Modeling and Research of the Deformation Treatment Process of 585 Gold Fineness Alloys for Obtaining Wire for Jewelry Purpose

Sergey Borisovich Sidelnikov

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Yuliia Dmitrievna Ditkovskaia

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Ekaterina Sergeevna Lopatina

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Denis Sergeevich Voroshilov (✉ d.s.voroshilov@gmail.com)

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia   https://orcid.org/0000-0002-1406-3665

Olga Sergeevna Lebedeva

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Igor Lazarevich Konstantinov

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Roman Ilsurovich Galiev

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Yulbarskhon Nabievich Mansurov

   Tashkent State Transport University

Vladimir Ivanovich Ber

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Edvard Anatolyevich Rudnitskiy

   Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

Vladimir Aleksandrovich Lopatin

Siberian Federal University School of Non-Ferrous Metals and Material Science: Sibirskij federal'nyj universitet Institut cvetnyh metallov i materialovedenia

MODELING AND RESEARCH OF THE DEFORMATION TREATMENT PROCESS OF 585 GOLD FINENESS ALLOYS FOR OBTAINING WIRE FOR JEWELRY PURPOSE

Sergey Borisovich Sidelnikov[1], Yuliia Dmitrievna Ditkovskaia[1], Ekaterina Sergeevna Lopatina[1], Denis Sergeevich Voroshilov[1]*, Olga Sergeevna Lebedeva[1], Igor Lazarevich Konstantinov[1], Roman Ilsurovich Galiev[1], Yulbarskhon Nabievich Mansurov[2,3], Vladimir Ivanovich Ber[1], Edvard Anatolyevich Rudnitskiy[1], Vladimir Aleksandrovich Lopatin[1]

[1] Siberian federal university, Krasnoyarsk, 660025, Krasnoyarsk Region, Russian Federation
[2] Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan, Tashkent State Transport University, Tashkent, 100000, The Republic of Uzbekistan
[3] Huanggang Normal University, Huangzhou District, Huanggang, 438000, Hubei, China
*E-mail: d.s.voroshilov@gmail.com

Abstract

The results of studies of the process of obtaining wire for the manufacture of jewelry chains from new nickel-free 585 gold fineness alloys are presented.

New 585 gold fineness alloys, alloyed with palladium, silver and other elements, and as modifiers - with rhodium and ruthenium in the stated quantities have been proposed.

By modeling the process of section rolling of rods in octagonal calibers using the variation method of minimum total power, the broadening of the metal and the energy-power parameters of rolling rods from the investigated alloys have been determined. The regularities of their change have been found. Software has been developed for designing processes for the production of longish deformed semi-finished products and technological modes of rolling and drawing of new gold alloys.

With the help of experimental studies, the adequacy of the results of calculations and modeling was checked and new data were obtained on the mechanical properties of the metal and its structure.

It has been found that the proposed alloys and the modes of their processing using the processes of section rolling and drawing make it possible in industrial conditions to obtain jewelry wire with a diameter of up to 0.25 mm with the level of mechanical and operational properties required for chain tying.

Keywords: Jewelry production, Gold alloys, Wire, Mechanical properties, Metal structure, Drawing.

1 Introduction

The gold market has been developing in recent years despite fluctuations and world events [1]. Single publications [2-7] are devoted to the issues of jewelry production, including the manufacture of deformed semi-finished products from precious metal alloys [4-7]. Research in this area is mainly the work of scientists from the Ural and Siberian Federal Universities and specialists from the Krasnoyarsk and Yekaterinburg plants of non-ferrous metals [8-11]. Therefore, the task of creating new hypoallergenic alloys with a given level of mechanical and operational properties, as well as technologies for their deformation processing, along with a decrease in anthropogenic load on the environment [12, 13] is urgent and requires modeling these processes and comprehensive theoretical and experimental studies.

On the basis of the analysis of scientific and technical literature and the results of patent search [14-23] for the manufacture of jewelry from 585 gold fineness alloys, new chemical compositions of such alloys were proposed [24-26], the distinctive features of which are the absence of nickel and the choice of modifying additives (Table 1) and the method of modification [27].

Table 1 – The chemical composition of new alloys based on 585 gold fineness alloys

Alloy	The chemical composition of the alloy, the mass fraction of the component, %									
	Au	Ag	Pd	Cu	Zn	In	Ru	Rh	Sn	Si
№1	58.5	21.6	10.0	8.4	1.5	-	0.01	-	-	-
№2	58.5	26.0	8.0	5.5	1.5	0.5	0.01	-	-	-
№3	58.5	26.0	8.0	5.5	1.5	0.5	-	0.1	-	-
№4	58.5	26.0	8.0	5.5	1.5	0.5	0.05	0.05	-	-

Analysis of the technological scheme for the production of rods and wires for the manufacture of jewelry chains, equipment and gauge systems for section rolling of precious metals showed that to obtain longish deformed semi-finished products a cast rod made of precious metal alloys with a diameter of 8-10 mm is used. Cast rod is subjected to cold section rolling on continuous mills in three stages in 28 passes with intermediate anneals. A square billet with a size of 1.1×1.1 mm is drawn to obtain a wire with a diameter of 0.25-0.35 mm.

The analysis of scientific, technical and patent literature made it possible to draw the following conclusions:

1. One of the important trends in the production of longish deformed semi-finished products for the production of jewelry chains is the creation of new nickel-free gold alloys and technologies for their deformation processing to improve their mechanical, technological and operational properties, reduce the cost of products made from them and ensure compliance with existing safety standards.

2. Improving the technology for the production of rods from alloys of precious metals, obtained in industrial practice by cold section rolling using octagonal gauges, is an urgent task and requires new scientifically grounded solutions.

3. Existing methods for calculating the shape change and energy-power parameters of section rolling are developed mainly for other gauge systems and conditions for hot rolling of steels, or are based on the use of empirical formulas. Therefore, for new alloys of precious metals, a comprehensive study of the rolling process in octagonal gauges using methods of mathematical and physical modeling.

4. Development of software for designing technological processes of section rolling and calibration of rolls is advisable in the Delphi programming environment, based on the obtained mathematical model with a block of graphic support and using the capabilities of Microsoft Acces and Autodesk FeatureCAM software products, and computer modeling of section rolling for new alloys according to the proposed routes are recommended to be carried out in the DEFORM-3D software package, since there are numerous examples of its successful use for metal forming processes.

