Journal of Siberian Federal University. Engineering & Technologies 4 (2012 5) 457-464
~ ~ ~

УДК 621.777

Development and Research of Technology Manufacturing of Semi-Finished Products from Solder Alloys Based on Silver

Sergey B. Sidelnikov*, Oleg O. Vinogradov, Alexander V. Stolyarov and Ekaterina S. Lopatina
Siberian Federal University,
79 Svobodny, Krasnoyarsk, 660041 Russia [1]

Received 13.08.2012, received in revised form 20.08.2012, accepted 27.08.2012

Proposed new compositions of solder alloys based on silver. Developed technological schemes of production of wire diameter 1,2 mm. Developed scheme of production of wire diameter 1,2 mm from alloy SAg-40I with operation combined casting, rolling and extruding. Modeling of temperature-rate parameters of the process of combined casting, rolling and extruding has been made. Designed and constructed the installation CCRE-80. The analysis of the structure and properties of semi-finished solder alloys based on silver has been done.

Keywords: solder, alloy, SAg-40I, combined casting, rolling and extruding, indium, modeling, mechanical properties, technology, metal forming.

For today, the market of manufacturing semi-finished silver-based alloys is a significant increase in production due to the expansion of applications of this product. In this regard, the deep processing of silver is one of the most promising areas of work of profiled metallurgical plants, such as the Krasnoyarsk Plant of Non-Ferrous Metals. One of perspective directions is the production of bars, wire and powder of solder alloys such as SAg-40 SAg-72, including using the combined methods of treatment [1], because of the demand for these semifinished products by factories of Krasnoyarsk region, such as the Krasnoyarsk Refrigerator Plant «Birjusa» Divnogorsk's plant of low voltage automata, Minusinsk's plant «Elektrokompleks», etc. These alloys are used for soldering tubes of refrigeration compressors, soldering of contacts and low voltage equipment, etc.

One of the main tasks of modern industry is to reduce the hazards that arise during the processing. Alloy SAg-40 used in the practice of factory contains cadmium and, if formed in the solder alloy during melting and subsequent soldering of volatile compounds of cadmium are highly toxic, and not recommended for use in the production. Thus, the actual task of developing a silver solder without cadmium is complicated by the fact that any change in the chemical composition worsen as the temperature, so the electrical characteristics of the solder alloy.

* Corresponding author E-mail address: sbs270359@yandex.ru

The task of finding new alloys SAg-40 that do not contain cadmium, but with a high level of mechanical and technological properties, was conducted using analysis of binary phase diagrams of silver with indium, zinc, cadmium, tin and some other metals. Based on the results of this analysis have been developed solder alloys [2-4] that meet standards for the chemical composition of the main component and technological properties. The chemical composition of alloys is presented in Table. 1.

Developed alloys showed high adaptability, have required complex electro-physical, technological and mechanical properties (solder temperature, corrosion resistance, wettability, electrical resistance, tensile strength, etc.) and tested in Krasnoyarsk Plant of Non-Ferrous Metals.

However, as with most solder alloys, they are hardly-deformed and require a lot of added value processing and intermediate annealing.

For the production of long-products in the form of wire 1.2 mm in diameter were tested different technological schemes, including the operation of casting, bar rolling, extruding, drawing, annealing, etc. (Fig. 1).

To plant JSC «Krastsvetmet» was developed and tested technological scheme shown in Fig. 2. This scheme was adapted to the plant equipment and use it to obtain the wire solder coarsened party, that held industrial tests in one of factory-consumers.

The presented schemes are high-cycle, and include a number of intermediate operations. This has an impact on increasing production costs and, consequently, reduces its competitiveness. In international practice, to solve the problem are working to create technologies and devices that combine in one continuous line of melt, crystallization, and forming. The most promising technology for the production of long semi-finished products is the technology of the combined casting, rolling and extrusion (CCRE). Previous studies have focused on the combined treatment methods applied to aluminum alloys [1], and they were not considered particularly of deformation of silver-based alloys. One of the technical solutions to implement the process CCRE is a device for continuous casting, rolling and extrusion of metal [5]. For the design of technological modes of processing on such a device must know the patterns of temperature distribution of semi-finished products and thermal process conditions. For this purpose process CCRE simulated [6], using previously developed program “CCRE” using a programming system DELPHI (Fig. 3).

