Emerging melt quality control solution technologies for aluminium melt

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Abstract: The newly developed “MTS 1500” Melt Treatment System is performing the specifically required melt treatment operations like degassing, cleaning, modification and/or grain refinement by an automated process in one step and at the same location. This linked process is saving time, energy and metal losses allowing - by automated dosage of the melt treatment agents - the production of a consistent melt quality batch after batch. By linking the MTS Metal Treatment System with sensors operating on-line in the melt, i.e., with a hydrogen sensor “Alspek H”, a fully automated control of parts of the process chain like degassing is possible. This technology does guarantee a pre-specified and documented melt quality in each melt treatment batch.

Furthermore, to ensure that castings are consistent and predictable there is a growing realization that critical parameters such as metal cleanliness must be measured prior to casting. There exists accepted methods for measuring the cleanliness of an aluminum melt but these can be both slow and costly. A simple, rapid and meaningful method of measuring and bench marking the cleanliness of an aluminum melt has been developed to offer the foundry a practical method of measuring melt cleanliness.

This paper shows the structure and performance of the integrated MTS melt treatment process and documents achieved melt quality standards after degassing, cleaning, modification and grain refinement operations under real foundry conditions. It also provides an insight on a melt cleanliness measuring device “Alspek MQ” to provide foundry men better tools in meeting the increasing quality and tighter specification demand from the industry.

Key words: melt quality; aluminum casting; melt treatment; cleanliness; measuring

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Aluminum and its alloys are used where structures and parts with good strength-to-weight ratio is desired. The demand for higher quality and tighter specification castings is becoming more critical and foundry men are looking for solutions to the industry’s demands. One area in the aluminum casting process that is crucial to providing consistent and high quality castings is melting. A substantial part of casting rejects or early component failure is due to melt quality not adjusted to the requirements of the specific casting.

Today different melt treatment operations are often carried out one after the other, sometimes at different locations or by different operators. Beyond this a consistent check of melt quality is often patchy.

There are two main impurities in molten aluminium which critically affects the final casting quality; non-metallic inclusions and dissolved hydrogen. Excess hydrogen can cause gas porosity but on the other hand insufficient hydrogen can result to shrinkage porosity in the finished casting. Inclusions can lead to leaks in the casting wall, reduce the mechanical properties of the casting component and, if precipitated as hard spots, damage machine tools during machining.

The quality and performance of the casting component depend directly on the quality of the molten metal from which the product is cast. Therefore the melt quality must be adjusted according to the requirements of the specific castings. A large variety of melt treatment operations and melt quality measurement systems are known.

It will be beyond the scope of this paper to cover all of them.

This paper will provide a summary of experiences with new melt quality control solution technologies for aluminium melt treatment.

1 Melt treatment system

Melt treatment operations in aluminium foundries are often carried out one after the other, sometimes at different locations and manually by different operators. Some treatment operation can interfere with the results of the previous treatment, i.e. the sodium modification may raise the hydrogen level in the melt that has been degassed beforehand. Often, the non-synchronized melt treatment leads to melt quality check that is often unreliable.

A new technology, the Melt Treatment Station “MTS 1500”, allows the melt to be prepared according to specification at one place and in one single mechanised and automated treatment

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process. The basic function of this metal treatment system comprises of a rotary degassing unit extended by additional features.

The Melt Treatment Station “MTS 1500” can inject successively or simultaneously into the melt up to two treatment agents. These agents are stored in one or two hoppers which are mounted on suitable parts of the degassing unit. The flux dispensing unit is mounted at the hopper outlet and allows for a fully automated injection of flux into the vortex. An electrically driven screw feed is capable of delivering accurate and consistent amounts of fluxes. The baffle plate is mounted in an electrically driven device which is capable of moving it in or out of the melt at any point during the treatment cycle. The whole system, shown in Fig.1, is centrally controlled by a Programmable Logic Controller (PLC) to enable optimum treatment cycle to be established.

