Quality upgrade of the copper wire rod produced by combined continuous casting and rolling method

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The paper is concerned with the technological peculiarities of wire rod producing out of oxygen-containing copper by continuous casting and rolling. Pouring defects which have an impact on the copper wire rod quality are listed. There was shown that gas pores in a cast billet are among the main causes for appearance of cracks in the copper wire rod. Such cracks are bringing out in the course of the standard wire rod twist test with the following untwisting. There has been studied the behavior of the gas pores arising from continuous casting process in an oxygen-containing copper billet for the ensuing rolling into wire rod. There has been fulfilled a metallographic analysis of cast and rolled billets, selected along the full length of rolling mill. It is determined an average size of pores which are not completely healed during plastic deformation and exert influence upon formation of cracks in wire rod. In the paper, there has been studied how the main copper melt gasing sources in case of the Controid wire rod manufacturing process influence on the probability of gas defects appearance in a continuously cast billet. Metallographic analysis of the continuously cast billet samples has been carried out. Average size of gas pores and porosity volume fraction have been determined. The hydrogen content in copper estimation procedure with due regard for gas pores volume fraction has been proposed. The hydrogen content in the continuously cast billet samples was determined depending on the different process variables of melt preparation for continuous casting. Besides, there was fulfilled the quality analysis of copper wire rod obtained under different process variables.
Results of the fulfilled research testify that the moisture presented in the nitrogen gas injected into the melt is of considerable importance in the process of copper melt saturation by hydrogen. Adjustment of the continuous casting process regulations has allowed diminish probability of cracks appearance on copper wire rod during standard twist testing with subsequent untwisting.

Key words: copper, continuous casting, rolling, Controid method, casting billet, wire rod, gas defects, cracks.

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Current technologies of copper wire rod manufacturing are characterized by continuous casting and rolling combination, which provides significant increase in efficiency. Copper wire rod may be produced in a variety of ways, as for instance Properzi, Southwire, Essex, Contirod, Dip-Forming, Outokumpu UPCAST [1, 2]. The most effective method of continuous casting and rolling is a Contirod one with an average productivity of 112 thousand of tons per year [3, 4]. It incorporates the continuous fusion of copper cathodes in an Asarco shaft furnace and the melt feeding to a mixing furnace by connecting spoute for the chemical composition and temperature averaging. After that the melt arrives over a foundry chute to a foundry ladle, out of which the continuous casting into a two-belt water-cooled mould is implemented. Having passed a secondary cooling zone, the cast copper billet in size of 120×70 mm is fed to a SMS Meer 14-stand rolling mill for the wire rod with diameter of 8 mm manufacturing of a M00 copper with the dissolved oxygen content no more than 400 ppm [5, 6].

Continuous casting and rolling combination essentially makes difficulties for establishing the reasons for defects appearance in the copper wire rod [7]. Cracks revealed in the course of the wire rod standard twist testing with subsequent untwisting with a 10×10 cycle, are among such defects [5]. The copper melt gasing depending on the different process variables of the melt preparation for continuous billet casting has been studied in [8], as well as ways of the gasing influence diminishing or its sources elimination. It was found that stopping an air supply to the connecting spout in order to correct oxygen content in copper as well as the nitrogen gas of special purity injection for the melt level monitoring, lead to reduction of the hydrogen content in the melt. Increased hydrogen content in the copper melt results in appearance of gas defects in the continuously-cast billet. After first rolling passes, gas pores open and are not healed during the following plastic deformation.

In order to study a behavior of gas pores in a cast billet during its plastic deformation on a rolling mill, an experimental-industrial experiment was carried out. In course of that, there was fulfilled a copper billet of rectangular cross section with 120×70 mm dimensions continuous casting and consequent rolling to wire rod. The following parameters have been hold during the casting: casting temperature varied from 1120 to 1130 °C, casting speed was from 10.4 to 10.5 m/min. On the casting-rolling unit stop, cross templates of thickness from 10 to 15 mm has been cut from the cast billet, and cross templates of thickness from 10 to 20 mm has been cut from the rolled billet after each mill stand. Surface of the template has been exposed to abrasive grinding and polishing with consequent etching by concentrated nitric acid. Obtained etched slices have been studied on Altami Met-1M (Альтами Мет-1М) digital microscope. Microstructures of cross-sections of the cast and rolled billets as well as the wire rod are shown as an example in Fig. 1.

