Deliverable 3.9

EC's Framework Programme for Research and Innovation Horizon 2020 (2014-2020)
Grant agreement no. 636820

Cross-sectorial real-time sensing, advanced control and optimisation of batch processes saving energy and raw materials (RECOBA)

Start of the project: Jan 1st, 2015
Duration: 36 month

Report on performance of FBG fibre optical temperature measurement in refractories

Due date: June 30, 2016
Actual submission date: June 15, 2016

Lead contractor for this deliverable: BFI

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Dissemination level

PU	public	☒
PP	restricted to other programme participants (incl. the Commission Services)	☐
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CO	Confidential, only for members of the consortium (incl. the Commission Services)	☐

CONTENT

1 Introduction

Thermal state of the refractory depends on the history of the aggregate and influences significantly the batch process. Here, the feasibility is studied using fibre Bragg gratings (FBG) as fibre optical sensors for refractory temperature monitoring at elevated temperatures above 250°C.

2 Theoretical background

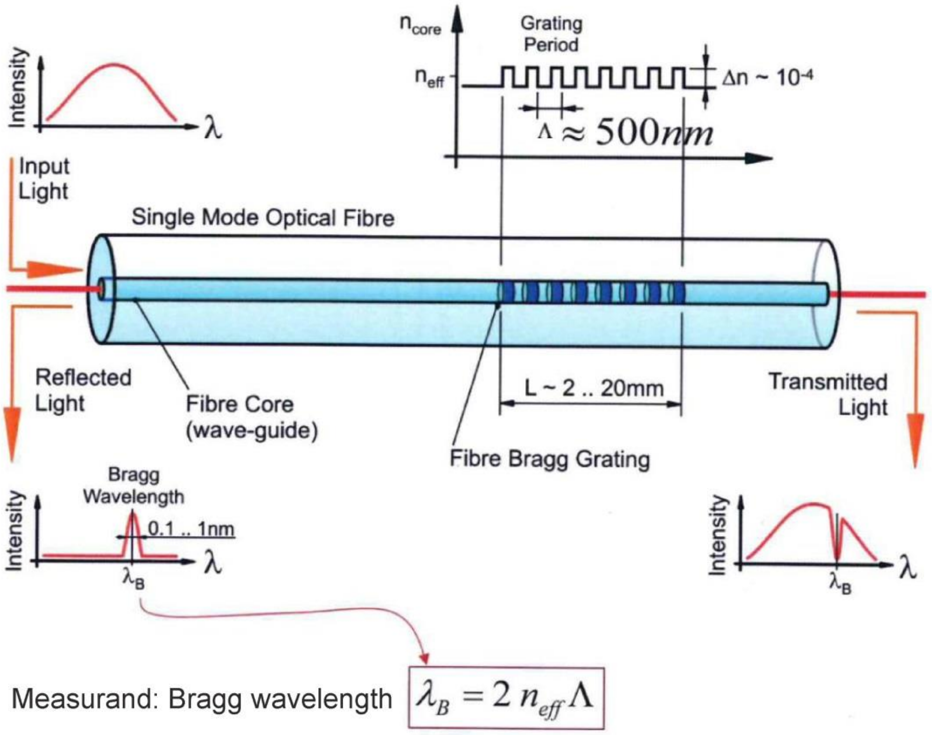

Figure 1: Schematic drawing of FBG fibre and basic spectral properties

In the core of the FBG fibre a periodic variation of the refractive index is introduced at a length of about 1 mm. The grating with a line spacing Λ is used as an optical sensor. The grating acts as a wavelength specific dielectric mirror. From an optical pulse the Bragg-wavelength λ_B is reflected:

$$\lambda_B = 2\, n_e \Lambda$$

The effective refractive index of the grating n_e can be influenced by the temperature. The distance of the lines Λ is sensitive to strain. Thus, by measuring the wavelength shift $\Delta\lambda$ of the reflected Bragg-wavelength with respect to the Bragg-Wavelength λ_{ref} at a reference temperature T_{ref} the sensor temperature T can be deduced:

$$T = 1/TK * \Delta\lambda / \lambda_{ref} + T_{ref}$$

1/TK denotes the Temperature calibration factor, which is determined by comparison to a reference measurement.