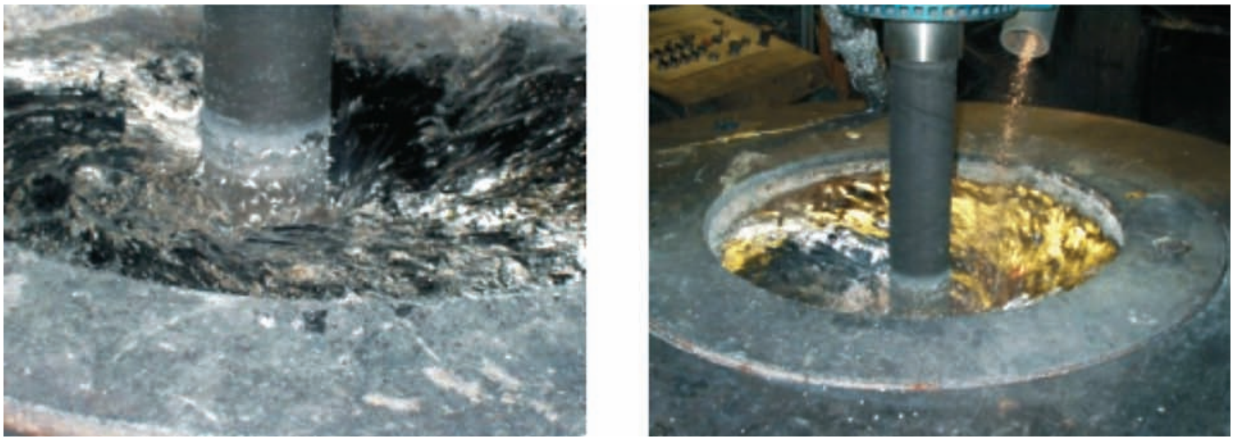
A standard treatment cycle using a melt treatment station consists of a series of stages that can be summarized according to Fig. 2.

(a) Shaft and rotor introduction and vortex formation: The

Foundry degassing unit Hopper system

Screw dispensing unit Adjustable baffle plate

Fig.1: Elements of the Melt Treatment Station



(a) Vortex formation, 10–20 s, 550–700 rpm (b) Granular flux addition, ~30 s, 550–700 rpm

(c) Vortex removal, ~5 s, 350–500 rpm

(d) Degassing process, 120–600 s, 350–500 rpm

Fig. 2: Metal treatment cycle

shaft and rotor is first lowered into the melt. At this stage of the cycle the baffle plate remains in the upper position. Then the rotor speed is increased to about 700 rpm to create an adequate vortex around the shaft.

(b) Addition of treatment agents: During a time period of about 30 seconds the hopper feed system dispenses the required amount of flux into the vortex. The flux is drawn down into the metal by the vortex and is efficiently mixed throughout the melt by the rotor action.

(c) Vortex termination: The rotor speed is decreased to 350–500 rpm within a time frame of 5 seconds. Simultaneously the baffle plate is lowered into the melt to terminate the vortex.

(d) Degassing: With the baffle plate in position the melt is now cleaned for the treatment of product residues and degassed to required level within 120 to 600 seconds.

Case study 1

During extensive foundry applications the performance of the melt treatment system could be demonstrated in various melt treatment operations.

Reducing the amount of aluminium contained in dross a foundry can make a great deal of cost savings. The first example shows the results of an aluminium foundry changing from manual application of drossing flux to MTS 1500 application with substantial metal savings.

For example, one foundry was able to reduce the amount of aluminium wasted by 12 tons per year as detailed in Table 1.

Case study 2

By changing from manual application of sodium modifying flux to MTS system another foundry could achieve a greater process stability with respect to the metallurgical properties of the casting.

Additionally, costs benefit had been realized by reducing the total treatment time and significant reduction of the flux dosage as shown in Table 2.

Figure 3 demonstrates the increase of sodium yield between manual and MTS flux addition. The graph shows the yield as a function of the amount of sodium uptake and flux addition, the gradient of the curve is a measure of the efficiency of the process. The results of this graph show that the MTS treatment is 2.44 times more efficient than the manual flux addition.

