Practical infrared thermometry for aluminium hot rolling mills

Fiona Turner, Physics Section Manager at Ametek Land, looks at how aluminium presents significant challenges for accurate infrared temperature measurement and how those challenges can be overcome with modern infrared technology.

Aluminium presents significant challenges for those who need to measure its temperature by non-contact thermometry. The material has low emissivity which varies with wavelength and surface condition, and aluminium is processed at lower temperatures than most metals so there is fundamentally less emitted energy.

For infrared temperature measurements of rolled or extruded aluminium surfaces to be taken successfully, sensitive multi-wavelength pyrometers or infrared thermometers are required, which can interpret the complex emissivity behaviour in real time.

Infrared temperature measurement and emissivity

Infrared thermometers are non-contact instruments that sense emitted radiation and convert the received signals into temperature measurements. Every object emits electromagnetic radiation – hotter objects emit more radiation and at shorter wavelengths. A blackbody object emits the full radiation profile predicted by Planck's Law, but, for real objects, the emission is less efficient, and the emitted radiation is scaled down by a factor known as the surface emissivity.

For surfaces of known and constant emissivity, a simple compensation factor can be used in the thermometer software to correct the measured radiation up to that expected from a blackbody source. If the surface emissivity is not known, a more complicated thermometer is required that can measure in more than one band of infrared wavelengths. If the relative emissivity at two wavebands (the 'non-greyness') of the surface remains constant, a ratio thermometer can be used to calculate temperature from the ratio of the radiance in the two different wavebands. For aluminium, the non-greyness is not constant. A more complicated algorithm relating to the signals from the different wavebands is required for accurate temperature measurement.

Algorithm thermometry

Algorithm thermometers have been available since the first Land Instruments ASTS (Aluminium Strip Thermometer System) was introduced in 1993. The current generation of Ametek Land SPOT thermometers also includes a dedicated pyrometer for aluminium measurements, the SPOT AL EQS (Aluminium Extrusion, Quench and Strip): it uses a more complicated proprietary algorithm than the ASTS, fitting a dataset of combinations of radiance, temperature and emissivity at the different thermometer wavebands to offer an extended temperature range. The SPOT thermometers offer full digital functionality with live configurations possible via a rear display / keypad or webserver / Modbus TCP software interface. The AL EQS provides live output of emissivity as well as temperature.

Three different algorithms, or APPs, within the AL EQS cover the different oxide layers encountered in extrusion, quench and strip applications. Land research has shown that freshly formed oxide layers of all different series of aluminium, from 1xxx up to 8xxx, follow the same relationship between temperature, emissivity and radiance at the SPOT AL EQS wavelengths. Thus, one pyrometer algorithm can be used for all alloys soon after a fresh surface has been produced by extrusion, and a similar algorithm applied after quenching. However, the extended heating that precedes hot rolling allows key elements such as magnesium to diffuse from the bulk to the surface. Very different oxide structures can form during several hours in a furnace, and a further level of complex data fitting is required to optimize the pyrometers for extended hot formed oxide layers of different base alloys.

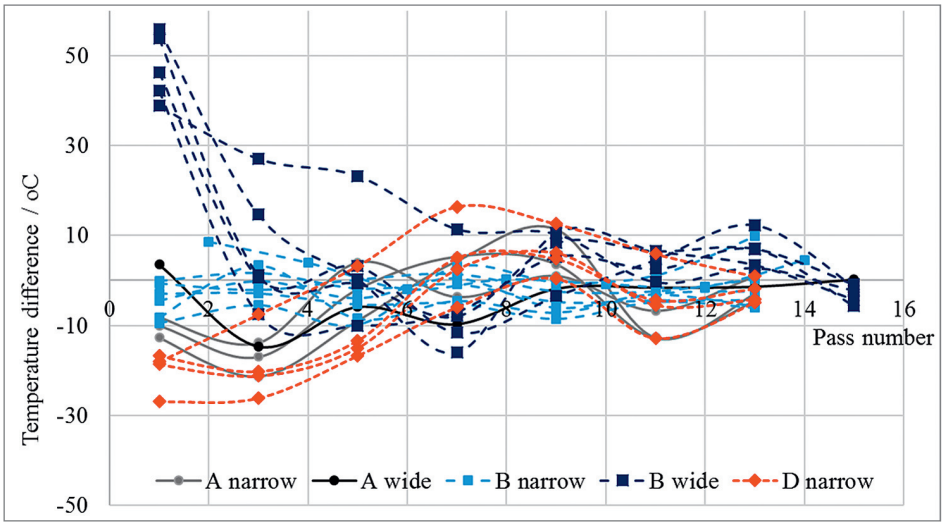

Fig. 1: The difference between SPOT AL EQS uncorrected AL S algorithm and surface thermocouple measurements for the different alloys. The initial measurements of the larger slabs of alloy B are particular outliers.

Infrared temperature measurement for aluminium hot rolling

Ametek Land investigated the emissivity of aluminium during hot rolling in a collaborative project with Bridgnorth Aluminium Ltd during the site trials of the new SPOT AL EQS thermometer. Results were published at the Aluminium Two Thousand World Congress in 2017 [1]. Those results are summarized here.

