

# Development of a new online sensor for steel surface contamination

*Sarclad and CRM Group have successfully developed a new on-line sensor for steel strip contamination. The system utilizes laser-induced breakdown spectroscopy to give a continuous and real-time assessment of the contamination levels post-cleaning on a typical steel strip processing line.*

*Critically, this is the first system that can distinguish between surface carbon and iron fines contamination with quantitative data. This will enable the highest product quality alongside optimized core cleaning section parameters to give the greatest process efficiency. This paper describes the technology used, its advantages and performance in industrial trials and addresses the practical considerations of implementing the technology in the commercial industrial environment.*

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## INTRODUCTION

Strip processors, and in particular galvanisers, have long been looking for a way to measure the residual contamination of the substrate surface accurately and reliably at the exit of the cleaning section. This is indeed a key parameter for the quality of coated steel, especially in the automotive sector where there should be no surface defects.

The contamination sources are various, but two main pollutants are generally mentioned: surface carbon from mill oil and iron fines. In the long term, carbon will turn into soot in the furnace, reducing its efficiency, and will eventually fall onto the rolls and the strip. Iron fines can create pick-up defects on the rolls and increase the dross content in the zinc bath by combining with zinc and aluminium, leading to a drift in the bath composition. In addition, all these problems can result in aspect defects on the final product.

If residual contaminations are continuously monitored online, corrective actions can be planned before being forced to downgrade a whole production due to aspect defects. In addition, if the contamination source can be differentiated from the others, its cause can quickly be identified and eliminated by making targeted corrections to the cleaning section.

CRM Group and Sarclad have therefore developed a new online technology able to differentiate between iron fines and surface carbon pollutions. This equipment uses a Laser-Induced Breakdown Spectroscopy (LIBS) method

developed by CRM Group. It can be placed at the exit of a cleaning section in galvanizing lines to measure the residual contamination levels. This paper describes the work carried out to achieve this on-line monitoring with a LIBS-based sensor and the engineering developments to create the Sarclad Contamination Monitoring System, a device ready for installation and integration to any strip processing line.

## DISCUSSION

### Introducing Laser Induced Breakdown Spectroscopy (LIBS)

LIBS is a spectral analysis technique. It has many applications in geology, metallurgy, and other physical sciences. Over the years, it has been implemented in several industrial environments provided a robust design as well as adequate protective equipment against the harsh external conditions, such as temperature, humidity and dirt.

In galvanising lines, two major contamination sources to be monitored are the surface carbon coming from the mill's oil and the iron fines. Being able to differentiate both sources is highly valuable to galvanisers, as the causes, and subsequent mitigations, of an increase in pollution levels are not the same for surface carbon or iron fines.

### LIBS quick-start guide

A short-pulsed laser beam with a very high energy density is delivered to the surface being

analysed through a focusing lens. That energy is sufficient to ionize matter and create a high-temperature plasma around the laser impact. Inside the plasma, electronic transitions occur continuously, powered by the laser beam energy. When dropping from an energized state back to a lower layer, an electron emits a photon at a specific wavelength given by the Planck-Einstein relation (Equation 1):

$$E = h\nu = hc / \lambda \quad (\text{Eq 1})$$

Where E is the photon's energy in Joules (J), h is the Planck constant in J·s,  $\nu$  is the photon's

frequency in s<sup>-1</sup>, c is the speed of light in m/s and  $\lambda$  is the photon's wavelength in m. In an electronic transition, E is simply the energy difference between the energized state and the layer where the electron stops. The set of wavelengths emitted by a chemical element is called its emission spectrum and uniquely identifies it. The electromagnetic range covered by the lines in such a spectrum can extend from UV to visible and infrared. Molecular vibrations and rotations can also occur in the plasma, due to thermal agitation. In this case, photons are emitted in molecular bands i.e., groups of lines so closely spaced to each other that they all appear as a single band.

All these wavelengths come out of the plasma in all directions with the intensity being maximal at an angle perpendicular to the surface where the plasma was created. In the LIBS, this emitted light is then collected and directed by an appropriate combination of lenses and mirrors to an optical fibre. The fibre transmits the light to a spectrometer and all the information it carries about the elements present in the plasma can be analysed (Figure 1).



**Fig 1** Schematic of the LIBS process, showing a pulsed laser beam (in red) generating a plasma on the surface and an associated spectral of light being collected for analysis.

### Overview of the demonstration unit

CRM Group and Sarclad developed an industrial demonstration sensor shown in Figure 2 and based on the LIBS technique described above. The objective of this equipment is to measure the residual contamination levels on the strip at the exit of the cleaning section in galvanising lines. Both surface carbon and iron fines contaminations are considered.

