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Hrystyna Dvoryanyn, Sergiy Shvachco
Lviv Polytechnic National University, Lviv, Ukraine

WAYS OF IMPROVEMENT OF TECHNOLOGICAL PROCESS OF COPPER WIRE ROD PRODUCTION

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Abstract. Copper is a unique chemical element which is used since ancient times due to its universal chemical properties.

By means of the method of continuous founding, hundreds of items of rod-like billets of different cross-section shapes are manufactured from copper. The problem of production of defect-free copper wire rods is important nowadays, because the market of cable products still increases. As the deposits of cooper ore in the nature are being exhausted, the processing of copper scrap becomes of still growing interest for non-ferrous metallurgy. There emerged the necessity of further study and improvement of the technology of production of copper wire for electrical engineering and that of copper wire rods.

In manufacturing of copper wire rods according to the method of continuous founding, there emerge violations of technological process because of formation of hot cracks in a cast billet. Just for this reason, in this article, such problems are described, and ways of their solving are considered. The character of their structure formation during crystallization of copper wire rods is analyzed. Advantages and drawbacks of the method of continuous founding of copper wire rods are described. The possibility of the use of ultrasonic oscillations for improvement of the quality of finished products is shown.

Introduction

Application of copper dates back to B.C. centuries. Production of copper developed with development of technology. In the second half of the XIX century, alongside with the development of electrical engineering and with the enhancement of requirements to copper purity, a new process in metallurgy emerged – electrolytic refinement, which is scientifically based on physical chemistry. Copper is obtained from copper ores or from copper scrap. Nowadays, the situation is the following: the number of high-grade copper ore depositions becomes less and less; and the high-grade deposits are already exhausted. Given that in XIX century copper was extracted from ores containing 6…10 % of this element, nowadays 5 % - copper ores are considered to be technologically valuable. In countries which are poor in such natural resources, the ore which contains only 0.5 % of copper is to be processed.

Therefore, it is clear that for non-ferrous metallurgy the processing of copper scrap is of growing interest, about 40% of copper products being produced from such scrap. A copper wire rod, whose technological process of production is mainly based on the processing of secondary row materials, is an example of this. It is known that manufacturing lines of continuous foundry and rolling are the most wide-spread processes of production of copper wire rods. In its turn, cables, bars of different cross –sections, and conductors are produced from copper wire rods.

Problem statement

The oxygen-free copper from which cable products, parts of radio-engineering and electro-engineering devices are manufactured must meet the following requirements:

– high electric conductivity and heat conductivity;

– minimal amount of impurities (no more than 0,001% of oxygen and less than 1,5ml of other gases per 100g of the metal);

– homogeneous and defect-free microstructure, no part of foreign inclusion [5].

Further improvement of the technology of production of wire rods and electrical conducting wires is urgent, because it is caused by the increasing demand of modern market in high-quality products. It is according to methods of continuous horizontal foundry that billets of different cross-section, for example, round of 10…400mm in diameter, square-shaped, hexahedral, rectangular and polyhedral, are produced. This method is also used for casting in production of bars, slides machines, bearing housings, billet-sections for rails, gearwheels, and other articles.

The process of horizontal continuous founding is shown in Fig. 1.