Table 1: Metal savings

Manual treatment	MTS treatment
Dross weight = 2.069 kgs	Dross weight = 1.035 kgs
Aluminium content = 45%	Aluminium content = 36%
Number of ladle treatments per week = 480	Number of ladle treatments per week = 480
Aluminium content of dross per week = 446 kg	Aluminium content of dross per week = 179 kg
Amount of aluminium wasted per year = 20 tons	Amount of aluminium wasted per year = 8 tons
Metal savings	12 tons per year
Cost savings (EUR 1,750 per ton) LME price Aug'08	EUR 21,000 per year

Table 2: Improvements in flux addition and flux yield

	MTS treatment	Manual treatment
Furnace size	600 kgs	600 kgs
Alloy used	AlSi12	AlSi12
Temperature	740 – 760°C	740 – 760°C
Flux used	Coveral GR 2712	Coveral GR 2712
Amount of flux addition	0.08% (480 grams) +/- 3.6%	0.28% (1,680 grams) +/- 8%
Treatment time	3 minutes	10 minutes
Sodium pick up	78 ppm	80 ppm
Variation in sodium content	+/- 5%	+/- 12.7%

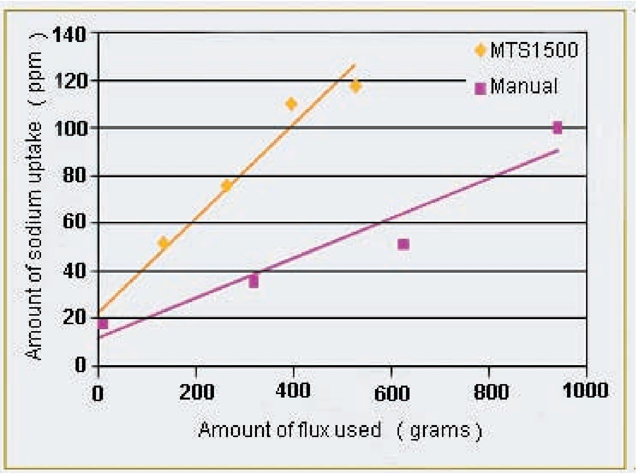


Fig. 3: Comparison in flux yield between MTS and manual treatment

2 Electrochemical hydrogen sensor

The rotary degassing process is now the state of the art of degassing aluminium melts. Most foundries are using preset parameters for the degassing process which means that the melt can be under degassed which could lead to hydrogen porosity or in other extreme cases over degassed with too low hydrogen values which could lead to shrinkage formation during solidification. In order to achieve the right balance quickly and more efficiently it will require an on-line hydrogen measurement method as traditional sampling method would always lead to delayed results.

A new device has been developed now which offers the possibility of measuring hydrogen concentrations in such a way that allows real control over the degassing process. Thus, allowing the possibility of improving the quality and consistency of the finished casting. It comprises of three basic components; an electrochemical sensor that can measure hydrogen concentrations in the gaseous phase, a probe that carries this sensor into the molten metal and an analyser that processes the signal from the sensor and calculates the concentration of dissolved hydrogen in the melt.

The sensor is an electrochemical device based upon a calcium zirconate solid electrolyte. Under certain conditions calcium zirconate becomes a proton conductor allowing its use as a selective sensor for hydrogen. To function as a sensor the calcium zirconate needs to encapsulate a reference material with a known partial pressure of hydrogen. A schematic of the sensor is given in Fig. 4. A particular feature of this sensor that differentiates it from similar devices is that it includes a solid-state reference meaning that it does not require an external source of hydrogen to provide the reference. This makes the sensor a self contained device and thus an ideal basis for a practical piece of foundry equipment.

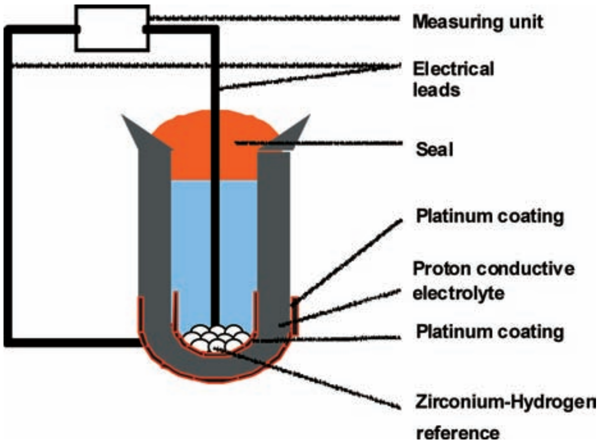


Fig. 4: Schematic of the sensor

The sensor cannot operate in direct contact with molten aluminium therefore a probe is required to protect and carry the sensor into the melt. The specifically designed probe has a cavity in which the sensor is located and a porous window that allows the instant diffusion of dissolved hydrogen but not the ingress of aluminium. A schematic of the probe section containing the sensor is given in Fig. 5.

