LOCAL FRACTURE OF THIN ALUMINIUM FOIL

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In the rolling process of thin Al-foil, gauge approx. 10 μm, defects often occur in the form of local breaking which cause the so-called porosity of the foil. This reduces its applicability since it worsens the quality and outward appearance of the surface. In the final stage Al-foil is rolled two-fold from the gauge of 20 μm to the final gauge. The sticking together is prevented by a sealing liquid the use of which causes the occurrence of drops contributing to the porosity in the foil. A brief description of relationship between the size of liquid drops and surface damage is given.

INTRODUCTION

The contribution treats the process of Al-foil rolling where the ratio between the rolling area length and the average double thickness of the strip at a neutral point is greater than 80. In the final stage Al-foil is rolled two-fold from the gauge 20 μm to the final gauge. The sticking together of the foil strips is prevented by a sealing liquid. Between the contact surfaces, there often remain some drops of the sealing liquid of various size, for which it has been confirmed that they contribute to the occurrence of porosity in the foil. The purpose of the work is to determine the relationship between the thickness of the sealing liquid drops and kinds of the damage in Al-foil.

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COMPRESSIVE STRESSES IN THE ROLLING AREA

The compressive stress function was determined using the method treated by V. Masterov and V. Perkovshy (1). Considering Mises' plasticity condition in the plane strain state, the compressive stress function in the backward slip zone $\alpha_N \le \alpha \le \alpha_z$ is:

$$p(\alpha)_z = 2k\,(1-\delta)\,\ln[h(\alpha)/h_z] + 2k\,(1-\xi_z) \tag{1}$$

and in the forward slip zone $0 \le \alpha \le \alpha_N$

$$p(\alpha)_N = 2k\,(1-\delta)\,\ln[h(\alpha)/h_p] + 2k\,(1-\xi_p) \tag{2}$$

where $k = \sigma_Y/\sqrt{3}$, $\alpha_z = \mathrm{Arcsin}(l_p/R) \approx l_p/R$, $\delta = \psi\, l_p/(h_z-h_p)$, $\psi = \tau(\alpha)/k$, $\xi_z = \sigma_z/(2k)$, $\xi_p = \sigma_p/(2k)$

The position of the neutral area α_N is defined from the condition $p(\alpha_N)_z = p(\alpha_N)_p$ and on the basis of equations (1) and (2) also the double thickness of the foil in this area is defined

$$h_N = h(\alpha_N) = h_p\left(\frac{h_z}{h_p}\right)^{\frac{\delta-1}{2\delta}}\; e^{-\frac{\xi_p-\xi_z}{2\delta}} \tag{3}$$

The rolling force at constant thickness b of the foil strip is

$$F = bR\left[\int_0^{\alpha_N} p(\alpha)_p\, d\alpha + \int_{\alpha_N}^{\alpha_z} p(\alpha)_z\, d\alpha\right] \tag{4}$$

The foil double thickness in the rolling area is determined approxtimately as cube function which runs through three known points: T_1, T_2, T_3, Figure 1.

$$h(\alpha) = h_p + 2(a_1\zeta + a_2\zeta^2 + a_3\zeta^3),\quad \zeta = \alpha R \tag{5}$$

TEMPERATURE FIELD IN THE ROLLING AREA

Due to material plastification in the rolling area which represent an adiabative process, the plastic deformation work W_d is completely transformed into heat Q (2), whose consequence is the increase in the strip temperature. The change of the temperature field is also a result of the action of the tangential friction force between the rolls and the strip W_μ and the transfer of heat onto the rolls per unit of time. Besides this, other kinds of energy are also present, but in the discussed energy balance they were neglected.

$$W'_d(t) + W'_\mu(t) = Q(t) - \Phi \qquad (6)$$

The temperature field in the backward slip zone ($i=j=z, \eta=\alpha, \varphi=-1$) and in the forward slip zone ($i=p, j=N, \eta=\varphi=1$) is,

$$T(\alpha)_i = T_j \, e^{\beta_1(\alpha-\alpha_j)} + e^{\beta_1 \alpha} \int_{\alpha_j}^{\alpha} Q(\alpha)_i e^{-\beta_1 \alpha} d\alpha \qquad (7)$$

where $\beta_1 = m \; \alpha_t/\omega$, $m = 2/(\rho \, c_v \, h_N)$

$$Q(\alpha)_i = R \, m \left[\frac{\eta \, h_N}{h(\alpha)} + \varphi \left(1 + \frac{h_N}{h(\alpha)} \right) \mu \right] p(\alpha)_i - \beta_1 T_{vi}$$