As the significant were selected following parameters: h_l – minimum clearance between the rolls; h_p – height of matrix mirror; $h_{вх}$ – height of the entrance of the melt to the active zone, which can be

Table 1. Chemical composition of developed and used in the production alloys

Alloy	composition	Content of the components, wt. %					
		Silver	Copper	Zinc	Cadmium	Indium	Tin
SAg-40I	1	40	34	21	-	5	5
	2	40	35	22	-	1	2
	3	40	36	19	-	3	1
SAg-40 according to the standard	4	40	16,9	16,9	26,2	-	-
SAg-72 according to the standard	5	72	28	-	-	-	-

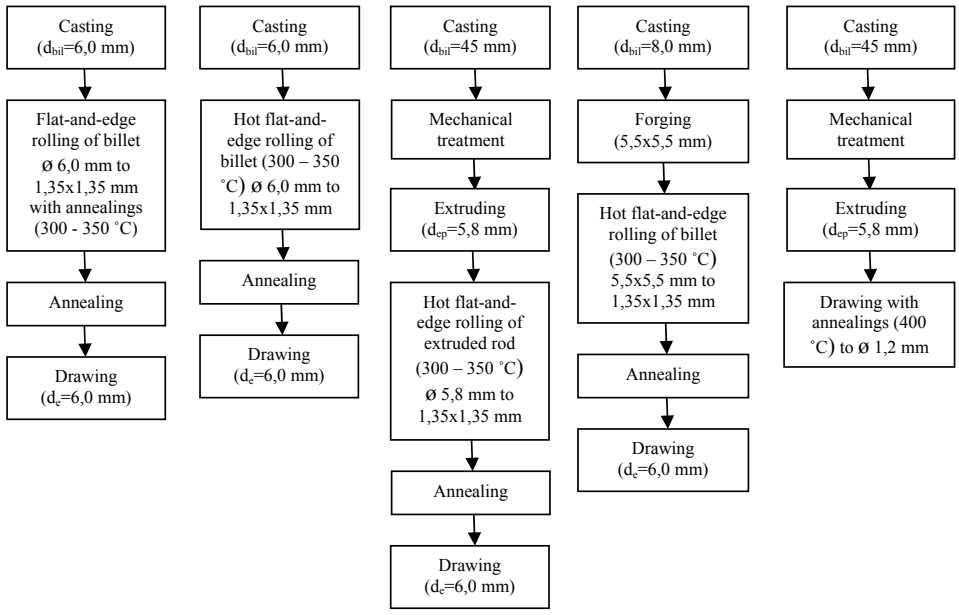


Fig. 1. Technological schemes receipt of wire

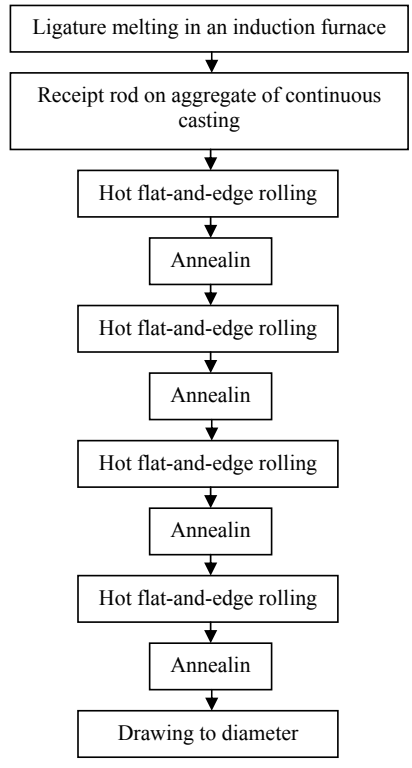


Fig. 2. The scheme of technological process of receipt the wire 1.2 mm in diameter at the JSC «Krastsvetmet»

