Processing and Characterization of 10TiNiCr180 Tubes with Thin Walls by Drawing in Ultrasound Field

ELENA CHIRILA, MIHAI SUSAN *, BOGDAN-LUCIAN GAVRILA, ANDREI-VICTOR SANDU
Faculty of Materials Science and Engineering, Gheorghe Asachi Technical University of Iaşi, 41 D. Mangeron Str., 700050, Iasi, România,

The paper represents a study about the processing and the characterization of the cylindrical symmetry tubes with thin walls made of 10TiNiCr180 plastic deformed without inner support in ultrasound field, ultrasonics vibration drawing (UVD) in comparison with the classic technology (CT), correlated with the chemical composition. Studying the UVD processing, it wants the obtaining of the ultrasound surface effect or the reducing of the metal – tool contact friction. The characterization of the two technologies, is made based on the force and drawing safety, and for the drawn products, the resistance and plasticity mechanical characteristics are considered. The efficiency of the UVD technology in comparison with that of the classic one is made based on the relative reductions of the force and drawing safety ($\Delta F$ and $\Delta C$).

Keywords: tubes with thin walls, stainless steel, ultrasound field, physical-structural characteristics, efficiency

The paper presents some researches in the obtaining and characterization of the cylindrical symmetry tubes with thin walls made of stainless steel and plastic deformed in ultrasound field by drawing without inner support, when the tool of the plastic deformation/the die is placed in the maximum of the waves oscillation/antinode and it is ultrasonics activated along the drawing direction, “ultrasonics vibration drawing” – UVD system [1-4, 8].

When the die is activated in this way, it obtains the reducing of the metal-tool contact friction, explained assuming the Severdenko’s model and taking into account the relative rate of drawing ($v_{dir}/v_v$), where $v_{dir}$ is the rate of drawing and $v_v$ is the maximum vibratory rate of the die [1, 5, 6]. The tubes with thin walls are characterized by the ratio $g/D \leq 0.16$, where $g$ is the thickness of the wall and $D$ is the diameter of the tube.

The tubes with thin walls processing in ultrasound field is motivated by the fact that the ultrasound damping in the thickness of the tubes with thin walls is very diminished in comparison with that of the tubes with normal and thick walls. Our researches have been developed in two main directions: (a) the particularities of the UVD Technology and the force parameters determination; assuming the theorem of the consumed total power, the authors will present in this paper, a calculation method; (b) the experimental researches were made on stainless steel tubes.

For the tubes processing without inner support in ultrasound field/UVD Technology, the research is developed especially, for the drawing of the tubes made of metallic materials strong hardened by cold plastic deformation [4, 5, 9-14]. The experimental researches were made on tubes with thin walls, small diameters, made of 10TiNiCr180/AISI 321 stainless steel. The next researches may be developed, especially for the study of the processing of the capillaries; in this case, the UVD Technology is legitimated from the technical and economical point of view.

Theoretical part

For the particularities study of the tubes processing by UVD Technology, there were used the following notations: $D_e$ – external diameter of the semi-finished tube; $D$ – external diameter of the processed tube; $\alpha$ – half-angle of the die cone; $\tau$ – shear stress; $\sigma_n$ – normal stress; $F^{1/2}$ – drawing force of the UVD Technology.

According to figure 1, any point $P$, arbitrarily chosen on the metal – tool surface, performs an oscillator motion, with the maximum vibratory rate of the die, $v_v$, and a slip motion, along the generating line of the cone, with the feed rate, $v_{dir}$.

Fig. 1. Geometry and kinematics of the axial – symmetrical conical motion: $R_0$ – external radius of the semi-finished tube; $r_0$ – internal radius of the semi-finished tube; $R$ – external radius of the processed tube; $\beta_0$ – half-angle of the initial cone with velocity discontinuities; $\beta_f$ – half-angle of the final cone with velocity discontinuities; $g_0$ – thickness of the semi-finished tube; $g$ – thickness of the processed tube; $v_0$ – initial rate of the tube; $v$ – rate of the tube in the area of the deforming focus; $v_{dir}$ – rate of drawing; $A$ – vibration amplitude: —— progressive wave; - - - - regressive wave

* email: mihaisusan@yahoo.com
The resulting vector of the relative rate determined by the composition of the rates \( v_v \) and \( v_a \) changes the displacement direction of the arbitrary point \( P \), along the generating line of the cone, as follows: during the interval \( T/2 - 2t_1 \), both point \( P \) and the metal, move in the same direction; during \( T/2 + 2t_1 \), they move in the opposite direction.

Assuming the Coulomb type friction at the metal – tool contact surface, the above model represents the principle of “the reversal mechanism of the mean friction”; the friction becomes positive during \( T/2 - 2t_1 \) time and negative during \( T/2 + 2t_1 \) time \([1, 5, 6]\). In the case of the processing in Classic Technology of the tubes made of strong hardened metallic materials, only small degrees of the section reduction are allowed, so that, the half-angle of the die is \( \alpha = 6...10^\circ \).