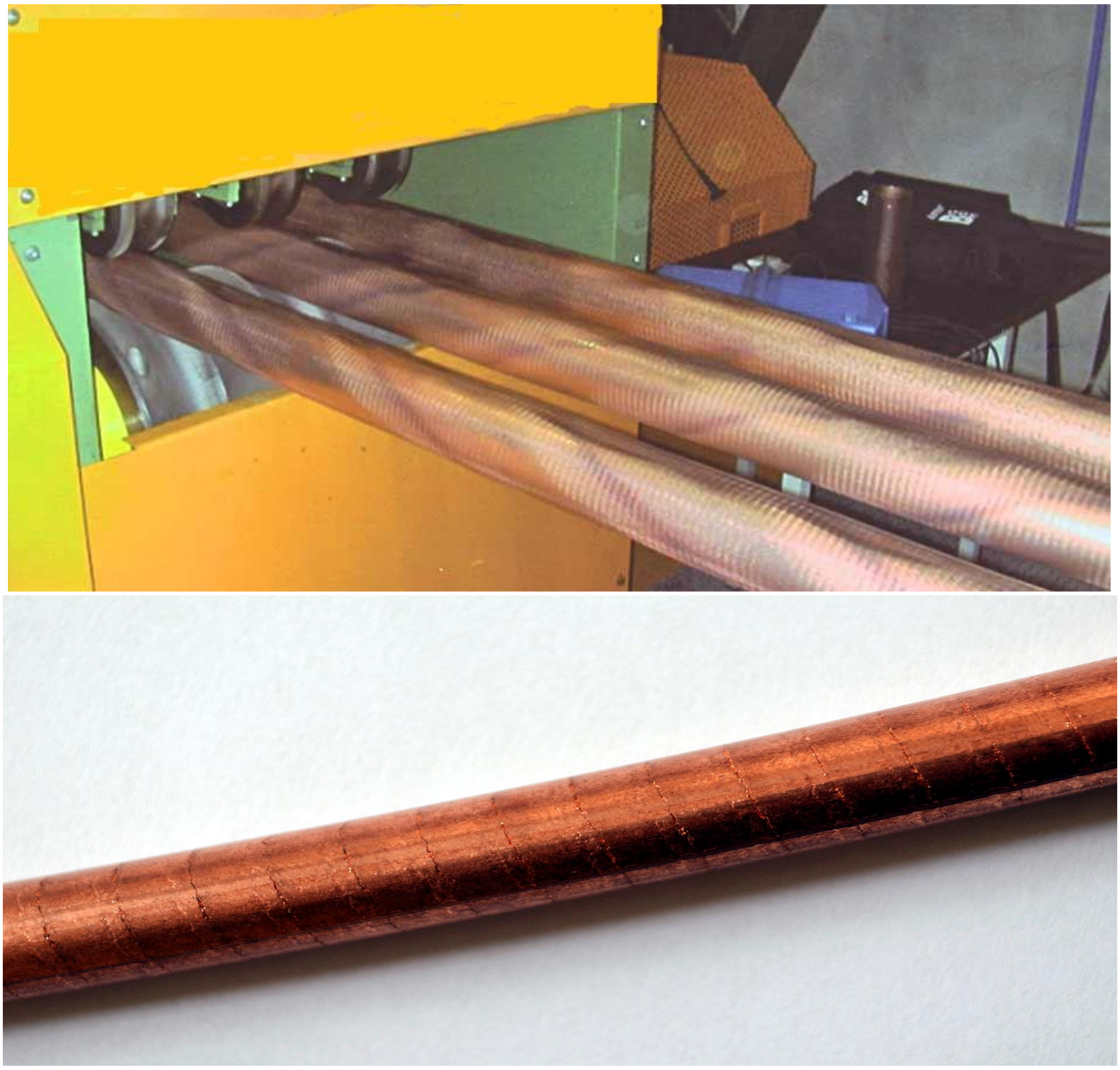

Fig. 1. *Horizontal continuous founding [7]*

In such plants, the modes of drawing are mainly non-continuous. In initial instant of hardening, a is pulled from billets m the surface of the crystallizer, and a site of the surface the size of which is equal to the step of the drawing becomes free. Fresh portions of melt come to the free site of the crystallizers surface, and a sequential process of "freezing" of a billet proceeds. Simultaneously with this, a copper layer grows on the butt surface of the displaced workpiece. During a stop the crust, which is formed all over the perimeter joins with the , and in billet the next cycle it is pulled out of the crystallizer. Then, the cycle of continuous founding repeats. It should be noted that at there appear characteristic traces at the surface of a, which is a billet, consequence of the process of non-continuous withdrawal. The distance between these sites corresponds to the step of the withdrawal [8].

The process of crystallization of billets and formation of their structure is to a great extent conditioned by constant pressure of the melt which is in crucible-mixer; it is also conditioned by a great rate of heat removal. The consequence of this is the absence of characteristic of traditional methods of foundry defects (porosity, gas pockets, impurities, slag inclusions) in the obtained billets. Ruptures of such castings are characterized by a dense fine-crystalline structure, and their surface is plane. The advantages of this method of founding, in combination with continuity of this process, enable us to achieve the efficiency of 90 %, which is impossible in all the other methods of founding.

