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SATURATION DYNAMICS OF ALUMINUM ALLOYS WITH HYDROGEN

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ABSTRACT

This work presents research results on the dynamics of the saturation of aluminum and its alloys with hydrogen in a flow chart for preparing melts in the manufacture of flat-shaped ingots at UC RUSAL. It is demonstrated that one of the main sources of the saturation of an aluminum melt with hydrogen is its interaction with atmospheric moisture during open metal pouring in the course of its transportation from an electrolyzer to a mixer. According to the results of the conducted works, new technical solutions have been proposed whose introduction will ensure, in the long term, a considerable decrease in hydrogen content in aluminum ingots and low-alloyed aluminum alloys.

Keywords: hydrogen content, aluminum alloys, manufacturing technology, vacuum-transport ladle.

INTRODUCTION

UC RUSAL is one of the largest companies in the global aluminum industry. It accounts for almost 9% of the world's primary aluminum output and is expected to boost its proportion of alloys up to 80%. One of RUSAL's promising development trends is the manufacture of bulk (flat-shaped) low-alloyed aluminum alloy ingots. A number of technical and technological solutions aimed toward improving the existing technology and ensuring a decrease in hydrogen content in aluminum melt up to a level of less than 0.1 cm^3 /100 g have been developed in order to increase these products' competitiveness.

CONDUCTING THE RESEARCH

Hydrogen, whose content in an aluminum melt and its alloys is at least 70% of the total amount of gases, is one of the most harmful gas impurities that negatively affect the technological properties of products made of aluminum and its alloys [1-3]. A liquid aluminum alloy contains up to 1.0 cm^3/100 g of hydrogen. The only exception is aluminum alloys that contain titanium and zirconium. These alloys contain hydrogen of up to 2.0 cm^3/100 g [4]. When a melt's temperature decreases and it subsequently crystallizes, hydrogen solubility in aluminum plummets (Figure-1) [3-6].

The increased hydrogen content in the aluminum ingots results in porosity, and the plasticity of metal plummets during subsequent deformation processing.

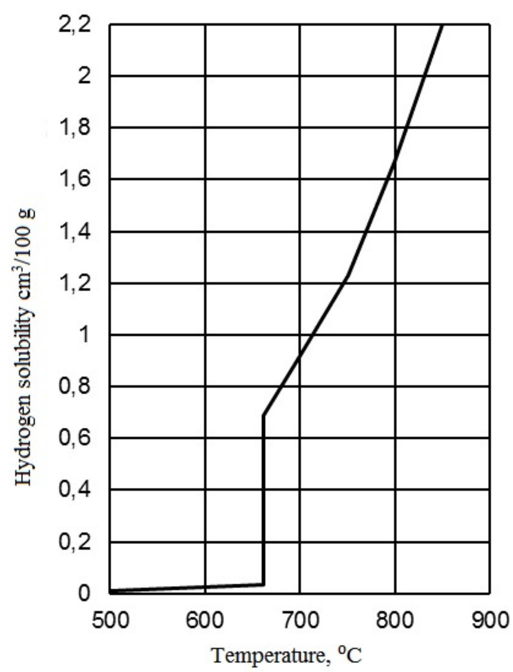

Figure-1. Change in the hydrogen solubility in aluminum depending on the temperature [3-6].

The hydrogen content in the air is very low, less than $5\cdot10^{-5}$ %. Therefore, the main source of hydrogen in aluminum alloys is water vapors that are contained in atmospheric moisture, charging materials and fluxes, and on the surfaces of equipment in contact with the melt in the course of its preparation and founding. An aluminum melt interacts with moisture at all stages of the manufacture of castings and at a temperature of more than 300°C decomposes water into hydrogen, which is actively dissolved in the melt when the temperature increases [6]:

$$2Al + 3H_2O = Al_2O_3 + 3H_2.$$

In order to improve the manufacturing technology of flat-shaped ingots for the purpose of decreasing the hydrogen content in marketable aluminum and its low-