Considering that \( v_a = v_{dr} \cos \alpha \), it is a good approximation to assume \( \cos \alpha \to 1 \) and \( v_a \approx v_{dr} \). Under these circumstances, the friction coefficient in the UVD Technology, \( \mu_{UVD} \), is given in relation (1):

\[
\mu_{UVD} = \mu_{CT} \left( 1 - \frac{2}{\pi} \arccos \frac{v_{dr}}{v_v} \right)
\]

where:

- \( \mu_{CT} \) – friction coefficient in the Classic Technology;
- \( \frac{v_{dr}}{v_v} \leq 1 \) – relative rate of drawing;
- \( v_v = \max(du/dt) = \max[dAsin(2\pi ft)/dt] = 2\pi fA \) – maximum vibratory rate of the die, \( (A \text{ and } f \text{ are the amplitude and the frequency of the die oscillation, respectively).} \)

The relation shows that, assuming \( \mu_{CT} = \text{const.} \), the only way to reduce \( \mu_{UVD} \) is to minimize the relative rate of drawing \( v_{dr}/v_v \). The kinematics particularities of the tubes processing in the UVD Technology are schematically shown in figure 2 \([7]\).

The procedure and the plastic deformation kinematics during the tubes processing in UVD system is presented in figure 3.

**Experimental part**

The determination of the drawing force in UVD Technology is based both on the theorem of the consumed total power and on “the reversal mechanism of the mean friction”; the geometry and the kinematics of the axial – symmetrical conical motion into the deformation focus are illustrated in figure 1.

The geometrical elements are: \( R_0 \) and \( R \), the external radius of the semi-finished and of the processed tube, respectively; \( r_0 \) and \( r \), the internal radius of the semi-finished and of the processed tube, respectively; \( g_0 \) and \( g \), the wall thickness of the initial and of the final tube, respectively; \( \beta_0 \), the half-angle of the initial cone and \( \beta_f \), the half-angle of the final cone \([2]\).

The kinematics elements are: \( v_0 \), the initial rate of the tube; \( v \), the rate of the tube in the deformation focus; \( v_{dr} \), the rate of drawing; \( F_{UVD} \) and \( \sigma_{UVD} \), the drawing force and the stress, respectively. In addition, the following assumptions are adopted: (i) the metallic material is totally incompressible; (ii) the die is a rigid body; (iii) the metal deformation is performed accordingly with the Von Mises’ flowing condition; (iv) the kinematical rate field provides a Bernoulli type continuity; (v) at the metal – tool surface, the Coulomb type friction is considered constant for a given drawing process; (vi) at the oscillator system level, only the longitudinal elastic waves act under a stationary regime (forming nodes and antinodes); (vii) the plastic deformation process is isothermal, the thermal effects of internal friction being neglected.

With this above assumptions and according to figure 1, it can be calculated the drawing force using the relation (2):

\[
F_{UVD} = \pi \cdot \left( R^2 - r^2 \right) \cdot \sigma_{UVD}
\]

For the geometry and kinematics of axial – symmetrical conical motion, schematized in figure 1, the following coefficients were introduced, rel. (3):
The tube has been divided into three zones with continuous fields of rates: zones I and III, that have a uniform axial rates (the direction of the rate of drawing coincides with the symmetry axis of the tube); zone II (deformation area), where the direction of the rate makes an angle \(\alpha\) with the symmetry axis (the direction of the metal flow is parallel with the active surface of the die); it is limited by the conical surfaces \(G_1\) and \(G_2\), represented by the segments BD and AC and defined by the angles \(\beta_f\) and \(\beta_0\), respectively, and externally, by the surface \(G_3\). The experimental results have shown that the thickness of the tube wall decreases only at the beginning of the proper plastic deformation process. This means that, considering the geometry of the tube (the deformation area), the angles \(\beta_0\) and \(\beta_f\) are:

\[
\beta_0 = (\pi - \alpha) / 2, \quad \beta_f = \arctg \left( \frac{K_k \sin \alpha}{1 - K_k \cos \alpha} \right)
\]

where \(K_1 = K_4 = K\). From the continuity condition of the metal flow, it results rel. (4):

\[
\frac{v_0}{v_\alpha} = \frac{R^2 - r^2_1}{R^2 - r^2_0} = \frac{K_1^2 - K^2_2}{1 - K^2_3} 
\]

During the drawing process, the consumed total power must compensate the losses produced: (i) by proper plastic deformation, \((W_d)\); (ii) by the shear due to the discontinuities of the rates on the surfaces \(G_1\) and \(G_2\), \((W_{G1,2})\); (iii) by friction on the surface \(G_3\), \((W_f)\). From the balance of the consumed total power in UVD Technology, it follows that the drawing stress can be expressed:

\[
\sigma_{UVD} = \frac{2\sigma_0}{\sqrt{3}} Q_1 + \sigma_\theta \mu_{UVD} Q_2
\]

\[
Q_1 = \frac{\sin \alpha}{2 \sin \beta_f \sin (\alpha + \beta_f)} + \frac{\pi \alpha}{2}
\]

\[
Q_2 = \left[ \frac{1 - K_1 \cos \alpha}{1 - K_3} \frac{2 - (1 - K_1) \cos \alpha}{2 K_1 - (1 - K_3) \cos \alpha} \right] \sin \alpha
\]

where \(e_{\theta 0}\) and \(e_{\theta f}\) are the components of the deformation rate, in spherical coordinates, as deformation degree time derivative.