Fig. 2. *Scheme of rolled copper production line by horizontal Continuous Casting Process*

The essence of such technological process that ensures obtaining a high-quality casting consists in the fact that the row material must be a cathode copper, whose structure consists mainly of crystals whose texture axis relative to the direction of sediment growth is <111>; the presence of crystals whose texture axis is <110> being acceptable, provided the packing of crystallographic planes by copper atoms is dense. With this, the control over the quality of the cathode copper for rolled copper production is conducted on the basis of the date of crystallographic analysis with recording the number of crystals of these textures. It is conducted according to know methods, for example, by means of diffractional or metallographic methods. The cathode copper which meet the aforesaid requirements can be easily rolled. Such approach enables us to improve the quality of rolled copper, as well as to ensure on-line incoming and outcoming inspection concerning the quality of the product.

A drawback of rolled copper, according to the available standards, is the absence of guaranteed workability during hot forge-rolling of sheet billets. The emergence of hot cracks is possible under these conditions, which leads to reduction in the grade of quality of products. In the world practice, there is no method of prognostication of rollability of cathode copper; there is no known way of inspection and control concerning these data during the stage of production of high-quality wire rods. Therefore, the London Metal Exchange requires a successful verification of it in rolling mills of 2-3 leading firms as a basic condition for registration of cathode copper; this is a long-lasting and expensive process [8]. It is known, that hot cracks are considered as the most wide-spread kind of rejects in continuous founding; it is hard to eliminate such rejection. Hot brittleness depends on parameters of the crystallization process, level of residual stresses, and high content of impurities, in particular, oxygen, whose solubility in a liquid phase is considerably greater than in a solid one, in a copper melt [1–2].

It is also know that the main cause of initiation of hot cracks is saturation of the melt copper with hydrogen Wurz hydride with subsequent expulsion of water wapours and formation of microspores during crystallization of copper. The content of dissolved hydrogen or Wurz hydride in cathode copper is recorded according to modern methods of gas analysis, which determine the total content of hydrogen in the sediment in the form solid solution of electrolyte, unremoved electrolyte, and inclusions of organic substances [7].

A considerable effect of the character of structure formation during copper crystallization on properties of copper wire rods is noteworth. In particular, in order to get rid of formation of dendrite inhomogeneity of castings, it is necessary to ensure surplus of crystallization centers in front of the crystallization propagation front [3]. The real melt is not of ideal structure, there are many non-metal phases, it is a so-called "plankton". Usually it does not participate in the process of solidification. Therefore, it is quite possible to activate this process from outside. For example, during active outer action of cavitation treatment upon the melt, it is possible to essentially reduce the level of micrononhomogenity and to increase thermodynamic stability of the system. With this, the main fraction of solid non-metal inclusions is not moistened by the melt, because microdefects (pores, cracks) are filled with a gaseous phase [6].

The main material presentation

Degassing action of ultrasonic oscillation is successfully used in many branches of industry ensuring more rapid and deep, as compared to other methods, reduction of concentration of dissolved gas.

Our imaginations about the mechanism of crystallization in an ultrasonic field are based on general laws of the process of solidification of metals and alloys. On the basis of experimental and theoretical works of many scientists (D. Chernov, A. Bochvar, N. Kolmogonov, V. Starko and many other), it is established that the process of crystallization begins from emergence of centers of crystallization and their further growth in a melt. The greater the rate of initiation of crystallization center and the less the linear speed of their growth are, the less is the size of the grain in the structure [11].

The shape of the liquid pool of an ingot and the temperature field of the pool determine the structure of the obtained ingot in continuous casting into a catalyst. Application of external factors of action upon melt metal in the pool of an ingot causes expansion of the zone of liquid metal with a temperature below the liquids curve over considerable of the hollow. The greater the intensity of mixing, the greater volume of the ingot pool the zone of decreased temperature occupies. With increase of extent of mixing, the zone of the melt which is being cooled extends over the whole volume of the hollow. The number of crystallization centers is in direct dependence on the rate of mixing.

The crushing of grains during mixing is accompanied by raising the non-homogeneity of the structure of the grain with increase in the intensity of mixing, the time during which dendrites are in liquid state increases because the rate of sedimentation of particles essentially decreases, correspondingly decreases the rate of crystallization of dendrites. Ultrasonic treatment of high intensity enables us to heighten the temperature of liquid metal under the conditions of the existence of a liquid pool of the ingot in continuous casting with cooling of the melt. [12].