3 Experimental Setup

The experiments are performed on a novel high temperature resistant FBG fibre. To improve mechanical stability the optical fibre is covered in a stainless steel capillary with diameter 1x0,1 mm. The fibre with a total length of two meters contains one sensor at a position of

0,5 m. For calibration another sensor at the beginning of the fibre is used, which is exposed only to ambient temperature. The centre reflection wavelength of the sensor is at 1550 nm.

The fibre is connected to an interrogator containing a laser source and a spectrometer (figure 2). A laser pulse is injected into the optical fibre, and the reflected light is detected by the spectrometer. The center wavelength of the reflection peak is analysed (Figure 3). To account for the slow temperature variation and the long measurement duration a measurement frequency was set to 1 per minute.

Figure 2: Experimental setup of heat resistance test with tube furnace (left), notebook for data evaluation (mid), and interrogator with applied fibre optical sensor (right)

The temperature resistance tests of the optical fibre were performed using a high temperature tube furnace. The furnace allows a maximum temperature of 1600 °C. Within the central alumina tube with a length of 1500 mm and a diameter of 60 mm the temperature can be kept constant at a range of 610 mm. The optical fibre was introduced into the tube such that the sensor was situated in the middle of the tube. To reduce energy loss and the temperature gradient within the furnace, both ends of the tube were closed by fibre mat for isolation.

A thermocouple for reference temperature measurements was placed within the tube furnace next to the optical sensor. The thermocouple of type B had a measurement range from ambient temperature to 1820 °C with an accuracy of 1,5 K. The heating power was set by a PID Eurotherm controller to achieve a constant furnace temperature.

4 Thermal resistance test

To test the thermal resistance, the fibre optical sensor was exposed to elevated temperatures. The sensor was placed in the furnace at 600 °C for 15 days (Figure 4). To check the performance of the sensor, the temperature was measured during the entire period. After calibration, the reference temperature and the values of the fibre optical sensor agreed with a root mean square deviation of 1,5 K. Also the spectra did not change significantly. The coating of the fibre did not degrade, change color or show any embrittlement. The fibre could be removed from the capillary and was recoiled after heat treatment. Thus the sensor did not show any signs of aging. The fibre optical sensor has proven to be long-term resistant at elevated temperatures of 600°C.

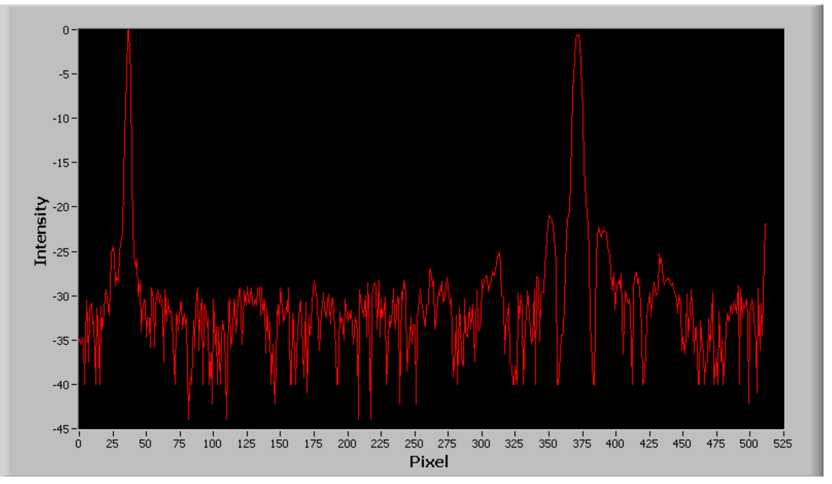

Figure 3: Measured reflection spectrum of the sensor at 600°C.

To identify the maximum temperature, the sensor was exposed to higher temperatures. The temperature in the furnace was raised in steps until the measurement fails (Figure 5). For temperatures up to 976 °C the temperatures measured with the fibre optical sensor are in accordance with the thermocouple measurements. Further temperature increase destroyed the sensor, so that no light was reflected from the sensor grating.

