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Improvement of Manufacturing Technology for Thin-Walled Pipes Made of Copper Alloys

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Abstract. Thin-walled pipes made of copper alloys – the brass grades L96, L68, L63, LANKMc; the bronze grade BrOF (the GOST state standard) are of great demand in aircraft, shipbuilding, automotive, defense, diesel and instrument-making industries. Pipe diameter ranges between 4.0 and 20 mm, and wall thickness is in the range from 0.1 to 0.6 mm. The manufacture of these pipes using traditional technological schemes is characterized by high labor input and low stability in providing quality characteristics, such as dimensional accuracy, the presence of surface defects and the level of mechanical properties. This study presents scientific evidence, new technological schemes developed for manufacturing pipes made of copper alloys with the use of the equipment and technology of multiple drawing on a long movable mandrel and results of their adoption at Revda Non-Ferrous Metal Processing Works JSC.

Introduction

The manufacture of thin-walled and extremely thin-walled pipes from copper alloys, including pipes with an external diameter from 4.0 to 20.0 mm and with a wall thickness from 0.1 to 0.6 mm, is associated with the problem of ensuring a high dimensional accuracy. In accordance with GOST 21646-2003 for pipes of different size, it is necessary to provide deviations in diameter within the range (−0.16 to−0.30) mm and maximum deviations in the wall thickness within the range (±0.07 – ±0.25) mm. Among copper alloys, most widely used brass grades for pipe production are L96, L68, L63, LANKMc 75-2-2.5-0.5-0.5 (GOST 15527-2004), bronze grades BrOF6.5-0.15, BrOF4-0.25 (GOST 5017-2006). Their chemical composition is presented in Table 1 [1].

Table 1. Chemical composition of copper-based alloys.

Alloy	Chemical composition
L96	(95 – 97) Cu; rest Zn
L68	(67 – 70) Cu; rest Zn
L63	(62 – 65) Cu; rest Zn
BrOF6.5-0.15	(6 – 7) Sn; (0.1 – 0.25) P; rest Cu
BrOF4-0.25	(3.5 – 4) Sn; (0.15 – 0.25) P; rest Cu
LANKMc 75-2-2.5-0.5-0.5	(73 – 76) Cu; (1.6 – 2.2) Al; (2.0 – 3.0) Ni; (0.3 – 0.7) Si; (0.3 – 0.7) Mn

Hollow billets with a diameter of 40 to 60 mm and a wall thickness of 3.5 to 6.0 mm are made by pressing ingots on hydraulic presses. For the further processing of semi-finished products, equipment which ensures the high dimensional accuracy and quality of the inner and outer surfaces of pipes is used; namely, a cold pilgering mill (CP-mill), a roller cold pilgering mill (RCP-mill), a drawing bench for drawing on a short fixed plug, on a floating plug mandrel, on a long movable mandrel or without a mandrel. Each method of deformation has its own range of the allowable elongation ratio $\lambda = \frac{F_0}{F_1}$ (Table 2). A significant difference in the diameter and wall thickness of the pressed billet and thin-walled pipes, as well as the limited elongation ratio λ, predetermines the cyclic operating mode.

Table 2. Elongation ratios for various methods of manufacturing cold-deformed pipes.

Method	Elongation ratio λ
Cold pilgering mill	3.5…5.0
Roller cold pilgering mill	2.0…2.5
Drawing without a mandrel	1.3…1.7
Drawing on a short fixed plug	1.4…1.6
Drawing on a floating plug mandrel	1.4…1.8
Drawing on a long movable mandrel	2.0…2.5

Fundamentals of Designing Flows for the Manufacture of Cold-Deformed Pipes

When developing the technological process of manufacturing thin-walled and extremely thin-walled pipes, the choice of the pipe processing method must meet the following criteria: reduced production cyclicality ensuring high elongation ratios and productivity.

It is necessary to satisfy the process limitations at each technological operation of the production cycle of pipe processing (pipe preparation for manufacture, including inspection and repair of blanks, physical and chemical preparation for deformation; deformation by one or another of the above-mentioned methods; heat treatment and subsequent pipe straightening). For example, when drawing pipes on a long movable mandrel, one must see to it that geometric limitations are met to ensure forging of the front end of the pipe and free entry of a mandrel into the pipe. Also, it is necessary to satisfy the process power parameters corresponding to the driving power of the drawing bench, as well as the single elongation ratio limit based on the strength of the pointed end and the pipe metal under drawing. When designing flows for manufacturing cold-deformed pipes by multiple drawing without intermediate heat treatment, it is necessary to satisfy the limitation of the maximum permissible metal damage ω that accumulates in the passes and may cause cracking or reduce the level of the operational reliability of the pipe. The scientific basis for calculating metal damage ω during deformation and changing its level during heat treatment is the mechanics of ductile fracture of a metal [2, 3].

Development of a technological process for manufacturing thin-walled and extremely thin-walled pipes made of copper alloys is based on the calculation of metal damage ω, which should not exceed 0.65, and the relative drawing stress $\frac{\sigma_{dr}}{\sigma_s}$ (where σ_{dr} is drawing stress, σ_s is the strain resistance of work-hardened metal), which should not exceed 0.85.