2 Materials and method of carrying out research

Based on the conclusions made, a mathematical and computer model of the process of section rolling in octagonal gauges has been developed.

The solution of the variational problem of determining the shape change of cold section rolling in octagonal calibers of precious metal alloys was carried out using the methodology of Professor V.K. Smirnov based on the use of the principle of minimum total power and the power balance method [28]:

$$\delta(N_{in} + N_{sh} + N_{ss} + N_r) = 0, \tag{1}$$

$$N_{in} + N_{sh} + N_{ss} + N_r = 0 \tag{2}$$

where N_{in} – power of internal forces; N_{sh} – power of the shear forces in the plane of metal entry into the rolls; N_{ss} – power of friction forces at sliding speeds; N_r – power supplied by the rolls.

When solving the problem the independent dimensionless parameters which uniquely describe the deformation zone during rolling in octagonal calibers (Fig. 1) varied at three levels for the ranges of their variation used in practice within the following limits: $1/\eta = h_0 / h_i = 1.0$-1.5; reduced roll diameter $A = D_0 / h_i = 10$-80; aspect ratio $a = 0.92$-1.08; shape factor $k_a = 1.23$-1.37 (square gauge – $k_a = (1.85 \cdot b_{i-1})/b'_{i,}$, rhombic gauge – $k_a = (0.8 \cdot b_{i-1})/b'_i$), where h_i – caliber height; D_0 – roll diameter; b_i – caliber width, b'_i – caliber pad width. The friction coefficient is $\psi = 0.1$-0.5.

The symmetry of the deformation zone allows considering the fourth part of it. The geometric zone of deformation consists of contact zones A and B, lateral non-contact zone C and vertical zones in the planes of entry and exit of metal from the rolls at $x = 0$ and $x = l_{mk}$. To simplify the solution of the problem, it is assumed that the intermediate zone at $l^* < x < l_{mk}$ and $0 < y < b'_k$ is small and negligible. In accordance with the methodology for solving the problem [28], the broadening coefficient β and the advance coefficient ν were chosen as unknown variable parameters.
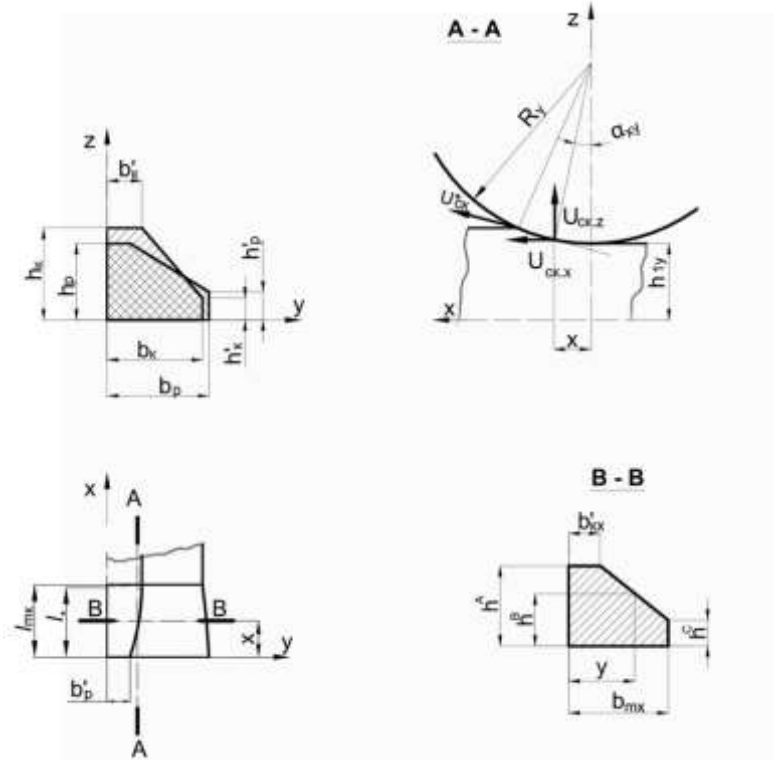
Fig. 1. Scheme of rolling in octagonal caliber

The surface equations have the form:

$$h^A = h_{1y} + 0{,}5\frac{x^2}{R_y}, \tag{3}$$

$$h^B = a_{0k}(b_{mx} - y), \tag{4}$$

The unknown parameters were the broadening coefficient β and advance coefficient ν,

$$h^C = b_{mx} \cdot \sqrt{\beta^2 - (\beta^2 - 1) \cdot \frac{x^3}{l^3} \cdot \left(10 - 15 \cdot \frac{x}{l} + 6 \cdot \frac{x^2}{l^2}\right)}. \tag{5}$$

Here $a_{0k} = \frac{h_0}{b_0}$ – aspect ratio of the previous caliber, b_{mx} – width of the caliber, taking into account the area on the metal vertically.

The current cross-sectional area of the workpiece in the deformation zone:

$$w_x = \frac{1}{2} \cdot h_{1y}(b'_{kx} + b_{mx}) + h'_{kx} \cdot b_{mx}, \tag{6}$$

where b'_{kx} and h'_{kx} – dimensions of pads in width and height of the caliber.

The metal flow velocity field was determined taking into account the hypothesis of flat sections, the hypothesis of straight verticals, the incompressibility condition, and the kinematic boundary condition. In this case the longitudinal V_x, transverse V_y and vertical V_z speeds of metal movement are described as follows:

$$V_x = V_1 \cdot \frac{w_1}{w_x}, \tag{7}$$

where w_1 and V_1– respectively, the cross-sectional area of the roll and the longitudinal speed of the metal in the plane of the exit of the metal from the rolls (at $x = 0$); w_x – cross-sectional area of the roll flowing along the x-axis.

For zone A $\qquad\qquad V_y = -\frac{1}{h^A} \int_0^y \frac{\partial}{\partial x}(V_x \cdot h^A);$ $\qquad\qquad\qquad$ (8)

For zone B $\qquad\qquad V_y = -\frac{1}{h^B} \int_{b_{kx}}^y \frac{\partial}{\partial x}(V_x \cdot h^B) - V_y \cdot h^A|y = b_{kx};$ $\qquad$ (9)

For zone C $\qquad\qquad V_z = V_x \cdot \frac{\partial h^C}{\partial x} \cdot \frac{1}{h^C} \cdot z.$ $\qquad\qquad\qquad$ (10)

The rolling speed in the section of the exit from the rolls is equal to:

$$V_1 = v \cdot V^*{}_r, \tag{11}$$

where v – advance coefficient, $V^*{}_r$ – the circumferential speed of the roll in the longitudinal-vertical section at $y = 0$.

