On-line Chemical Analysis in an Aluminium Recycling Plant using LIBS Technology and Automation

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Abstract

We report on the implementation of fully automated chemical composition analysis in an aluminium recycling plant. The system is based on robotic extraction of liquid alloy from a furnace sidewell, followed by automated chemical analysis using laser-induced breakdown spectroscopy (LIBS). We will discuss the system configuration, analytical capabilities, cycle times, long-term drift, laser safety, and other practical considerations for industrial implementation of LIBS technology. On-line chemical analysis improves plant safety and offers new opportunities for casthouse process control by providing immediate feedback and frequent data points.

Keywords: LIBS, Chemical composition analysis of liquid aluminium, Casthouse process control, Industry 4.0, Process automation.

1. Introduction

Recycling of aluminium plays an increasingly important part in global aluminium industry. Even as production increased from 20 Mt in 1980 to 100 Mt in 2020, the share of recycled aluminium grew from 20 % to 30 % and is projected to reach 50 % of an approximately 170 Mt global production in 2050. Initially, most of the recycled aluminium using in production was pre-consumer scrap. Since 1990, however, the share of post-consumer scrap has exceeded that of pre-consumer scrap [1]. With an increasing share of recycled input into the production process comes an increased uncertainty of the chemical composition, especially in the case of post-consumer scrap. Although high-throughput sensor technologies are increasingly being applied for improved sorting of solid scrap before melting [2] there will still be impacts from incomplete sorting, foreign objects, coatings, etc., into the production process. Once introduced into the melt, most impurities are difficult to remove and may therefore make it impossible to meet the desired targets in alloy production without dilution with primary metal or known alloys. Tight control on melt chemistry during melting is therefore essential when maximizing the use of mixed scrap in production.

In the aluminium industry, melt chemistry has traditionally been monitored by manually extracting samples of the liquid metal and casting them into moulds for laboratory analysis. In some cases, smelters have container labs close to the sampling points with built-in automation for sample preparation and handling. The chemical analysis itself is most often performed using the method of spark optical emission spectroscopy (spark-OES), also referred to as spark atomic emission spectroscopy (spark-AES). The measurement instrument itself is sometimes referred to as a quantometer or simply a spark-OES. The manual handling of molten metal puts plant operators at risk and while high-end quantometers can be highly accurate, it has been shown that the main sources of measurement uncertainty in an industrial situation arise from the sample collection, preparation, and handling, rather than the measuring instrument itself [3].

In recent years, automated laser-induced breakdown spectroscopy (LIBS) has emerged as an alternative to more conventional methods of chemical analysis. LIBS is suitable for analysis of materials in the solid, liquid, or gas phase [4]. Furthermore, it is suited for deployment in harsh environments [5] and its potential for production control in the metals industry has long been recognized [6]. We have previously reported on the industrial applications of LIBS analysers for primary aluminium from reduction cells [7] and transport crucibles [8], as well as laboratory tests on various aluminium alloys [9]. In the present paper, we describe automated sampling and analysis of liquid alloys from an aluminium recycling furnace.

2. System Description

DTE's sampling and analysis system consists of a foundry-grade robot that collects liquid metal from an open side pocket of a recycling furnace and a non-immersive LIBS analyser that measures the chemical composition of the extracted molten metal sample, as illustrated in Figure 1. After analysis, the sample is returned to the furnace. The full cycle time (collecting a sample, bringing it to the analyser, performing the chemical analysis, returning and discarding the sample) is under 5 minutes. The actual measurement time is 45 seconds.

Figure 1. Automated sampling and chemical analysis system. Left: schematic illustration of a typical setup. Right: a system installed in a recycling plant.

In the LIBS analyser, the laser head approaches the surface of the molten metal. A sequence of focused laser pulses is directed onto the surface, generating a plasma that emits specific wavelengths of light for the different elements present in the sample. Using a high-resolution spectrometer, the spectral fingerprints of each element can be identified and separated from the signal of the host metal. Basic principles of LIBS analysis and device calibration have been described in more detail in a previous paper [8]. The analyser is certified as a Class 1 laser device, meaning that no harmful laser light or emitted plasma radiation escapes the device enclosure.

