Influence of the method of out-of-furnace melt treatment on hydrogen content in 5083 aluminum alloy

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The work was carried out in laboratory conditions at the semicontinuous ingot casting installation (SICI) in the casting laboratory of the Siberian Federal University. The article presents the results of comparative studies of the dynamics of aluminum saturation with hydrogen over the entire hardware and technological scheme. The article gives a schematic diagram of the semicontinuous ingot-casting unit. Studies were carried out using a single- and two-stage aluminum melt filtration system with the use of ceramic foam filters with an alumosilicate binder bonded with stabilized borosilicate glass. The results of investigations of the ceramic foam filter heating temperature influence (less than 500 ^oC and higher than 500 ^oC) on hydrogen concentration in an aluminum alloy are presented. The hydrogen content studies have been carried out during complex passing of aluminum melt through a single- or two-stage filtration by a ceramic foam filter. The paper presents the results obtained by applying a degassing unit that operates on the principle of the molten metal inert gas blowing (argon). During the study, it was found that the average hydrogen concentration in an aluminum alloy before passing through a ceramic foam filter was 0.19 cm^3/100 g Al, and that after passing through the filtration system with ceramic foam filters was 0.185 cm^3/100 g Al.
The paper shows that the ceramic foam filter heating degree does not affect the aluminum alloy saturation with hydrogen. In the course of the work, it was found that the most significant effect of reducing hydrogen concentration could be achieved by blowing aluminum with inert gas (argon) along with filtration by a ceramic foam filter (CFF), which was confirmed by a series of experiments.

Key words: aluminum, hydrogen, non-metallic inclusions, aluminum alloys, degassing, CFF, ceramic foam filter.
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Introduction

The competitive capacity of engineering products in the foreign market is largely determined by their quality. Considering that parts made of aluminum and its alloys are used in the designs of machines and aggregates, special attention is paid to the technology of their manufacture. One of the priorities in this direction is reducing gas impurities (primarily hydrogen) in aluminum [1–5]. The need to reduce hydrogen content in aluminum and its alloys is motivated by the ever-increasing requirements for the quality of commodity output. First of all this applies to the export of metal. In particular, a number of large companies — RUSAL (Russia), Alcoa (USA), Norsk Hydro (Norway) — have already established the level of hydrogen content for most types of products no more than 0.10 cm^3/100 g Al.

At the moment, aluminum industry enterprises use a set of measures to reduce gas impurities, including hydrogen, providing for: closed reladling when pouring raw aluminum from an electrolyzer into a vacuum transport ladle with a removable siphon, metal settling in a vacuum transport ladle, vacuum treatment of molten metal, melt filtration by ceramic foam filters and the use of special fluxes [6].

Technologies of casting through a ceramic foam filter (hereinafter referred to as CFF) in world practice have been proposed for implementation by such large companies as Pyrotek (USA), Selee (USA), Drache (Germany), but at the moment there is no implemented finished solution that allows using more than one filtration stage because of technical characteristics of the filters used, namely: alumophosphate (the binding phase of CFF), which has low heat resistance and reacts with Mg in Al – Mg alloys, and also hydrogenates the metal due to the presence of alumophosphate hydrate (at least 0.005–0.03 ml H_2 per 100 g of aluminum) [7–9]. A promising direction is the use of aluminosilicate binder bonded with stabilized borosilicate glass in CCF. This binder is more resistant to chemical impact of liquid aluminum and has a lower coefficient of thermal expansion of CFF two-phase microstructure. This will allow using an alternative system of combined heating of filters installed into a two-level system, which will ensure uniform CFF heating, increasing its service life to standard one and maintaining filtration efficiency from all kinds of impurities throughout the whole casting process [10].

Analysis of mechanism and dynamics of saturation of aluminum and its alloys with hydrogen has allowed developing technical and technological solutions, including complex two-stage filtration by ceramic foam filters [11].

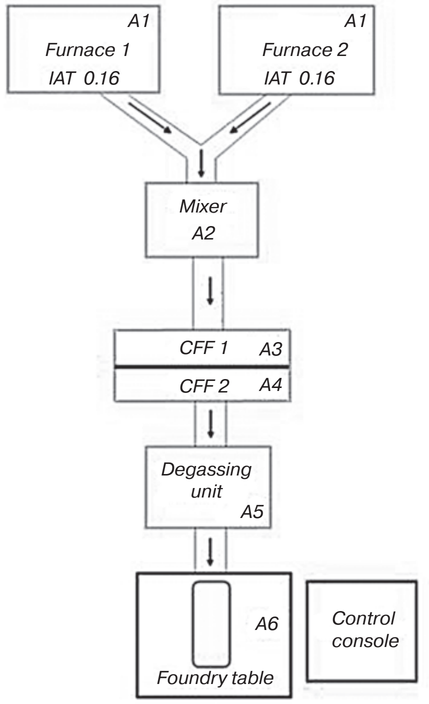

Fig. 1. Hardware and technological diagram of SICI (letters and numbers on the diagram indicate the places of sampling of molten aluminum; arrows indicate the metal movement direction)