Investigation of a Pipe Deformation Zone during Drawing on a Long Movable Mandrel

Simulation of the process of brass pipe drawing on a long movable mandrel is set in the Deform-3D software complex. Workpiece material is assumed to be plastically hardened, the dimensions of the workpieces, the dies and the mandrels are selected in accordance with the drawings of Revda Non-Ferrous Metal Processing Works JSC (RNMPW JSC). The movement pattern and shaping of the cells marked in the longitudinal section of the pipe are shown in Fig. 1. As shown in Fig. 1, it is possible to identify areas of severe deformation, which are represented by two shear surfaces and three rigid blocks 1 – 3. As can be seen from Fig. 1, each elementary particle passing through the shear surface AC rotates clockwise relative to the eigenvector of the principal stress σ_2 and then counterclockwise on the BC surface; this indicates the alternating nature of the deformation with the amplitudes $\varepsilon_1 = \frac{1}{\sqrt{3}} \cdot \frac{\Delta v_\tau}{v_n}\Big|_{AC}$ on the AC surface and $\varepsilon_2 = \frac{1}{\sqrt{3}} \cdot \frac{\Delta v_\tau}{v_n}\Big|_{BC}$ on the BC surface, where Δv_τ is the value of the discontinuity in the tangential component of the velocity vector on the AC and BC surfaces, and v_n is the normal component of the velocity vector, which is found from the velocity hodograph of the rigid blocks 1 – 3. The value of the yield stress on the AC and BC surfaces is determined by taking into account the strain hardening of the metal on the shear surfaces. The stress state indicators on the shear surfaces are determined as follows: $\frac{\sigma}{T} = \frac{\sigma_n}{\tau_s}\Big|_{AC}$ on the AC surface and $\frac{\sigma}{T} = \frac{\sigma_n}{\tau_s}\Big|_{BC}$ on the BC surface, where $\sigma_n\big|_{AC}$ and $\sigma_n\big|_{BC}$ are determined from the equilibrium condition of the rigid blocks. The Lode parameter μ_σ neglecting the tangential component of the strain tensor ($\varepsilon_{\varphi\varphi} = 0$), is equal to zero on the shear surfaces ($\mu_\sigma = 0$).

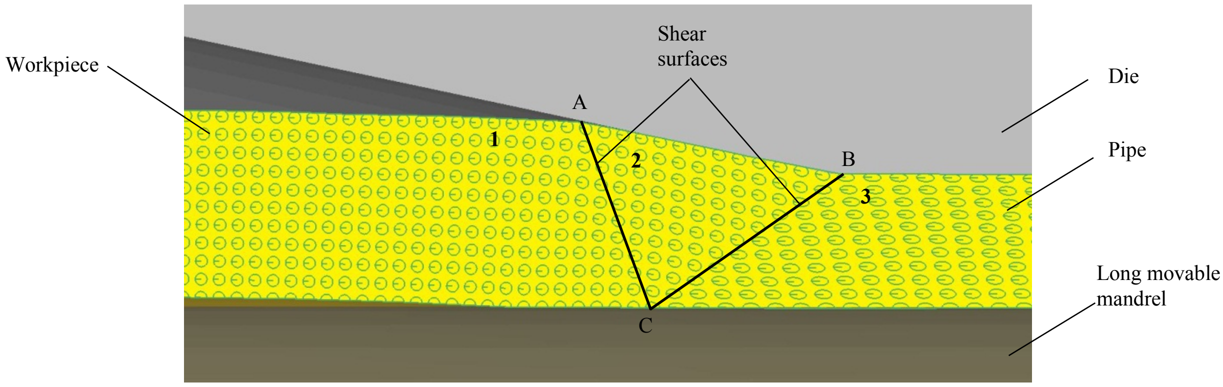

Fig. 1. Deformation zone scheme for pipe drawing on a long movable mandrel.

The indicated patterns correspond to the stress-strain state pattern for the thin-walled pipe drawing process described in [2]. On the basis of the pattern, the damage ω is determined by integrating the relation

$$\omega = \int_0^{\Lambda_1} \frac{a\Lambda^{a-1}}{\Lambda_f^a} d\Lambda \,, \tag{1}$$

where Λ is shear strain, Λ_f is a measure of metal ductility (plastic strain), and a is a functional coefficient characterizing the damage accumulation rate during plastic deformation.

For drawing on a long movable mandrel, when the deformation zone consists of several zones and the thermomechanical parameters change abruptly when passing from one stage to another, relation (1) can be represented in the form of a recurrence formula as

$$\omega = \left\langle \left\{ \left[\left(\frac{\Lambda_1}{\Lambda_{f1}} \right)^{a_1/a_2} + \left(\frac{\Lambda_2}{\Lambda_{f2}} \right) \right]^{a_2/a_3} + \ldots + \frac{\Lambda_i}{\Lambda_{fi}} \right\}^{a_i/a_{i+1}} + \ldots + \frac{\Lambda_n}{\Lambda_{fn}} \right\rangle^{a_n} , \tag{2}$$

where n is the number of stages in the zone of monotonic deformation.