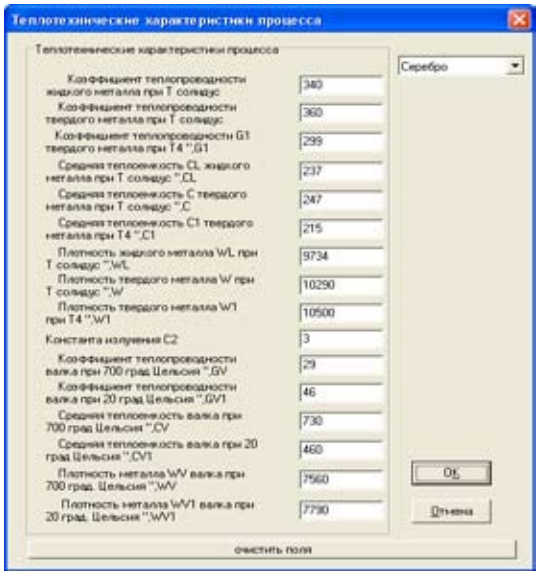


Fig. 3. Baseline data for the modeling process

calculated from the known geometric relationships; ω – angular speed of the rolls; R – average radius of the rolls. And the temperature of the melt at the core inlet was strictly fixed and equal $T_0 = 990^oC$. The temperature of the rolls at the start was $T_в = 20^oC$. Also, asked the corresponding thermotechnical characteristics for silver (Fig. 3) and K-value at a contact exchange (K=100). The value of K is used as an additional correction factor that takes into account the processes of heat transfer by other mechanisms (convection, evaporation, boiling liquid, etc.).

The calculation results for different conditions of the process (water-cooled rolls and rolls without water cool) represented in the form of graphs of metal temperature on the time of the process along the length of the source zone of deformation-crystallization (Fig. 4) in three specific areas (sections): in the center of semi-finished products (1), on the surface of contact of the metal with the rolls (3) and on the axis, equidistant from rolls (2).

The temperature distribution is nonlinear, while as seen from the graphs in section 3, the temperatures are much lower than in section 1, due to the selection of the heat of rolls. A characteristic feature of the dependencies is a slight decrease in temperature in a section 3 for water-cooled rolls, only 80 –100^{0}C. Apparently, this phenomenon is caused by thermophysical properties of the alloy. The theoretical calculations of temperature change in the process of casting, rolling and extrusion have shown that this process can be accomplished with minimal power consumption.

For its implementation were created an experimental setup based on the proposed device [5] and is designed instrumental unit in order to obtain thin wire sizes. The installation (Fig. 5) includes the following main elements: base frame made of two steel plates connected together by four tie rods; roll unit, consisting of a roll with the tab and roll with a notch, forming a closed box caliber size 9x4 mm; pressing tool and spring-type hydraulic clamp unit; rolling bearings located in the holes of base frame and provide rotation of the rolls. Rolls is driven by an electric motor power 320 W via worm gearbox. Circumferential speed of rolls was 2,5 rpm.

