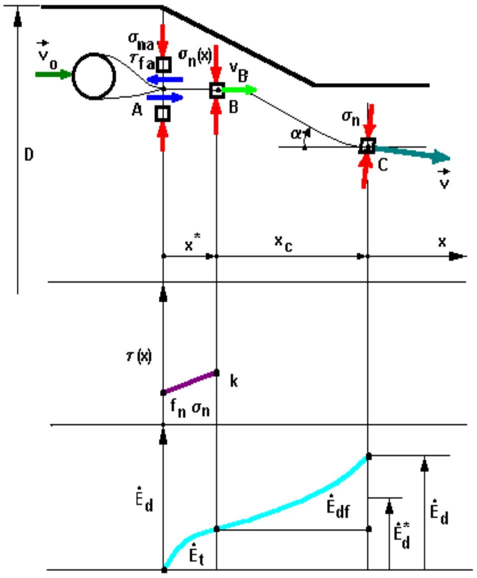

Fig. 1. Longitudinal welding in direct hot extrusion
Rys. 1. Wzdłużne spawanie strug podczas ekstruzji termicznej

As given by equation (1) the friction shear stresses at point B are assumed to attain the maximum admissible value $\tau = k$. Along AB there is a relative motion of the particles of the upper stream with respect to the lower stream with relative velocity v. At point B for $x = x^*$ the strains adhere to one another and from now one more with the same velocity. The distance $x = x^*$ can be evaluated on the basis of the following equation of motion (the streams are being treated as rigid bodies):

$$M\frac{dv}{dt} = -\tau(x)l\,dx \tag{2}$$

where M – is the stream mass:

$$M = \rho hl\,dx \tag{3}$$

l and h are transversal dimensions of the stream and ρ is the material density and moreover:

$$\frac{dv}{dt} = v\frac{dv}{dx} \tag{4}$$

After substituting equation (12) into (13) and some algebraic transformations one obtains:

$$x^* = \frac{v_0^2\rho h}{k + f_n\sigma_n} \tag{5}$$

The above relations gives the co-ordinate of the point from where the velocities of the streams become permanently bonded only at some point C located further along the flow line. It is assumed that a permanent bond is created at the interface once the intensity of the deformation energy accumulated along the flow line attains a critical value (as illustrated in the lower part of Figure 2.):

$$\dot{E}_{df} \geq \dot{E}_d^{\,*} \tag{6}$$

The intensity of deformation energy can be written as a sum of the energy of shear straining and normal straining as follows:

$$\dot{E}_{df} = \int_{t^*}^{t_f} \tau_f\dot{\gamma}_f\,dt + \int_{t^*}^{t_f} \sigma_n\dot{e}_n\,dt \Bigg|_{\text{along the flow line}} \tag{7}$$

It is assumed that the energy $\dot{E}_t$ consumed on frictional stresses along AB is small in composition to the energy consumed on plastic deformation along the contact zone $\dot{E}_{df}$. The tangential stress τ_f , the normal stress σ_n as well as the shear strain rate $\dot{\gamma}$ and the normal strain rate $\dot{e}_n$ along the flow line are assumed to be known from the solution of the boundary value problem.

Relations (6) and (7) lead to the following:

$$\int_{t^*}^{t_f} \tau_f \dot{\gamma}_f \, dt + \int_{t^*}^{t_f} \sigma_n \dot{e}_n \, dt \geq \dot{E}_{df} \Bigg|_{\text{along the flow line}} \tag{8}$$

The threshold value of the adhesion energy is now written as:

$$\dot{E}_d^* = C \int_{t^*}^{t_f} k \dot{\gamma}_f \, dt \Bigg|_{\text{along the flow line}} \tag{9}$$

where t^* is the time required for the velocities of the streams to equalise (i.e. corresponding to point B in Fig. 1), t_f is the time required for the permanent bonding to be created (i.e. corresponding to point C in Fig. 1),
$C > 1$ – is an empirical coefficient.

