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ANALYSIS OF MANUFACTURING BIMETALLIC TUBES BY THE COLD DRAWING PROCESS

Drawing processes apply to obtain the bimetallic tubes from the different metals and alloys, combined in the solid state, which significantly affects the specificity of this process. The manufacturing of bimetallic tubes by drawing process depends on many factors which include: preparation of the surface of materials joined in the solid state, the geometric parameters of the working tool, technological parameters of the drawing process (drawing speed, type of lubricant, the use of back pull etc.). Generally, the cold drawing process of producing the bimetallic tubes refers to metals which have high ductility (copper, aluminum, etc.). The tube sinking (tube drawing without a mandrel) of bimetallic tubes together with joining them at the interface of the two metal in the solid-state is applied for tubes of the diameter range between 6 to 20 mm and based on of the reducing the diameter of the tube. However, a slight increase of wall thickness ca. $0.05 \div 0.10$ mm can appear, which is not dangerous phenomenon in case of producing the bimetallic tubes by joining in the solid-state. The aim of the research was to investigate the technology of tubes drawing process from non-ferrous metal, drawing process of bimetallic tubes and the production of bimetallic tubes in layers composition: cooper Cu-ETP - brass CuZn37 and CuZn37 brass - copper Cu-ETP in the tube sinking process. The research program included: production of bimetallic tubes with a different composition (Cu-ETP-CuZn37 and CuZn37-Cu-ETP) and a different percentage of the cross-section components; analysis of changes of tube wall thickness and the layer composition of the bimetallic tube, based on measurements on the workshop microscope; analysis of the material flow in the process of the bimetallic tubes production based on the measurements results of a profilograph CP-200.

Keywords: bimetallic tube, drawing of the bimetallic tube, plastic flow of the bimetallic tube layers

1. Introduction

The drawing process is one of the ways of producing the tubes with small diameter, with high accuracy of shape and high surface quality. The tube sinking process (Fig. 1), also called the free tube drawing is used in order to reduce the outer diameter of the tube. The size and nature of changes in tube wall thickness depends on the ratio of the wall thickness to outer diameter of tube (for different tube wall thickness can be obtained thickening or thinning of the wall). The deformation of the tube during a draw is no more than $30 \div 35\%$, so an elongation factor $\lambda = 1.1$ to 1.5 [1, 2, 3].

The scheme of the tube sinking process together with the scheme of stress and strain occurring in the process is shown in Fig. 1. For the element in the tube wall (in the area of deformation) occur the three principal stresses: σl – axial stress, σr, $\sigma \theta$ – radial and circumferential stress.

Radial stress σr varies along the thickness of the wall, with the maximum value of $\sigma_r = pn$ (unit pressure) occurring on the contact surface of tube with the drawing die and the minimum value of $\sigma_r = 0$ on the inner surface of the tube. It can be assumed that this is linear variation, and therefore the average value of the stress σ_r (occurs in the middle of the wall thickness) is equal to half of unit pressure pn occurring at the contact surface of the metal with the drawing die.
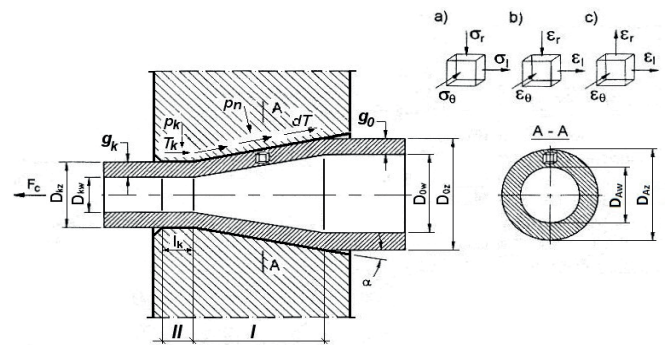

Fig.1. The scheme of tube sinking process: a) diagram of stress, b, c) the possible diagrams of strains [1-3]