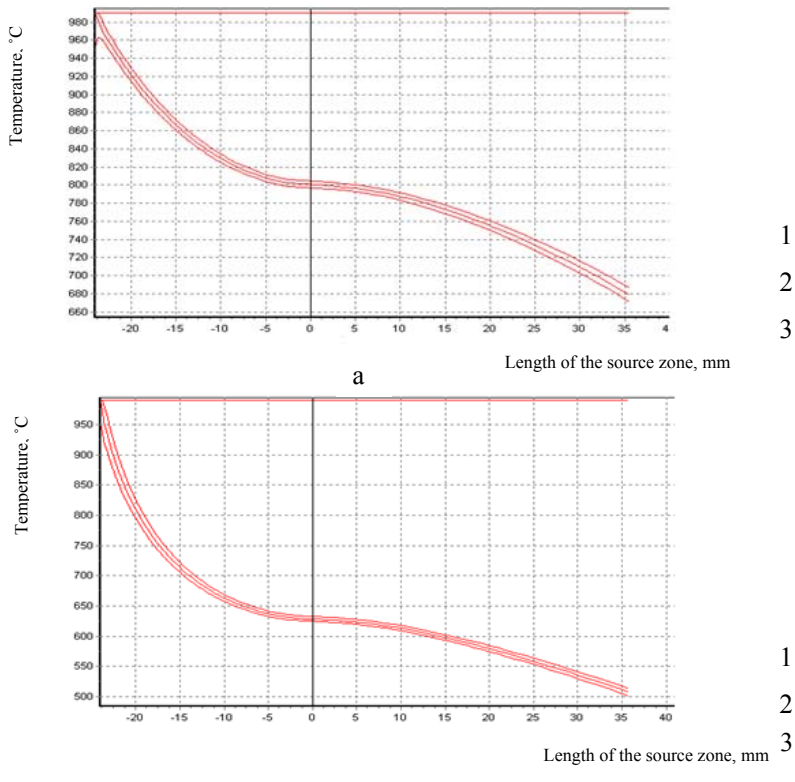


Fig. 4. Dependencies of the temperature along the length of the source zone of deformation and crystallization: a – rolls without water cool; b – water-cooled rolls

Fig. 5. The general form of the model set CCRE-80

Fig. 6. Press residues and press products obtained by the combined treatment of alloy SAg-40 in different experimental setups

Table 2. Mechanical properties of rod from alloy SAg-40

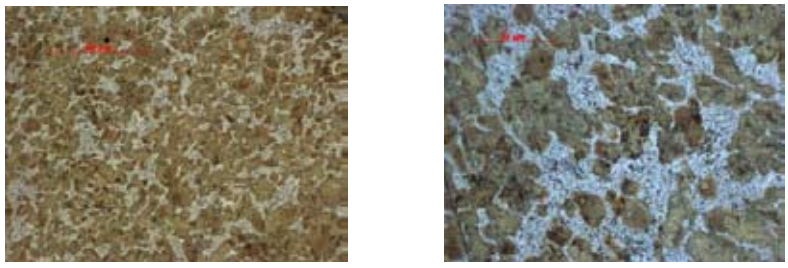
Parameter	After deformation	After annealing
Tensile strength , MPa	579.7	392,2
Yield strength , MPa	141,9	33,3
Elongation , %	4,1	16,5
Percentage reduction , %	9,0	0,3

Testing processes of combined treatment was performed on the alloy SAg-40 by the combined method of casting, rolling and extruding on the model set CCRE-80 and laboratory installation CCRE-200 [1]. Obtained samples in the form of press residues and press products shown in Figure 6, it should be noted that the process of obtaining press products sufficiently small size (diameter 2.0-3.0 mm) was tested experimentally for the first time.

Another aim of this study was to determine the energy-power parameters of the process for the formation of the requirements for a pilot unit. With the help of load cells and fixing equipment at the facility CCRE-200 measured the forces acting on the rolls and the matrix of the implementation process of pouring the metal directly into the roller and subsequent crystallization-deformation to produce press products with a diameter 7-9 mm. With the recorder was built waveforms and recorded the following values of power parameters:

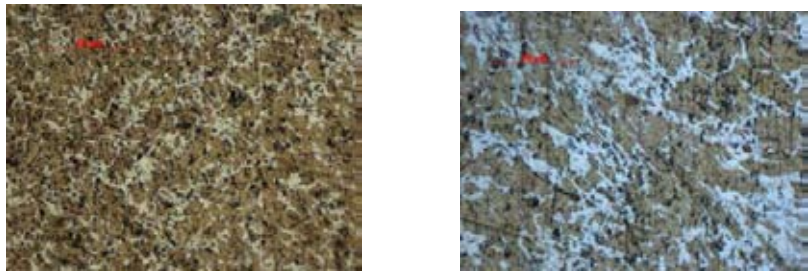
- for rod diameter of 7 mm full force on rolls was 195.31 kN, and the maximum force on the matrix – 258, 35 kN;
- for rod diameter of 9 mm full force on rolls was 94,96 kN, and the maximum force on the matrix – 163,96 kN.

