Discussion of Bi-Film Index and LiMCA Data in Industrial Aluminum Remelting Trials

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Abstract

The trend in the aluminum high end market is to set unrealistic quality requirements e.g. inclusion free metal. The importance of quality and the ability to measure is growing. LiMCA is a unique, well-established tool for monitoring inclusions in molten aluminum. However, the cost of LiMCA and/or availability sometimes becomes a problem. The "old" vacuum test has long been a simple tool for qualitative analysis of the quality. This vacuum method has been developed further into a quantitative method for estimating metal quality in terms of a bi-film index. In this paper, industrial remelting trials are presented where both bi-film index and LiMCA measurements were performed. The two measurement techniques are compared. The conclusion is that the bi-film index and LiMCA demonstrate a similar behavior with time. Thus, the bi-film index may become an additional tool also for quantitative analysis of aluminum quality.

Keywords

Aluminum • Melt quality • Bi-film • LiMCA

Introduction

Metal quality includes many aspects, from chemical specifications to lack of complaints from the customer. The problem with molten metal quality is mainly inclusions. Inclusions can vary in size (µm to mm) and composition with borides (TiB_2), carbides (Al_4C_3), oxides (Al_2O_3, MgO), salts (chlorides/fluorides), refractory, intermetallic particles ($TiAl_3$), nitrides (AlN) and others.

The two techniques compared in this paper are the electrical method LiMCA, and bi-film index vacuum method. Techniques used to evaluate inclusions, that will not be discussed here are: chemical, filtration and metallography, and ultrasonic. However, parallel hydrogen measurements with AlSCAN are taken into account.

Characterization Methods

Bi-Film Index

The bi-film index, or Reduced Pressure Technique (RPT), is a vacuum method where a metal sample solidifies under reduced pressure. This expands the bi-films/oxides with pores in the metal so that they are more easily measured. Samples are machined to the center, and image analysis is performed on the samples. The sum of the maximum length of the expanded pores gives a measure in mm of metal quality. This method was developed and refined by John Campbell, University of Birmingham UK and Derya Dispinar [1, 2]. If the sum of lengths is low, giving a low bi-film index, the metal quality is good. On the other hand, if the sum of lengths is high, the metal quality is bad.

The other technique that is used is the well-known LiMCA-method (Liquid Metal Cleanliness Analyzer). The patent by Doutre, D. and Guthrie, R. I. L from 1985 [3] has laid a foundation for process developments in furnace practices and metal treatment since the 90s. LiMCA counts and measures individual inclusions, by measuring the resistance change in an orifice when the inclusion passes through.

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Laboratory Study of Bi-Film Index

Bi-Film Index Robustness

The bi-film index involves inspection of the cross section of the metal sample with optical microscopy. Figure 1 shows the results from the evaluation of the same set of samples done by two different persons. The samples were taken from an experiment which involved three different crucibles where scrap was added four different times (Add. B–E) to the initial melt (A). After each addition, ten bi-film samples were collected from each crucible and are represented by one data point as presented in Fig. 1, giving a bi-film index. Thus, every person analyzed 150 samples. As seen from Fig. 1 the bi-film index results follow the same trends for the two persons.

Gas Purging and Salt Additions Effect on Bi-Film Index in Small Scale

Procedure of Lab Scale Trials

In addition to the lab-test with addition of scrap (Fig. 1), another experiment was conducted where the bi-film index characterization technique was used to study the effect of gas fluxing on melt cleanliness. The metal (alloy 5083) was melted in a Morgen resistance furnace and held at 750 °C.

Again, three crucibles, as shown in Fig. 2, with 15 kg metal in each were used to compare effect of stirring (without gas), two types of gas purging, and the addition of salt on bi-film index. The two gas purging tests were (i) Ar + 0.5% Cl_2 and (ii) pure Ar. The gas treatment was performed twice. After gas purging, salt was added to the

