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APPLICATION OF MODIFIED TOOLS IN THE PROCESS OF THIN-WALLED TUBE DRAWING

ZASTOSOWANIE ZMODYFIKOWANYCH NARZĘDZI W PROCESIE CIĄGNIENIA RUR CIENKOŚCIENNYCH

In this paper the concept of tools new geometry used during drawing of thin-walled tubes (D/d > 20, t < 0.4 mm) has been presented. In the concept the real conditions of process realization has been taken into account. Particularly, the influence of changes in the tube wall-thickness in the sinking zone on the equilibrium conditions of the forces acting on the floating-plug in the deformation zone have been taken into consideration as well as on the changes of tool geometry. Especially the shortening of the sinking zone can substantially improve the process stability – which is very important in the case of thin-walled tube drawing with a floating plug. The new set of tools for drawing process were manufactured and drawing experiments were carried out using a chain draw-bench with a maximum drawing force of 40 kN, and at a drawing speed of 4 m/min. Drawing tests were carried out for verification of the results of calculations performed for tubes made of CuZn37 brass and OF-Cu copper. The results obtained from theoretical calculations and experiments proved that proposed method of tool modification was right. In practice the new tool provides the minimization of the zone of tube sinking, increases the wall-thickness reduction and assures a more stable performance of the drawing process.
Keywords: tube drawing, tool geometry, tool designing

Praca prezentuje wyniki doświadczeń prowadzonych podczas ciągnienia na trzpieniu swobodnym rur cienkościennych (D/d > 20, t < 0.4 mm). Propozycja takiego procesu uwzględnia rzeczywiste warunki jego realizacji, a zwłaszcza wpływ zmiany grubości ścianki w strefie swobodnego ciągnienia na warunki równowagi sił działających na trzpień w strefie odkształcenia, jak również na wynikającą z tej sytuacji zmianę geometrii narzędzi. Badania procesu ciągnienia przeprowadzone na ciągarce ławowej o sile ciągnienia 40 kN z prędkością 4 m/min na rurach z mosiądzu CuZn37 oraz miedzi OF-Cu potwierdziły przewidywania teoretyczne i wykazały możliwość realizacji procesu ciągnienia przy zmniejszonej strefie ciągnienia swobodnego. W efekcie uzyskano zwiększenie redukcji ścianki ciągnionej rury oraz istotną poprawę stabilności procesu.

1. Introduction

The process of tube drawing with a floating plug requires tool geometry designed to make it in such way that the equilibrium of forces acting on the plug in deformation area is possible. Determination of the tools geometry is of great importance in the process of drawing small-size and thin-walled tubes, particularly when high relative deformation of the tube's wall is required. In these cases minimisation of a free tube drawing zone in the drawing area is necessary. Many methods used to describe dependencies in the deformation zone in the process of tube drawing with a floating plug can be found in the literature [1-3]. Possible ranges of the angles for drawing dies and plugs, and optimum differences between these angles are determined. Tool geometry is proposed in the literature and that used in practice contributes mainly to minimisation of the drawing stress and, simultaneously, to obtain stable conditions of the drawing process.

2. Tool geometry designing

In actually used analytical methods of the tubes drawing process the $(\alpha - \beta)$ difference and back-track "n" of the floating-plug are the principal tool geometry parameters.

The formulae which determine values of $n_{\min}$ and $n_{\max}$ are well known, and they are as follows:

$$n_{\min} = g_k \tan\frac{\beta}{2} \tag{1}$$

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$$n_{\max} = \frac{g_0}{\sin\alpha} - g_k c \tan\alpha. \tag{2}$$

The maximal axial displacement of the plug in the deformation zone L can be calculated using the equation:

$$L_{\max} = n_{\max} - n_{\min} = \frac{g_0 \cos\frac{\alpha}{2} - g_k \cos\left(\alpha - \frac{\beta}{2}\right)}{\sin\alpha \cos\frac{\beta}{2}}. \tag{3}$$

The inner tube diameter at the origin of contact area within the conical part of the floating-plug is as follows:

$$d_r = 2\left[g_k \tan\frac{\alpha}{2} + \frac{g_0 - g_k \cos(\alpha-\beta)}{\sin(\alpha-\beta)}\right]\sin\alpha + d. \tag{4}$$

Since $\beta \cong \alpha$, then

$$d_r = 2\left[g_k \tan\frac{\alpha}{2} + \frac{g_0 - g_k}{\sin(\alpha-\beta)}\right]\sin\alpha + d. \tag{5}$$

The inner tube diameter at the end of deformation zone can be calculated from the formula:

$$d' = 2g_k \tan\frac{\alpha}{2}\sin\alpha + d. \tag{6}$$

Consequently, knowing the α and β values it is possible to design the tool geometry for the floating-plug drawing process [1].