Substituting eq. (5) into eq. (2), it was obtained for the drawing force, eq. (8):

\[
F_{UVD} = \pi \left( R^2 - r^2 \right) \left[ \frac{2\sigma_0}{\sqrt{3}} Q_1 + \sigma_\theta \mu_{UVD} Q_2 \right]
\]

In the case of the Classic Technology (CT), the drawing stress can be determined with eq. (9):

\[
\sigma_{CT} = \frac{2\sigma_0}{\sqrt{3}} Q_1 + \sigma_\theta \mu_{CT} Q_2
\]

This fact allows the determining of the drawing force, eq. (10):

\[
F_{CT} = \pi \left( R^2 - r^2 \right) \sigma_{CT}
\]

The value of the drawing stress must not exceed the stress strength value, even the increment caused by strong hardening. This condition can be expressed by means of the safety coefficient of drawing, eq. (11):

\[
C = \frac{S}{\sigma_r} \frac{\sigma_r}{F}
\]

where \(\sigma_r\) is the tensile strength, \(S\) is the cross section surface (at the end of the deformation zone) and \(F\) is the drawing force \((F_{CT}\) or \(F_{UVD}\)).

Results and discussions
The constructive – functional scheme of the oscillator system used in our research is presented in figure 4. The experiments have used the ultrasonic equipment EUS made in Rusia, IL10-2.0-0.1 / LTD type, “Ultrasonics Technique” – INLAB.

The proper construction of the oscillator system (OS), with magnetostrictive transducer and graded cylindrical concentrator, used for the experiments is presented in figure 5.

The chemical composition determined by optical spectrometry of the 10TiNiCr180 stainless steel is presented in table 1. According to the chemical composition the steel is high alloyed with Cr and Ni, being corrosion resistance with high hardness.

The main kinematics and technological characteristics in UVD system \((f = 17500Hz, a = 25\mu m, \nu = 2.74m/s)\) for 10TiNiCr180 stainless steel is presented in table 2.

In table 3 there are presented the results obtained using classic technology (CT) and UVD technology.

The researched test bars were made of 10TiNICr180 stainless steel; initially, they had \(D_0 = 5.50\) mm, \(g_0 = 0.70\) mm and the length 1200mm; after the drawing process, it results \(D_1 = 5\) mm, \(g_1 = 0.65\) mm and the...
The experimental results regarding the influence of the relative drawing velocity, to the deformation force, and to the economic efficiency, ($\Delta F$), of the drawing process applied on tubes made of 10TiNiCr180 stainless steel are presented in table 2 and figure 6.

The experiments have taken place on the 15kN drawing machine, BTL – 0.1.000 type, which is placed in the Plastic Deformation Research Laboratory of the Faculty of the Materials Science and Engineering – Technical University “Gheorghe Asachi” from Iași.

The drawing force is determined with and without ultrasound using the force transducer CT – A – KN1C of the drawing bench BTL – 0.1.000. The following mechanical properties were analyzed: the mean resistance, ($R_m$), the yield point, ($R_{p0.2}$), and the breaking elongation, ($A_5$). In order to determine the mechanical characteristics, $R_m$, $R_{p0.2}$, and $A_5$, the tensile tests were made according to SR EN 10002 – 1/1995 standard (identical with standard SR EN 10002 – 1/1990). Tensile tests were made on a MTS 810.24/USA machine, with the precision class 0.5 and with the drawing velocity of 20 mm/min. The results of the experimental researches where were used the two technologies (CT and UVD Technology) are indicated in table 3 and figure 7.

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Conclusions

The modification of the force parameters and of the drawing safety during the processing of cylindrical symmetry tubes with thin walls made of 10TiNiCr180 stainless steel and of the resistance and plasticity mechanical characteristics, during the processing in UVD system in comparison with the Classic Technology – CT are explained based on the obtaining, in the plastic deformation process, of “the ultrasound surface effect” or “the reduction of the metal – tool contact effect”, when \( \frac{v_{dr}}{v_v} << 1.0 \).

In the given research conditions, the best parameters are obtained for \( \frac{v_{dr}}{v_v} = 0.021 \), respectively: \( F_{UVD} = 940N; R_m = 459MPa; R_{p0.2} = 328MPa \) and the safety coefficient of the drawing force is 6.33.

According to these conditions for the experiments, there are obtained \( \Delta F = 29.38\%; \Delta C = 24.64\%; \Delta R_{p0.2} = 6.01\%; \Delta R_m = 9.82\% \) and \( \Delta A_5 = 6.21\% \). The obtained experimental results in the processing and characterization of the cylindrical symmetry tubes with thin walls made of 10TiNiCr180 stainless steel recommend the new technology – UVD, generally, for the manufacturing of the tubes with thin walls by drawing without inner support; the tubes are made of metallic materials strong hardened by cold plastic deformation with small rates of drawing, so that \( \frac{v_{dr}}{v_v} << 1.0 \).

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