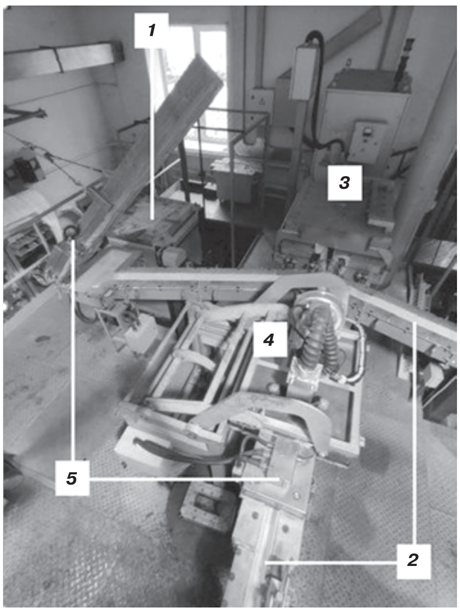

Fig. 2. Installation of semicontinuous casting (SICI):
1 — induction furnace IAT-0.16; *2* — tray system (metal flow path); *3* — rotary mixer; *4* — single- or two-stage filtration installation; *5* — heating lids

The purpose of investigations: to study hydrogen content in the 5083 aluminum alloy ingots depending on the out-of-furnace processing method (when using different variants of single- or two-stage filtration system and argon degassing of the melt) under laboratory conditions of the Siberian Federal University at a semicontinuous ingot casting installation (hereinafter referred to as SICI).

Experimental technique

A comparative study of hydrogen content in an aluminum alloy depending on the out-of-furnace processing method has been carried out according to the hardware and technological scheme of SICI (**Fig. 1**) [12]. The experiments have been carried out at identical temperature and process variables when using an aluminum alloy of 5XXXX group corresponding by chemical composition to 5083 alloy (AMg4.5).

Alloys have been prepared in an IAT-0.16 induction furnace with a total load of charge materials of 50 kg. A85 aluminum was used as the base of alloy, as well as alloying and modifying additives conforming to GOST R 53777-2010 (State standard). During the experiment, the melt temperature was 850 ^{o}C in the induction furnace, 750 ^{o}C in the mixer and 700–705 ^{o}C on the casting machine table. Upon reaching the required chemical composition of 5083 alloy, the metal was poured into a rotary mixer, where feeding with a modifying ligature Al–5Ti–1B has been fulfilled at the rate of 1.5 kg. per 1 ton of melt. Next, the metal was hold in the mixer until the set temperature was achieved. The prepared alloy was fed into the mold of a casting machine with a cross section of 60×200 mm from a mixer, the tilt speed of which automatically varies depending on the ingot casting rate and level of molten metal in the mold (**Fig. 2**).

The filtration units have employed CFFs with dimensions of 9×9×2 inch and porosity of 20 ppi made by the use of an aluminosilicate binder bonded with borosilicate glass. The CFF heating temperature over 500 ^{o}C and less than 500 ^{o}C was selected taking into account the power inputs required for heating the filters.

The aluminum melt degassing has been carried out with high purity argon (TU 2114-001-99420244-2016); the gas consumption was 0.3 m^3 per ton of metal at a pressure of no more than 0.4 MPa and a blowing time of 15 min.

In accordance with the objective of the work, the number of experiments was determined taking into account the controlled variables. The experimental plan is presented in **Table 1**.

Liquid metal sampling has been fulfilled using a conical sample mold, which eliminates human factors affecting sampling, provides representative metal samples, reduces sampling time and allows sampling from metallurgical tanks from different depths [13].

An ALU COMPACT II device has been used to measure hydrogen concentration in an aluminum alloy. The hydrogen content was determined by emission of the “first bubble” of gas from the cooled metal.

Results and discussion

According to the results of the experiments conducted at SICI, a comparative data analysis was carried out depending on CFF heating temperature and the use of liquid metal degassing with argon (**Table 2**).

The average hydrogen content after alloy preparing in the IAT-0.16 furnace (Fig. 1, point A1) was 0.2 cm^3 /100 g Al. This hydrogen content is conditioned by high metal temperature of 850 ^oC in the furnace at the time of sampling. When aluminum alloy is subsequently poured from induction furnaces into a rotary mixer, hydrogen concentration decreases (Fig. 1, point A2) to an average of 0.18 cm^3/100 g Al because of a drop in temperature by 100 ^oC on average.