The value and the sign of ε_r (radial strain) deformation depend on the ratio of stresses σ_l (axial stress) and $\sigma \theta$ (circumferential stress). Under the influence of circumferential stress σ_θ the metal will flow into the tube causes the increasing the wall thickness. At the same time, the action of tensile stresses σ_l seeks to reduce the wall thickness, that is, thinning the tube wall. Depending on whether the effect of stress σ_θ or the effect of stress σl will have the bigger influence, the final wall thickness will be bigger or smaller than the initial thickness. While mutual balancing out the impact of stresses σ_θ and σ_l the wall of the tube does not change. In the tube sinking

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process the zone of plastic deformation can be divided into two sections:

- I zone - area in which occurs the change of the wall thickness of the tube,
- II zone - the area of calibration the outer diameter of the tube.

2. The influence of the value of deformation for change of the wall thickness during the tube sinking process

The change of wall thickness of tube drawn in the tube sinking process is the uncontrolled value, since it depends on the mutual relation between stresses occurring in the area of deformation. The ability to determine the expected change of the wall thickness has the practical importance especially during drawing the thin-walled tubes, because it allows for the proper design of the process. The numerous experimental studies [3, 4, 5, 6], as well as the analysis of known in the literature analytic relationship, shows that for the change of the tube wall thickness have the influence such parameters of the drawing process as: value of deformation, ratio of wall thickness (g_0) to outer diameter of the tube (D_{0z}), friction coefficient and the working angle of the drawing die 2α. The Fig. 2 shows the changes of wall thickness (Δg) depending on the value of deformation and ratio of wall thickness to outer diameter of the tube.
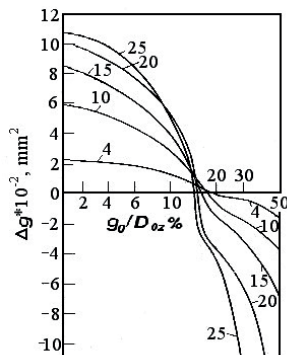

Fig. 2. The diagram of change the tube wall thickness Δg in the tube sinking process, depending on the value of deformation and ratio of wall thickness to outer diameter of the tube [6]

It should be noted that the tube ratio of wall thickness to outer diameter of the tube significantly affect the change of wall thickness. For thin-walled tubes (g_0/D_{0z} small) is observed thickening of the walls of the entire range of applied strains and the trend is decreasing with increasing values of g_0/D_{0z}. For a thick-wall tubes (g_0/D_{0z} large) may occur slight thickening of the wall, thinning of the wall or under certain conditions, no change in wall thickness.

3. Production of bimetallic tubes

The bimetallic tubes can be produced in the cold drawing process. This method is used for metals (components of the bimetallic tube), which have high ductility (copper, copper alloys, aluminium, aluminium alloys, etc.), as well as those in which one has the different plastic characteristics from the second (eg. low-carbon steel, high alloy steel).

Of the known methods of drawing the bimetallic tube the tube sinking is used. Simultaneously tube sinking of bimetallic tubes together with joining them at the interface of the two metals in the solid-state is applied in the tube diameter range between 6 to 20 mm and consists in the reducing the diameter of the outer tube. At the same time, together with the reducing the diameter of the bimetallic tube may be followed a slight increasing of the wall thickness of $0.05 \div 0.10$ mm, but this process is not dangerous. More unsafe is the occurrence of the folds and other defects, including the increase of surface roughness of the tube wall and others. Occurrence of this is disadvantageous depends on the degree of deformation and also the initial size of grain of the input material of tubes. Recommended elongation ratio of bimetallic tubes in all methods of drawing should not exceed $\lambda = 1.5$ and the deformation expressed as percent reduction of area should not be greater than 25% [7, 8].
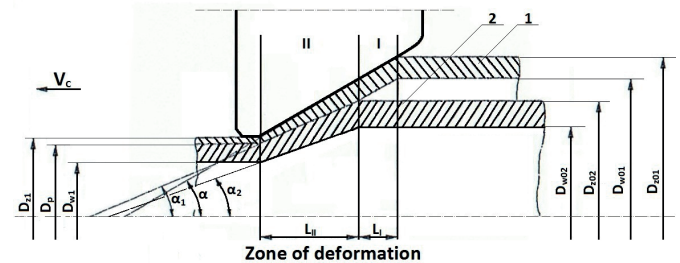