Site trials were conducted on the hot rolling mill at Bridgnorth Aluminium. This is a reversing mill, so a SPOT AL EQS thermometer mounted on the entry side of the mill measured the initial slab delivered by robot from the preheat furnace, then every other pass as the slab passed back and forth through the mill with decreasing roll gap to produce a thinner and longer strip. A second AL EQS instrument was mounted on the exit side of the mill to measure the interim passes.

Bridgnorth Aluminium processes various grades of aluminium, and the mill is highly automated. The number of passes, the height reduction of each, the speed and quantity of coolant are controlled in line with initial slab

dimensions and alloy hardness to ensure the desired product quality. During the site trials, three different alloys were processed: those labelled as A, B and D in Table 1.

SPOT temperature and emissivity data were recorded continually as the slabs passed back and forth through the mill. Surface thermocouple measurements were taken for comparison during the reverses, when the strip necessarily is stopped in order to change direction. The difference between the SPOT AL EQS measurements and thermocouple readings is plotted by pass number in Fig. 1. The SPOT measurements were taken with the uncorrected AL S algorithm.

The surface thermocouple (Anritsu S-223K-10-1-TPC1-W) was calibrated prior to the trials, but good surface contact was hard to achieve from a 2-metre distance so the maximum reading for each pass was used for a set of slabs, giving rise to the visible ripple in the measurements, and limiting the accuracy of each individual comparison point to around 10 °C. However, several trends could be deduced.

The AL S algorithm is not a good fit to the thermocouple measurement for the initial passes, but the errors diminished, and the traces converged over successive passes. Initial slab measurements vary significantly from alloy to alloy. The larger slabs of alloy B were particular outliers in both the temperature and emissivity data.

Aluminium oxide composition

To explain the temperature and emissivity effects observed, Bridgnorth Aluminium investigated the oxide composition of the different alloys on samples prepared to recreate the conditions of the preheat furnace and taken from plate gauge strip after rolling. Composition was measured using a Bruker Tensor 27 FT-IR spectrometer, and film thickness was derived from oxide film standards of known thickness measured using XPS and TEM. The results are shown in Fig. 2.

Despite relatively small differences in nominal composition from alloy to alloy, the type of surface oxide film formed in the preheat furnace varied significantly, with magnesium diffusing towards the surface. A thicker oxide layer was formed on the wide slabs, which were preheated for longer and at higher temperatures: 266Å for wide slabs and 175Å for narrow slabs of Alloy A.

In contrast, once the rolling process was completed, all three alloy types exhibited nearly identical amorphous surface oxide films of thickness 15-20Å. After rolling to plate gauge,

Table 1: The alloy type, processing settings and initial slab temperature grouping of the aluminium slabs processed during this study

Alloy / Slab size	Size category	Number of passes	Preheat exit temperature	Principal alloy component
A	Small	13	Medium	Fe
A	Large	15	Medium	Fe
B	Small	13	Low	High purity; various elements
B	Large	15	High	High purity; various elements
C	Small	13	Medium	High purity; Mg
C	Large	15	High	High purity; Mg
D	Small	13	Medium	High purity; Fe

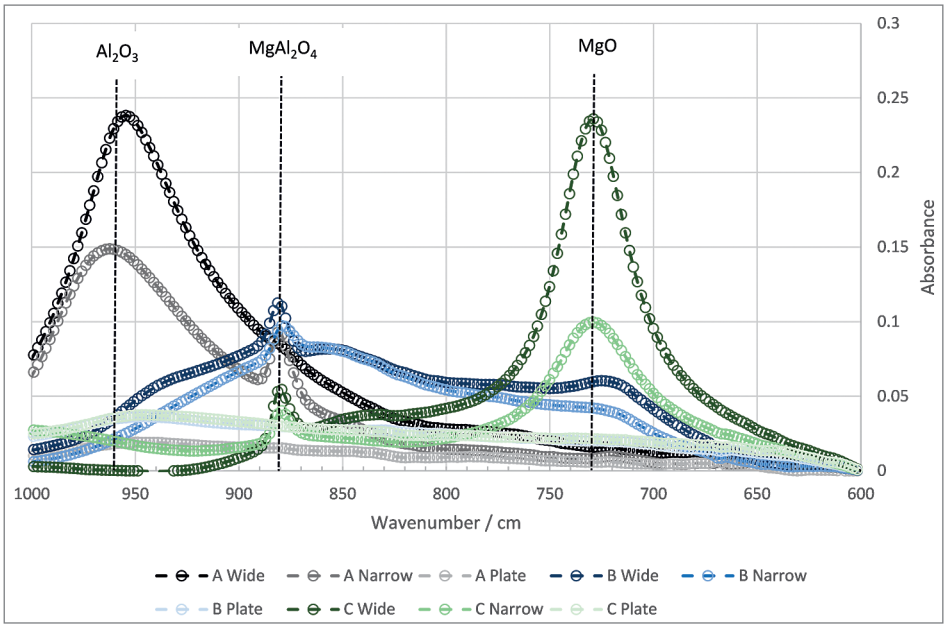

Fig. 2: FT-IR measurements of initial slab and final plate samples of three different alloys, and two different initial slab sizes