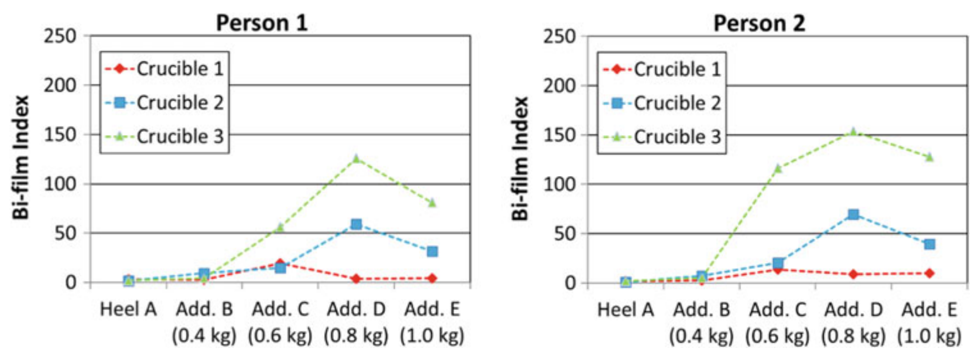

Fig. 1 Bi-film index measured by two independent persons, showing same trends

Fig. 2 The experimental set-up

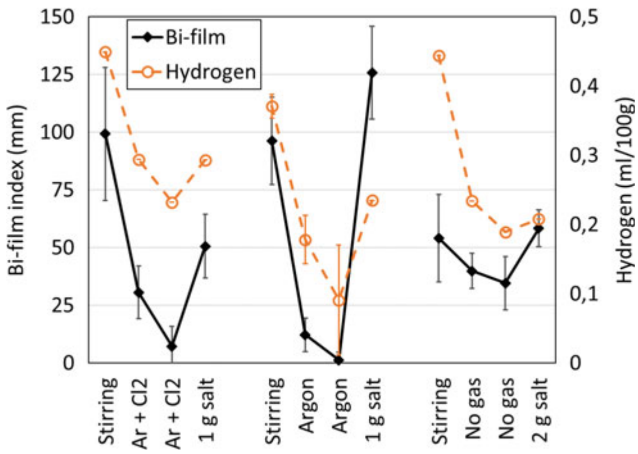

Fig. 3 Influence of various melt treatments on hydrogen and bi-film index. Each measurement series correspond to one of the three crucibles in the parallel setup. The three first hydrogen measurements in the second series (with error bars) are the average value of two analysis. The end points of these error bars give the value of these two analysis

crucibles. Ten melt samples for bi-film index measurements were taken after each melt treatment from all three crucibles.

Results of Lab Scale Trials

Before first stirring, ten bi-film samples were taken from the melt and analyzed to be 0.1 mm, which means a clean melt. Figure 3 shows that stirring with the impeller increased the bi-film index, while the use of Cl_2 reduced the index (first data point of 0.1 mm is not included in the graph). Addition of salt increased the index again. Hydrogen tended to follow the bi-film index.

The hydrogen level in Fig. 3 was measured on solid samples with a Galieo-G8 from Bruker Corporation [4]. The three first samples of the second series in Fig. 3 were measured two times. The end points of the corresponding error bars shows the two values of measured hydrogen in the samples.

Test Material and Procedure for the Industrial Trials

Five remelting trials were conducted in a 50-tonnes industrial gas-fired furnace. The material was melted and cast in accordance with normal practice, i.e. gas fluxing, holding, degassing and filtering. Charge No. 1–4 was alloy AA5042 while charge No. 5 was a AA5083-alloy. In Table 1 the alloy compositions are given. The Mg content is highest in charge No. 5.

The raw material was a blend of liquid metal from the electrolysis cell and scrap metal. The re-melted scrap consisted of 1–3 mm thick compacted sheets with 4–5% Mg, shown in Fig. 4. Table 2 gives the scrap ratios for charges No. 1–5. Gas fluxing and addition of salt bags were done in the furnace before the holding time started. Both LiMCA, bi-film samples and hydrogen measurement were performed in the launder by the furnace spout, before any launder melt treatment.

Results from Industrial Trials

Bi-Film Index and LiMCA Versus Casting Time

The bi-film index results are presented as the median in each group of ten measurements. Figure 5 shows an example of such a set. In Fig. 6 the bi-film index and LiMCA results are plotted for all 5 charges verses casting time. All LiMCA results presented for particles larger than 20 µm (N20) are normalized by the same value for all the charges. (In order to anonymize the true N20-value, all N20 values for all charges are divided by the same constant.)