The sensor thus sits in a gaseous environment where it measures the partial pressure of hydrogen in the probe cavity that is in equilibrium with dissolved hydrogen in the melt. The level of hydrogen measured in the cavity then needs to be

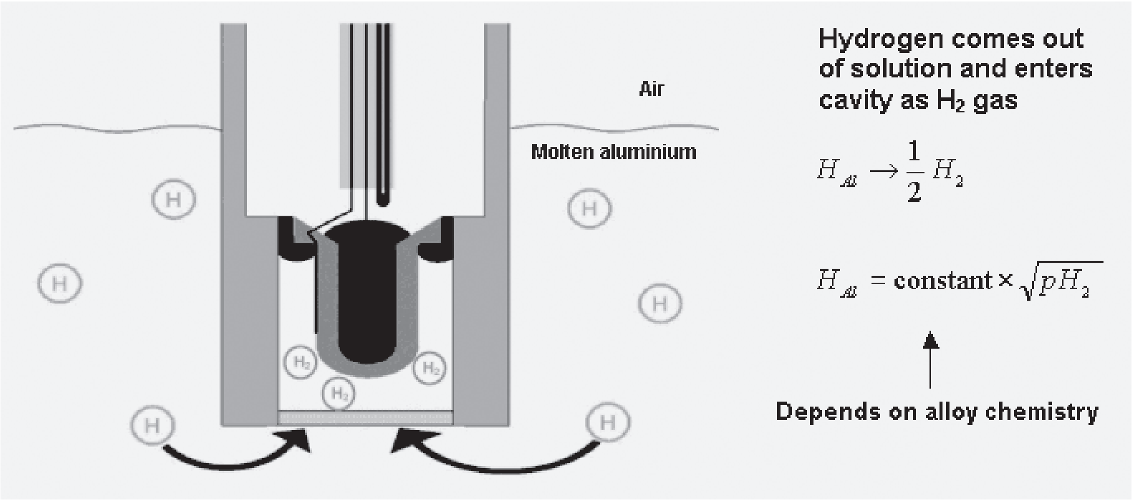


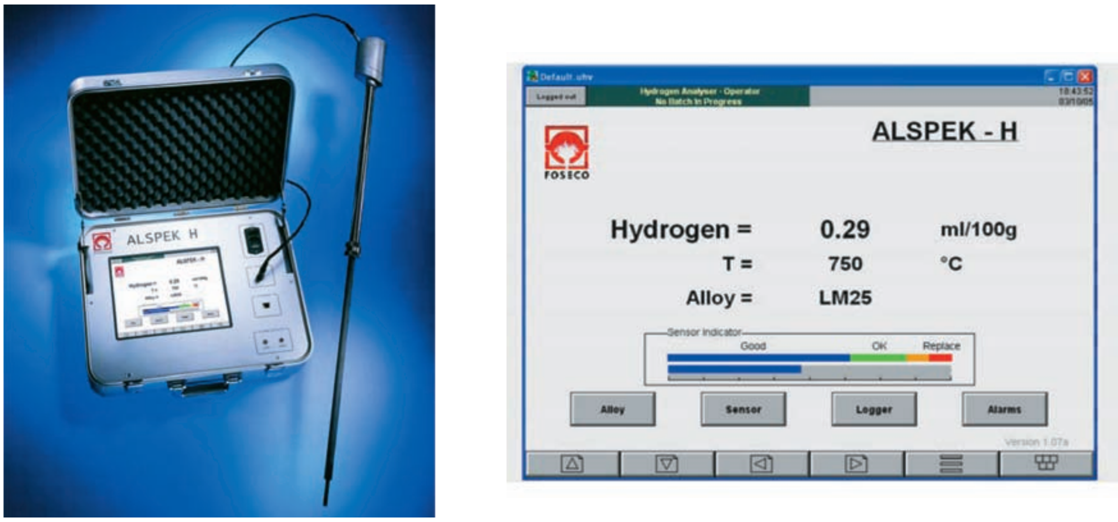
Fig. 5: Schematic and function of the probe section containing the sensor

related to the level of dissolved hydrogen in the melt, which is the value of real interest. This is done by the analyser using an equation based on Sievert's Law.