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alloyed alloys, this work focuses on the study of the dynamics of changing hydrogen content in liquid metal when it is transferred along the process chain from an aluminum electrolyzer to a mixer, as well as during the preparation of a melt and founding at one of RUSAL's metallurgical plants. A process flow chart for the transportation, preparation, and pouring of metal at the plant includes the following fundamental operations [7]:

a) pouring liquid aluminum out of electrolyzers into vacuum-transport ladles;
b) transporting metal in vacuum-transport ladles from an electrolysis shop to a foundry one;
c) removing slag from the surface of the aluminum in ladles and sampling the metal for spectral analysis of its chemical composition;
d) settling a melt in vacuum-transport ladles for up to 40 min before pouring it into a mixer;
e) pouring metal out of vacuum-transport ladles into a mixer;
f) introducing and dissolving alloying elements in liquid metal to manufacture an alloy of a certain composition;
g) processing a melt in a mixer with refining and covering fluxes, removing slag from the surface of a ready-made alloy;
h) technological settling of a melt in a mixer, sampling metal for spectral analysis of its chemical composition, and bringing the temperature of metal in a mixer up to specified values;
i) pouring metal out of a mixer into a metal duct along with degassing and filtration of the liquid metal and its subsequent crystallization in the form of flat-shaped ingots.

In order to study the saturation dynamics of aluminum alloy 1XXX with hydrogen within the above main technological operations, the metal sampling has been conducted for the purpose of determining hydrogen content. The samples have been cast into a copper mold in accordance with the instructions at the plant. When sampling the metal, the main technological parameters have been registered regarding the preparation of metal in the mixers and modification and refinement of alloys during the founding of marketable products.

In order to prepare an alloy, electric reflection mixers have been used of 80 t of melt. Alloy samples from the mixers have been taken from each prechamber immediately after filling the mixer with aluminum and preparing the alloy before pouring. Alloys 1XXX have been used in order to cast large flat-shaped ingots on the vertical foundry machine with the use of the Wagstaff foundry equipment and the Epsilon crystallizers [8]. The ingots are founded with the use of thermoformed closed-bottom metal distributors: Combo-bag. The melt, when founding the ingots, has been refined via purging with argon an inert gas, during the SNIF P-140UHB two-rotor secondary treatment installation. Aluminum was additionally filtered in a tubular metal filter by Mitsui. The purification of metal has been finished with filtration through a ceramic foam filter. In order to modify the metal, a rod-shaped hardener has been used, AlTi5B1 by KBM Affilips [8, 9].

According to the inspection results, the samples taken have been prepared according to GOST R 50965 and analyzed in the plant laboratory with the use of the G8 Galileo gas analyzer.

The diagram (Figure-2) presents the analysis results on the hydrogen content in the melt in different areas of the process flow chart on casting, transportation, preparation, and pouring of the metal under the production conditions of UC RUSAL.

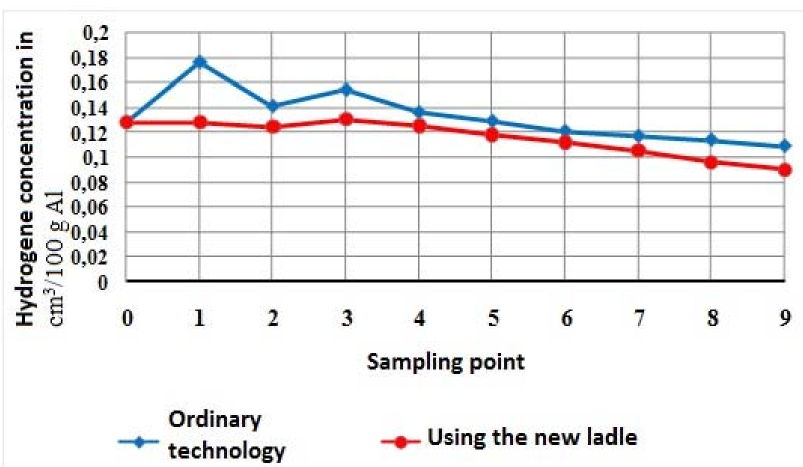

Figure-2. Change dynamics of hydrogen concentration in the liquid metal, whereby 0 - in the electrolyzers; 1 - in the ladles before the metal's settling; 2 - in the ladles after the metal's settling; 3 - in the mixer after pouring the metal; 4 - in the mixer before pouring the metal; 5 - before the argon's refining installation (SNIF); 6 - after installation (SNIF); 7 - after the metal filter by Mitsui; 8 - after the ceramic foam filter by Mitsui; 9 - before metal is fed into the foundry machine crystallizer.