The average hydrogen content in the metal without CFF application and alloy degassing with argon in the sample taken at the foundry table (Fig. 1, point A6) averaged 0.17 cm^3/100 g Al (Table 2, Experiment No. 1); this is due to the melt temperature decrease during its passage through the metal flow path.

Table 1
The plan for conducting experiments at SICI

Controlled variables	Experiment number									
	1	2	3	4	5	6	7	8	9	10
Mode without filtration	+	+	–	–	–	–	–	–	–	–
The first stage of filtration	–	–	+	+	+	+	–	–	–	–
The second stage of filtration	–	–	–	–	–	–	+	+	+	+
Heating temperature of the filter/filters: less than 500 ^oC	–	–	+	–	+	–	+	–	+	–
Heating temperature of the filter/filters: more than 500 ^oC	–	–	–	+	–	+	–	+	–	+
Without a degassing device	+	–	+	+	–	–	+	+	–	–
With a degassing device	–	+	–	–	+	+	–	–	+	+

Table 2
The results of SICI experiment obtained during sampling for hydrogen concentration in an aluminum alloy (5083), depending on the experiment number (A1, A2, A3, A4, A5, A6 — are the symbols of sampling points, see Fig. 1)

Experiment No.	Heating temperature of the filtration system, ^oC	Hydrogen concentration, cm^3/100 g						Degassing
		A1	A2	A3	A4	A5	A6	
1	Without filter	0.2	0.18	–	–	–	0.17	–
2	Without filter	0.22	0.19	–	–	0.13	0.12	+
3	<500	0.2	0.18	0.19	–	–	0.18	–
4	>500	0.22	0.2	0.2	–	–	0.19	–
5	<500	0.2	0.19	0.19	–	0.14	0.13	+
6	>500	0.23	0.2	0.2	–	0.14	0.13	+
7	<500	0.22	0.2	0.19	0.19	–	0.17	–
8	>500	0.21	0.2	0.2	0.2	–	0.18	–
9	<500	0.22	0.21	0.18	0.17	0.12	0.12	+
10	>500	0.19	0.18	0.17	0.17	0.12	0.11	+

Hydrogen concentration in the metal alloy at the main stages of casting without the use of CFF, but applying argon degassing of the melt in the samples obtained was: 0.13 cm^3 /100 g Al in the degassing unit (Fig. 1, point A5), which is the effect of the inert gas bubbling. On the foundry table, hydrogen concentration was 0.12 cm^3/100 g Al (Fig. 1, point A6), which is the result of the melt temperature decrease during its passage through the metal flow path (Table 2, Experiment No. 2).

Hydrogen concentration in the metal alloy at the main stages of casting using a single-stage filtration system (with CFF heating to 500 ^oC) and without applying argon degassing of the metal was: in the CFF filtration system — 0.19 cm^3/100 g Al (Fig. 1, point A3) due to the fact that heated less than 500 ^oC CFF does not significantly affect hydrogen content in the alloy. On the foundry table, the hydrogen content (Fig. 1, point A6) in the selected sample averaged 0.18 cm^3/100 g Al, which is the result of the melt temperature decrease in the course of its passage through the metal flow path (Table 2, Experiment No. 3).

Hydrogen concentration in liquid metal at the main stages of casting using a single-stage filtration system (with CFF heating over 500 ^oC) without the use of argon degassing of the molten metal was: in the CFF filtration system — 0.20 cm^3/100 g Al (Fig. 1, point A3) due to the fact that heated over 500 ^oC CFF prevents the melt from cooling during filtration, and 0.19 cm^3/100 g Al on the foundry table (Fig. 1, point A6), which is the result of the melt temperature decrease during its passage through the metal flow path (Table 2, experiment No. 4).

Hydrogen concentration in the aluminum alloy at the main stages of casting using both single-stage filtration system (with CFF heating less than 500 ^oC) and argon degassing of the melt at the stage of passing of the molten metal through a single-stage ceramic foam filter was: in the CFF filtration system — 0.19 cm^3/100 g Al (Fig. 1, point A3) due to the fact that heated less than 500 ^oC CFF does not significantly affect the hydrogen content in the alloy. At the melt degassing stage, there was a decrease in hydrogen (Fig. 1, point A5) to 0.14 cm^3/100 g Al, which is the effect of the molten metal bubbling with an inert gas. On the foundry table, the hydrogen content (Fig. 1, point A6) in the selected sample averaged 0.13 cm^3/100 g Al, which is the result of the melt temperature decrease in the course of its passage through the metal flow path (Table 2, Experiment No. 5).