The third element required enabling the sensor to be used as a practical device is an analyser to convert the electrical output of the sensor to a measure of the hydrogen content of the melt. The analyser first processes the voltage output from the sensor and calculates the partial pressure of hydrogen in the cavity. Using data on the hydrogen solubility of the alloy being measured the analyser then calculates the level of dissolved hydrogen in the melt and displays this value in terms of either ppm or ccm/100g. Both of the calculations the analyser performs are temperature dependent therefore a thermocouple is positioned adjacent to the sensor to provide accurate temperature data.

In addition to calculating the dissolved hydrogen concentration, the analyser also has a built in data logger that allows both hydrogen and temperature readings to be recorded and subsequently downloaded onto a PC system. A sensor diagnostics tool is also built in which performs a permanent health check of the sensor status and starts an alarm function when the sensor is failing or due to replacement. Figure 6 shows the analyser box with touch screen display and the attached sensor probe.

The first test described here should demonstrate the ability of the device to record the hydrogen level permanently in a melt during rotary degassing and gassing cycles as well as during holding periods at low and high hydrogen levels.



Hydrogen Analyser - Operator
No Batch In Progress
18:43:52
03/10/05

ALSPEK - H

Hydrogen = 0.29 ml/100g
T = 750 °C
Alloy = LM25

Sensor Indicator
Good OK Replace

Fig. 6: Sensor probe with Analyser box and touch screen display

A rotary degassing machine was modified to enable two different gases to be injected through the spinning rotor, pure nitrogen and a commercially available hydrogen (20%) and nitrogen (80%) gas mixture. The equipment arrangement is shown in Fig. 7.

The hydrogen sensor probe was placed in the metal throughout these degassing and gassing cycles and holding periods and data on hydrogen content and temperature was monitored constantly and recorded using the inbuilt data logger in the analyser. A typical curve generated from the data points collected by the data logger is given in Fig. 8.

Accuracy is obviously one of the most important characteristics of any method of hydrogen determination. The next test will demonstrate the accuracy of the hydrogen measurement by gassing up a melt with a known mixture of nitrogen and hydrogen. If the amount of hydrogen added to the melt is known together with the alloy type and temperature, then the

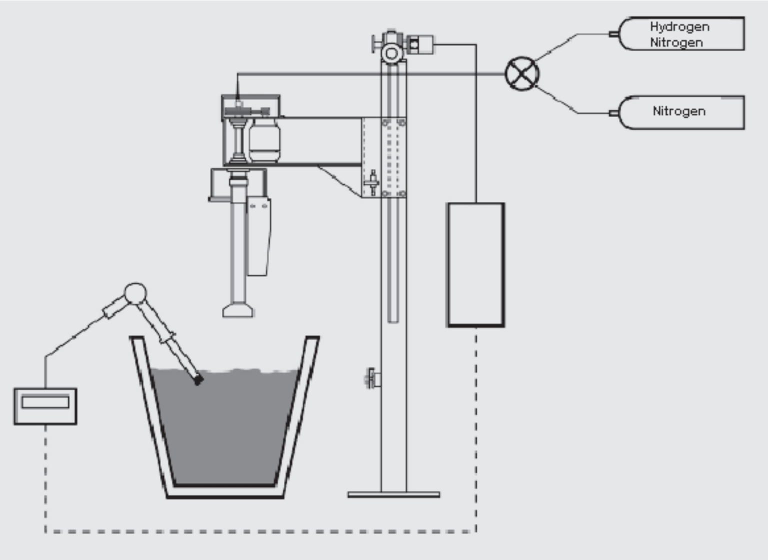


Fig. 7: Equipment setup for gassing and degassing of aluminium melts

theoretical equilibrium can be calculated. The experimentally determined value of 0.42 ppm was in excellent agreement with the calculated value of 0.43 ppm in Fig.9 and is a good indication of the level of accuracy possible with the new sensor.

The following measurements have been performed in a German automotive aluminium foundry. The alloy AlSi 11 was treated with a nitrogen / hydrogen mixture of 70% / 30% over a period of 8 minutes. After the gassing up treatment the sensor was immersed into the melt and reached a stable reading of the hydrogen concentration within 3 minutes. Melt temperature was in the range of 730 – 740°C.

Simultaneously a sample for the "First Bubble Test" (Alu Schmelztester) was taken and the results of both measurements were compared. The results are summarised in Table 3 and show a very good agreement of both measurements.

