# Integrated sensing system of Fe-C coated LPFG for life-time corrosion monitoring with strain and temperature compensation

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## INTRODUCTION

In this study, a corrosion threshold-controllable sensing system of long period fiber gratings (LPFG) is developed and validated for life-cycle monitoring of steel bars in corrosive environments. Three Fe-C coated LPFG sensors with two bare LPFG sensors in LP06 and LP07 modes for strain and temperature compensation were multiplexed and deployed inside three miniature, coaxial steel tubes to measure three critical mass losses through the penetration of tube walls and their corresponding corrosion rates in the life span of steel bars. Thermal/mechanical loading and accelerated corrosion tests were conducted to validate the functionality, sensitivity, accuracy, and robustness of the proposed sensing system. Since both the steel tube and Fe-C layer represents the material composition of steel bars in the context of corrosion, the mass loss correlation among any two of the steel tube, Fe-C layer and steel bar is independent of the test conditions such as the current density and sample length, and thus applicable to engineering practices. The outer tube can notably delay and decelerate the corrosion process of its inner steel tube due to the reduced current effect.

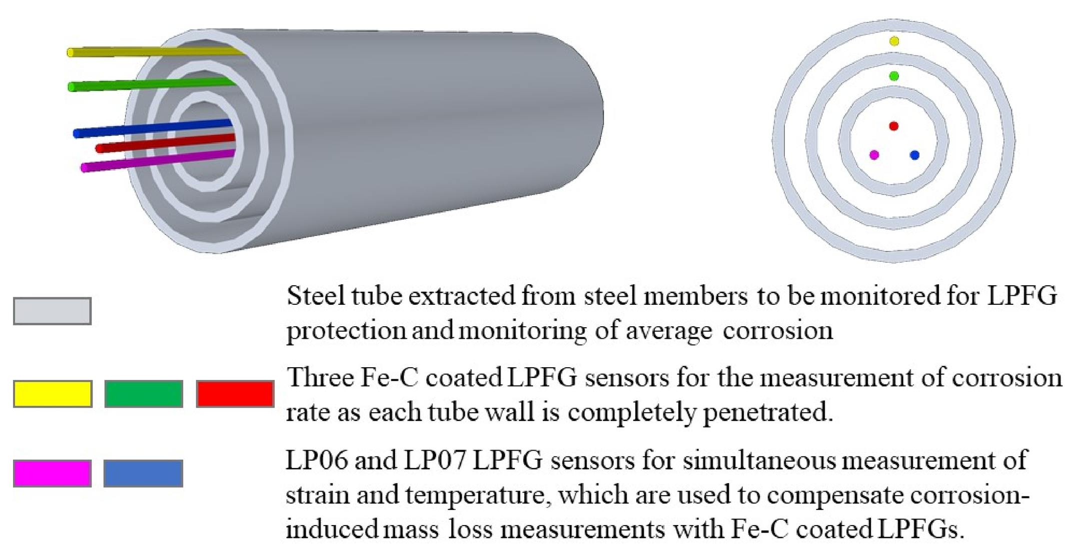


**Fig.1** Schematic view of an integrated sensing system: (a) three-dimensional view and (b) cross-sectional view

## METHODS

### Long Period Fiber Grating Sensor

In this study, the $CO_2$ laser aided grating technique was used to fabricate LPFG sensors on single-mode optical fibers (Corning SMF28e+). Specifically, LPFG sensors in LP06 mode with a grating period of 353 ± 0.1 μm and LPFG sensors in LP07 mode with a grating period of 301 ± 0.1 μm were fabricated, both having a resonant wavelength of 1550 nm. The total sensor length is approximately 4 cm..

### Integrated Sensor System

To protect fragile LPFG sensors and extend their service life for long-term corrosion monitoring, an integrated sensing system is proposed and designed. As shown in Fig. 1, three steel tubes, A, B and C, with different diameters are designed and arranged in a coaxial pattern.


**Fig.2** Cross section and image of three steel tubes

## RESULTS

Simultaneous measurement of strain and temperature with LP06 and LP07 mode LPFG.