Program and Analysis of Flows for Pipe Manufacturing by Multiple Drawing on a Long Movable Mandrel without Intermediate Heat Treatment

To carry out technological calculations for drawing on a long movable mandrel, a special program developed at the Metal Forming Department of the Ural Polytechnic Institute was used. Empirical data on the hardening curves and plastic properties of brasses L96, L68 and L63 taken from [2] were used as initial data in the program. Single elongation ratios along the passes were adopted as variable parameters: $\lambda_1 \cdot \lambda_2 \cdot \lambda_3 = \lambda_\Sigma$. First of all, the distribution of the single elongation ratios with the same value of the total elongation ratio λ_Σ was varied. As an example, the results of calculations for pipes made from L96 brass, with a total elongation ratio λ_Σ equal to 4.0 are presented in Table 3.

Table 3. Results of calculating the pipe damage and relative drawing stress for the process of drawing on a long mandrel for L96 brass and the total elongation ratio λ_Σ equal to 4.0.

No.	Distribution of single elongation ratios $\lambda_1 \cdot \lambda_2 \cdot \lambda_3$	Relative drawing stress in the first pass n_1	Relative drawing stress in the second pass n_2	Relative drawing stress in the third pass n_3	Accumulated damage ω of the pipe metal at the end of the third pass
1	1.9·1.5·1.4	0.72	0.45	0.36	0.32
2	1.8·1.6·1.4	0.69	0.5	0.36	0.29
3	1.7·1.6·1.47	0.65	0.51	0.4	0.26

As we can see from the table, when passing to a more uniform distribution of the single elongation ratios λ_i, the accumulated damage ω decreases, while the relative drawing stress in the last pass increases. In view of this, for each alloy and the total elongation ratio λ_Σ, an optimal distribution of the single elongation ratios was found. The research results for the brass grades L96, L68 and L63 are presented in Table 4.

Table 4. Results of calculating pipe damage ω during drawing on a long mandrel.

Alloy	Elongation ratio in the first pass λ_1	Elongation ratio in the second pass λ_2	Elongation ratio in the third pass λ_3	Total elongation ratio λ_Σ	Accumulated damage ω
L96	1.9	1.85	1.7	6.0	0.46
	1.7	1.6	1.47	4.0	0.26
	1.6	1.5	1.4	3.36	0.19
	1.5	1.4	1.3	2.73	0.12
L68	1.7	1.6	1.47	4.0	0.7
	1.6	1.5	1.4	3.36	0.55
	1.5	1.4	1.3	2.73	0.41
L63	1.5	1.4	1.3	2.73	0.79
	1.4	1.3	1.2	2.18	0.59

As can be seen from Table 4, L96 brass has the highest ductility, and it can be deformed with a total elongation ratio λ_Σ equal to 6.0, after which the drawn pipes must be heat-treated, or, with a total elongation ratio λ_Σ equal to 4.0, no intermediate heat treatment is necessary. Brasses L68 and L63 have lower plasticity: L68 can be deformed with a total elongation ratio λ_Σ equal to 3.4 with subsequent heat treatment; brass L63 can be deformed with a total elongation ratio λ_Σ equal to 2.2 with subsequent heat treatment.

Equipment of the Line of Multiple Drawing of Pipes on a Long Movable Mandrel

The developed and implemented line of triple pipe drawing on a long movable mandrel at RNMPW JSC has the following advantages: there are 12 technological operations in an automatic mode in the line; the line has a high productivity of ~ 1400...1600 m/h (for comparison, the productivity of the CP-mill is 120…160 m/h, and the productivity of the RCP-mill is 8…60 m/h). The number of processing cycles reaches 3 to 15 on drawing benches for drawing on a short fixed plug or without a mandrel due to the limitation of the single elongation ratio λ_i, and this considerably reduces the productivity of the manufacturing area, stability in ensuring the product quality index and increases the level of defects. Rational drawing flows were developed and two processing lines for manufacturing pipes from brass of the grades L96, L68, L63, LANKMc 75-2-2.5-0.5-0.5, bronze of the grades BrOF6.5-0.15, BrOF4-0.25 were implemented at RNMPW JSC.

Technology of Manufacturing Coated Pipes from Copper-Based Alloys

One of the demanded products of the plant is brass pipes with tin coating for heat exchangers (according to GOST 21646-76). The technological scheme consists in producing a preliminary hollow blank from brass with a size of 14.95×0.68 by the bull-block drawing method, freezing the tin on the outer surface and further plastic deformation of the blank with a coating on the lines of triple pipe drawing on a long movable mandrel, drawing on a short fixed plug and profiling. The thickness of the tin coating during deformation decreases from 0.125 mm to 0.025 mm. The practical effect of mastering the technology of manufacturing brass coated pipes is an increase in the pipe performance characteristics. Relevant objectives for the described technological scheme consist in the reduction of the defect rate (variation in wall thickness, cracks or flaws). The solution of the problem is achieved by increasing the uniformity of the applied coating along the length of the workpiece and optimizing the deformation modes.

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