Let us assume that the energy of shear straining is small compared to the energy of normal straining:

$$\int_{t^*}^{t_f} \tau_f \dot{\gamma}_f \, dt << \int_{t^*}^{t_f} \sigma_n \dot{e}_n \, dt \Bigg|_{\text{along the flow line}} \tag{10}$$

Substituting (20) into (19) and taking into account relation (10) give:

$$\int_{t^*}^{t_f} \sigma_n \dot{e}_n \, dt \geq C \int_{t^*}^{t_f} k \dot{\gamma}_f \, dt \Bigg|_{\text{along the flow line}} \tag{11}$$

The above can be rewritten as:

$$\int_{t^*}^{t_f} \frac{\sigma_n}{k} \, dt \geq Ck \int_{t^*}^{t_f} \frac{\dot{\gamma}_f}{\dot{e}_n} \, dt \Bigg|_{\text{along the flow line}} \tag{12}$$

Denoting the right hand side of the inequality (23) as C_{kr} one finally obtains:

$$\int_{t^*}^{t_f} \frac{\sigma_n}{k} \, dt \geq C_{kr} \Bigg|_{\text{along the flow line}} \tag{13}$$

Hence, the energetic criterion (8) has under certain assumptions been reduced to a relatively simple condition involving stress (13). The parameter C_{kr} should be determined from a special experiment. If the above parameter is assumed to be independent on the deformation history then it can be evaluated for example by compressing two tubular samples put together on one another with simultaneous torsion in the plane of contact.

CONCLUSIONS

The theoretical welding criteria proposed in the current paper can be off value for industrial applications and particularly for optimisation of hot extrusion of aluminium alloys. By basing on the criteria useful guidelines have been drawn concerning favourable effect of an increase of the normal stresses and shear stresses on the connecting surfaces, increase of the material volume in the initial phase of the deformation process and increase of the duration of contact.

It is thus concluded, that the existing numerical models can be made more elaborate by inclusion of welding criteria. Any qualitative analysis of welding would in fact require numerical solution of the underlying flow problem, since to apply the criterion has to known the velocity and stress fields.

Apart from numerical analysis also physical modelling can be used successfully to get valuable information regarding the flow pattern. Different process parameters can be investigated and the obtained results can be directly applied in the design.

Concurrent application of theoretical welding criteria, numerical analysis and physical modelling can constitute a sound foundation for rational and effective analysis of hot extrusion of aluminium alloys and its systematic improvement.

REFERENCES

[1] Giljdengorn, M. S. et al., „Pressovanie so svarkoj poljih izdelij iz Aljominievljih splavov" (Extrusion of Hollow Aluminium Sections with Welds). Metalurgija, Moscow, 1975.

[2] Plata M., Piwnik J.: Theoretical and experimental analysis of seam weld formation in hot extrusion of aluminium alloys. Report, Alusuisse Technology Center. 2000.

[3] Arif A. F. M., Sheikh A. K., Qamar S. Z.: A study of die failure mechanisms in aluminium extrusion, Journal of Materials Processing Technology, 134, (2003) 318 – 328

[4] Akeret, R., „Extrusion Welds – Quality Aspects are Now Center Stage", Proceedings of 5th International Aluminium Extrusion Technology Seminar ET'92, Chicago, Vol. I (1992) 319-336.

[5] Misiolek, W. Z. and Kelly, R. M., „Dead Metal Zones in Extrusion of Complex Shapes", Proceedings of 5th International Aluminium Extrusion Technology Seminar ET'92, Chicago, Vol. I (1992) 315-318,.

[6] Valberg, H. and Groenseth R. A., „Deformation and Metal Flow when Extruding Hollow Aluminium Profiles", Int. J. Mat. & Prod. Techn. Vol. 8, No. 1, (1993) 235-239.

[7] Skorulski G., Patejuk A.: Pękanie utwardzonej warstwy przejściowej w procesie wyciskania współbieżnego. III Sympozjum Mechaniki Zniszczenia Materiałów i Konstrukcji. Augustów (2005) 377-380.

ENERGETYCZNE KRYTERIUM SPAJANIA WZDŁUŻNEGO STRUG W PROCESACH WYCISKANIA NA GORĄCO STOPÓW ALUMINIUM

STRESZCZENIE

W pracy przedstawiono energetyczne kryterium wzdłużnego spajania strug plastycznych podczas wyciskania stopów aluminium na gorąco. Analizowane kryteria mogą być efektywnie wykorzystane w wielu sytuacjach projektowania procesów technologicznych. Ułatwiają również ustalenia warunków eksperymentu przy symulacji numerycznej procesu. Chodzi tu o ułatwienie oszacowania pól prędkości i naprężeń w obszarze płynięcia plastycznego.

Recenzował: Prof. Bazyli Krupicz