Fig. 3. The zones/areas (I and II) of forming the bimetallic tube in the drawing die, during the preliminary, simultaneous drawing of two tubes; 1 – outer tube; 2 – inner tube; D_{z01} – the outer diameter of the outer tube, D_{w01} -the inner diameter of the outer tube, D_{z02} – the outer diameter of the inner tube, D_{w02} – inner diameter of the inner tube, D_{z1} – the outer diameter of the bimetallic tube, D_p – the outer diameter of the inner tube after drawing, D_{w1} – inner diameter of the bimetallic tube, α - angle of drawing die, α_1 - angle of parting plane.

The area of deformation the bimetallic tube in the drawing die can be divided into two zones (Fig. 3): first (I) in which occurs the deformation of the outer layer of the outer tube so that it has a contact with the outer surface of the inner tube, second (II) in which the simultaneous deformation of the two tubes take place, and through the connections in the solid state, the bimetallic tube is produced.

4. The input materials for the production of bimetallic tubes

The input material for drawing of bimetallic tubes is derived from the drawing process the copper and brass tubes with the following dimensions (outer diameter x wall thickness; D_{z0} x g_0) and characteristics:

- tube CuZn37 (ø 25.0 x 2.0 mm; ø 25.0 x 1.5 mm; ø 20.0 x 2.0 mm; ø 21.0 x 2.5 mm) Rm = 323 MPa, A10 = 64%,
- tube Cu-ETP (ø 25.0 x 2.0 mm; ø 25.0 x 1.5 mm; ø 20.0 x 2.0 mm; ø 21.0 x 2.5 mm) Rm = 365 MPa, A10 = 3%.

For production the bimetallic tubes were used the copper Cu-ETP with the chemical composition according to PN-77/H-82120 and brass CuZn37 with chemical composition according to PN-92/H-87025 (Table 1).

TABLE 1

The chemical composition of the input material for production of bimetallic tubes

Cooper Cu-ETP ac. PN–77/H–82120 (in wt.%)										
Cu	Bi	Pb	Sb	As	Fe	Ni	Sn	Zn	S	O_2
99.9	0.001	0.005	0.02	0.002	0.005	0.02	0.002	0.003	0.004	up to 0.600
Brass CuZn37 ac. PN–92/H–87025 (in wt.%)										
Cu	Fe	Pb	Sn	Al	Ni	Σ Mg, P, Mn, Si			Zn	
62.0÷65.0	0.200	0.300	0.100	0.030	0.300	0.100			35.00÷37.00	

5. Production and drawing of bimetallic tubes

The bimetallic tubes were obtained in the tube sinking process. For a composition I and III the drawing die ø = 22.0 mm was used, whereas for a composition II and IV the drawing die ø = 23.0 mm was used. For the next drawn the drawing dies with the same dimensions were used (ø = 20.0 mm and ø = 18.5 mm). Due to problems with tightening for each composition were carried out only three draws. For the first composition the third draw were not carried out, because after the second draw the tube crack occurred. The summary of geometrical parameters of bimetallic tubes produced in the tube sinking process is shown in Table 2.

TABLE 2

The summary of geometrical parameters of input tubes and bimetallic tubes produced in the tube sinking process

