HySpex by neo

HYPERSPECTRAL REFRACTORY BRICK COMPOSITION PREDICTION FOR BRICKS FROM CEMENT ROTARY KILNS

ReSoURCE application note

JULY 2023
WWW.HYSPEX.COM

The EU-funded ReSoURCE project aims to increase the recovery of spent refractory bricks by sensor-based automated sorting. The project concentrates on spent bricks obtained from cement rotary kilns (CRK) and steel casting ladles (SCL) as feedstock. The developments in the project shall enable a fast and accurate sorting process to introduce recycled materials back into the production of new bricks without compromising on product quality. Innovative technologies for recycling processes such as hyperspectral imaging will be a key to reach these goals. Global leader in the refractory business RHI Magnesita (RHIM) is coordinating the ReSoURCE project with the aim of evolving sensor-based automated sorting combining HySpex hyperspectral imaging cameras as well as laser-induced breakdown spectroscopy (LIBS) equipment from LSA GmbH, Fraunhofer ILT and InnoLas Laser GmbH in an optimized sorting system.

Recycled material (used bricks) from cement rotary kilns (CRK) were provided by RHI Magnesita . Used recycled bricks of different compositions from different CRK facilities were scanned using the HySpex VNIR-1800 and SWIR-384, see Figure 1.

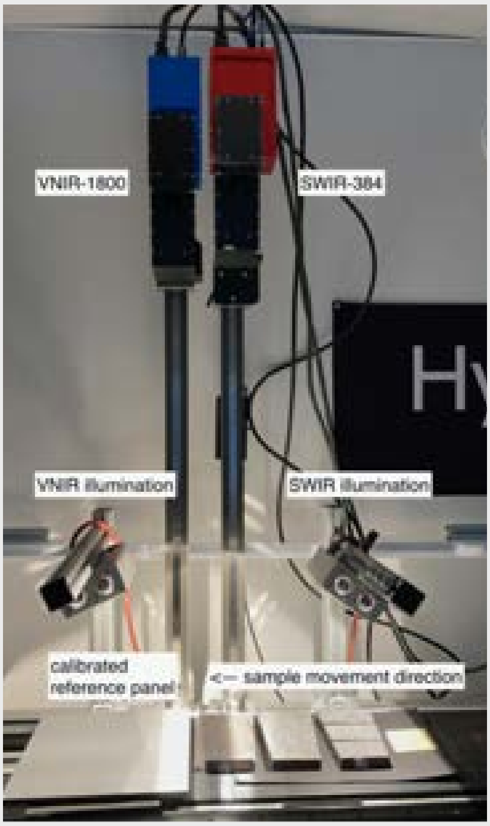


Figure 1: Laboratory setup for scanning refractory bricks with the HySpex VNIR and SWIR cameras.

Two different brick composition models were trained based on RHIM labels for the cement rotary kiln (CRK) bricks. In this initial feasibility study, only the SWIR data is being used to train a model. The goal is to classify the bricks based on three existing sorting classes:

- Brick type A: Fired low iron magnesia-based bricks containing hercynite spinel ($FeAl_2O_4$))
- Brick type B → Fired high iron magnesia-based bricks containing hercynite spinel ($FeAl_2O_4$)
- Brick type C → Fired low iron magnesia-based bricks magnesia spinel ($MgAl_2O_4$)

First model: 3x3 grid
A brick composition type model was trained based on the CRK samples. Here, both the original (unused) and used bricks of brick types A, B, and, C were scanned. Using Prediktera's Breeze software, the original and the used bricks were segmented from the background and labeled based on their overall brick composition type. A PLS-DA classification model was trained within Breeze to differentiate between the main brick types. By subsampling each sample by a 3x3 grid (see Figure 2) and balancing the training sample set per class, a total of 341 sub-samples were used to train the model, of which 190 were used for training and 151 for testing using all 288 bands of the shortwave infrared data (SWIR).