It was decided to investigate some of the conditions influencing on the process of tube drawing with a floating plug. It was assumed, as a criterion for determination of tools geometry, that metal flows towards the geometrical centre of a drawing die A schematic realization of such process is shown in Fig. 1.

This work was intended to determine geometry of the deformation area based on theoretical analysis of the process of tube drawing with a floating plug, with an account of real conditions under which the process is carried out. In the real process the changes in the wall-thickness takes place and also the unit pressures acting in different part of the tool are not constant. The main problem in this case was to determine the position of the floating plug and inclination angle of the conical portion of the plug β, which decide about the required metal flow. According to the designations shown in Fig. 1, a plug starting diameter d_r with which the process of tube wall deformation begins, is very significant in the investigated process. The diameter makes the border between a zone of free tube drawing on the conical surface of a drawing die and an appropriate zone of a tube drawing with a floating plug. For established initial and final dimensions of a tube it could be stated that for the greater d_r value the free drawing zone is smaller.

The **plug position** in a deformation area may be calculated according to the following relationships [5]:

$$n_r = n_{\max} - \frac{(d_r - d_k)\sin(\alpha + \varpi - \beta)}{2\sin(\alpha + \varpi)\sin\beta}, \tag{7}$$

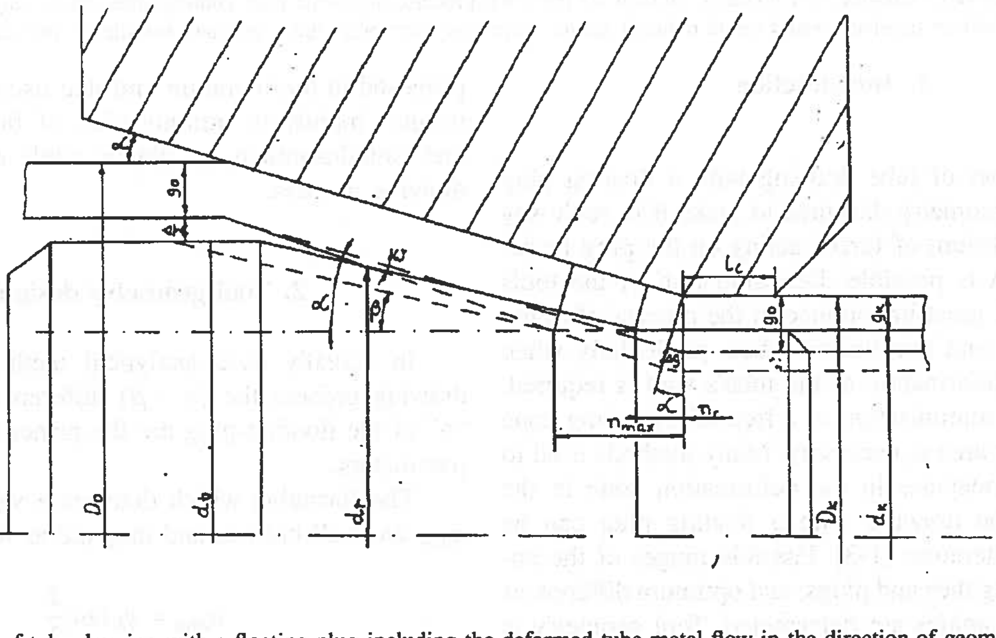

Fig. 1. A schematic of tube drawing with a floating plug including the deformed tube metal flow in the direction of geometrical centre of a drawing die [4]

where

$$n_{\max} = g_k \tan\alpha + \frac{(g_0 + \Delta g - \frac{g_k}{\cos\alpha})\cos\varpi}{\sin(\alpha+\varpi)}. \quad (8)$$

The real value of back-track "n_r" should be between the extremal "n" values:

$$n_{\max} > n_r > n_{\min}.$$

From the very known equilibrium conditions of the forces acting on the floating-plug in the deformation zone we can state that the β angle decreases with shortening of the cylindrical part of the die. A reduced length of the cylindrical part of the die value causes the $(\alpha-\beta)$ difference to increase in the case when the angle is strictly defined.