		CuZn37/ Cu-ETP	D_z, mm	g_0, mm	Percentage, %	
Composition I (CuZn37/44%Cu-ETP)	Input tubes	CuZn37	25.00	2.00	56.1	
		Cu-ETP	20.00	2.00	43.9	
	Bimetallic tubes					
	Drawing die-ø, mm	D_z, mm	g, mm	Layer CuZn37, mm	Layer Cu-ETP, mm	Percentage CuZn37/ Cu-ETP, %
	22.0	21.95	3.968	1.906	2.062	53.55% / 46.45%
	20.0	19.90	3.801	1.758	2.043	52.12% / 47.88%
	18.5	-	-	-	-	-
		CuZn37/ Cu-ETP	D_z, mm	g_0, mm	Percentage, %	
Composition II (CuZn37/57%Cu-ETP)	Input tubes	CuZn37	25,00	1,50	43,3	
		Cu-ETP	21,00	2,50	56,7	
	Bimetallic tubes					
	Drawing die-ø, mm	D_z, mm	g, mm	Layer CuZn37, mm	Layer Cu-ETP, mm	Percentage CuZn37/ Cu-ETP, %
	23.0	23,05	3,753	1,293	2,460	38,84%/ 61,16%
	20.0	19,90	3,825	1,303	2,522	39,41%/60,59%
	18.5	18,65	3,613	1,023	2,590	33,18%/66,82%
		Cu-ETP/ CuZn37	D_z, mm	g_0, mm	Percentage, %	
Composition III (Cu-ETP/44%CuZn37)	Input tubes	Cu-ETP	25,00	2,00	56,1	
		CuZn37	20,00	2,00	43,9	
	Bimetallic tubes					
	Drawing die-ø, mm	D_z, mm	g, mm	Layer Cu-ETP, mm	Layer CuZn37, mm	Percentage Cu-ETP/CuZn37, %
	22.0	21,90	4,329	1,594	2,735	42,55%/57,45%
	20.0	19,95	4,003	1,242	2,762	36,38%/ 63,62%
	18.5	18.65	3,965	1,318	2,647	39.23%/60.77%
		Cu-ETP/ CuZn37	D_z, mm	g_0, mm	Percentage, %	
Composition IV (Cu-ETP/57%CuZn37)	Input tubes	Cu-ETP	25.00	1.50	43.3	
		CuZn37	21.00	2.50	56.7	
	Bimetallic tubes					
	Drawing die-ø, mm	D_z, mm	g, mm	Layer Cu-ETP, mm	Layer CuZn37, mm	Percentage Cu-ETP/CuZn37, %
	23.0	22.90	4.192	1.461	2731	39.94%/60.06%
	20.0	19.85	4.101	1.397	2.704	39.91%/60.09%
	18.5	18.55	3.786	0.983	2.803	30.88%/69.12%

To determine the percentage and the relative deformation on the thickness of the layer and the whole wall the equation were used:

- relative deformation on the thickness of the layer and the wall has been determined by the equation:

$$\varepsilon_g = \frac{g_0 - g_1}{g_0} \cdot 100\%, \qquad (1)$$

where: g_0 – wall thickness (layer) before drawing

g_1 – wall thickness (layer) after drawing

- the percentage of particular component on the cross-section of bimetallic tubes was determined from the equations:

for brass:
$$U_{M63} = \frac{S_{M63}}{S_{M63} + S_{Cu}} \cdot 100\% \qquad (2)$$

for cooper
$$U_{Cu} = \frac{S_{Cu}}{S_{Cu} + S_{M63}} \cdot 100\% \qquad (3)$$

where: S_{CuZn37} – cross-section of brass tube

S_{Cu} – cross-section of cooper tube

6. Results

The measurement of the thickness of the inner and outer layer of bimetallic tubes was carried out on the workshop microscope, by determination the thickness of the layers of bimetallic tubes in eight locations on the circumference at each 45°. Exemplary results of measurements and calculations for IV composition – Cu-ETP/57%CuZn37 are shown in Tables 5, 6, 7 and in Fig. 4, 5, 6.
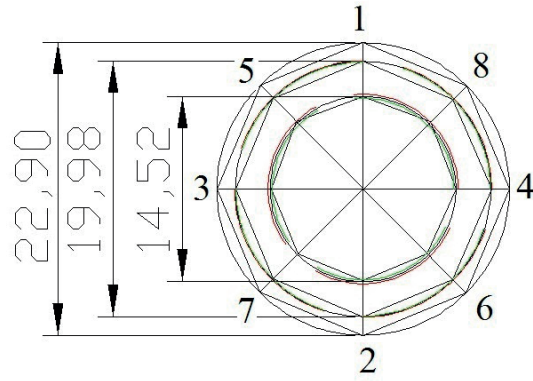
Fig. 4. Cross section of bimetallic tube after the simultaneous pre-drawing for the IV composition (1÷8 – measure points)