Summary of Comparison Between LiMCA and Bi-Film Results

Figure 6 shows that the time behavior of the bi-film measurement and LiMCA are similar. Plotting the LiMCA values together in Fig. 7 shows that the LiMCA curves overlap. Please note that the x-axis is plotted from start of the holding time of the furnace, as settling effects the LiMCA values. As seen in the figure charge No. 3 has a long holding time and a slightly higher LiMCA values. In Fig. 8 the bi-film index is plotted from start holding of the furnace. Compared to LiMCA results in Fig. 8 the bi-film index has a much larger variation between the different charges.

Relation Between Bi-Film Index and Hydrogen

The variation in bi-film index is in Fig. 9 plotted as a function of measured hydrogen using AlSCAN (see Table 2). The bi-film index number used here is the second (median) value after start casting in the plots of Fig. 6. Figure 9 indicates that hydrogen and the presence of films are correlated.

Table 1 Composition of alloys AA5042 and AA5083 in wt% [5]

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others
AA 5042	0.20	0.35	0.15	0.20–0.50	3.0–4.0	0.10	0.25	0.10	0.15
AA 5083	0.40	0.40	0.10	0.40–1.0	4.0–4.9	0.05–0.25	0.25	0.15	0.15

Fig. 4 The compacted sheets used in the remelting trials

Table 2 The cold metal ratios for charge No. 1–5, together with hydrogen content and treatment of the melt

Charge no	1	2	3	4	5
Scrap metal (%)	7.5	7.5	10	0	30
Hydrogen (ml/100 g)	0.40	0.42	0.40	0.45	0.55
Gas fluxing	Yes	Yes	Yes	Yes	No
Salt addition	Normal	Normal	Normal	Normal	Twice
Alloy	5042	5042	5042	5042	5083

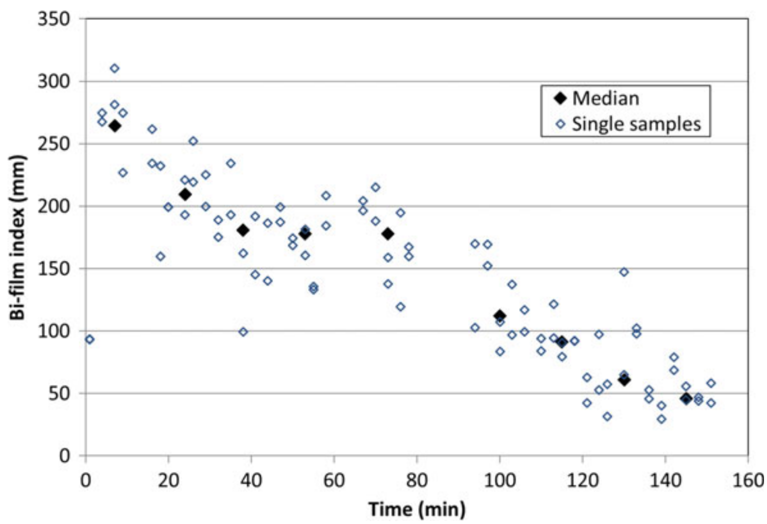

Fig. 5 All bi-film index results from charge together with the median bi-film index of each group of ten samples taken

Discussion

An explanation for the large bi-film index variation between charge No. 1–4 and charge No. 5 could be the higher Mg content, gas fluxing and use of salt. Charge No. 5 did not have any gas fluxing, but employed twice the amount of salt.

Care must be taken comparing the LiMCA and bi-film index values as they are not measuring the same property. With a LiMCA you will not be able to measure a large oxide film since the orifice is only 300 μm in diameter. The bi-film index is by far more sensitive for oxide films.

The bi-film index measures the length of films. The number includes information about the oxide (possibly from scrap or Mg alloying additions), metal treatment (fluxing and salt use), and some effect of hydrogen. Based on this, it is sometimes possible to discover batches with low quality already during casting.