The laser beam is focused through a set of diverging-converging lenses. Due to the



**Fig 2** LIBS demonstration unit with (1) the laser, (2) the laser controller, (3) the laser beam focusing unit and (4) the light collecting unit

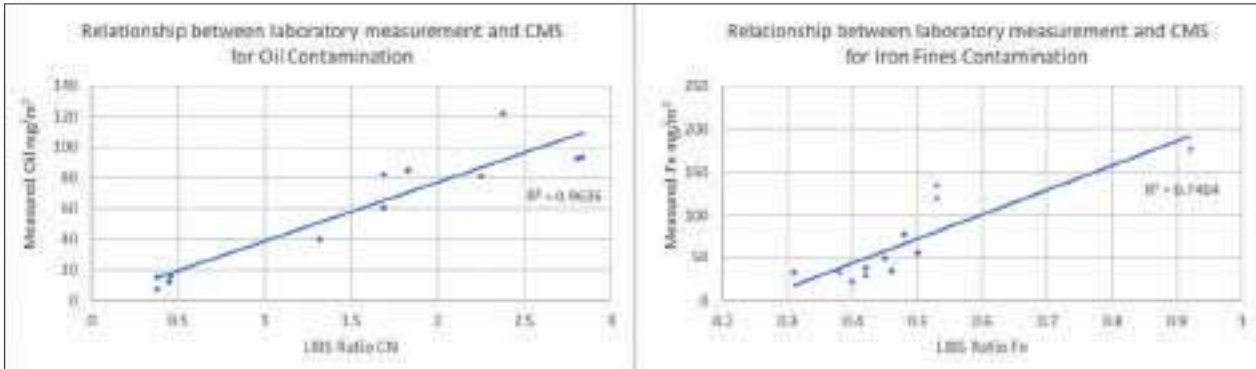


Fig 3 Correlations between LIBS ratios and laboratory tests

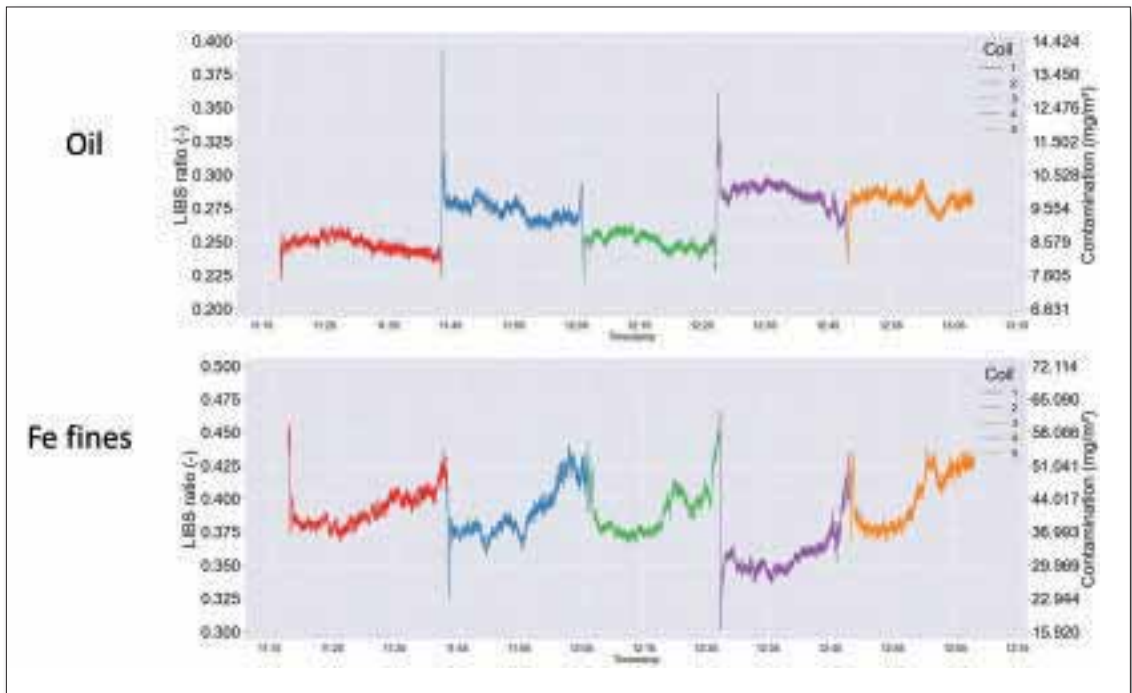


Fig 4 Example data traces of LIBS data for five consecutive coils, with calculated contamination levels included