Hydrogen concentration in the aluminum alloy at the main stages of casting using the single-stage filtration (with CFF heating over 500 ^oC) and with the use of argon degassing of the molten metal was: in the CFF filtration system (Fig. 1, point A3) — 0.20 cm^3 /100 g Al, which is due to the fact that heated over 500 °C CFF prevents the melt from cooling during its filtration. At the degassing stage of 5083 alloy, hydrogen decreased (Fig. 1, point A5) to 0.14 cm^3/100 g Al, which represents the effect of the molten metal bubbling with an inert gas. On the foundry table, the hydrogen content (Fig. 1, point A6) in the selected sample averaged 0.13 cm^3/100 g Al, which is explained by the aluminum melt temperature decrease during its passage through the metal flow path (Table 2, Experiment No. 6).

Hydrogen concentration in liquid metal at the main stages of casting using a two-stage filtration system (with CFF heating less than 500 °C), but without the use of argon degassing of the melt was: in the CFF filtration system (Fig. 1, points A3 and A4) — 0.19 cm^3/100 g Al as a consequence of the fact that heated less than 500 °C CFF does not significantly affect the hydrogen content in the alloy. On the foundry table, the hydrogen content (Fig. 1, point A6) averaged 0.17 cm^3/100 g Al, which is the result of the molten metal temperature decrease in the course of its passage through the metal flow path (Table 2, Experiment No. 7).

Hydrogen concentration in liquid metal at the main stages of casting using a two-stage filtration system (with CFF heating more than 500 °C), but without applying argon degassing of the melt metal was: in the CFF filtration system (Fig. 1, points A3 and A4) — 0.20 cm^3/100 g Al; this is due to the fact that heated more than 500 °C CFF prevents the melt from cooling during filtration. On the foundry table, the hydrogen content (Fig. 1, point A6) in the selected sample averaged 0.18 cm^3/100 g Al, which is the result of the melt temperature decrease during its passage through the metal flow path (Table 2, experiment No. 8).

Hydrogen concentration in the molten metal at the main stages of casting with the use of the two-stage filtration system (with CFF heating less than 500 °C) as well as argon degassing of the melt was: in the CFF filtration system — 0.18 and 0.17 cm^3/100 g Al (Fig. 1, points A3 and A4), respectively, this is due to the fact that heated less than 500 °C CFF does not significantly affect the hydrogen content in the melt. At the stage of degassing of the aluminum melt, hydrogen decreased (Fig. 1, point A5) to 0.12 cm^3/100 g Al, which is the effect of molten metal bubbling with an inert gas. On the foundry table, the hydrogen content (Fig. 1, point A6) in the selected sample averaged 0.12 cm^3/100 g Al (Table 2, Experiment No. 9).

Hydrogen concentration in the aluminum alloy at the main stages of casting with the use of the two-stage filtration (with CFF heating over 500 °C) and using argon degassing of the melt was: in the CFF filtration system — 0.17 cm^3/100 g of Al (Fig. 1, points A3 and A4) due to the fact that heated over 500 °C CFF prevents the melt from cooling during its filtration. At the stage of aluminum alloy degassing, hydrogen concentration has decreased (Fig. 1, point A5) to 0.12 cm^3/100 g Al, which is the effect of metal bubbling with an inert gas. On the foundry table, the hydrogen content (Fig. 1, point A6) in the selected sample averaged 0.11 cm^3/100 g Al, which is the result of the melt temperature decrease during its passage through the metal flow path (Table 2, experiment No. 10).

Conclusions

During the progress of the research at the semicontinuous ingot casting installation in the casting laboratory of the Siberian Federal University it was found that the average concentration of hydrogen in the aluminum alloy before passing CFF was 0.19 cm^3/100 g Al, and after passing through the CFF filtration system it has decreased to 0.185 cm^3/100 g Al. The paper shows that the ceramic foam filters heating degree does not significantly affect the saturation of aluminum alloy with hydrogen. In the course of experiments it was found that the most significant effect of reducing hydrogen concentration can be achieved by blowing the aluminum alloy with an inert gas (argon), which was confirmed by the experiments 2, 5, 6, 9, 10 (Table 2). It was found that the average hydrogen concentration obtained before passing through the degassing device was 0.185 cm^3/100 g, and after being treated by the degassing process this characteristic decreases to 0.13 cm^3/100 g on average.

Thus, the use of a single- or two-stage CFF filtration system (with an aluminosilicate binder bonded with stabilized borosilicate glass) together with the melt argon degassing permits to reduce hydrogen concentration in 5083 aluminum alloy. Nevertheless, in view of the fact that the tasks of the research team did not include finding out the economic effect of the implemented development and the research was carried out on a laboratory installation. The authors suggest that this will potentially increase the competitive strength of finished products. Since researches on this subject continue, it will be possible to talk about economic efficiency when the proposed technology is implemented at a specific production facility.

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