To investigate the mechanical properties of the semifinished products from rod 9 mm in diameter from new alloy SAg-40 were prepared specimens for testing by tensile [3]. Samples had a length of the working area of 30 mm and a diameter of 6 mm. One sample was subjected to annealing at 500° C, the second was hardened. Tests were conducted on a universal machine LFM 400, and their goal was to determine the ultimate tensile strength, yield strength, elongation and percentage reduction in the destruction of the sample. As a result, the tests were determined the mechanical properties of deformed and annealed samples (Table 2)



a b

Fig. 7. The microstructure of deformed specimens of rod 9 mm in diameter at different magnification x800(a) and x1600(b)



a b

Fig. 8. The microstructure of annealed samples of rod 9 mm in diameter at different magnification x800(a) and x1600(b)

For metallographic studies were prepared from these microsections samples (Fig. 7), and material of rod 9 mm in diameter was investigated in deformed and annealed state. The cut of samples was subjected to grinding, polishing and etching. The study was conducted using a microscope having a magnification ratio of 800 and 1600. The study found that the ratio between silver and copper 40:35 matches a few hypereutectic position of alloy on double diagram Ag-Cu. Therefore, the structure of the solder in the cast state contains enough plastic excess crystals of the solid solution components based on copper and eutectic between solid solutions based on copper and silver. Zinc and indium are part of the solid solutions without forming independent intermetallic phases. However, in the system Cu-In is possible the selection of secondary intermetallic precipitates of δ-phase, that may lead to the achievement of sufficient strength of solder alloy.

To secure the plastic deformation alloy should be subjected to annealing at 400 – 450º C with time about 1 hour. Conditions of hot deformation are determined by the same temperature intervals. Exceeding these temperature parameters can lead to burnout effects as thermal treatment, and during hot plastic deformation. The structures of the samples are shown in Fig. 8.

Thus, it was held computer and physical modeling of the combined casting, rolling and extruding, results of which are allowed to say that for press products of small cross-section from silver and its alloys can apply the method of combined treatment using as starting material molten metal. Revealed distributions of temperature along the center of deformation-crystallization and the influence of cooling

of the tool. On the experimental units with a diameter of rolls 80 and 200 mm practiced modes combined treatment, determined implementation of structural features of individual units, specified temperature and speed conditions of the process CCRE, measured energy-power parameters and obtained samples of press products. Performed metallographic studies of the structure and evaluation of mechanical properties obtained from semi-finished products from solder alloy SAg-40 based on silver.

References

[1] *Sidelnikov S.B., Dovjhenko N.N., Zagirov N.N.* Combined and complex methods of treatments of non-ferrous metals and alloys: a monograph. M.:MAKS Press, 2005. 344 p.

[2] *Dovjhenko N.N., Hodukov B.P., Sidelnikov S.B. and others.* Silver-based solder. Patent RF №2335385. Publ. 10.10.2008.

[3] *Dovjhenko N.N., Sidelnikov S.B., Bironf V.S. and others.* Silver-based solder. Patent RF №2367552. Publ. 20.09.2009.

[4] *Dovjhenko N.N., Sidelnikov S.B., Bironf V.S. and others.* Silver-based solder. Patent RF №2367553. Publ. 20.09.2009.

[5] *Sidelnikov S.B., Dovjhenko N.N., Lopatina E.S. and others.* A device for continuous casting, rolling and extruding of non-ferrous metals and alloys. Patent RF №73245 RF.

[6] *Sidelnikov S.B, Dovjhenko N.N, Vinogradov O.O. and others.* Modeling of the process of combined casting, rolling and extruding for solder alloys based on silver / Bulletin of the Magnitogorsk State Technical University named after G.I. Nosov. – Magnitogorsk, 2010. – №1. – P. 72-75.

Разработка и исследование технологии производства деформированных полуфабрикатов из припойных сплавов на основе серебра

С.Б. Сидельников, О.О. Виноградов,
А.В. Столяров, Е.С. Лопатина
Сибирский федеральный университет,
Россия, 660041, Красноярск, пр. Свободный, 79

Предложены новые составы припойных сплавов на основе серебра. Разработаны технологические схемы производства проволоки диаметром 1,2 мм. Разработана схема производства проволоки диаметром 1,2 мм из сплава ПСр-40И с применением операции совмещенного литья, прокатки и прессования. Проведено моделирование температурно-скоростных параметров процесса совмещенного литья, прокатки и прессования. Спроектирована и изготовлена установка СЛИПП-80. Проведен анализ структуры и свойств полуфабрикатов из припойных сплавов на основе серебра.

Ключевые слова: припой, сплав, ПСр-40И, совмещенное литье, прокатка и прессование, индий, моделирование, механические свойства, технология, обработка металлов давлением.