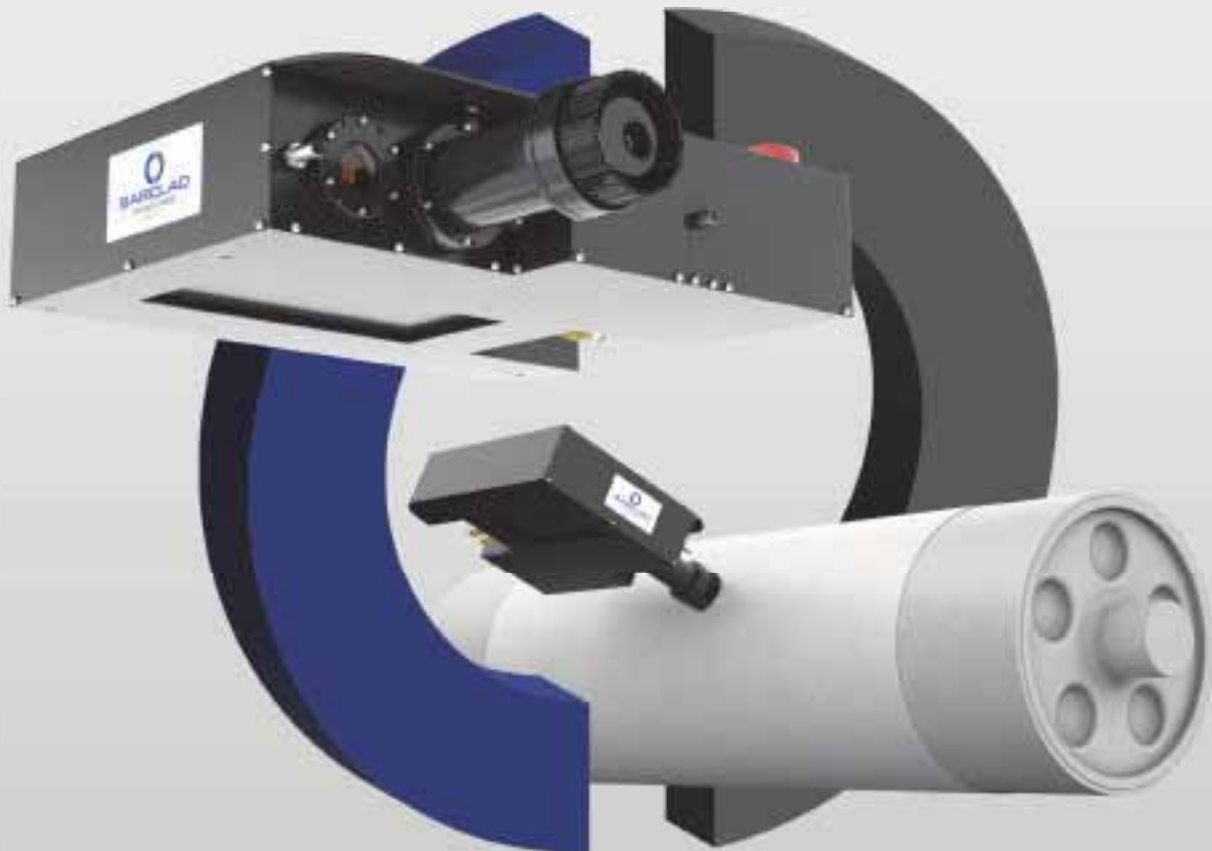
combination of a low backlash translation stage and a distance sensor, the focal point is always maintained at the surface of the strip, even if the thickness of the steel strip changes. The system targets specific wavelengths for the analysis that ensure it is not susceptible to absorption by any remnant water on the surface and is also unaffected by deviations in surface roughness. A spectra acquisition and analysis software outputs two monitoring signals: one for the surface carbon and one for the iron fines. It also controls the different components of the sensor head and continuously checks if all the conditions to safely operate the unit are met.

## INDUSTRIAL DEMONSTRATION OF THE CONTAMINATION MONITORING SYSTEM

The unit described above has been successfully installed and tested on three lines: the laboratory pilot line at CRM and two full-scale continuous strip galvanising production plants. The data generated from these trials has been used to validate the measurement methodology. Moreover, the trials have demonstrated the suitability of the measurement technology for the steel product and the robustness of the engineered solution of the measuring device in the industrial environment.

# CONTAMINATION MONITORING SYSTEM


The first continuous monitor of strip cleanliness providing real-time data with unprecedented precision that distinguishes between oil and iron fines contamination.