TABLE 3

The results of the relative deformation on the thickness of the layers and the wall for simultaneous pre-drawing process for composition IV(Cu-ETP/57%CuZn37)

	No.	Layer CuZn37, mm	Layer Cu-ETP, mm	g, mm	$\varepsilon_{gCu\text{-}ETP}$, %	$\varepsilon_{gCuZn37}$, %	$\varepsilon_{gCuETP/CuZn37}$, %
Drawing die ø = 23.0 mm	1	1.404	2.785	4.189	6.40	-11.40	-
	2	1.428	2.826	4.254	4.80	-13.04	-
	3	1.503	2.795	4.298	-0.20	-11.80	-
	4	1.417	2.736	4.153	5.53	-9.44	-
	5	1.458	2.56	4.018	2.80	-2.40	-
	6	1.498	2.847	4.345	0.13	-13.88	-
	7	1.476	2.785	4.261	1.60	-11.40	-
	8	1.504	2.514	4.018	-0.27	-0.56	-
	Average	1.461	2.731	4.192	2.60	-9.24	-

TABLE 4

The results of the relative deformation on the thickness of the layers and the wall of the bimetallic tube for the first draw, composition IV (Cu-ETP / 57%CuZn37)

	No.	Layer CuZn37, mm	Layer CuETP, mm	g, mm	$\varepsilon_{gCu\text{-}ETP}$, %	$\varepsilon_{gCuZn37}$, %	$\varepsilon_{gCuETP/CuZn37}$, %
Drawing die ø = 20.0 mm	1	1.364	2.669	4.033	6.64	2.27	3.79
	2	1.442	2.722	4.164	1.30	0.33	0.67
	3	1.526	2.893	4.419	-4.45	-5.93	-5.42
	4	1.328	2.501	3.829	9.10	8.42	8.66
	5	1.444	2.896	4.34	1.16	-6.04	-3.53
	6	1.353	2.531	3.884	7.39	7.32	7.35
	7	1.414	2.748	4.162	3.22	-0.62	0.72
	8	1.306	2.674	3.98	10.61	2.09	5.06
	Average	1.397	2.704	4.101	4.37	0.98	2.16

The results of the relative deformation on the thickness of the layers and the wall of the bimetallic tube for the second draw, composition IV
(Cu-ETP / 57% CuZn37)

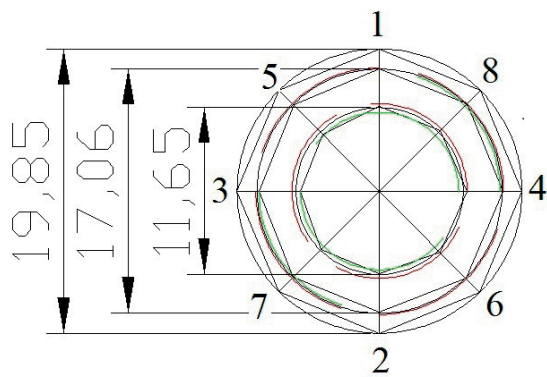|	No.	Layer CuZn37, mm	Layer Cu-ETP, mm	g, mm	$\varepsilon_{gCu\text{-}ETP}$, %	$\varepsilon_{gCuZn37}$, %	$\varepsilon_{gCuETP/CuZn37}$, %
Drawing die ø = 18,5 mm	1	0.952	2.873	3.825	31.86	-6.24	6.74
	2	0.981	2.798	3.779	29.78	-3.47	7.86
	3	1.003	2.899	3.902	28.21	-7.20	4.86
	4	0.945	2.716	3.661	32.36	-0.43	10.74
	5	1.016	2.841	3.857	27.28	-5.06	5.96
	6	0.982	2.72	3.702	29.71	-0.58	9.74
	7	0.974	2.732	3.706	30.29	-1.03	9.64
	8	1.008	2.846	3.854	27.85	-5.24	6.03
	Average	0.983	2.803	3.786	29.67	-3.66	7.70