The plots in Fig. 6 shows that both the N20 value and bi-film index follow decreasing trends. In addition, Fig. 9

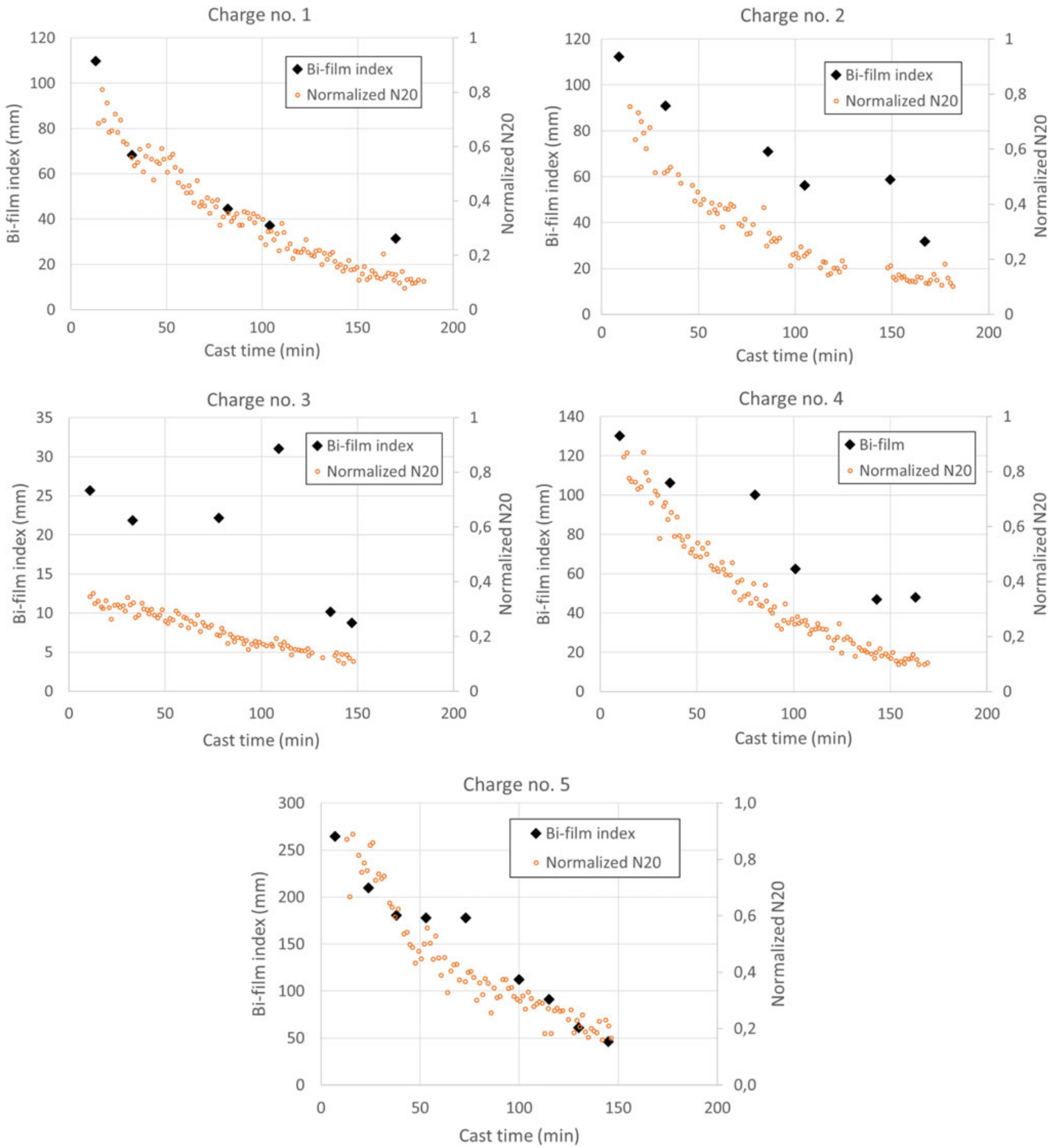

Fig. 6 The bi-film index and LiMCA versus casting time is plotted for 5 charges

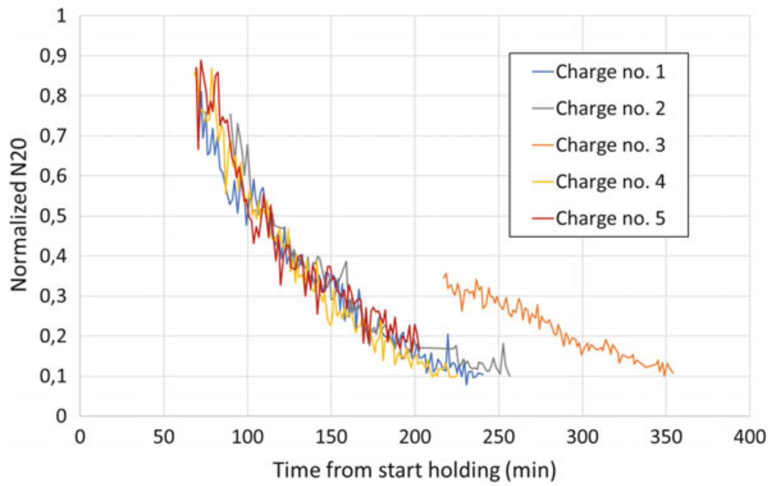

Fig. 7 LiMCA plotted from start of the holding for the 5 charges, showing that that the normalized are similar. Charge No. 3 had a very long holding time

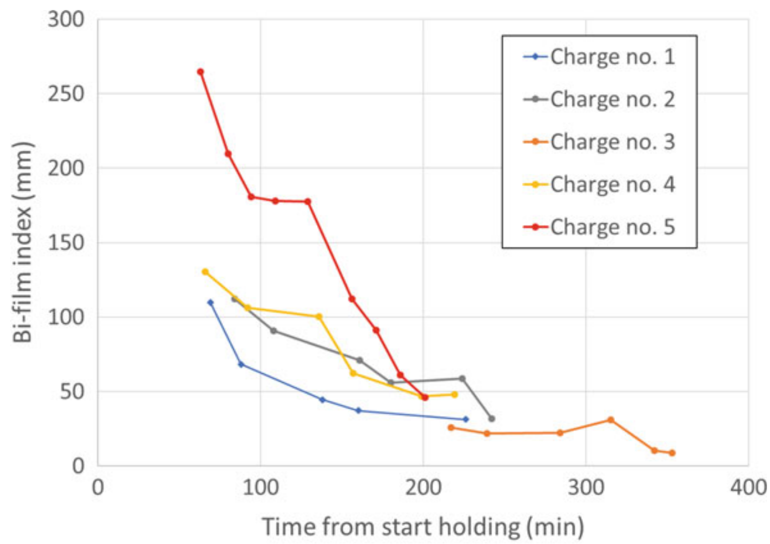

Fig. 8 Bi-film index plotted from start of the holding for the 5 charges, showing variation in bi-film index values

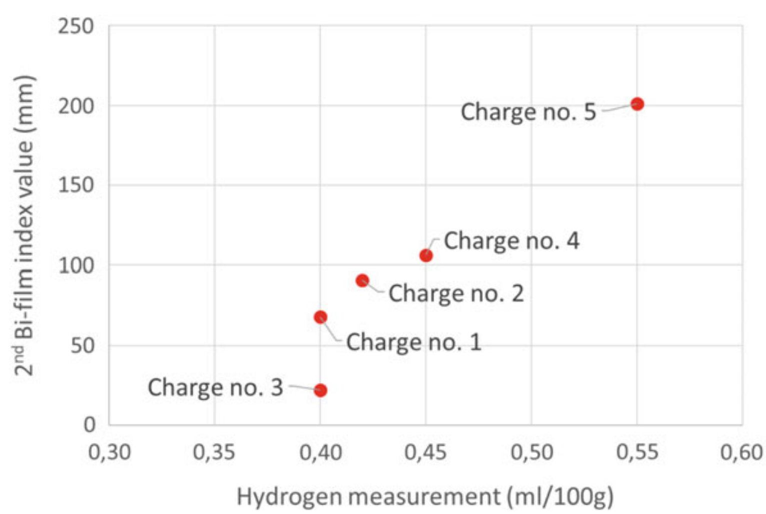

Fig. 9 Bi-film index versus measured hydrogen for all the 5 charges. Hydrogen is measured with AlSCAN at the same point as samples for the bi-film index were taken

also shows a positive correlation between hydrogen and the bi-film index. This indicates that a bi-film index measurement can be used as a melt quality indicator; a low bi-film index means high quality and high bi-film index means bad quality. Additional measurements are then needed to determine the reason for the bad quality.

Conclusions

Measurements of inclusions are essential for understanding and process control of metal quality. LiMCA is a standard method for on-line detection. In this work, it is shown that the bi-film index can be a very useful tool to evaluate quality, and an alternative in cases where LiMCA equipment is not available or too expensive.

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