- ⊖ The only system to differentiate between Oil and Iron Fines
- ⊖ Real-time cleanliness monitor for strip processing lines
- ⊖ Utilising Laser Induced Breakdown Spectroscopy (LIBS)
- ⊖ Non-contact sampling
- ⊖ 20Hz sample rate
- ⊖ Eliminates need for 'tape test'

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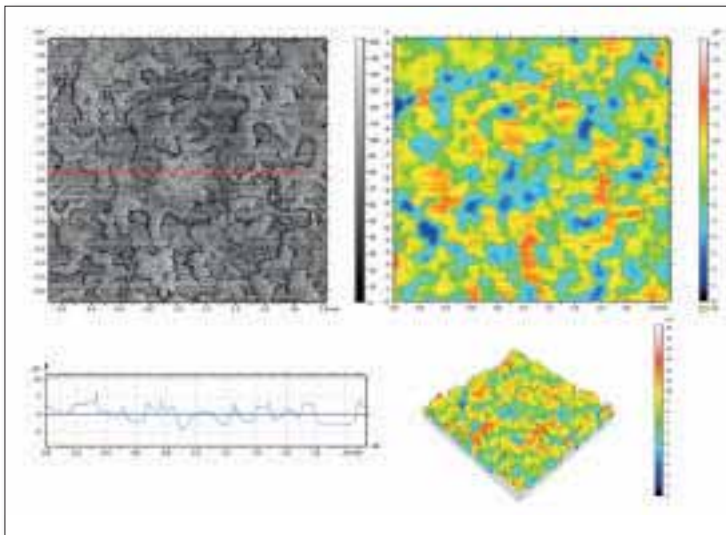
  
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Contamination species	Range mg/m <sup>2</sup>	Sensitivity mg/m <sup>2</sup>
Oil	0-120	+/- 1
Iron fines	0-200	+/- 2

📌 Table 1 Range and sensitivity of contamination species



📌 Fig 5 Photograph of blemishes on processed coil (industrial trial)



📌 Fig 6 Confocal imaging of the steel strip surface at the area of plasma generation: a) reflective intensity, b) topographical view of same area, c) linescan of topography of marked intersection, and d) 3D view

### Data validation

To determine the validity of the LIBS technology it was necessary to undertake a comparison of measured LIBS ratios of wavelengths with verified contamination levels across the range of contamination levels of interest. To achieve this, a number of physical steel samples were taken from both industrial and laboratory steel coils. Adjacent samples were then subjected to both LIBS measurement by the demonstration unit and independent laboratory tests. In the case of oil contamination this was the Total Organic Carbon (TOC) method and for iron fines the Inductively Coupled Plasma (ICP) technique. Both techniques are recognized as reliable characterization methods for the given contamination species. The results achieved are shown in *Figure 3*.

Statistical analysis by linear regression shows an excellent correlation for both contamination species, demonstrating that the technique gives a reliable measure of contamination in the ranges of interest for cleaned steel strip in industrial processing lines (*Figure 4*). By transposing the above relationships to full coil data traces it can be seen that the LIBS technique gives very high levels of measurement sensitivity.

Statistical analysis of the trace data shows a tight distribution of measurement variation giving standard deviations of measurement for oil at 0.47 mg/m<sup>2</sup> and iron fines at 0.88 mg/m<sup>2</sup>. If we therefore consider measurement sensitivity to be defined by +/- 2 standard deviations the overall measurement performance can be stated as shown in *Table 1*.

### Suitability of the measurement technology

Surface quality is of paramount importance to many steel strip products. Indeed, it is the

very intent of this technology to facilitate improvements in such. The LIBS technology is a non-contact process and so does not impart any mechanical damage to the product surface. However, it should be noted that the generation of the plasma by the LIBS process does impart a light blemish on the surface the strip (<0.5mm diameter), as seen in *Figure 5*.

Work has been undertaken to characterize this blemish to ensure that it is of no material concern to either the subsequent processing steps or final product quality of the coated steel strip. Characterization by confocal microscopy (*Figure 6*), to accurately measure the surface topography and derive a 3D map of the area affected by the plasma generation, clearly shows that despite the sample area giving a visible difference by reflectance of light, no discernable change has been made to the strip surface texture.

