Laser Induced Breakdown Spectroscopy in Aluminum Cast Houses:
The New Technology Promises to Reduce Downtime and Energy Consumption

The evolution of spectroscopic technologies holds an important promise for the advancement of the metals industry, including the aluminum casting sector. Despite being confined to laboratory settings, traditional methods such as X-ray Fluorescence (XRF) and Optical Emission Spectrometry (OES) have been instrumental in understanding material compositions. While XRF has been preferred for determining the surface concentration and distribution of elements in sediments, OES has been widely used in the aluminum industry for elemental analysis of chemical composition. However, as the industry seeks faster, on-site solutions, the introduction of LIBS is heralding a new era. With advancements in laser technology, data analysis algorithms, and fundamental plasma physics, LIBS is expected to be a game-changer in the aluminum industry. Its ability to provide real-time, non-destructive, and comprehensive analyses of molten metals can easily revolutionize quality control, operational efficiency, and safety protocols within aluminum cast houses. The transition from benchtop analysis to LIBS' immediate, in-situ capabilities highlights not only the evolution of spectroscopic technologies but also their profound impact on optimizing processes, minimizing downtime, and enhancing product quality across the aluminum sector.

To understand why LIBS holds such a great promise, one must understand the current spectroscopy applications in the industry. While spark-OES is widely used for the elemental analysis of chemical composition in current metal alloy applications and recycling processes, this method requires the sample to be taken from the melting furnace, cooled, and analysed while tons of molten aluminum wait inside the furnace at high temperatures for the process to be complete. According to the result of the analysis, the alloying element is added. Causing significant energy loss, it also results in approximately an hour of downtime for each casting cycle. This problem of inefficiency caused by the use of existing spark-OES systems has intensified the studies on LIBS, which provides on-site analysis for molten metals.

In addition to the in-situ analysis, LIBS boasts the other unparalleled ability to analyse a wide array of materials including metals, semiconductors, glasses, biological tissues, plastics, soils, plants, coatings, and electronics. With the development of powerful chemometric software for the LIBS data analysis and the advancement of research in understanding the fundamentals of laser ablation, LIBS has been effectively applied in both quantitative and material classification studies. With LIBS, in addition to the other elements in the periodic table, the analysis of elements with low atomic numbers such as H, Be, Li, C, N, O can be easily carried out. Small amounts of metals in the sample at low limits can be analysed.

While measurements are often taken in the laboratory environment, with the appropriate design, LIBS can perform analysis concurrently with production. Depending on the energy of the laser pulse, LIBS can be used in a wide working range for the aluminum industry. In general, the distance from the head of the mechanism to the surface to be analysed can vary between 10 and 100 cm. With current applications that do not include LIBS technology, the elemental analysis of metal alloys is carried out on solid samples. LIBS, on the other hand, allows for measurement on liquid samples. The simultaneous and multi-element analysis capability of LIBS technology, including light elements, provides a significant advantage for the metallurgical field. With its real-time and on-site analysis capability, LIBS eliminates the sample preparation process and enables the transition to automation.

The integration of LIBS with Industry 4.0 principles redefines industrial processes, transforming aluminum cast houses into fully automated environments that utilise data and make decisions autonomously. This is an area of research that the Sistem Teknik R&D Centre has given much attention to in the past years. The company has been working on data processing and predictive analytics in aluminum cast houses since 2019 and has been determined to integrate its expertise on data science and software technologies with spectroscopy solutions. After being awarded with a research fund by the Scientific and Technological

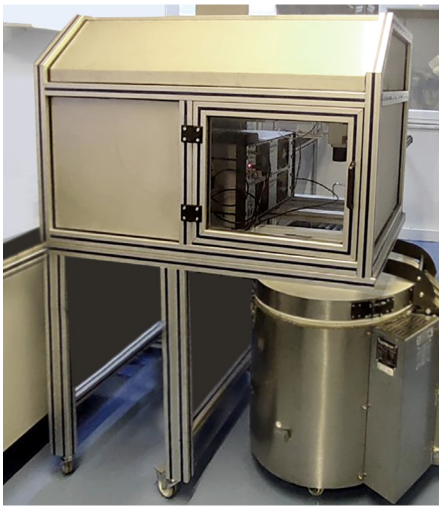

Figure-1 ST LIBS molten aluminum analysis prototype in the STAR Lab

Research Council of Turkey, Sistem Teknik has developed its own LIBS system in late 2022 and has been carrying out experiments in the Sistem Teknik Advanced Research (STAR) laboratories since then. A prototype was developed for the detection of different elements in molten aluminum alloys in the STAR lab (Figure 1).