Thus, the kinematically possible velocity field in the deformation zone is determined with an accuracy of two unknown quantities: the broadening coefficient β and the advance coefficient v.

It is assumed that the metal slides relative to the rolls over the entire contact surface and the average friction stress is

$$\bar{\tau}_{fr.ad} = \psi \cdot \tau_S, \tag{12}$$

where ψ – friction coefficient depending on the rolling temperature and the surface condition of the rolls; τ_S – metal shear yield strength.

It is assumed that the average friction stress is distributed over the lagging and leading zones in proportion to the average sliding speeds in these zones. Taking this into account, the average friction stresses in the lagging and leading zones are calculated by the formulas:

$$\bar{\tau}_{fr.ad} = \bar{\tau}_{fr} \cdot \frac{\bar{v}_{sl.ad}}{\bar{v}_{sl}}; \tag{13}$$

$$\bar{\tau}_{fr.ad} = \bar{\tau}_{fr} \cdot \frac{\bar{v}_{sl.ad}}{\bar{v}_{sl}}. \tag{14}$$

Average sliding speeds are

$$\bar{V}_{sl.lag} = \frac{1}{F_{lag}} \cdot \int_{F_{lag}} \bar{V}_{sl}dF; \tag{15}$$

$$\bar{V}_{sl.ad} = \frac{1}{F_{ad}} \cdot \int_{F_{ad}} \bar{V}_{sl}dF; \tag{16}$$

$$\bar{V}_{sl} = \bar{V}_{sl.lag} \cdot \frac{\bar{V}_{sl.ad} \cdot F_{lag} + \bar{V}_{sl.ad} \cdot F_{ad}}{F_{lag} + F_{ad}}. \tag{17}$$

The boundary between the contact surface into the lead and lag zones is the neutral line, the equation of which is determined from the condition that the projection of the total sliding speed on

the tangent to the roll circumference is equal to zero. Since the projection $V_{sl.y}$ on the tangent to the surface of the gauge, lying in the longitudinal-vertical plane passing through the selected point, is equal to zero, then

$$V^*{}_{sl} = V_{sl.x} \cdot \cos \alpha_{xy} + V_{sl.z} \cdot \sin \alpha_{xy}. \qquad (18)$$

To determine the power components, the following expressions are used:
for the power of internal forces

$$N_{in} = \int_V \tau_s H dV, \qquad (19)$$

where H – shear strain rate intensity; τ_s – metal yield strength;
for the power of the shear forces in the plane of metal entry into the rolls

$$N_{sh} = \sum_1^n \int_{F_{sh.i}} \tau_s |V^+ - V^-| dF, \qquad (20)$$

where V^+ and V^- – the projection of the metal flow velocity on the tangent plane to the cut surface $F_{sh.i}$ from the inner and outer sides of the surface;
for the power of frictional forces at sliding speeds

$$N_{sl} = - \int_{F_{lag}} \bar{\tau}_{fr.lag} U_{sl} dF - \int_{F_{ad}} \bar{\tau}_{fr.ad} U_{sl} dF; \qquad (21)$$

for the power supplied by the rolls

$$N_r = \int_{F_{lag}} \tau^*{}_{sl.lag} U_r dF + \int_{F_{ad}} \tau^*{}_{fr.ad} U_r dF, \qquad (22)$$

where

$$\tau^*{}_{fr.lag} = -\bar{\tau}_{fr.lag} \frac{U^*{}_{sl}}{U_{sl}}, \qquad (23)$$

$$\tau^*{}_{fr.ad} = -\bar{\tau}_{fr.ad} \frac{U^*{}_{sl}}{U_{sl}}. \qquad (24)$$

The power of the friction forces at sliding speeds and the power supplied by the rolls are determined taking into account the difference in the values of the friction stress in the lead and lag zones.

The basic system of equations (1) and (2) was solved by a numerical method on a computer using the MATHCAD software package when changing independent parameters.

As a result approximating formulas were obtained for calculating the coefficients β and ν

$$\beta = 1 + 0.357 \cdot \left(1/\eta - 1\right)^{0.023} \cdot A^{-0.325} \cdot k_a{}^{-1.134} \cdot \psi^{0.095} \qquad (25)$$

$$\nu = 1 + 0.087 \cdot \left(1/\eta - 1\right)^{0.954} \cdot A^{0.084} \cdot k_a{}^{0.148} \cdot \psi^{0.036}, \qquad (26)$$

where $1/\eta$ – reduction ratio, an increase in which during rolling in drawing grooves leads to an increase in the degree of filling the deformation zone with metal, which ensures a decrease in the proportion of transverse deformation; A – reduced roll diameter; k_a – coefficient taking into account the shape of the octagonal caliber; ψ – friction coefficient.

Dimensionless independent quantities are

$$\text{reduction ratio } {}^{1}/_{\eta} = \frac{h_{i-1}}{h_i}; \qquad (27)$$

$$\text{reduced roll diameter } A = \frac{D_0 - H_i}{H_i}; \qquad (28)$$

coefficient taking into account the shape of the octagonal gauge:

$$\text{square gauge } k_a = \frac{1.85 \cdot b'_{i-1}}{b'_i}, \text{ rhombic gauge } k_a = \frac{0.8 \cdot b'_{i-1}}{b'_i}, \qquad (29)$$

where h_i – caliber height; H_i – geometrical height of the caliber; D_0 – roll diameter; b'_i – caliber pad width.

When solving the problem, the independent dimensionless parameters and the friction coefficient were changed at three levels for the ranges of their variation used in practice within the following limits:

– reduction ratio ${}^{1}/_{\eta} = 1.0 \div 1.5$,
– reduced roll diameter $A = 10 \div 80$,
– aspect ratio of the original roll $a = 0.92 \div 1.08$,
– aspect ratio $k_a = 1.23 \div 1.37$,
– friction coefficient $\psi = 0.1 \div 0.5$.