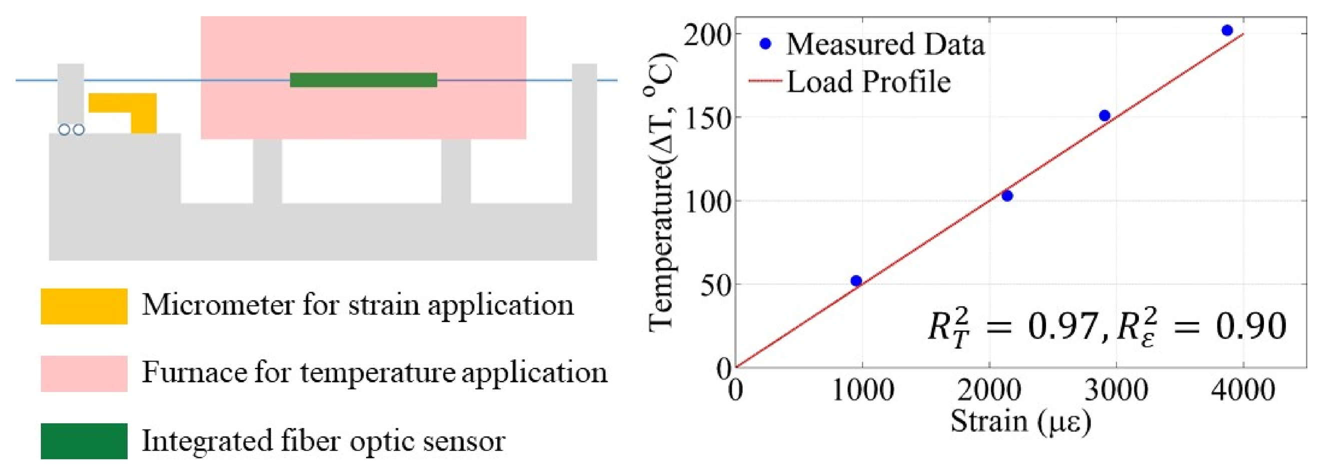


**Fig.3** Test setup and comparison of the sensor data under the thermal and loading profile

Corrosion induced mass loss monitoring

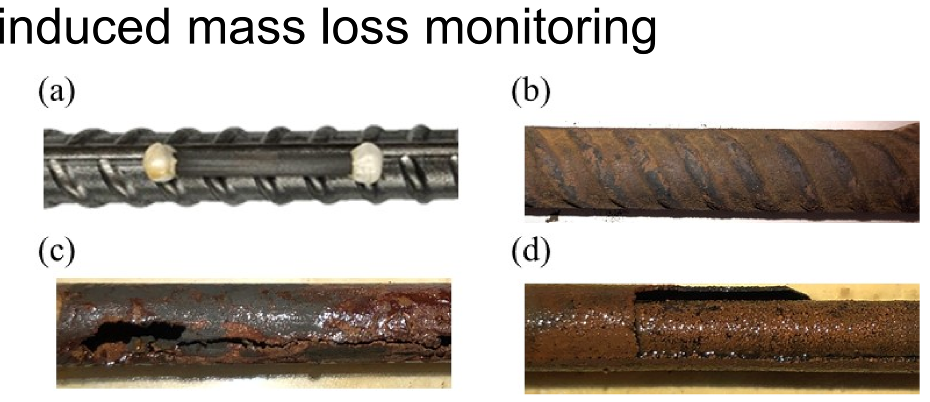


**Fig.4** (a) Steel tubes fixed on rebar, (b) corroded rebar (c) corroded single steel tube and (d) corroded double tubes