Figure 2 shows examples of simulated emission spectra for plasma conditions similar to those realized in the LIBS analyser. The calculated emission spectra are derived from the respective energy level configurations and transition probabilities [10], under the assumptions of local thermodynamic equilibrium and an optically thin plasma. For the elements shown here, the atomic emission mostly originates from neutral and singly ionized atoms and primarily occurs in the ultraviolet part of the optical spectrum. When using LIBS to analyse molten aluminium alloys, however, it is important to realize that the above assumptions do not hold for all alloying or trace elements. In the case of magnesium, for example, its electronic structure, activity, volatility, and oxygen affinity all play a role in shaping the observed LIBS spectrum [11, 12]. DTE has developed proprietary patent-pending measurement techniques to eliminate the resulting dependencies on melt temperature and melt chemistry to enable accurate Mg analysis. Additionally, numerous studies have been performed showing that the upper concentration limit of LIBS analysis in the

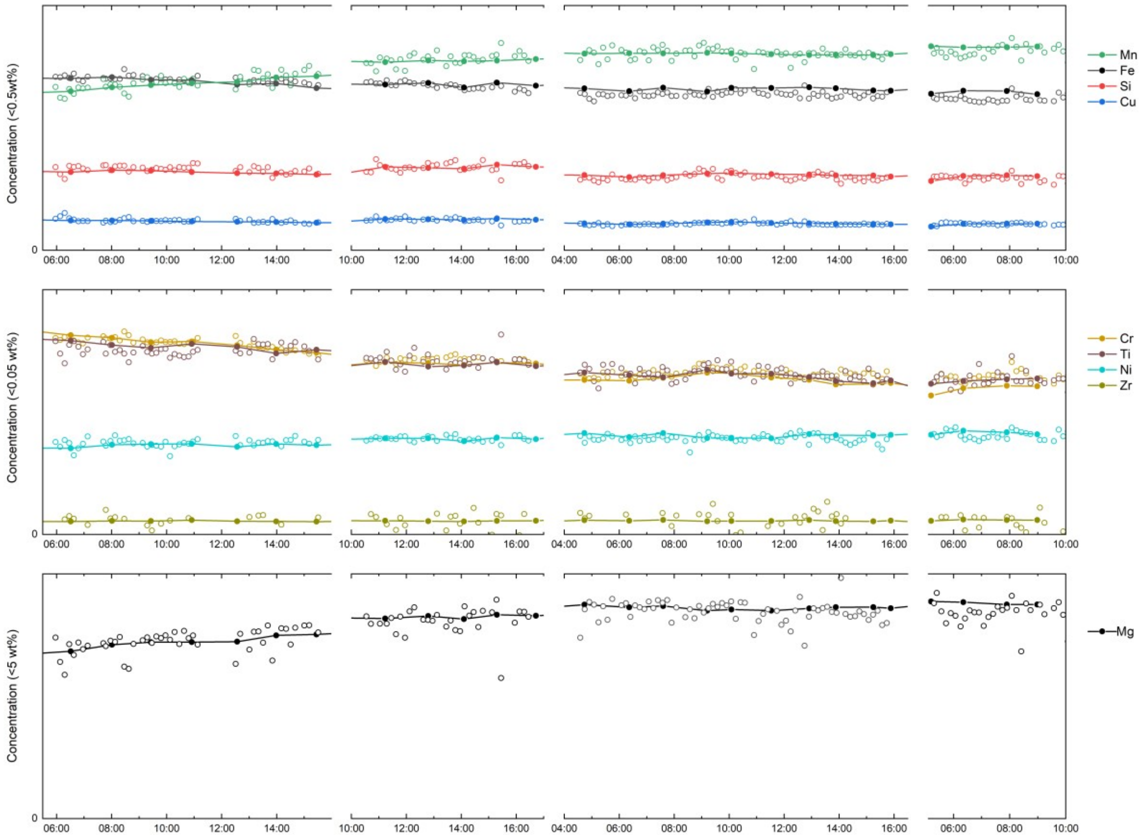

Figure 4. Results from fully automated chemical composition analysis of a recycling furnace (open symbols) compared with laboratory analysis of spark-OES (closed symbols). Absolute concentration values have been removed at the customer's request.

5. Conclusions and Future Work

We have demonstrated the applicability of automated molten metal sample retrieval from a side-well furnace, coupled with real-time LIBS analysis of chemical composition. The concentration of alloying and trace elements was monitored at 10–15-minute intervals, but more frequent analysis is also possible. In separate tests, the LIBS analysis was shown to be stable for several months without standardization, as well as being shown to be independent of melt temperature and insensitive to surface oxidation. For non-volatile elements, the coefficient of variance in the LIBS analysis was 2–4 %, which is about two times higher than typical values for spark-OES analysis for the same elemental concentrations, which can be compensated for by using a 3-point moving average of data points. Future work will focus on further reducing the measurement variance, particularly for magnesium in high-Mg alloys. In summary, the automated LIBS analysis yields rapid immediate analysis results (within 5 minutes from sampling), requires minimal standardization, and eliminates the personnel risks associated with manual sampling of molten metal from furnace.

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