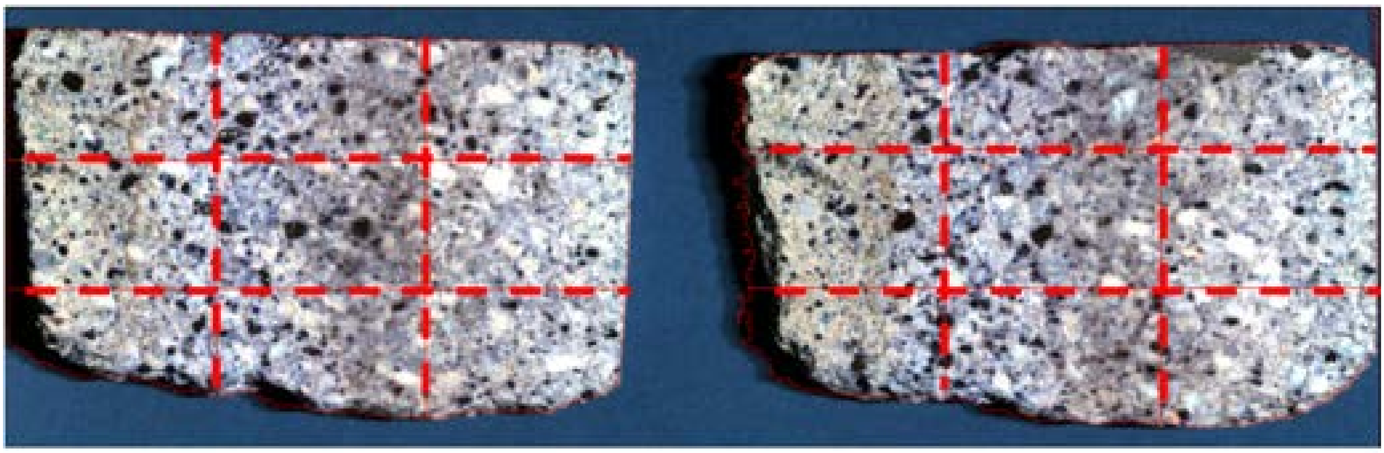
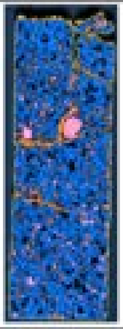
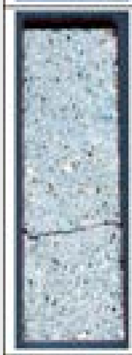
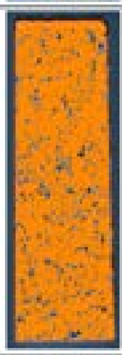
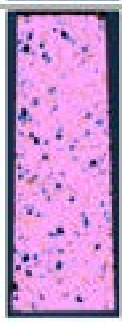
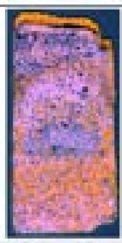
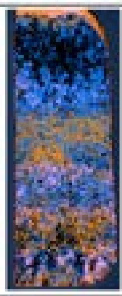


Figure 2: Sub-sampling via 3x3 grid shown on brick "used brick type 1A", showing which sub-samples were created for training the PLS-DA model.

This PLS-DA model predicts 97.4% of the training dataset correctly. For the test set (30% of the samples) 96.7% of the samples are predicted correctly. Predictions were done on a pixel level and based on pixel class majority (pixel count) as well as the average spectrum of the segmentation.

Table 1: Brick composition classification results for original and used bricks using the HySpex SWIR data, based on the 3x3 subsampling model.

Sample	Brick composition type	Per pixel classification	Classification based on average spectrum	Pixel class majority classification
	Type A (original brick)		Type A	Type A
	Type B (original brick)		Type B	Type B
	Type C (original brick)		Type C	Type C
	Type C (used brick)		Type C	Type C
	Type C (used brick)		Type C	Type C
	Type A (used brick)		Type A	Type A

The model was also trained on the average spectrum of the full 31 samples (not sub-segmented via a grid), both including used and original bricks, and was tested on the remaining 13 samples. When training based on the full sample segments instead of dividing them by a 3x3 grid, the classification results seem to improve. The overall classification matrix does not change radically. In the test set 92.3% of the samples are correctly classified, in the training data set 100% of the sample were classified correctly. The pixel-based prediction for the used bricks does not work as well visually when comparing the results within Breeze (see Table 1). Especially the used bricks, show a change of composition over a profile from the hot to the cold face and the classifier cannot classify each pixel in the brick with the correct brick composition label. Figure 3 shows the change of spectral signal over the profile from hot to cold face within a used brick type A.