According to the regulatory documents at the plant, the following activities are conducted on decreasing hydrogen content in an aluminum melt and its alloys:

- settling the metal in vacuum-transport ladles before it is poured into mixers;
- processing metal with fluxes in mixers along with subsequent holding of the melt;
- refining metal with argon, an inert gas, during the secondary treatment installation SNIF P-140UHB;
- filtering metal through ceramic foam filters and filters by Mitsui.

All this allows us to decrease hydrogen content in liquid aluminum with electrolyzers from 0.128 cm^3/100 g Al to 0.109 cm^3/100 g before the metal is fed into the foundry machine crystallizer. However, when the liquid aluminum is taken out of the electrolyzer and placed into the vacuum-transport ladle, there is a sharp increase in hydrogen content from 0.128 to 0.176 cm^3/100 g Al, despite the fact that the metal's average temperature decreases approximately by 100ºC, up to 860ºC. The liquid aluminum saturation with hydrogen when taking the metal in the ladle is caused by the interaction of an open jet of metal with atmospheric moisture, as well as by the ejection of moist air bubbles with a jet of metal poured into the volume of poured metal and is a result of the open overflow of aluminum during its founding. Furthermore, there is a decrease in hydrogen content in the metal melt during its movement along the metal duct up to its entrance into the crystallizer up to 0.109 cm^3/100 g, which does not always meet consumer requirements and is a basis for carrying out research works aimed toward decreasing hydrogen in the melt.

For the purpose of further decreasing hydrogen content in the aluminum alloy 1XXX melt in the manufacture of flat-shaped ingots, the vacuum-transport ladle design (presented in Figure-3 [13]) is intended for transporting liquid metal from the electrolyzer into the mixer has been improved.

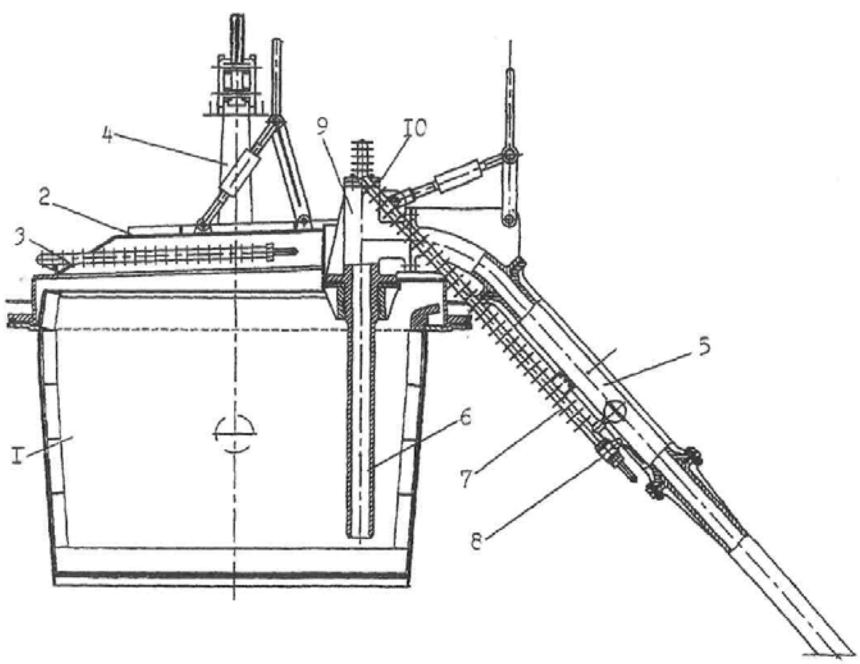

Figure-3. Improved design of a vacuum-transport ladle intended for transporting liquid metal: 1 - body 2 - removable cover; 3 - vacuum line pipeline; 4 - load-lifting beam; 5 - suction tube; 6 - internal tube; 7 - fire tube; 8 - locking device; 9 - reception cavity; 10 - metal-impermeable and gas-permeable filter [13].