Metallographic analysis has shown that cross sections of all samples have pores in top and bottom parts and the shape of these pores changes slightly when moving through mill stands. Peculiarity of the ContToid technology is copper cathodes melting in the shaft gas furnace while the melt is saturated by hydrogen. An additional hydrogen is introduced to the obtained copper melt during its movement along the foundry path [8]. In the process of crystallization, hydrogen dissolubility in liquid copper comes down along with hydrogen bubbles forming. In case of continuous casting to the belt water-cooling mold, these bubbles lead to gas porosity in the subsurface layer of cast billet. Besides, the melt incoming to the mold contacts to the oil applied over belts, resulting in its ignition. As this take place, arising organic products contain hydrogen which can take root to a subsurface layer, bringing to gas pores and blowholes [9].

In order to estimate porosity on the rolled billet over all rolling passes, total area of pores on the etched slice has been calculated with the use of Altami Studio software. Besides, an average size of gas pores and porosity volume fraction have been determined. The results of porosity analysis are tabulated in Table 1.

Analysis of the obtained results has reviled one general tendency, namely, lessening of porosity volume fraction and average size of pores in a rolled billet as it moves through the rolling mill. As this take place, a porosity volume fraction is decreasing from 3.98% to 0.04%, whereas an average size of pores is reducing from 62.42 to 7.09 μm, that is gas porosity is partially healed during the rolling process. However, several pores remain in the wire rod section. They may come out to the surface and cause cracks in case of standard testing, which is confirmed by the results of metallographic analysis of rod samples (Fig. 2).

Hence, the appearance of defects in the wire rod is mostly caused by gas porosity presence in a continuously cast billet, and their minimization is possible by adjusting the process variables of the copper melt preparation.

Series of experimental-industrial experiments on a billet of rectangular cross section with 120×70 mm dimensions continuous casting under different conditions of the melt preparation has been scheduled in order to study an