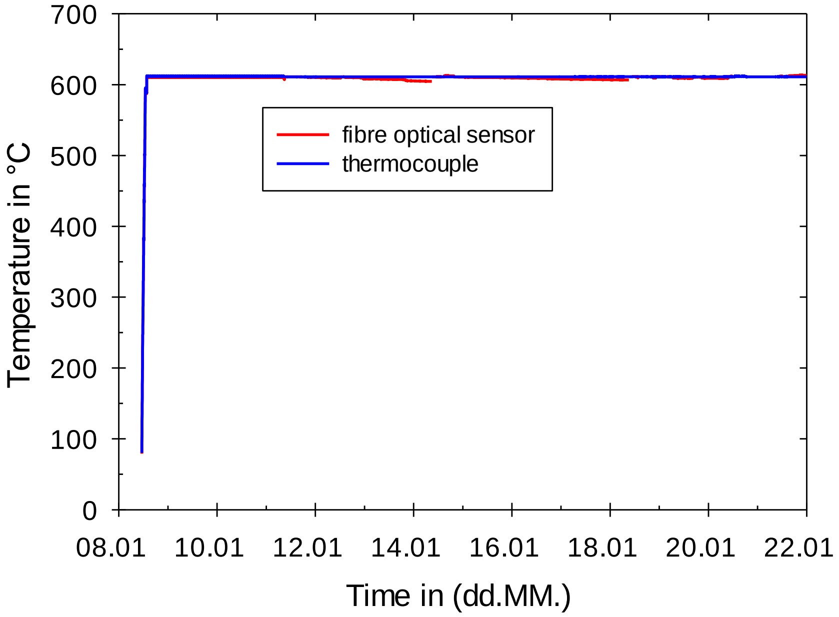

Figure 4: Long term heat resistance test of the fibre optical sensor for 15 days at 600 °C

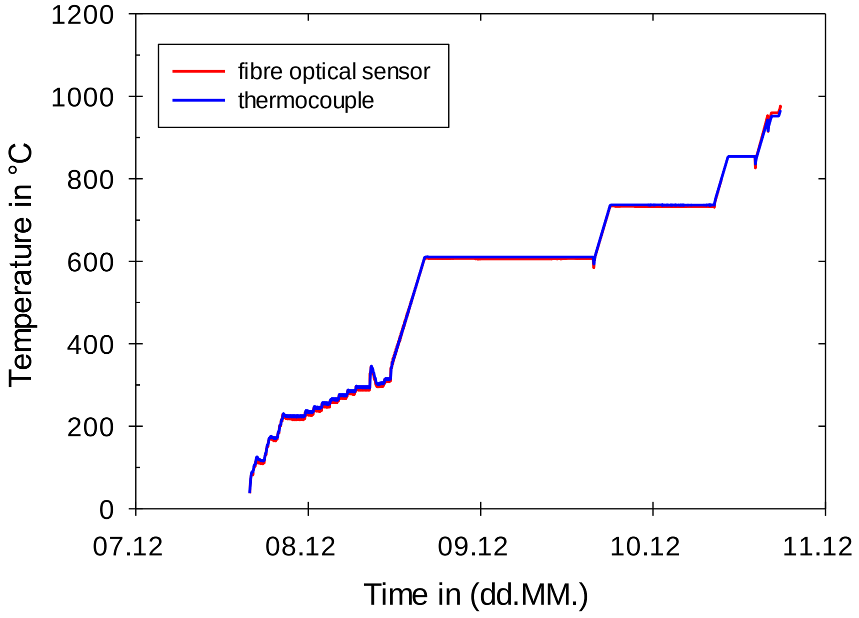

Figure 5: Heat resistance test of the fibre optical sensor at highest temperatures up to 1000°C

5 Conclusion

The fibre optical sensor is found to be high temperature resistant. It can withstand long term at elevated temperature of 600 °C and temperature peaks up to almost 1000 °C. However, for insertion in refractory material in an industrial environment the sensor is mechanically quite fragile. The interrogator unit should be stored in a control room without direct impact from industrial environment.