STRESS STATE DEPENDENCE ON THE DROP SIZE

The deformation of the foil around the sealing liquid drop occurs when the latter enters the rolling area. In this position the drop takes a characteristic form whose idealization can be seen from Figure 2. Because of small dimensions of the drop and small thickness of the foil we can make an approximation: $h_k = 2r_k = h(\alpha_k) - h_z$, $R_{k1} = h_k k_R$

where: $\alpha_k = \dfrac{l_p + l_k - r_k}{R + 0.5\, h_p}$, $k_R = 5 - 6$

Taking into account the Mises' hypothesis to determine equivalent stress, and considering the drop shape and size, the relationship between stress in Al-foil around the drop and the drop size can be expressed in the form, Figure 3:

$$\gamma(h_k) = \frac{p(\alpha_z)_z}{100\, \beta_k} = \frac{\sigma_p}{100\, h_k}, \quad \beta_k = \frac{h_z}{\sqrt{0.25 + k_R\,(k_R - 0.5)}} \qquad (8)$$

The maximum height at which the equivalent stress in the roll will reach the elastic limit σ^M_{EL} is

$$h_{k\,max} = a_k \frac{\sigma^M_{EL}}{E} \; \frac{4(1-\nu^2)}{\frac{1-2\nu}{2} + \frac{2(1-\nu)}{9} \sqrt{2(1+\nu)}} \qquad (9)$$

In Figure 3 curve a represents the case when the equivalent stress in Al-foil around the drop is in the elastic region. Curve b represents the case when the equivalent stress is in the plastic region and curve c represents the ultimate strength of the Al-foil surrounding the drop. According to the data from literature(3) the aluminium hardened in this way has σ_{TS}= 136 N/mm^2, σ_Y=0.9 σ_{TS}=122.5 N/mm^2, σ_{EL} = 0.9 σ_Y = 110 N/mm^2.

EXAMPLE

As an example for numerical calculation we chose the double rolling process of Al-foil in the IMPOL Slovenska Bistrica rolling mill. This manufacturer also provided all the necessary numerical values of the parameters relevant for the analysis of the double rolling process and foil deformation due to the occurrence of sealing liquid drops. These are the following: δ_z=0.019 mm, δ_p=0.009 mm, D=2R=250 mm, b=1250 mm, angular velocity of the rolls ω=34.72 s^{-1}, Poisson's ratio ν=0.3, Young's modulus of steel E=2.1 $10^5 N/mm^2$, σ^M_{EL}=2200 N/mm^2, ξ_z=0.1, ξ_p=0.3, μ=0.084, ρ=2750 kg/m^3, specific heat of Al-foil strip c_v=896 J/kg K, coefficient of heat transfer α_t=5.78 $10^5 W/Km^2$, T_z=20 °C, T_{vz}=60 °C, T_{vp}=103 °C. The function of pressure (1), (2) and temperature (7), which can be seen from Figure 4 and the length of the rolling area l_p =2.3263 mm are defined by the method of successive approximation.

According to the above given equations, other numerical values are: α_z=1.06627°, α_N=0.5575°, $h_{kmax} \le$ 0.057777 a_k mm, $h(\alpha)$=914.06α^3+11.1α^2+0.57 α+ 0.018 mm. On the basis of the measured drop imprints on the inner side of the foil at which the foil hasn't broken yet, **Figure 5**, the average drop length was defined $a_k \ge l_k$= 0.34 mm and h_k = 0.005588 mm, whereas the height of a drop with a length l_k=0.64 mm, Figure 6, is h_k=0.01258 mm. The expression (8) provides 160 $N/mm^3 \le \gamma \le$ 193 N/mm^3. From the graph in Figure 3 we can see that the foil around the drop having that kind of height will break.