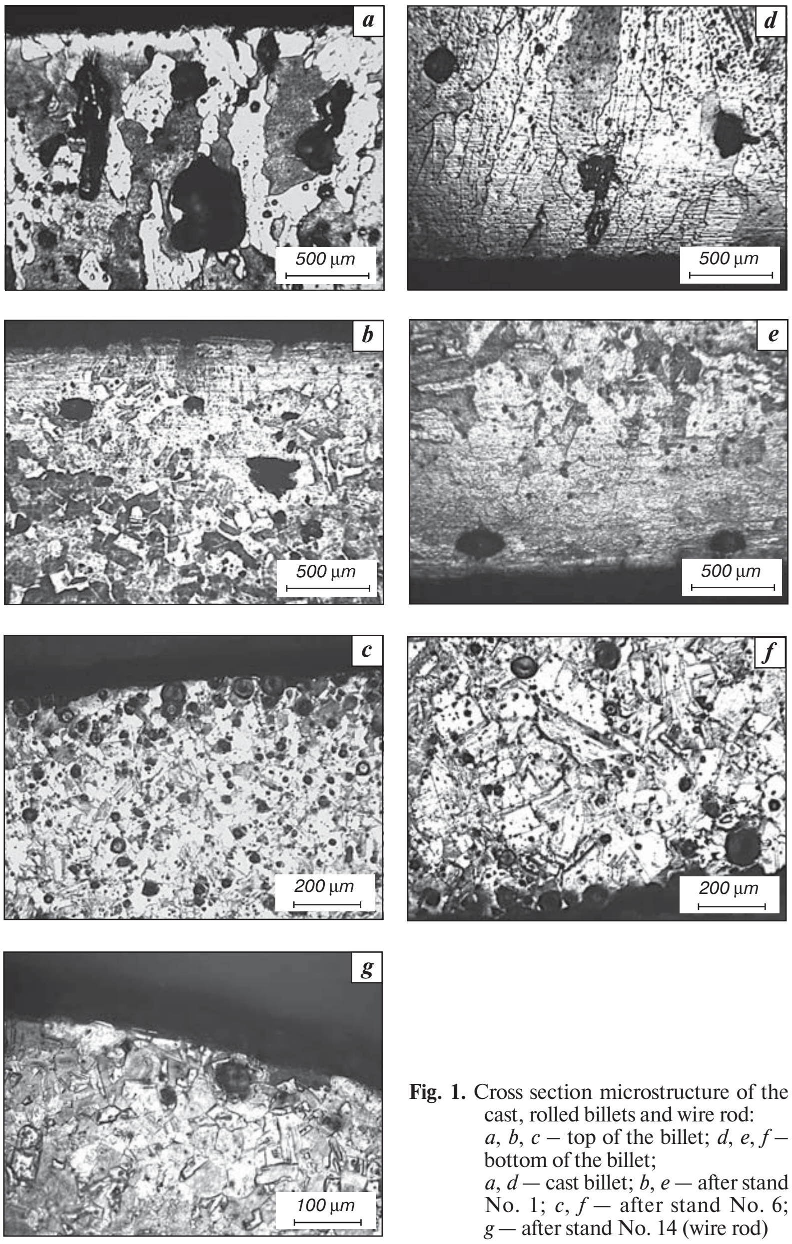

Fig. 1. Cross section microstructure of the cast, rolled billets and wire rod:
a, *b*, *c* – top of the billet; *d*, *e*, *f* – bottom of the billet;
a, *d* — cast billet; *b*, *e* — after stand No. 1; *c*, *f* — after stand No. 6; *g* — after stand No. 14 (wire rod)

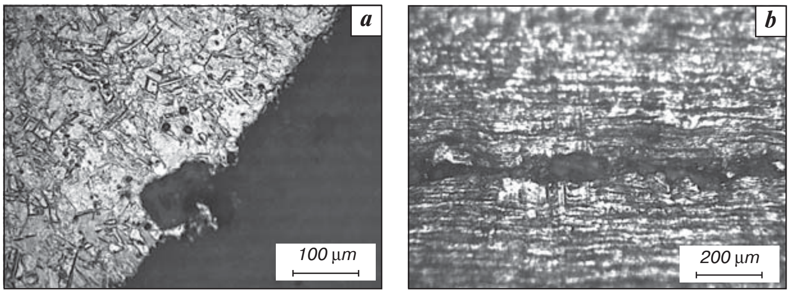

Fig. 2. Cross section microstructure (*a*) and the copper wire rod surface (*b*) after twist testing with subsequent untwisting

influence of the hydrogen content in a copper melt on the cast billet quality, namely, the probability of gas defects appearance during crystallization process. There was put forward an assumption that the air injected to the melt as well as nitrogen gas fed to it have influence on the probability of gas defects appearance in a continuously cast billet. To check that assumption, the following experiments have been run: casting under the current regulations, at the time of which air is injected to the melt through a connecting spout and industrial nitrogen gas is fed by a foundry spout [10]; casting without air injection to the melt; casting with industrial nitrogen gas injection to the melt and without that; casting with the use of nitrogen gas of special purity 6.0 [11]. Over the experiments, the temperature and billet casting speed have been invariable and have amount to 1120–1130 °C and 10.4–10.5 m/min, respectively.

During the experiments, there were conducted a planned stop of the cast and roll unit for selecting samples of cast billet at different parameters of melt preparing for continuous casting. Cross-cut templates 10–15 mm thick have been cut out from the obtained cast billet samples and then they have been cut into 8 pieces according to the scheme of the Fig. 3.

As it has been found in [12, 13], the cross-section macrostructure of the cast billet obtained by Contirod continuous casting technology represents four zones of columnar crystals of different extension which are joining by five planes. Such a structure possess a pronounced symmetry, therefore the metallographic analysis has been implemented for the samples No. 3, 4, 7, 8, which cover all zones of microstructure and allow to determine a porosity presence over the entire height of the billet. The obtained samples have been exposed to abrasive grinding with consequent etching by concentrated nitric acid. The microstructure analysis has shown that gas pores may be observed in all the cast billet samples, selected under different process conditions of the melt preparing for continuous casting. Samples,

Table 1

Results of the rolled billet porosity analysis

Stand number	Ratio of the etched slice area, occupied by pores, %	Porosity volume fraction, %	Average size of pores, μm
Cast billet	13.17	3.98	62.42
1	9.05	2.13	61.67
2	3.33	0.48	27.88
3	7.04	1.59	29.95
4	4.15	0.67	22.69
5	6.84	1.43	26.71
6	9.47	2.34	27.96
7	12.66	3.57	25.27
8	4.56	0.85	12.35
9	4.01	0.61	10.94
10	3.63	0.53	12.71
11	3.32	0.49	12.99
12	2.15	0.25	11.41
13	0.75	0.05	7.67
14	0.66	0.04	7.09