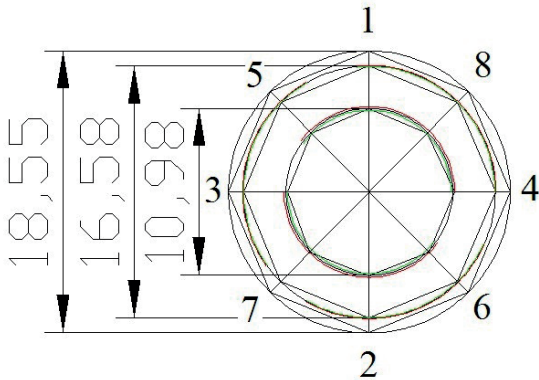Fig. 5. Cross section of bimetallic tube after the first draw for the IV composition (1÷8 – measure points)

Fig. 6. Cross section of bimetallic tube after the second draw for the IV composition (1÷8 – measure points)

7. Analysis of flow of bimetallic tubes in the pre-drawing process

Studies of flow layers of bimetallic tube were carried out using the profilograph CP-200 and on samples prepared during the preparation of bimetallic tubes (the simultaneous pre-drawing - putting the outer tube on the inner and withdrawal from the drawing die). For the analysis of percentage the layers of bimetallic tubes were cut samples covering an area of deformation of the material in the drawing die and the shape of surface on outer and inner site of the sample was determined. An angle α_1 and radii R_1 and R_2, using the software "Conturpak" Fig. 7, which allows the transfer the data to the CAD system [9]. The measurement results are shown in the following Fig.: 8, 9, 10, 11 and calculations are given in Tables 6, 7, 8, 9.

Fig. 7. An outer profile of the bimetallic tube during the simultaneous pre-drawing with marked output radius R1, the output angle a1 and input radius R2

Summary of the radii and the output angles on the layers of bimetallic tubes during the pre-drawing process for a composition I

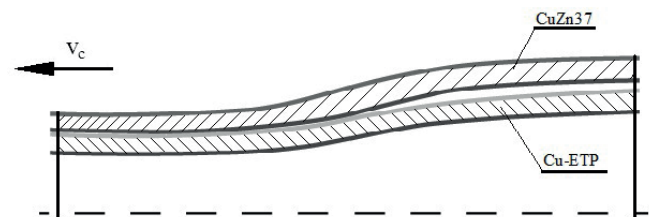| Composition I				
CuZn37/Cu-ETP	ø, mm	draw →	Drawing die ø, mm	
CuZn37	25.0 x 2.0		22.0	
Cu-ETP	20.0 x 2.0			
	Outer tube		Inner tube	
	outside	inside	outside	inside
R_1, mm	15.8160	18.8178	27.4718	8.6340
R_2, mm	19.7878	27.1919	32.4515	28.5860
Angle a1	14°11'	9°53'	9°49'	9°51'

Fig. 8. The flow of material during the simultaneous pre-drawing of outer tube 56% CuZn37 and inner tube Cu-ETP - composition I

TABLE 7

Summary of the radii and the output angles on the layers of bimetallic tubes during the pre-drawing process for a composition II

Composition II			
CuZn37/Cu-ETP	ø, mm	draw	Drawing die ø, mm
CuZn37	25.0 x 1.5	→	23.0
Cu-ETP	21.0 x 2.5		
	Outer tube		Inner tube	

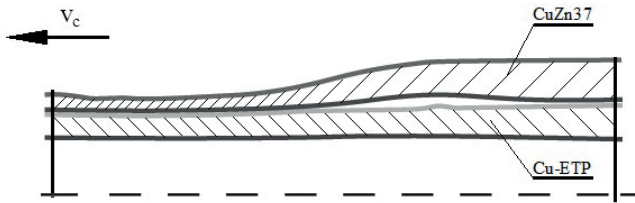|	outside	inside	outside	inside
R_1, mm	8.8908	17.6446	-	-
R_2, mm	18.6429	9.0926	-	-
Angle a1	13°21'	8°15'	-	-

Fig. 9. The flow of material during the simultaneous pre-drawing of outer tube 43%CuZn37 and inner tube Cu-ETP - composition II