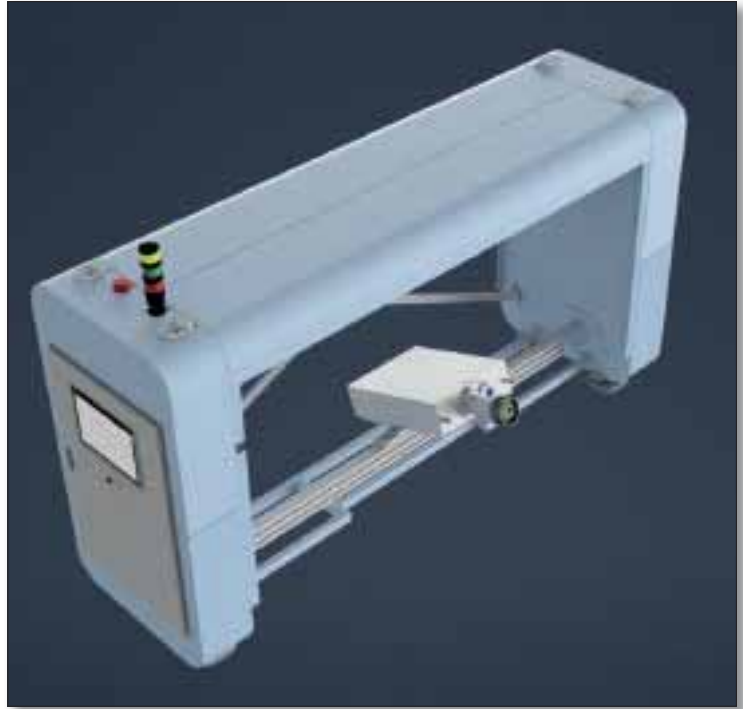
Further studies using scanning electron microscopy and utilising backscattered electrons similarly show no topographical, or chemical analysis change in this region. It has also been demonstrated that wettability in the zinc coating process is unaffected and bend tests show no deterioration in zinc adherence. This minimal impact can be attributed to the carefully controlled process applied by the LIBS device, giving precise control of the conditions for plasma generation allowing for a lower energy laser pulse of typically ~1W, reducing the potential for material damage.

### COMMERCIAL INSTALLATION

Having established reliable data acquisition and demonstrated the suitability of the technology in the industrial environment, Sarclad has developed a robust commercial design for permanent installation at any typical cleaning line. The design incorporates principles of design for manufacture, maintenance and use and considers the operating environment and intent of the steel producer (*Figure 7*).

### Automated line traverse

A clear requirement for process line installation is the ability to provide measurements at any point across the width of the strip. To facilitate this, the unit is mounted on a motorised traverse rail which is controlled



**Fig 7** Overview of the designed commercial solution

by an industrial PLC capable of integration with the strip processing line process control. This will allow movement to set points according to strip width and desired pattern of measurement. The PLC also facilitates system safety protocols and performance diagnostics.

### Operator interface, data analytics and integration to production systems

A web-based user interface has been developed to allow real-time access to the data by operators and control of core commands. The interface has been designed on a modular basis to cover all aspects of controls and communications utilising Industrial IoT methodology in a unified namespace to ensure seamless integration to plant systems and safe operation. The system is Industry 4.0 ready, utilising data structures that are efficient for network traffic and are fully scalable.

The HMI has an intuitive design (*Figure 8*) and allows the operator to access real-time data, review historical data and export data for further analysis offline and perform system operational set up according to product mix/line operation. Communication to plant operating systems is via OPCUA. →



Fig 8 System HMI showing the live data view

### Laser safety and system security in the operational environment

The installations in this study have fully complied with laser safety requirements by utilising a combination of robust systems interlocks, shielding and exclusion zones. This is enhanced in the commercial product by designing in key shielding arrangements to the housing and site-specific working practices. Further, the integrated design facilitates armouring to protect the measuring head in the event of a strip break etc. with only the sacrificial laser beam shroud being exposed. The equipment is rated to IP53 to protect from dust and water, with the innovative laser beam shroud protecting the external optic. Site specific measures will be incorporated to mitigate the effects of extreme temperatures, humidity, and vibration.

### CONCLUSIONS

The application of the LIBS technology has been successfully demonstrated to reliably measure the contamination levels of oil and iron fines as independent and discrete species on the steel strip. Furthermore, this has been achieved in the industrial environment with an online sensor taking live measurement on

the production line at full operating speed. The reliability of the measurement has been demonstrated over a suitable range with very high levels of measurement sensitivity.

Practical experience has shown that the minor blemish made by this non-contact measurement is not visible after coating. Further microscopy and laboratory tests have shown that the blemish makes no topographical change to the steel surface and no chemical or microstructural change occurring. Thus, the measurement process does not adversely affect either the galvanizing process, or the end product quality.

A robust engineering solution has been developed to implement the technology in the industrial environment of a steel strip processing line. The unit has been exposed to the rigors of operation in such an environment and performed effectively. An appropriate software and control system has been developed to make this product ready for implementation and integration to any strip processing line. **MS**

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