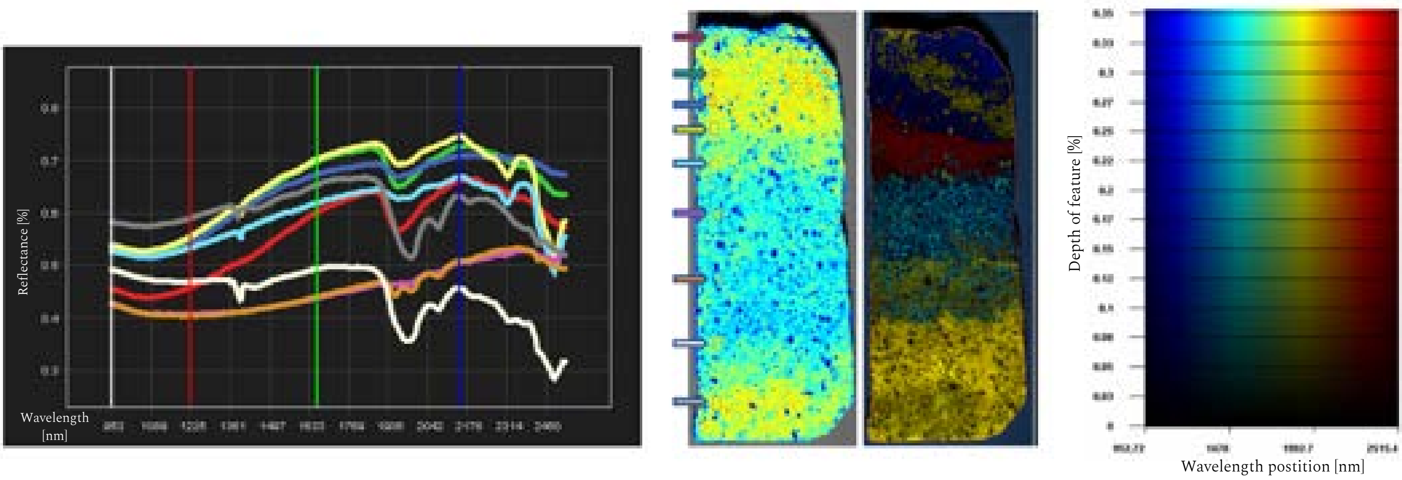


Figure 3:

Left: plotted spectra, color-coding corresponding arrows in the center image.

Center: PCA representation of sample BT 1B (sample nr. 2), hot face towards the top and cold face towards the bottom of the image. The color coding of the image represents areas of similar spectral properties. The areas where the spectra were extracted are shown by the colored arrows, please note that the plotted spectra are color-coded accordingly.

Right: a dominant spectral feature analysis shows a change of the deepest absorption feature position from hot to cold face. The colors represent the wavelength position of the deepest feature while the brightness represents the depth of the feature. The pattern and changes along the brick are of more importance at this point than an interpretation of them.

This feasibility study is part of Horizon-Europe funded ReSource project, showing how hyperspectral imaging can help identify refractory bricks and classify them spatially. Though more research is needed to give conclusive results, the initial ability to map the three main CRK brick composition types using hyperspectral imaging is promising. It is also important to highlight, that hyperspectral imaging enables to map of small-scale changes in used bricks caused by mineralogical changes originating from changing temperature and pressure as well as infiltration of gases during the brick's service. This will change the surface and give indications of the brick's composition and re-use potential.

HySpex offers a varied selection of turn-key solutions for mining and raw material-related studies as well as other scientific and industrial applications. Visit www.hyspex.com or contact us at hyspex@neo.no to discuss your application and requirements with our specialists.

Samples and expert input were provided by RHI Magnesita. For more information about the project see https://www.project-resource.eu/

Funded by the European Union

This project is funded by the European Union's Horizon Europe Frame Program (HORIZON) under the Grant Agreement Number: 101058310.