Experimental data were used to verify the solution results. The accuracy of the approximating formulas was determined by the formula:

$$x = \frac{x_{cal.} - x_{exp.}}{x_{exp.}}, \qquad (30)$$

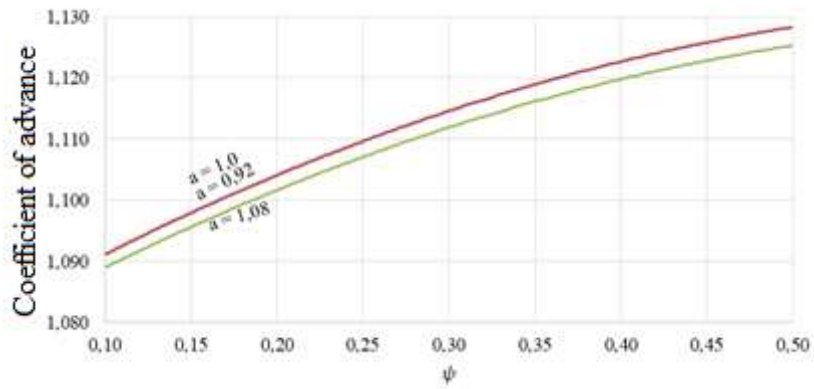where $x_{cal.}$ and $x_{exp.}$ – respectively, the calculated and experimental values of the investigated parameter.

3 Results and discussion

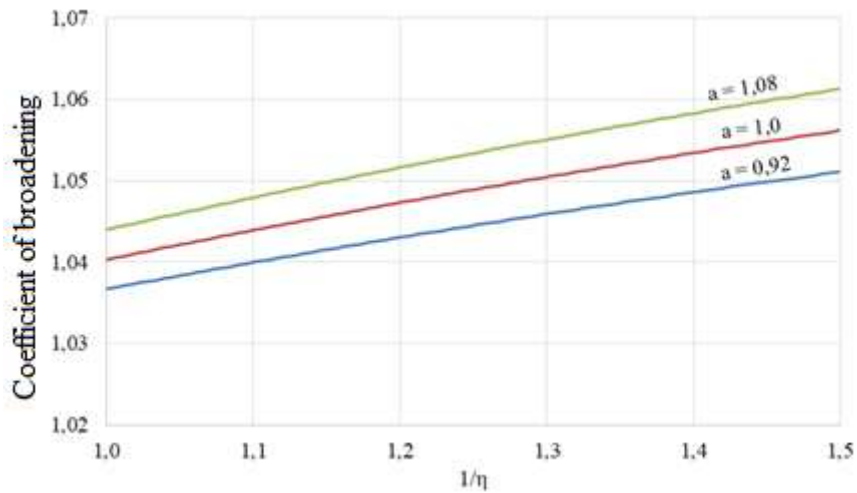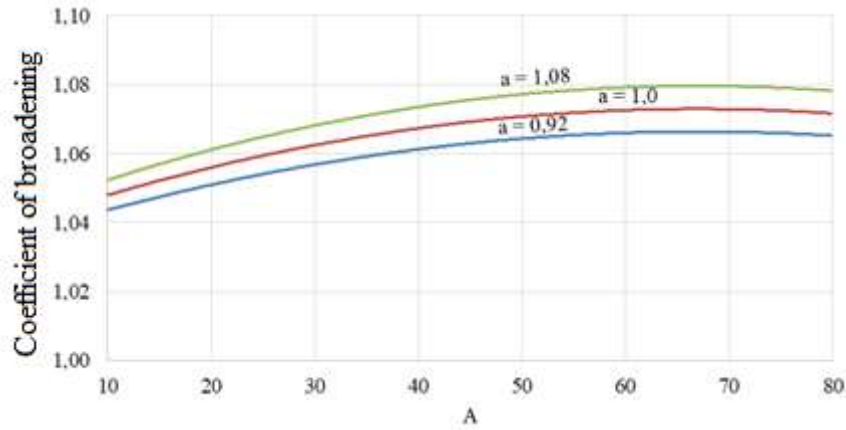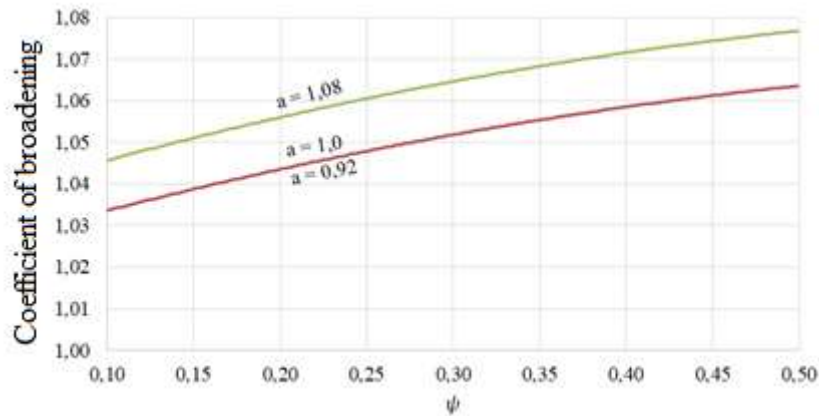The results of solving the variational problem are shown in Fig. 2 and 3.

a
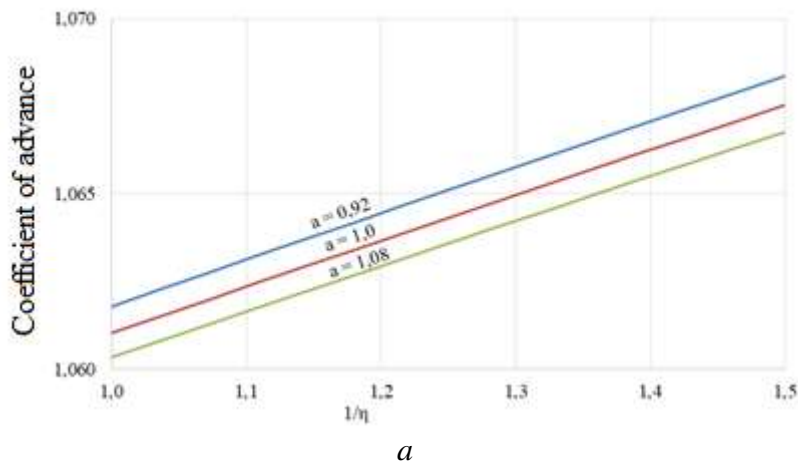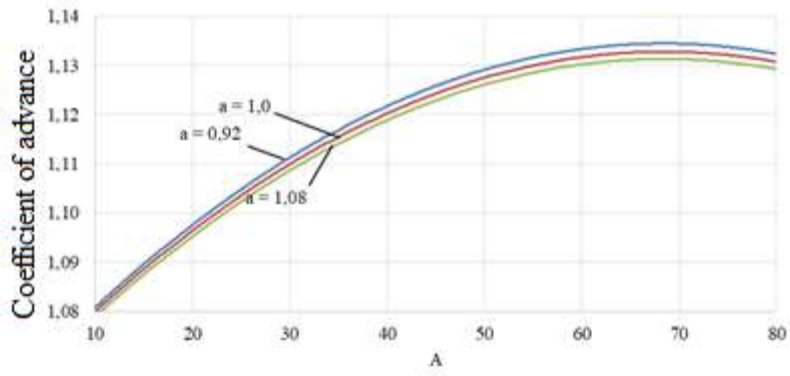
Fig. 2. Influence of dimensionless independent parameters on the coefficient of advance during rolling in octagonal gauges: a – compression ratio (at $A = 45$, $\psi = 0.4$); b – the reduced diameter of the rolls (at $1/\eta = 1.25$, $\psi = 0.4$); c – friction coefficient (at $A = 45$, $1/\eta = 1.5$)