Table 3: Batch measurements and comparison with Alu Schmelztester

Batch No.	Hydrogen Sensor	Alu Schmelztester
1	0.29 mL / 100 g	0.29 mL / 100 g
2	0.31 mL / 100 g	0.33 mL / 100 g
3	0.32 mL / 100 g	0.34 mL / 100 g
4	0.32 mL / 100 g	0.36 mL / 100 g
5	0.33 mL / 100 g	0.35 mL / 100 g
6	0.29 mL / 100 g	0.29 mL / 100 g

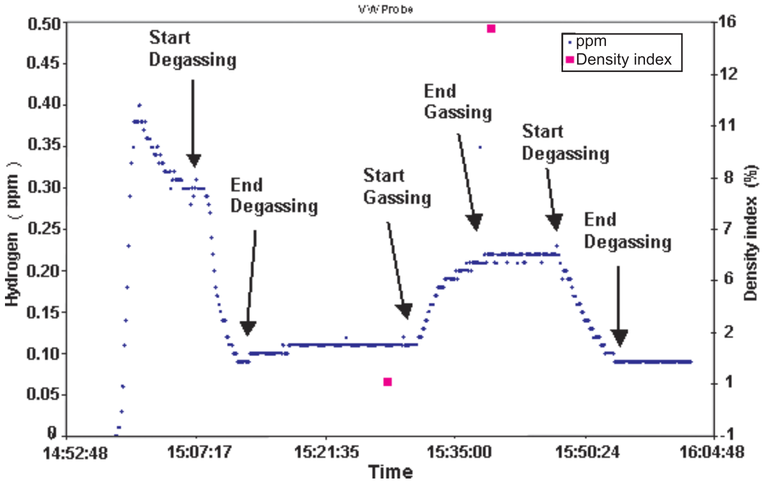


Fig. 8: Continuous hydrogen measurement during melt treatment cycles

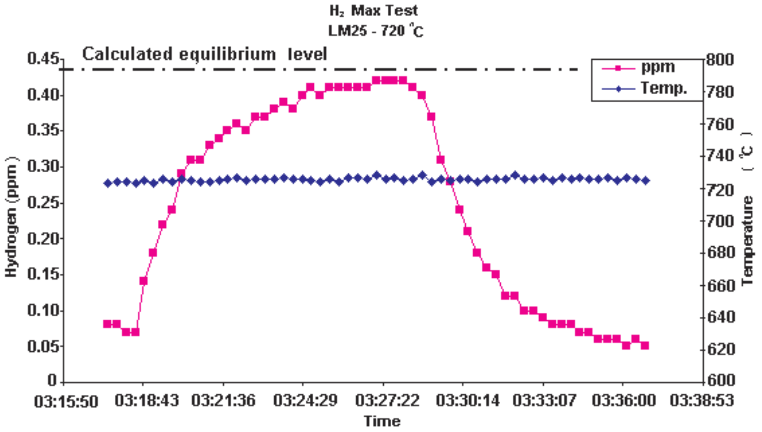


Fig. 9: Accuracy test of probe response

A set of 89 batch measurements has been performed in the aluminium foundry of a German motor company over a period of 1 month. Each measurement was taken after an 8 minute rotary degassing treatment in a 2- ton transfer ladle. Simultaneously, each time a sample for the Density Index(DI) measurement was taken. The results of both measurements are plotted in a graph in Fig. 10. Within the examined field of values a reasonably good linear correlation between the hydrogen concentration in ppm and the Density Index can be obtained. As expected the regression line is not crossing the zero/zero point but leaving a "hypothetical density index" of 0.46% at zero ppm hydrogen. This example is again stating that the Density Index is not only a measure of hydrogen level but dependent on other factors like oxide content in the melt.

It's been demonstrated that the probe's capability to measure hydrogen level in melt during a rotary degassing treatment is possible. Using the alarm output of the analyzer box, the required hydrogen level can be preset and the sensor will stop the degassing unit automatically upon reaching the preset hydrogen level.