The vacuum-transport ladle operates as follows. Removable cover 2 is hermetically fastened to the preliminarily heated ladle. Suction tube 5 is installed into the cover. Tube 5 is connected to additional internal tube 6. The nose of suction tube 5 is immersed in the metal melt in the electrolyzer. At the same time, locking device 8 on fire tube 7 must be closed for the purpose of sealing the ladle. By creating rarefaction inside ladle 1 due to the connection of pipeline 3 to the vacuum line, the metal is taken from the electrolyzer and placed into the vacuum ladle. When the level of liquid metal is increased in the ladle above the lower cut of drain tube, a further overflow takes place with regard to the level of metal. If it is necessary to interrupt the founding, (the end of a pouring process), pipeline 3 is disconnected from the vacuum line and the jet of metal in suction tubes 5 and 6 is broken by

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feeding through locking device 8 into cavity 9 of atmospheric air.

After the metal is taken in the ladle, suction tube 5 and the additional tube 6 connected to it are taken from the filled ladle and placed into another empty ladle in order to further found the metal from the electrolyzers in the body.

The improved design of the vacuum-transport ladle allows us to carry out a closed pouring of the metal from the ladle into another metallurgical reservoir (mixer, ladle, electrolyzer). For this purpose, the vacuum-transport ladle with liquid metal in it is brought to a metallurgical reservoir into which it is prepared to pour. The external end of suction tube 5 is immersed in melt contained in the metallurgical reservoir, up to a depth of 5÷10 cm. Fire tube 7 is connected to the vacuum line with opened locking device 8. In this case, rarefaction takes place in cavity 9 and inside tubes 5 and 6. Under the influence of rarefaction, the melt starts rising along tube 5 on one side and along tube 6 on the other side. The melt rising along tube 6 will more quickly reach the top point and will be poured into suction tube 5, thereby creating a directed flow from the ladle to the metallurgical reservoir. The melt is further poured out of the ladle in a spontaneous way, which is why rarefaction maintenance in cavity 9 is optional. Porous filter 10, a gas permeable one, prevents the melt from its possible ingress into the vacuum line.

The use of the improved design of the vacuum-transport ladle allowed us to feed the metal into the ladle with regard to the level of the melt and carry out closed pouring of the melt out of the vacuum ladle into another metallurgical reservoir with no ladle inclination, thereby considerably decreasing the content of nonmetallic impurities and hydrogen in the metal.

This thesis has been confirmed during experimental industrial tests with the new ladle when, as earlier stated for the above main technological operations, metal sampling has been carried out for the purpose of determining the hydrogen content. The research results are presented in Figure 1 for comparison. When liquid aluminum is taken from the electrolyzer and placed into the vacuum-transport ladle (point 1), we have managed to avoid an increase in hydrogen content in the metal. The liquid aluminum saturation with hydrogen has not been practically changed and remained equal to the hydrogen content in liquid aluminum. Furthermore, during the subsequent holding of liquid aluminum in the ladles, before it is poured into the mixers, there was a decrease in the hydrogen concentration in the metal from 0.128 to 0.124 cm^3/100 g Al. However, when preparing aluminum alloy 1XXX, the hydrogen concentration in metal poured into the mixer increased from 0.124 to 0.130 cm^3/100 g due to contact of moist air with the melt when the alloying elements dissolved in the liquid metal. Furthermore, there is a rather smooth decrease in the hydrogen content in the metal melt while it moves along the metal duct up to its entrance into the crystallizer up to 0.090 cm^3/100 g, which allows us to decrease the formation of porosity in aluminum ingots, thereby augmenting the technological properties of products.

CONCLUSIONS

As a result of the conducted research, we have registered increased hydrogen content (more than 0.10 cm^3/100 g) in the melt from the aluminum electrolyzer to the foundry machine in the course of manufacturing the flat-shaped aluminum alloy 1XXX ingots at UC RUSAL. In order to resolve this problem, we have decreased contact of the melt with the external environment when the liquid aluminum is taken out of the electrolyzer and placed into the vacuum-transport ladle as well as during its subsequent pouring into the mixer by way of improving its design [13], which has allowed us to decrease the hydrogen content in the melt just before its entrance into the crystallizer up to 0.079 cm^3/100 g. Furthermore, the effectiveness of a degassing process can be increased during the manufacture of flat-shaped aluminum alloy 1XXX ingots due to the use of special magnetohydrodynamic and ultrasonic devices as well as the use of a vacuum in the foundry equipment, including inside metal ducts just before the melts are poured into crystallizers [14 – 21].

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