The emergence of cavitation in ultrasonic treatment leads to the emergence of intensive streams which change the usual for calm conditions of, castings directions of movement of hot metal from the surface to the front of crystallization in liquid metal.

Application of ultrasonic treatment contributes to lessening of sizes of transient zone, because the action of ultrasonic treatment reduces the shrinkage of metal, and thus drawing the surface of an ingot nearer to the crystal crystallizer. In ultrasonic treatment of a melt, in the hollow of an ingot, with development of cavitation processes narrowing of the overcooled zone near the front of crystallization takes place due to an internal heat-source without prior overheat of the melt in the mixer.

Besides, the melt in a hollow is continuously being replenished by additional nucleation centers during passing through the zone of cavitation treatment. In ultrasonic treatment the temperature gradient near the front of crystallization increases. The influence of cavitation treatment enables the nucleating centers to begin their growth in the narrow overcooled zone, that leads to small size of the grain. Thus, the development of cavitation in hollow of continuous casting changes the temperature regime of the liquid pool of an ingot drawing the zone of crystal growth nearer to the front of crystallization making the zone essentially harrower.

In comparison with the structure of reference ingot (obtained without ultrasonic treatment), investigation of the structure of ingots obtained from continuous casting of lights alloys, during crystallization of which the liquid pool is subjected to ultrasonic treatment, indicate that the number of implemented nucleation centers after cavitation treatment increases by several orders. With this, the role of cavitation consists in activation small solid non-metal, inclusions by the melt and in increase, in this way, the number of potential nucleation centers [13]. In a crystallizing melt, the development of cavitation may lead to a stop of dendrite grown and to reproduction of nucleation centers [14-15]. But such action of cavitation manifests itself not only in the case of moving this cavitation domain close to the front of crystallization.

Non-dendrite structure does not change properties of strength of an ingot, but it raises its plasticity in cast hot-deformed state. The rise in plasticity in cast state enables us to increase sections of ingots; the non-dendrite crystallization in continuous casting with ultrasonic treatment also enables us to improve the surface of the ingot.

Because of this, the use of ultrasonic treatment of copper melt just before the process of crystallization is suggested in our work. Such approach provides for a complex action,. In particular, the process of degassing is being intensified, additional mixing of the melt also takes place; this prevents from emergence of dendrite liquation and concentration of non-metal inclusions on grains boundaries [4]. Besides, during crystallization, the action of ultrasound favorably influences the formation of homogeneous, dispersed microstructure of subdendrite type. Additional influence of ultrasonic oscillations enables us to improve the quality of finished products and to ensure high level of electro-conductivity. Taking into account amounts of production of copper wire rods in Ukrainian market, solution of problems which are considered in this work will ensure an increase in productivity and will minimize the expenditures for refining the melt.

Conclusions

It is known that properties of cast and deformed metal are determined by its structure: the more fine-granular structure of ingot (sizes of grains are lessened and made more uniform), the higher its ductility during casting and further deformation. I world and home practice, for making the structure fine, different external influences are applied, such as electromagnetic and vibrational treatment, introduction of active conditioning agent agents for initiation of crystallization centers, etc. With this, the structure of an ingot remains dendritic-like, i.e. it can be characterized by the two structural signs: the size of grains and the size of intersection of transverse branches of dendritic or "dendritic parameter". The dendritic parameter is unambiguously determined by the rate of cooling of the melt during its crystallization, and the grain size, usually, depends on many factors: temperature, purity of the melt as to its impurities, intensity of the melt mixing, cooling rate, and others. Peculiarities of the process of crystallization in metals have already been registered as a scientific discovery [9–10]. In particular, under the condition of creation of surplus of crystallizing nuclei in the melt in front of crystallization front, an extremely fine non-dendritic structure forms instead of dendritic-like structure; in such non-dendritic structure, the size of the sub-dendritic or non-dendritic grain is approximately equal to the “dendritic parameter”. The main parameter which ensures the formation of sub-dendritic type structure in an ingot is the cooling rate. Just this parameter enables us to control the number of crystallization centers in front of the solid-melt interface. In this case, the way in which the nuclei of crystallization are forming does not matter.