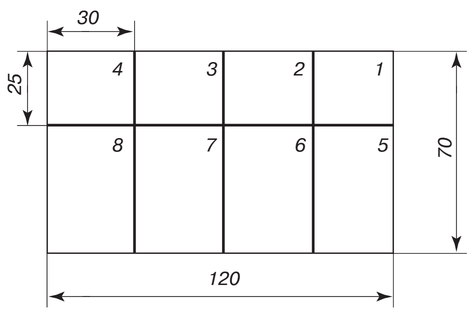

Fig. 3. Scheme of the cast billet template cutting in samples for analysis

Table 2

Results of determining the hydrogen content in cast billets

Casting mode	Ratio of the etched slice area occupied by pores, %	Porosity volume fraction, %	Average size of pores, μm	Calculated hydrogen content, ppm	Hydrogen content, determined in the cast billet sample, ppm	Total hydrogen content, ppm
Regulations currently in force	15.30	4.56	72.05	0.498	0.982	1.480
Without air injection to the copper melt	13.17	3.98	62.42	0.430	0.351	0.781
With nitrogen gas feeding to the melt	10.42	2.62	68.19	0.272	0.511	0.783
Without gas nitrogen feeding to the melt	8.20	1.77	52.58	0.182	0.192	0.374
With use of nitrogen gas of special purity	7.90	1.71	55.26	0.176	0.204	0.380

obtained by casting modes without use of industrial nitrogen gas as well as casting modes using nitrogen gas of special purity have been attacked by gas porosity to a lesser degree than that of the casting mode under the regulations currently in force.

Quantitative assessment of hydrogen content in samples cut out of the cast billet has been executed on a LECO ROH 600 gas-analyzer. However, the gas-analyzer is able to determine quantity of dissolved hydrogen only. Porosity on the etched slice surface may serve as an indirect estimation of the evolved hydrogen content in cast metal. It should be pointed out that the gas porosity presence is typical for billets obtained under all process variables. The metallographic analysis has covered determining the ratio of the etched slice area occupied by pores and calculating the pores volume fraction, their average size and hydrogen content. The results are tabulated in Table 2.

Analysis of the received data has shown that under the current casting regulations, considerable porosity of cast billet is observed and values of the indexes under consideration are the highest possible. Eliminating air injection into the melt allows decrease to some extent cast billet porosity and hydrogen content in the melt; in so doing an average size of pores decreases by 13% and hydrogen content decreases by 47% in comparison with the current casting regulations. Casting without nitrogen gas feeding into the melt allows reducing a porosity volume fraction of a cast billet by 61%; in so doing an average size of pores decreases by 27% and hydrogen content decreases by 75%. In case of the casting using nitrogen gas of special purity, a porosity volume fraction of a cast billet is decreasing by 62%, an average size of pores by 23% and hydrogen content by 74%.

In course of experimental-industrial experiments here were selected the copper wire rod samples both twist tested with consequent untwisting and without that. The obtained samples have been exposed to abrasive grinding and polishing with consequent microstructure analysis. Microstructure of samples at cross-section of the wire rod, obtained in different conditions of the melt preparing is shown as an example in Fig. 4.