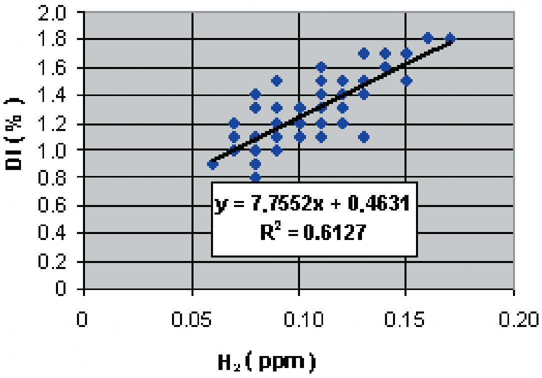


Fig. 10: Batch measurements and comparison with Density Index

A set of degassing cycles were controlled and monitored like this way in a German automotive aluminium foundry. In Table 4 the final results of the hydrogen level after treatment and additionally the density index values over one day are listed. The required density index level in this foundry is limited between 1.0 % and 1.5 %. To achieve this value the hydrogen alarm level was set at 0.12 ppm in the analyzer box.

With this installation, it clearly demonstrates the capability to maintain final hydrogen level in the degassed melts within a very narrow band of 1.2 % to 1.5 % density index values.

Table 4: Results of sensor controlled degassing process

Batch No	Hydrogen sensor ppm	Density index %	Temp. °C
1	0,10	1,2	759
2	0,12	1,5	758
3	0,11	1,2	744
4	0,13	1,5	745
5	0,13	1,3	771
6	0,13	1,2	763
7	0,13	1,2	760
8	0,12	1,3	770
9	0,12	1,5	768
10	0,12	1,3	767
11	0,11	1,2	748

3 Melt cleanliness measuring device

Monitoring hydrogen level accurately is not enough to indicate high quality of aluminium melt. Cleanliness level of the melt if known would complement the ability to measure hydrogen levels quickly and accurately and provide foundry men with tools for high melt quality assurance right first time every time in a production environment.

A new device known as Alspek MQ (Fig. 11) to indicate the cleanliness of an aluminum melt was recently developed. This will offer the foundry man a fast and reliable indication to the cleanliness of the melt prior to casting. Alspek MQ generates a Metal Quality Index (MQI) in less than a minute at an affordable cost. A 1.5 kg sample is tested directly in the bath with no loss of metal. Alspek MQ can be used to compare aluminium melts in different stages of preparation generating a MQI, which foundries can use as part of their process control and quality control procedure.

The principle behind Alspek MQ is the ability of a foam filter to trap fine inclusions. A 40 ppi foam filter is plunged a set distance below the surface of a melt and the time for 1.5 kg of aluminium to flow through the filter is noted. This is measured by the change in buoyancy of the floating device. Initially maximum buoyancy is experienced and once fully filled the chamber above the filter has neutral uplift. At this point the test is complete and a MQI index 1 – 6 is generated (Table 5).

Fig. 11: Alspek MQ assembly and application

Fig. 12: Operation protocol parts

Table 5: MQI after every preparation step of the melt

Metal condition	Melt Quality Index (MQI)
As melted	2
During Mg addition	3
After manual stirring	6
Settle for 20 minutes	4
Settle for 30 minutes	4
Settle for 50 minutes	2
After sodium addition	2
After MTS	1
After strontium addition	1
After GR addition	1

The selection of a controlled pore size of 40 ppi ensures that inclusions finer than 50 μm are allowed to flow through the filter; this means that metal treatment products such as

Titanium Di-Boride are ignored in the test. Larger inclusions such as the 200 – 500 μm sized inclusions, which can be so harmful to an aluminium casting, are trapped within the filter and reduce subsequent flow thereby resulting in a longer filling time.

Alspek MQ has been tested on common aluminium melt temperatures and almost every regular aluminium alloy. It measures the presence of oxides like the very harmful inclusions of 300 μm which can be seen in machined faces (Figs. 13 & 14).

The device is not temperature or alloy dependant as the presence of oxides and inclusions has a far greater effect on the ability to flow through the filter. It is best used as a comparison of one melt to another. The read out unit can be used with a series of sensitivities to allow a foundry to benchmark aerospace, safety critical, automotive and commercial casting types (Fig. 15).

The filter used in the Alspek MQ test is held within a lightweight refractory cup, which ensures there cannot be any bypass of the filter. It is designed to be easily inserted and removed after the test. To ensure accurate measurement the filter is changed after every test.