TABLE 8

Summary of the radii and the output angles on the layers of bimetallic tubes during the pre-drawing process for a composition III

Composition III			
Cu-ETP/ CuZn37	ø, mm	draw	drawing die ø, mm
Cu-ETP	25.0 x 2.0	→	22.0
CuZn37	20.0 x 2.0		
	Outer tube		Inner tube	

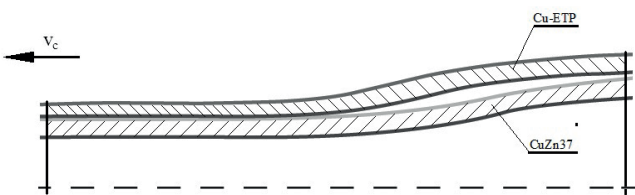|	outside	inside	outside	inside
R_1, mm	16.1245	23.2937	25.7036	27.7830
R_2, mm	27.7583	20.2148	34.6455	23.3806
Angle a1	14°23'	10°24'	12°20'	8°36'

Fig. 10. The flow of material during the simultaneous pre-drawing of outer tube 57% Cu-ETP and inner tube CuZn37 - composition III

TABLE 9

Summary of the radii and the output angles on the layers of bimetallic tubes during the pre-drawing process for a composition IV

Composition IV			
Cu-ETP/ CuZn37	ø, mm	draw	drawing die ø, mm
CuETP	25.0 x 1.5	→	23.0
CuZn37	21.0 x 2.5		
	Outer tube		Inner tube	

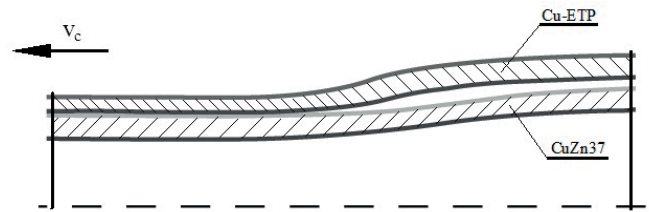|	outside	inside	outside	inside
R1, mm	8.4094	29.2526	44.7509	52.7375
R2, mm	24.9648	30.9083	59.8187	38.4610
Angle a1	12°48'	8°44'	6°35'	3°57'

Fig. 11. The flow of material during the simultaneous pre-drawing: outer tube 43% Cu-ETP and inner tube CuZn37 – composition IV

8. Conclusions

1. Simultaneous drawing of copper and brass tubes with different compositions of material layers (CuZn37/ Cu-ETP or Cu-ETP/CuZn37) and different weight percentages (between 30 - 60% share of the outer tube in the cross-section) allows for production the bimetallic tubes in the tube sinking process.

2. The analysis of the wall thickness of the bimetallic tube shows lack of uniformity of deformation at the perimeter. In the shell (outer tube) the predominant mechanism is thinning ($\varepsilon_g = 34.12\%$), while in the inner layer (inner tube) is the thickening ($\varepsilon_g = -32,34\%$).

3. In the simultaneous pre-drawing process the outer and inner tube in almost all cases occurs the thinning of the shell (outer layer) and a thickening of the inner layer, the exception is the composition II (for a lower proportion of a hard brass shell below 40%), where occurs the thinning of the both materials.

4. The analysis of tube materials flow shows the formation of bimetallic tubes during deformation in the drawing die. Both at the input and at output, seen that material deforms by deflecting like the arc - a measure is the radius (Table 6, 7, 8, 9). On the basis of the shape of the tube the angle of the drawing die was determined. It should be noted that the obtained values are different from the values specified by the manufacturer of drawing dies (Table 6, 7, 8, 9).

5. The carried our research confirms that in the tube sinking process of the bimetallic tube is difficult to predict the behaviour of the material in the drawing die, and the following options are possible:
   a) for a composition - the outer layer hard and inner soft: the thinning of outer layer, thickening of the inner layer or thickening both layers,
   b) for a composition- the outer layer soft and inner hard: the thinning of both layers, or thickening of the outer layer, thinning of inner layer.

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