Sistem Teknik's fundamental aim with this project has been reducing the energy consumption in aluminum cast houses as well as bolstering operational safety by providing fully automated on-site composition measurement. The project brings together LIBS' real-time material analysis with data-driven automation, empowering smart decision-making through instant quality control checks, remote monitoring, and supply chain integration. The technology's versatility and non-destructive nature align with Industry 4.0's emphasis on real-time insights, enhancing traceability and optimizing production parameters. When paired with machine learning algorithms, the collected data is used to generate alloy recipes automatically through the access to various casting parameters such as temperature, melting rate, and elemental composition.

The ST LIBS system is designed in accordance with the specific factory environment and is equipped with the software technology that allows rapid analysis of spectroscopic data. The ST LIBS software consists of an atomic database of all elements used in the periodic table for alloy preparations. There are automatic noise extraction and peak detection functions in the spectra taken with the ST LIBS system. By using the database, the elements in the spectra taken from the molten alloy are automatically detected and quantitative analysis is performed with the calibration data. Alloys are classified instantly with the Principal Component Analysis (PCA) approach. The system is equipped with immersed probes to provide high-precision measurement on the production line. A gas cooling mechanism is installed to ensure that the system is not affected by high temperatures and that analyses are accurate.

In the ST LIBS system (Figure 2), common measurement errors that occur due to the level differences in the immersed liquid aluminum are prevented with the automatic focusing and beam collection system. Calibration takes time especially in industrial conditions, and numerous trials are required. Since the plasma spectroscopy analysis method provides the thermal equilibrium conditions of the plasma environment in the ST LIBS system, the plasma temperature can be determined rapidly by analysing the data, and the amounts of the elements in the alloy content can be determined accordingly. Inert gas (mostly argon) is used to provide a stable environment for the plasma formed during molten material analysis. When the laser pulse ends, the plasma begins to cool. During the cooling process, the electrons of atoms and ions in the excited electronic levels drop to their ground energy levels, causing the plasma to emit light of different spectral wavelengths. The light emitted from the plasma is collected by the optics and separated into wavelengths with a spectrometer. Each element in the periodic table has different wavelengths of spectral lines: by determining the wavelengths for the analysed samples, the chemical composition is quickly determined.

To conclude, from rudimentary elemental analysis techniques to cutting-edge solutions like LIBS, the journey of spectroscopy has been marked by continuous innovation and adaptation. LIBS minimizes energy loss, reduces operational downtime, and enhances accuracy, positioning itself as the forefront solution for efficient and comprehensive material analysis in industries requiring precise elemental information such as aluminum casting. Sistem Teknik R&D Centre has been working on its own LIBS technology for over three years, focusing on its integration with Industry 4.0 to further enhance its appeal by enabling real-time process adjustments and data-driven decision-making. The ST LIBS technology serves the important goal of reducing energy consumption during melting operations while also saving time and providing safety.

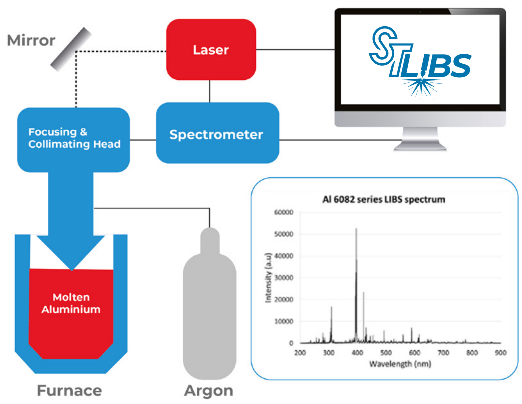

Figure-2 Diagram of the ST LIBS System