Fig. 3. Influence of dimensionless independent parameters on the coefficient of broadening during rolling in octagonal gauges: a – compression ratio (at $A = 45$, $\psi = 0.4$); b – the reduced diameter of the rolls (at $1/\eta = 1.25$, $\psi = 0.4$); c – friction coefficient (at $A = 45$, $1/\eta = 1.5$)

The error in determining the calculated values in comparison with the experimental ones did not exceed 1-3% (Fig. 4), which makes it possible to judge the adequacy of the obtained mathematical model. The calculation was carried out at fixed values of the friction coefficient and the reduced diameter of the rolls ($\psi = 0.4$, $A = 45$, the relationship of the sides of the original rolled product $a = 1.0$).
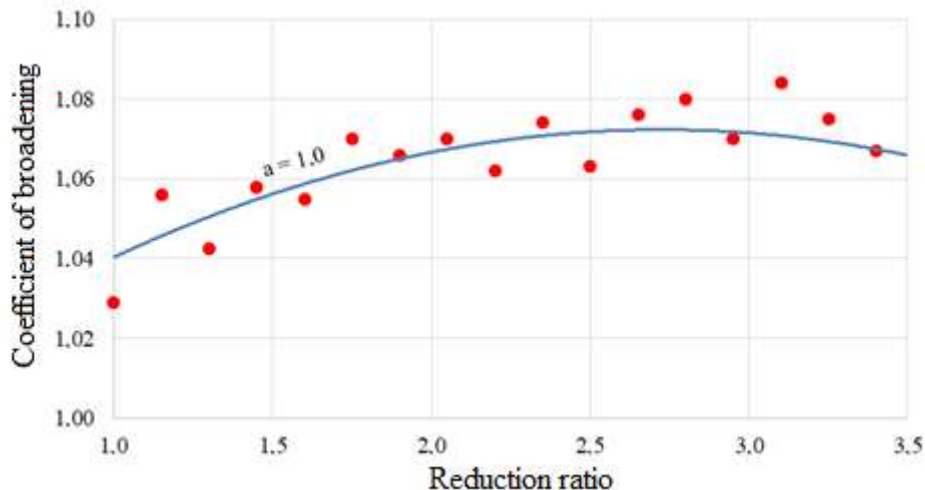
Fig. 4. Experienced and calculated values of the coefficient of broadening

Using the obtained mathematical model an algorithm and method for calculating the shape change of metal and energy-power parameters of cold section rolling have been developed. On their basis the "PROVOL" program was created for designing a technology for manufacturing semi-finished products from precious metal alloys and calibrating rolls (Fig. 5).