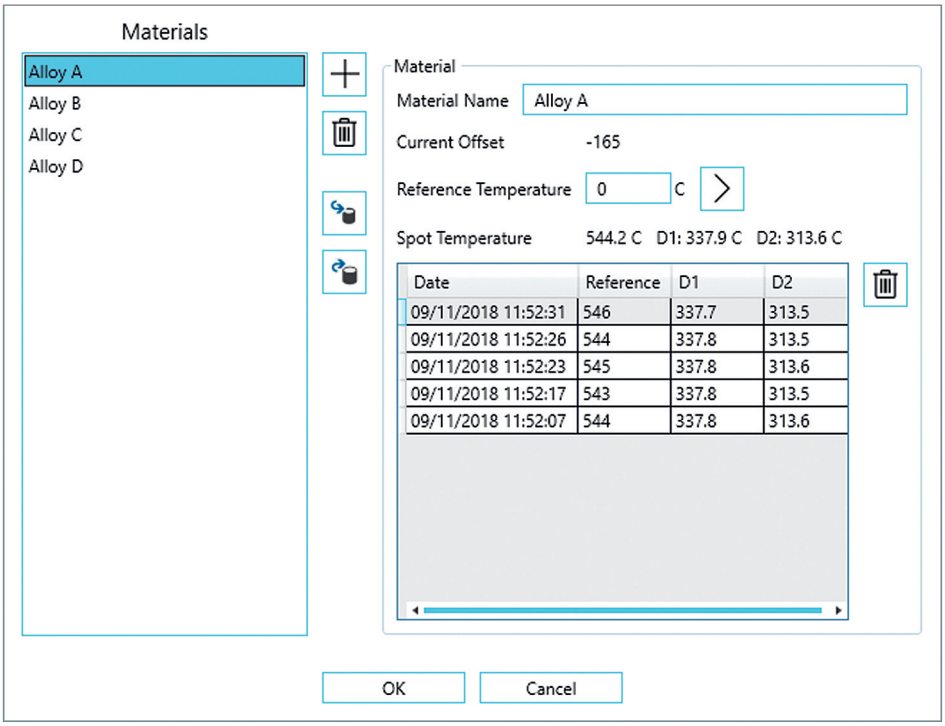

Fig. 3: Material calibration within Ametek Land's SPOTViewer software

the surface area was increased to around 40x its original size, so the surface film could be considered to be a freshly formed layer.

Recommendations

Fig. 2 explains how one Al S algorithm can work for freshly formed surfaces of many different alloys. After rolling to plate gauge, the oxide layer is a thin amorphous film with composition independent of alloy type. Thus, measurements taken with the SPOT thermometer can reasonably follow the same emissivity and non-greyness curve for all alloys during latter processing stages.

A surprise finding of the FT-IR study was the extent of the variation in furnace-formed oxide layers of different alloys. Magnesium enrichment of the surface and layer thickness affect the emissivity relationship at different wavelengths.

Given these results, it is recommended that, for reversing mill installations, SPOT AL EQS thermometers are used in conjunction with software taking input from the mill control system. If measurements of the first pass are required, onsite calibration should be performed. The AL EQS thermometer was designed to take thermocouple calibration input via its embedded webserver, Modbus TCP instruction or Ametek Land's SPOTViewer software, to automatically work out the non-greyness algorithm correction for that alloy. The Material Calibration screen of the SPOTViewer software is shown in Fig. 3.

For any pyrometer viewing the preheated slabs prior to rolling, a calibration should be performed in situ for each alloy and/or processing stages by entry of reference temperatures. The software compiles a database of reference measurements for each alloy, which it uses to calculate the best algorithm offset. Post calibration, the offset would be automatically configured on the instrument each time that alloy was selected from the calibration database. A further enhancement for a reversing mill is to integrate the system with control system input, so that the offset is applied for the initial preheated slab, but removed, along with the furnace-formed oxide layer after the first two passes through the mill.

Conclusion

Thanks to Bridgnorth Aluminium's spectroscopic measurements, it is now known that freshly formed films of different alloys exhibit nearly identical amorphous thin surface oxide films. This explains how a single algorithm pyrometer can be used 'out of the box' to measure freshly formed aluminium oxide layers of all alloy types – as seen in extrusion or quench applications, or on rolled strip after two or more passes through the mill.

In contrast, the type of surface oxide film formed in a furnace varies dramatically with alloy grade, despite relatively small differences in nominal composition from alloy to alloy. On-site calibration for different alloys and processing parameters is recommended for accurate temperature measurement of preheated slabs before the onset of hot rolling.

References

[1] S.F. Turner, R.W. Gagg, D.C. King, P. Drögmöller, L.K. Muman, R.D. Hunt: Practical Infrared Thermometry for Aluminium Hot Rolling, Proceedings of the Aluminium 2000 World Congress 2017