During casting of ingots and shaped casts, including that with the application of ultrasonic treatment, as a rule, the mechanism of heterogeneous crystallization works. At high rates of crystallization, the mechanism of homogeneous crystallization from supercooled melt begins to work. Thus, the sing of non-dendritic crystallization with obtaining of extremely fine grains is not a growth process, but the process nucleation of crystallization centers in supercooled melt. The real melt is micro-heterogeneous, and from the point of view of thermodynamics it is unbalanced thermodynamic system which is distinguished for its great interface-surface for reactions [author's works]. This means that, as to its structure, the real melt is not an ideal liquid, it contains a great number of sub-micron particle which is of the melt`s oxides and other solid non-metal phases – so called "plankton".

Because of this, in our work, the use of ultrasonic treatment of copper melt just before the process of the start of crystallization is suggested. Such approach provides for complex action. In particular, the process of degassing is being intensified, additional mixing of the melt takes place, this prevents from the emergence of dendritic liquation and concentration of non-metallic inclusions on grain boundaries. Besides, during crystallization, the action of ultrasound favorably influence the formation of homogeneous, dispersed microstructure of subdendritic type. Additional influence of ultrasonic oscillations enable us to improve the quality of finished products and to ensure high level of electric conductivity. Taking into account the amounts of production of copper wire rods in Ukrainian market, solution of problems which are considered in this work will ensure an increase in productivity and will minimize the expenses for refining the melt.

References

[1] Бочвар А. А. О температурной кривой начала линейной усадки бинарных сплавов / А. А. Бочвар, В. И. Добаткин // Изв. АН СССР. Отд.техн. наук. – 1945. – № 1–3. – С. 3–6.

[2] Бочвар А. А. О разрушении отливок под действием усадочных напряжений в период кристаллизации в зависимости от состава сплава / А. А. Бочвар, З. А. Свидерская // Изв. АН СССР. Отд. техн. наук. – 1947. – № 3. – С. 349–355.

[3] Добаткин В. И. Недендритная структура в слитках лёгких сплавов / В. И. Добаткин, Г. И. Эскин // Цветные металлы. – 1991. – № 12. – С. 64–67.

[4] Эскин Г. И. Ультразвуковая обработка расплавленного алюминия / Г. И. Эскин. – М. : Металлургия, 1988. – 232 с.

[5] Буров А. В. Литье слитков меди и медних сплавов / А. В. Буров. – М. : Металлургия, 1972. – С. 79–81.

[6] Структурно-енергетичний стан внутрішніх та зовнішніх меж поділу у металевих системах : монографія / З. А. Дурягіна, В. Ю. Ольшанецький, Ю. І. Кононенко. – Львів : Видавництво Львівської політехніки, 2013. – 455 с.

[7] Дурягина З. Modelling and optimization of manufacturing processes // З. Дурягина, А. Марынович, И. Махоркин / Manufacturing processes actual problems. – 2013. – Vol. 2. – P. 619.

[8] Берент В. Я. Материалы и свойства электрических контактов / В. Я. Берент. – М. : Интекст, 2005. – С. 69–88.

[9] Eskin G. I. Effect of ultrasonic (cavitation) treatment of the melt on the microstructure evolution during solidification of copper alloy ingots // Zt. Metallkunde. – 2008. – No 6. – P. 502–514.

[10] Jakani S. Effect of impurities on recrystallization texture in commercially pure copper-ETP wires / S. Jakani, T. Baudin, C.-H. de Novion, M.-H. Mathon // Materials science and engineering. – 2007. – P. 161–269.

[11] Агрант Б. А. Ультразвуковая технология / Б. А. Агрант. – М. : Металлургия, 1974. – С. 460–480.

[12] Ефимова В. А. Специальные способы литья / В. А. Ефимова. – М. : Машиностроение, 1991. – С. 466–474.

[13] Абрамов О. В. Кристаллизация металлов в ультразвуковом поле / О. В. Абрамов. – М. : Металлургия, 1972. – 256 с.

[14] Флемингс М. Процессы затвердевания / М. Флемингс. – М. : Мир, 1977. – 424 с.

[15] Баландин Г. Ф. Формирование кристаллического строения оливок / Г. Ф. Баландин. – М. : Машиностроение, 1973. – 286 с.