Fig. 5. Program window "PROVOL" for designing section rolling modes

The "PROVOL" program is implemented in the Delphi programming environment and includes modules for designing technological processes of rolling and drawing. It can be used independently or in combination for calculating deformation modes of longish deformed semi-finished products made of non-ferrous metals and their alloys, as well as for determining energy and power parameters and selection of equipment. With the use of the "PROVOL" program, rational routes for section rolling of longish deformed semi-finished products for jewelry chains from new precious metal alloys have been designed (Fig. 6). Their use makes it possible to reduce the number of passes, optimize the power load of the equipment and ensure uniform deformation of the billet during rolling along the proposed routes.
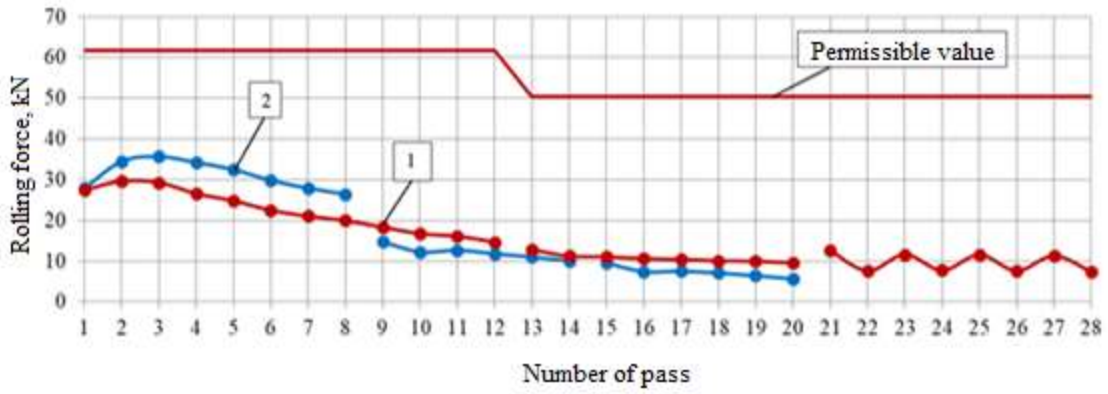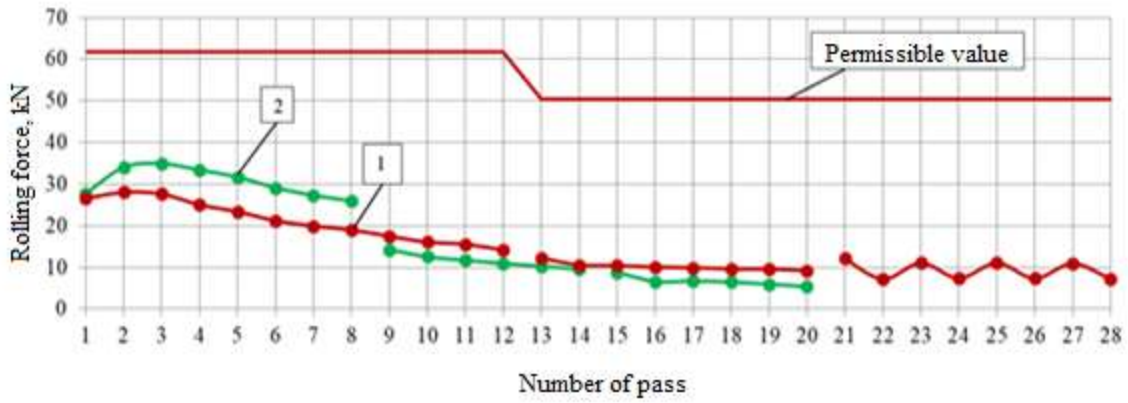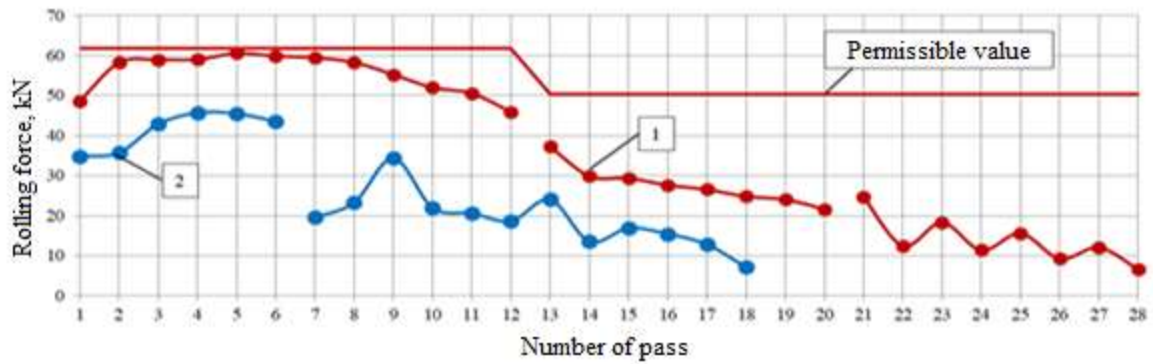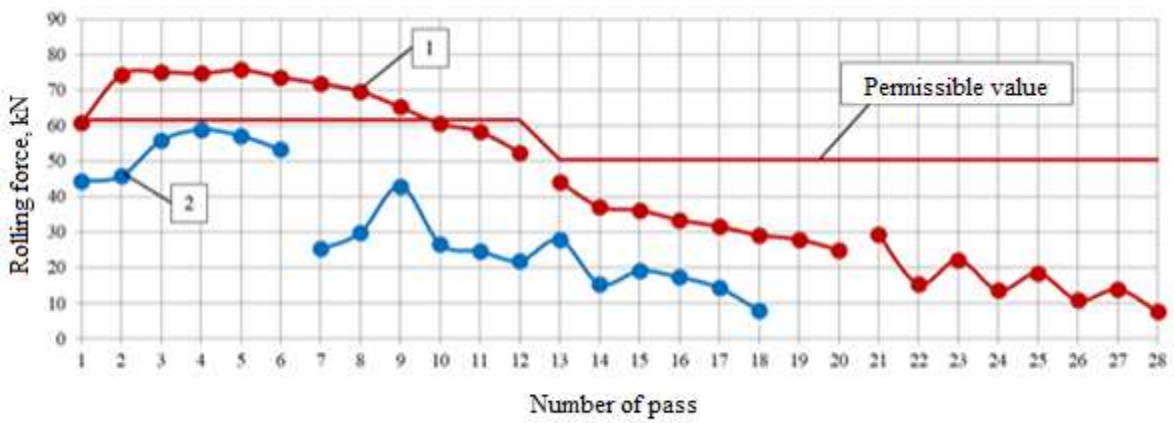
a

b

c

d

Fig. 6. Change in the rolling force along the existing (1) and proposed (2) routes for the investigated alloys: *a* – alloy №1; *b* – alloy №2; *c* – alloy №3; *d* – alloy №4

Computer modeling of the section rolling process and the tool was carried out using the DEFORM-3D software package (Fig. 7*a*) and the FeatureCAM system (Fig. 7*b*) in order to form a 3D model of the rolls and their calibration, as well as for their production on turning and milling equipment. Calculations based on the developed model confirmed the feasibility of the process of section rolling of rods from the investigated alloys along the developed routes without breaks and exceeding the permissible rolling force. Comparison of the simulation results with the experimental data showed that the calculation error does not exceed 5%.
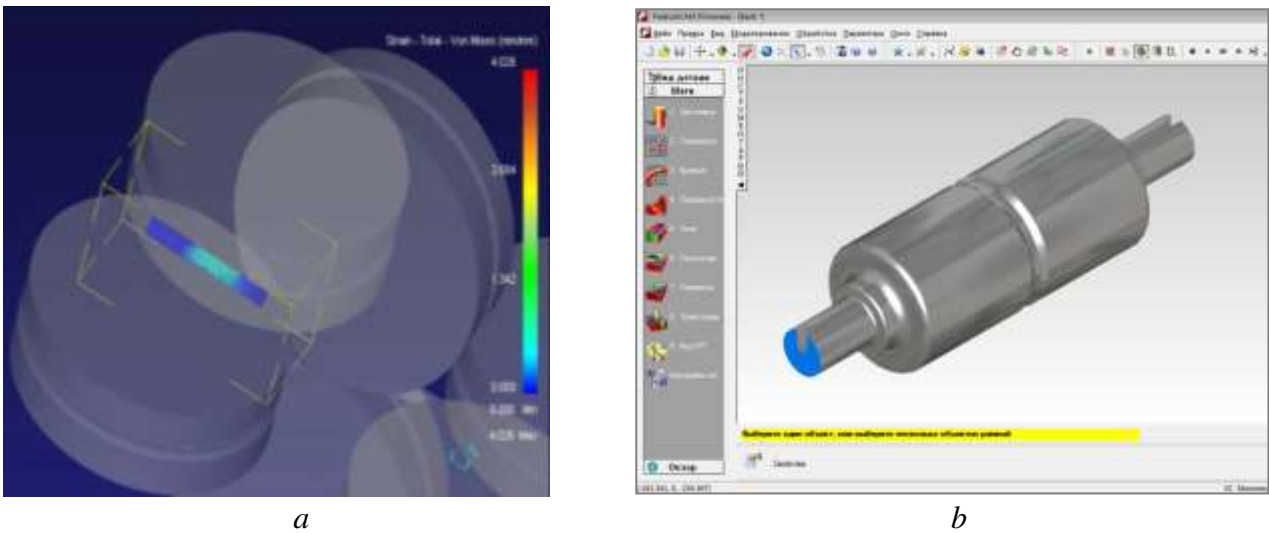