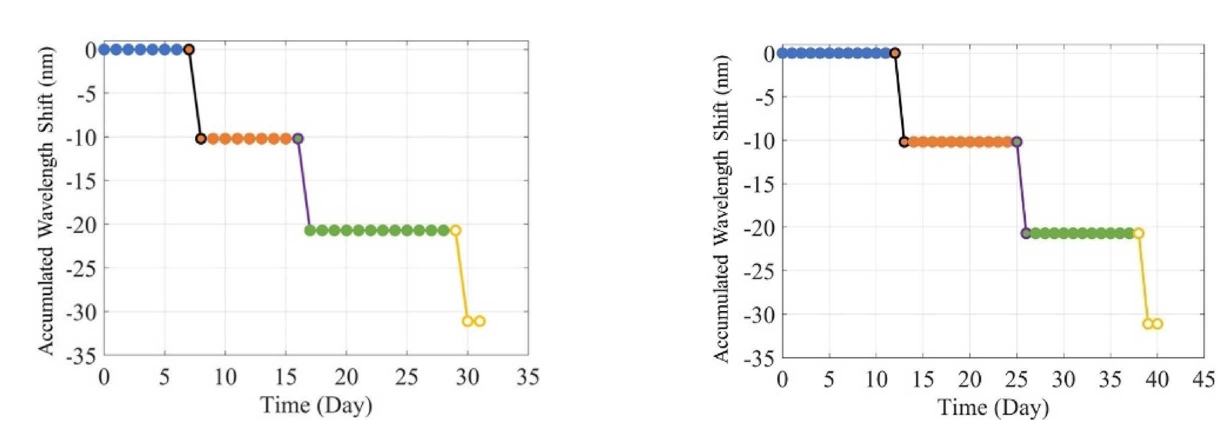


**Fig.5** Accumulated resonant wavelength shift over time under (a) constant and (b) varying current density

The estimated and measured mass losses and rates of the rebar under a constant current density

| Penetration of Tube | Mass Loss Rate (%/day) | | Error | Mass Loss (%) | | Error |
|---|---|---|---|---|---|---|
| | Estimated | Measured | | Estimated | Measured | |
| A | 0.46 | 0.48 | 4.2% | 3.1 | 3.4 | 8.8% |
| B | 0.43 | 0.46 | 6.5% | 6.9 | 7.4 | 6.8% |
| C | 0.42 | 0.46 | 8.7% | 12.2 | 13.3 | 8.3% |

Estimated and measured mass losses of the rebar under a time-varying current density

| Penetration of Tube | Rebar Mass Loss (%) | | Error |
|---|---|---|---|
| | Estimated | Measured | |
| A | 3.0 | 3.3 | 9.1% |
| B | 6.3 | 6.8 | 7.4% |
| C | 11.9 | 11.2 | 6.3% |

## CONCLUSIONS

In this study, an integrated sensing system of three steel tubes extracted from rebar, three Fe-C coated LPFG sensors in LP06 mode, and two LPFG sensors in LP06 and LP07 modes is designed and characterized for life-cycle monitoring of the rebar with strain and temperature compensation. Based on the test data and analysis, several conclusions can be drawn:

- Two LPFG sensors in LP06 and LP07 modes can be used together for simultaneous measurement of strain and temperature with high accuracy since they have dissimilar sensitivity coefficients. The maximum measurement error is 4.0% in temperature and 8.2% in strain.

- Under a constant current density, the mass loss rate of the rebar can also be derived accurately from the mass loss rate of the steel tube using the regression equation with less than 8.7% error. Under a time-varying current density, the mass loss rate of the rebar may not be obtainable from the equation since the penetration time of each tube differs from the penetration time taken during the correlation tests. In this case, the Fe-C coated LPFG sensor can provide the changing condition in corrosion current density through the measurement of Fe-C mass loss rate.

## REFERENCE

Y. Huang, F. Tang, X. Liang, G. Chen, H. Xiao, and F. Azarmi, “Steel bar corrosion monitoring with long-period fiber grating sensors coated with nano iron/silica particles and polyurethane,” Struct. Health Moni., 14 (2015) 178-189.

Y. Chen, F. Tang, Y. Bao, Y. Tang, and G. Chen, "A Fe-C coated long-period fiber grating sensor for corrosion-induced mass loss measurement," Opt. Lett. 41 (2016) 2306-2309.

C. Guo, L. Fan, C. Wu, G. Chen, and W. Li, "Ultrasensitive LPFG corrosion sensor with Fe-C coating electroplated on a Gr/AgNW film," Sensor. Actuat. B-Chem. 283 (2019) 334–342.

C. Guo, L. Fan, and G. Chen, "Corrosion-Induced Mass Loss Measurement under Strain Conditions through Gr/AgNW-Based, Fe-C Coated LPFG Sensors," Sensors, 20 (2020), 1598.

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