Taking into account the geometrical relationships in the deformation zone determining a deformed tube metal flow in the direction of the geometrical centre of a drawing die, the **floating-plug angle** β can be obtained from the formula:

$$\tan\beta = \frac{d_k \tan\alpha}{d_k + 2g_k + 2n_r \tan\alpha}. \quad (9)$$

The value of such defined β angle can be recognized as a $\beta_{\max}$ which allows the drawing process to operate in a stable manner.

The **real diameter** of the floating-plug "$\mathbf{d_r}$" can be calculated using formulae presented in our previous paper [6]:

$$d_r = \sqrt{d_k^2 + R^2\frac{\sin^2(\alpha+\varpi+\beta)}{\sin^2(\alpha+\varpi)} + 2Rd_k\frac{\sin(\alpha+\varpi+\beta)}{\sin(\alpha+\varpi)} + 4R(l_c\frac{p_c}{p_w} + n_{\max})\sin\beta} - R\frac{\sin(\alpha+\varpi+\beta)}{\sin(\alpha+\varpi)}, \quad (10)$$

where

$$R = \frac{\mu_2 d_k p_w}{(\sin\beta - \mu\cos\beta)p_s}. \quad (11)$$

The d_r value can be accepted as a minimal floating-plug diameter taking part in the process of tube deformation.

The minimal **length $\mathbf{l_t}$** of the cylindrical part of the floating-plug can be assumed to be the sum of the maximal value of floating-plug back-track in the deformation zone and the length of the cylindrical part of the die. According to [6], the final equation takes the form:

$$l_t = n_{\max} + \frac{1}{4}\frac{p_s}{p_w}\left(\frac{d_r^2}{d_k} - d_k\right)\left(\frac{1}{\mu} - ct\tan\beta\right) - g_k t\tan\frac{\beta}{2}. \quad (12)$$

In this equation p_w is the value of unit pressure acting on the cylindrical surface of the floating-plug in the working zone; p_c – on the conical surface, and p_c – on the cylindrical surface in calibrating zone of the floating-plug. Using the FEM analysis it is possible to obtain the all geometrical parameters of the tool.

3. Results of investigations and their analysis

Results of calculations were checked by drawing tubes made of copper OF-Cu and brass CuZn37 [4]. The nominal dimensions of the tubes were as follows: initial diameter D_0 = 18.0 mm, initial wall thickness g_0 = 0,8 mm and length of about 2 m.

The tubes were drawn to final diameter D_k = 16,0 mm and final wall thickness g_k = 0.6 mm in tools with various geometry; plug angles β in the range of 10°-18° (0,1745 0,3142 rad) and dies with the following angles and the lenghts of die calibrating zone: α = 15,5° (0.275 rad), l_c = 2,00 mm; α = 15,5° (0.275 rad), l_c = 4,25 mm; α =19° (0.3316 rad), l_c = 2,25 mm and α = 19,2° (0.3374 rad), l_c = 4,25 mm.

Trefil 1780 lubricant was used to lubricate the working surfaces of the drawing dies and the plugs. The drawing tests were carried out using chain drawbench with maximum drawing force of 40 kN, and at drawing speed of 4 m/min.

The results of calculations of a plug diameter d_r versus a plug geometry (angle β) for tubes made of CuZn37 brass are shown in Fig. 2.

The difference between the drawing die angle and the plug angle $(\alpha-\beta)$ vs. the drawing die angle α, which satisfy the stable drawing conditions are shown in Fig. 3.

Experiments show that the real position of the plug is located between its limiting positions, and that its value increases with increasing $(\alpha-\beta)$ difference. The range of $(\alpha-\beta)$ values increases with the reduction of l_c.

The calculated minimal values of initial tube diameters enabling to lead the process at the established reduction of the tube wall. We observe that the minimal values of initial tube diameters decrease with decreasing in the length of the calibrating zone, whereas the increase of angle difference influences the value of tube diameter significantly decrease, when the effect of sink is minimised.