a   *b*

Fig. 7. 3D models of section rolling process and rolls

To assess the effect of the value of the accumulated degree of deformation (ε_Σ) during section rolling on the level of mechanical properties (yield stress R_p and ultimate tensile strength R_m) a full factorial experiment was planned. A full factorial experiment made it possible to obtain regression dependences to determine the strength properties of new alloys:

Alloy №1:
$$R_p = -0.0096\ \varepsilon_\Sigma^2 + 2.60\ \varepsilon_\Sigma + 150.96;$$
$$R_m = -0.0023\ \varepsilon_\Sigma^2 + 2.55\ \varepsilon_\Sigma + 333.91.$$

Alloy №2:
$$R_p = -0.0041\ \varepsilon_\Sigma^2 + 2.02\ \varepsilon_\Sigma + 150.72;$$
$$R_m = -0.0017\ \varepsilon_\Sigma^2 + 3.11\ \varepsilon_\Sigma + 220.18.$$

Alloy №3:
$$R_p = -0.0045\ \varepsilon_\Sigma^2 + 6.20\ \varepsilon_\Sigma + 265.84;$$
$$R_m = -0.0434\ \varepsilon_\Sigma^2 + 9.44\ \varepsilon_\Sigma + 336.25.$$

Alloy №4:
$$R_p = -0.0036\ \varepsilon_\Sigma^2 + 9.41\ \varepsilon_\Sigma + 321.22;$$
$$R_m = -0.0074\ \varepsilon_\Sigma^2 + 12.39\ \varepsilon_\Sigma + 401.31.$$

In the course of experimental studies on a section rolling mill model AMBIFILO VELOCE ROSEN 180+200×Ø130 from Mario Di Maio with an octagonal gauge system, the designed compression modes for alloys №3, №4 were worked out. The metal broadening and contact area were measured, as well as using tensometric equipment and mesoscale recorded the rolling force. In the course of rolling samples were taken and the mechanical properties (Table 2) were determined by the stretching method on a universal tensile testing machine LFM 400.

Studies have shown that the new alloys have a high level of mechanical properties, a fine-grained structure, good manufacturability during casting and metal forming, which ensures the production of wire for chain-knitting with high consumer characteristics.

Metallographic studies made it possible to reveal that the structure of alloy №3 in the cast state (Fig. 8*a*) is characterized by the presence of dendritic segregation. However, it has finely branched dendrite branches with a small dendritic cell size. This ensures the production of dendritic crystals with a dendritic cell size of 4 μm. By the last rolling passes, a fibrous structure uniform along the length and cross-section of the semi-finished product was achieved (Fig. 8*b*). The increased strength and plastic properties of alloy №3 made it possible to exclude intermediate annealing operations in the processing flow chart.

Table 2 – Properties of cast and deformed samples from test alloys

Rolling pass after which a sample was taken	Degree of deformation, %	Yield stress R_p, MPa	Ultimate tensile strength R_m, MPa	Elongation to failure A, %	Microhardness, kgf/mm^2
Alloy №3					
Cast sample		266	336	33.8	150
4	44.3	487	680	13.0	201
12	78.8	730	794	8.3	204
13	83.6	802	814	4.9	210
14	87.2	804	816	4.7	212
17	92.6	809	830	4.1	214
18	93.8	878	891	4.0	217
Alloy №4					
Cast sample		307	384	31.0	158
4	44.3	667	716	11.9	202
7	69.0	799	882	4.9	207
17	92.6	883	903	4.8	215
18	93.8	907	927	3.9	219

Dendritic segregation is observed inside equiaxed large grains (from 260 μm), while it is not observed in smaller grains, since they have time to undergo equalizing diffusion processes. The average grain size of the investigated cast billet was 216 μm, and the average size of the dendritic cell was 7 μm, which indicates a high degree of supercooling during crystallization.

| *a* | *b* |

Fig. 8. Microstructure of bars from gold alloy №3:
a – in cast state, ×200; *b* – at degree of deformation 93.8%, ×200

Since the main task was the development of nickel-free alloys based on white 585 gold fineness alloys, with high corrosion resistance and products from it, having an increased level of consumer and mechanical properties, as well as obtaining their uniform distribution along the length of deformed semi-finished products, research was carried out on new alloys №1 and №2 based on gold with modifying additives. In the compositions of these alloys the gold content was in the range of 58.0-59.0%, due to which their fineness was ensured. The introduction of palladium was the main technical solution for replacing nickel, as a result of which an increase in corrosion resistance was achieved, prevention of embrittlement and provision of a color range of alloys. Copper was introduced to lower the melting temperature, provide the necessary ductility and improve the manufacturability of the alloys during casting. Zinc lowered the melting point, while silver imparted softness, malleability, and a lower melting point to alloys. Indium addition in the range of 0.4-0.6 wt. % provides the required melting temperature range of the alloy.