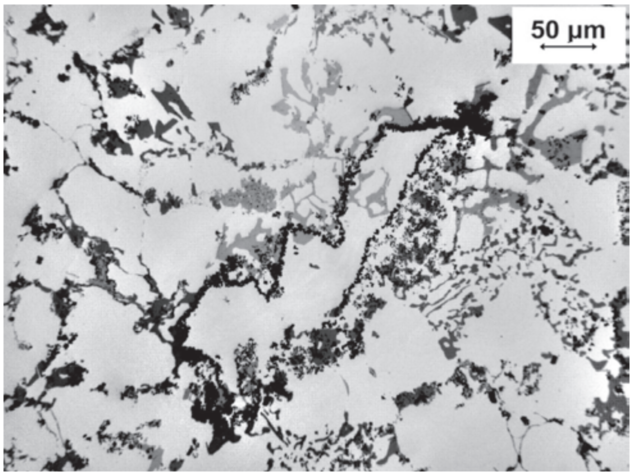


Fig 13: Spinel growth on oxide film in cylinder head

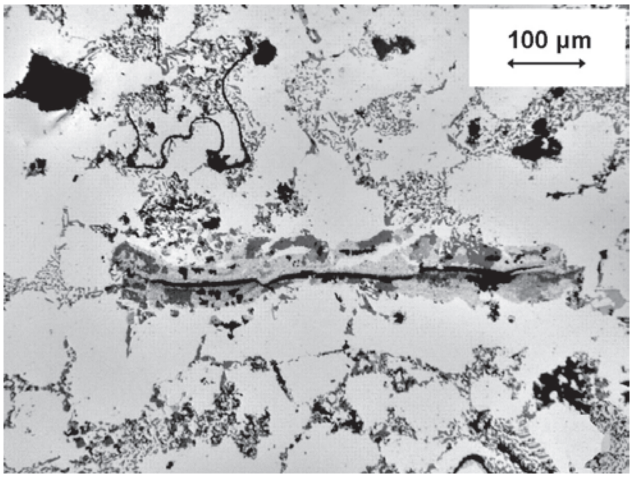
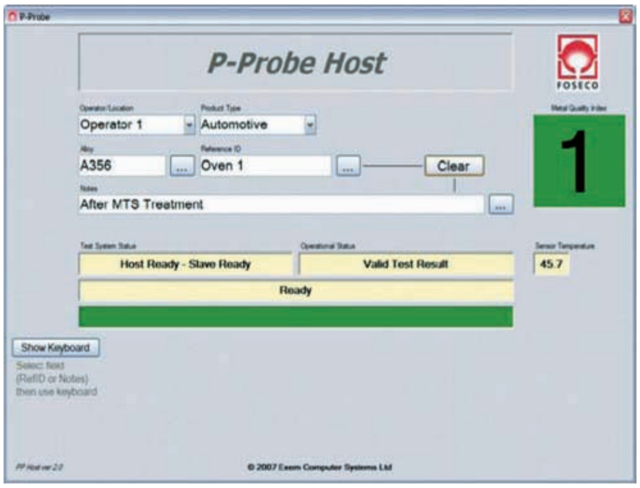


Fig 14: MgO inclusions in modified Al-Si alloy



P-Probe Host

Operator Location: Operator 1

Product Type: Automotive

Alloy: A356

Reference ID: Oven 1

Notes: After MTS Treatment

Metal Quality Index: 1

Test System Status: Host Ready - Slave Ready

Operational Status: Valid Test Result

Sensor Temperature: 45.7

Ready

Select field (RefID or Notes) then use keyboard

PP Host ver 2.0

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Fig. 15: Screen view of the read out

4 Conclusions

The new melt quality control solution technologies with their ease of operations give the foundry men the ability of performing accurate quantitative measurements without time delay. The data logging capability of the analyzers allows improved gathering and recording of measurements and their subsequent presentation for quality control purposes.

The new analyzers coupled with the automated MTS system offer new possibilities that would allow the foundry to work as never before such that the ability to manage the melt quality process right first time every time.

In addition to the quality control and process control possibilities by the hydrogen sensor, there is the potential for an improved understanding of hydrogen dissolution and removal in aluminium alloys. The ability to measure continuously and during the degassing or gassing process allows to study the behavior of hydrogen in different alloys and the effect of temperature or other influencing parameters in detail thus offering the possibility of further improvements in casting quality and optimization of melt treatment processes.

Finally, the cleanliness measuring device complements the hydrogen sensor offering a complete “Go-No Go” melt assessment with the measurement taken directly in the furnace or ladle. This ensures that measurements have no operator influence providing a reliable melt quality control check that is highly reproducible.

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