SYMBOLS USED

σ_{EL}^{M} = elasticity limit for steel with martensitic structure
W_{μ} = energy of the friction force per unit of time
Φ = heat flow
T_v = roll temperature
k_R = coefficient of the radius of the idealized drop

REFERENCES

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(3) Kroha, V.A., Krivulje utrjevanja gradiv pri hladni deformaciji, Mašinostrojenje, Moskva, 1968

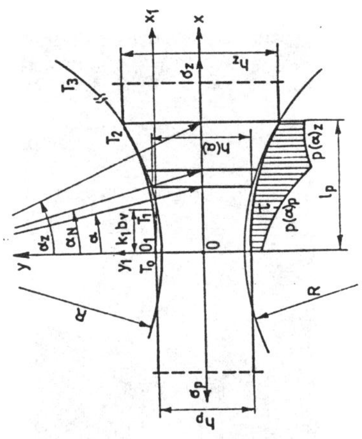


Fig.1 Rolling area

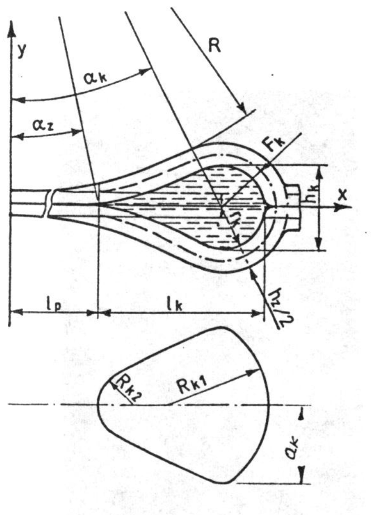
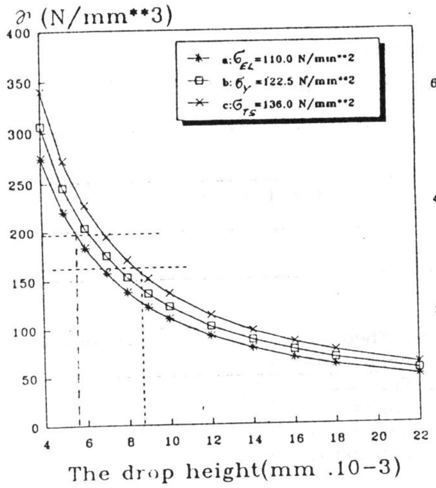


Fig.2 Drop before entry in the rolling area



3 Stress state in the foil

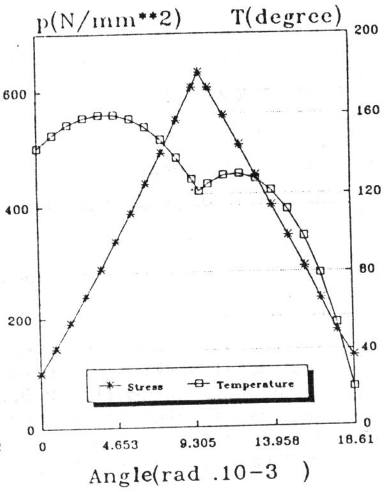


Fig.4 Stress and temperature

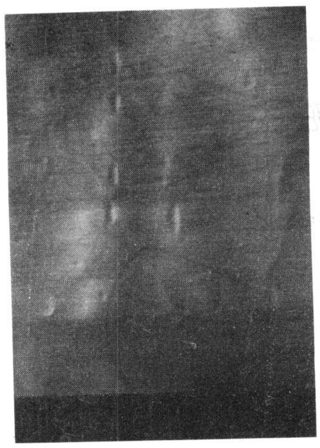


Fig.5 The foil around the drop which isn't broken.

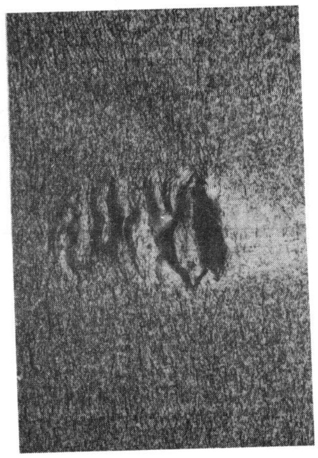


Fig.6 The foil around the drop which is broken.