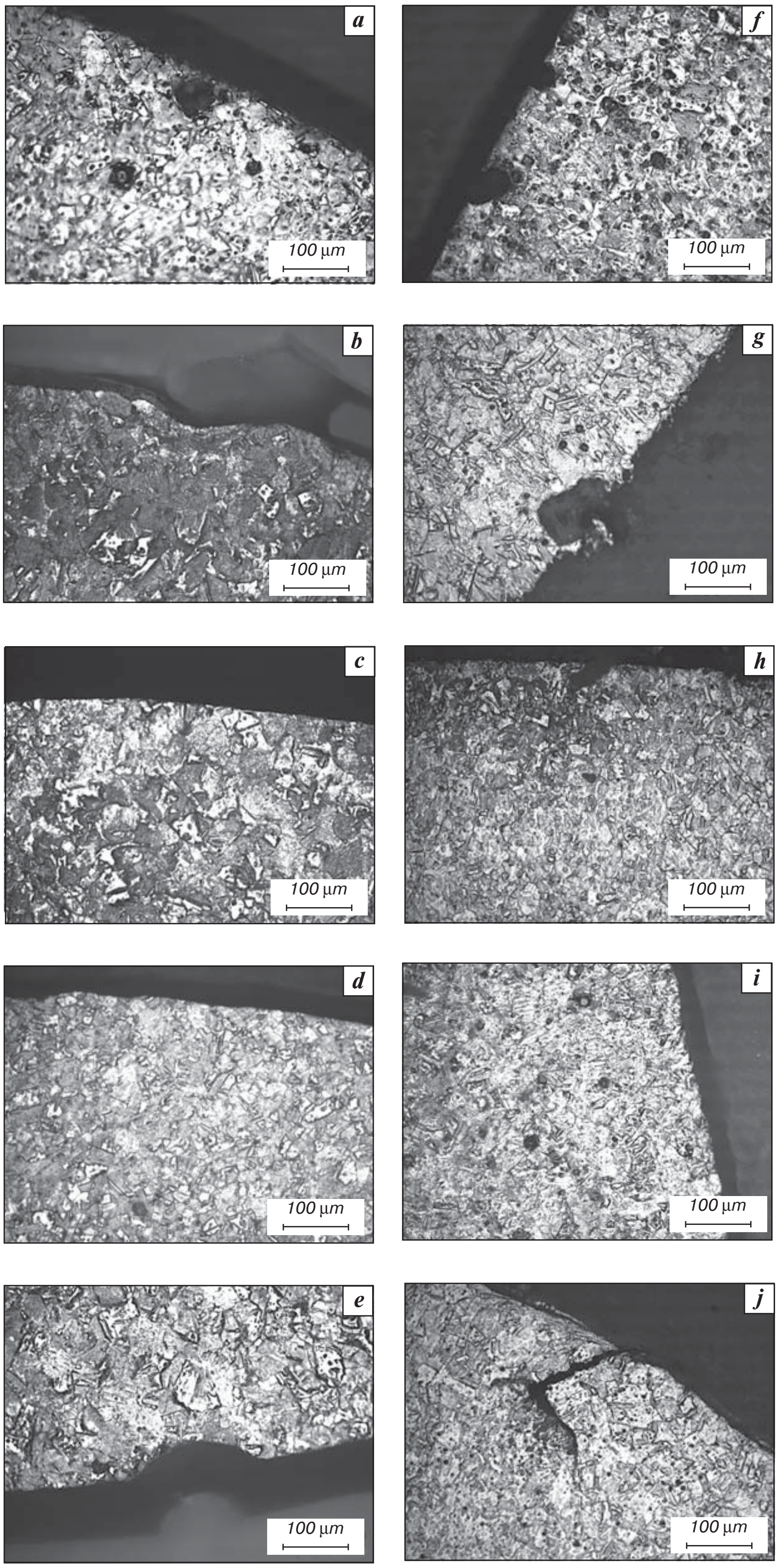

Fig. 4. Cross-section microstructure of the copper wire rod samples:
a, *b*, *c*, *d*, *e* — before testing; *f*, *g*, *h*, *i*, *j* — after twist testing with subsequent untwisting; *a*, *f* — casting regulations currently in force; *b*, *g* — casting without air injection into the melt; *c*, *h* — casting without nitrogen gas feeding to the melt; *d*, *i* — casting with the use of nitrogen gas of special purity; *e*, *j* — casting with nitrogen gas feeding to the melt

Metallographic analysis has revealed that in case of the current casting regulations, the surface layer of the copper wire rod samples contains considerable number of gas pores of size up to 80 μm. At the same time, pores located close by the rod surface have been opening during twist testing with consequent untwisting and form defects in the form of surface fractures. Eliminating air injection into the copper melt during casting allows decrease to some extent number of small pores in the surface layer of the wire rod. Nevertheless, big pores of size up to 70 μm, which have been opening during twist testing with consequent untwisting, still remain. In case of casting with nitrogen gas feeding to the melt, in the copper rod there are observed big pores of size up to 70 μm and clusters of small gas pores, which cause appearance of branched gaps 200 μm deep after the twist testing. In conditions of the melt preparing without nitrogen gas feeding into foundry spout, number of gas pores and their size has been sufficiently reduced. Maximum size of single pores which can be opened during the twist testing, amounts to 40–50 μm. Casting with nitrogen gas of special purity allow significantly reduce number of gas pores as well as their size. In cross-section of the rod samples there are observed single gas pores of 30 μm maximum. These pores don't come to the surface; they are positioned at significant depth below it. It must be pointed out that in some wire rode samples there are observed roundish cavities, placed along the full length of the wire rod samples. The cause of their origin may be some mechanical force applied to the wire rod during rolling, cooling and winding.

The indicated in [8] gasing sources influence on the quality of continuously cast billet, which determine probability of cracks formation in copper rod, was confirmed in the series of fulfilled experimental-industrial experiments. Adjustment of process requirements of the copper melt preparing for continuous casting has allowed lessen number of gas defects in a continuously cast billet and increase the copper wire rod quality, which appears in a diminished probability of the surface cracks appearance during standard twist testing with subsequent untwisting.

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