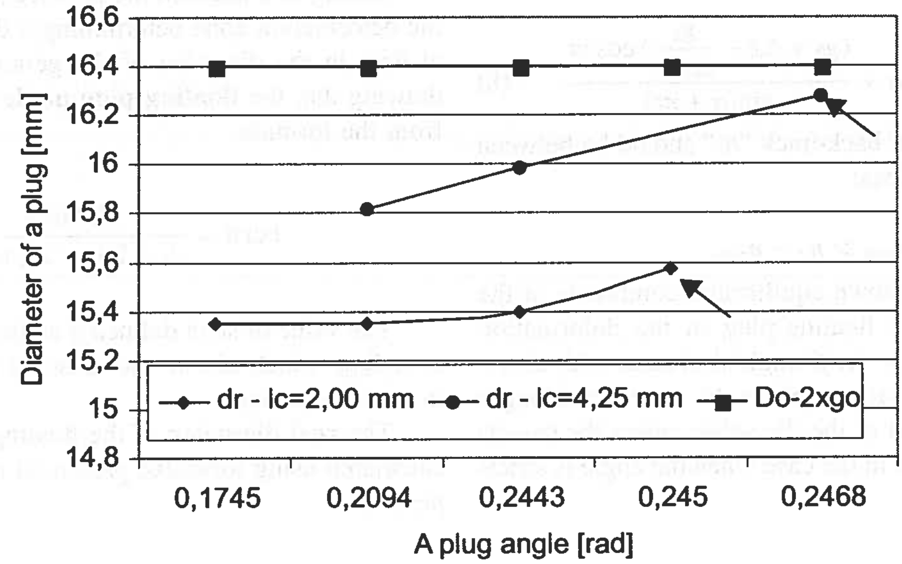

Fig. 2. Plug diameter vs. plug angle [7]

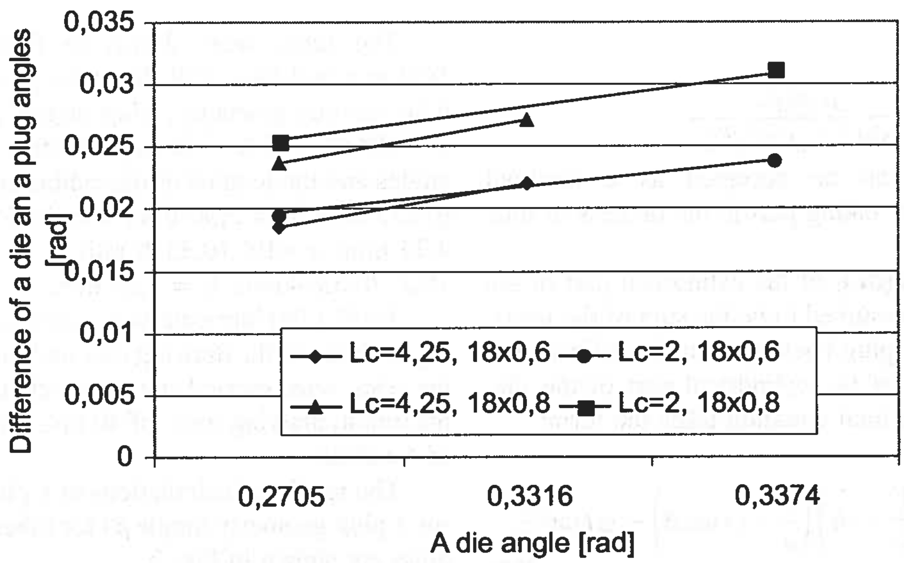

Fig. 3. The value of $(\alpha - \beta)$ difference vs. the drawing die angle α [7]

This observation is of importance, in the view of the fact that in plug drawing, the wall thickness reduction is the essence of the process. It is clear that when intensive wall thickness reduction is required, the minimising of tube diameter reduction could be important.

4. Conclusions

– The assumed criterion of the deformed metallic tube flow in the direction of geometrical centre of a drawing die enables determination of geometry of the drawing tools giving results close to applied in the practice minimal differences of the angles.

– The method of calculation of the initial diameter of the plug d_r, on which the process of wall reduction begins, is performed by analytical procedure that may be applied to determine the minimal initial tube diameter, and to reach the required reduction of the tube wall.

– Theoretical analysis of the thin-walled tube drawing process in which the variation of the wall-thickness in the zone of tube sinking and the real position of the plug in the deformation zone are taken into consideration indicated that it is possible to run a stable process using $(\alpha - \beta)$ difference greater than actually employed in practice.

– The results demonstrate that the range of angles of the conical part of the plug, β,which is possible to apply in practice depends distinctly on the reduction in the tube wall-thickness.

– The presented method and applied criterion can be used in the designing of floating plug geometry for the process of tube drawing, particularly in the case of small-sized and thin-walled tubes.

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