Ruthenium was chosen as the main modifying additive, which is in the range of 0.001-0.10 wt. % provided a fine-grained structure of alloys №1 and №2 and the required range of grain size variation within 5-10 microns, and also contributed to an increase in plasticity and equalization of properties along the length and section of the cast billet. At the same time, in the known method of introducing ruthenium into the melt, its limited solubility in gold due to the high melting temperature led to the formation of large inclusions in the alloy structure (Fig. 9*a*) which was the reason for the appearance of defects during metal forming.
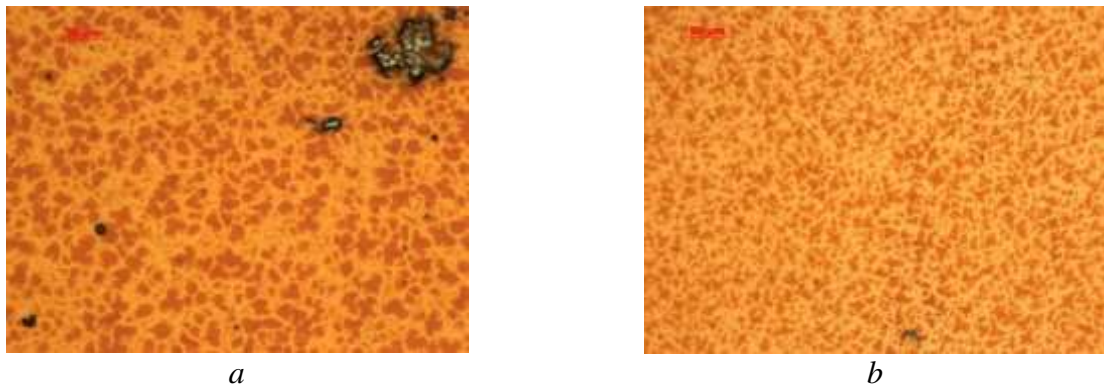

a   *b*

Fig. 9. Microstructure of 585 gold fineness alloys in the cast state, modified by various methods:
a – known; *b* – new; ×500

To increase the modifying ability of the alloy material, which is expressed in the refinement of the grain structure of gold alloy ingots, a new method of alloy modification was developed [27], according to which ruthenium was introduced into the melt in the form of an Ag-Ru alloy with a ruthenium content of 0.001 wt. % immediately before crystallization. This made it possible to improve its dissolution in gold, as a result of which a complete assimilation of the introduced modifier occurs in the alloy. In addition, this method provides an accurate determination of the amount of ruthenium added to the melt. Semi-finished products from a white 585 gold fineness alloys obtained using this technology have a uniform fine-grained structure along the entire length and section of the ingot (Fig. 9*b*), which confirms the high quality and efficiency of modification.

To check the results of theoretical studies and modeling, a pilot-industrial testing of the technology for producing wire for the production of jewelry chains from new white 585 gold fineness alloys (alloys №1 and № 2) was carried out. As a result of its implementation, pilot batches of wire were obtained, from which the most sophisticated jewelry chains of the "Snake" type were made on a chain tying machine (Fig. 10).

Studies of the mechanical properties (Table 3) of the experimental alloys have shown that they have a sufficiently high level of plastic and strength properties, which ensures the production of wire with high consumer characteristics.
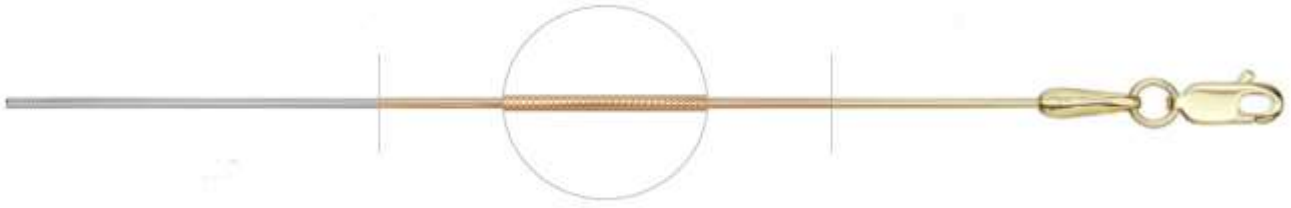

Fig. 10. Type of jewelry chains "Snake"

Table 3 – Mechanical properties of pilot melting alloys

Operation	Side size, mm	Deformed state			Annealed state		
		R_m, MPa	A, %	Microhardness, kgf/mm^2	R_m, MPa	A, %	Microhardness, kgf/mm^2
Alloy №1							
1 stage of rolling	3.7×3.7	940	4.0	307	533	35.0	242
2 stage of rolling	2.1×2.1	881	2.4	292	464	27.2	185
3 stage of rolling	1.1×1.1	820	1.5	294	489	31.0	160
Drawing	diameter 0.25	958	4.2	300	560	33.0	145
Alloy №2							
1 stage of rolling	3.7×3.7	942	3.6	228	450	35.0	124
2 stage of rolling	2.1×2.1	753	2.6	271	430	32.0	163
3 stage of rolling	1.1×1.1	661	1.9	264	434	25.0	149
Drawing	diameter 0.25	879	3.6	273	503	39.2	139

The results of the research, as well as the receipt of pilot batches of jewelry chains of the "Snake" type, allow asserting that the wire for jewelry purposes from new nickel-free 585 gold fineness alloy has the required level of mechanical properties and is suitable for making jewelry chains in industrial conditions.

4 Summary

Thus as a result of the research the following main results were obtained:

1. A number of new nickel-free alloys based on white 585 gold fineness alloys have been developed, which provide improved mechanical and operational properties of deformed semi-finished products intended for the manufacture of jewelry chains.

2. Mathematical model of the process of cold section rolling of bars in octagonal gauges created.

3. With help of created mathematical model the shape change of the metal and the force parameters of rolling of the investigated gold alloys were determined and the regularities of their change were found.

4. Computer models of the roll tool for the process of cold section rolling in octagonal gauges have been created.

5. Using the results of computer modeling the technological parameters of rolling were substantiated and the power load of the equipment was determined.

6. Software has been developed for designing processes for the production of longish deformed semi-finished products from the investigated alloys, with the help of which the regimes of reduction in section rolling of new alloys have been calculated.

7. Experimental studies and regression analysis of experimental data were carried out, on the basis of which formulas were obtained to determine the strength properties of new alloys.

8. Experimental-industrial approbation of technical and technological solutions for the manufacture of wire from which batches of jewelry chains of the "Snake" type from new white 585 gold fineness alloys having the required performance characteristics were obtained.

Declarations

Ethical Approval

The work contains no libelous or unlawful statements, does not infringe on the rights of others, or contain material or instructions that might cause harm or injury.

Consent to Participate

The authors consent to participate.

Consent to Publish

The authors consent to publish.

Authors Contributions

The authors declare that they are all participants in the work and none of them performed only administrative functions.

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Competing Interests

The authors declare about the absence of competing interests.

Availability of data and materials

Not applicable.

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