Summary

Over the past century, rail transportation has achieved remarkable gains in speed and efficiency through technological innovation. Modern trains now feature advanced safety systems, such as automated braking and collision-avoidance technologies, that mitigate many risks. Nevertheless, the rails themselves remain largely unmonitored in real time, and undetected cracks or structural defects can still trigger derailments with severe human and economic consequences.

To fill this gap, this PhD research focused on the design, testing, and implementation of a monitoring system for railway structural integrity based on Fiber Bragg Grating (FBG) optical fiber sensors. These sensors are ideally suited for track monitoring due to their high sensitivity, immunity to electromagnetic interference, low weight, and ease of fabrication.

An initial critical review of the state of the art was conducted to identify existing methods for joining steel to silica fiber. The survey of current solutions guided the development of approaches for creating a stable mechanical and optical heterojunction.

Based on insights from the literature, numerous experimental trials were carried out to optimize welding and bonding parameters. Various joining techniques were evaluated until a soldering method capable of producing a robust and reliable connection between the optical fiber and steel rail was identified. The resulting joints were subjected to mechanical tests, like vibrations, temperature-cycle, and impact testing to ensure long-term reliability under real-world rail conditions.

Following successful joint testing, a minimal design incorporating the optimal joining method and sensor configuration was assembled and installed on a test rail. This preliminary validation confirmed the soundness of the design choices and enabled progression to the development of a full prototype.

The architecture of the complete monitoring system was defined, including all necessary hardware and software components for data acquisition and transmission. Production and installation procedures were optimized to ensure repeatability and scalability.

The final prototype was manufactured and installed in an operational railway environment. Field trials were conducted to assess the sensors’ responses to load and temperature variations. Experimental results demonstrated the system’s effectiveness in detecting rail deformations and potential defects, representing a

significant advance in infrastructure safety, enabling predictive maintenance and reducing the human and financial costs of derailments.

Early in the PhD program, a parallel investigation examined the coefficient of friction (COF) of aluminium-alloy samples at ≈500 °C, varying speed and lubrication. Findings illustrate how these parameters influence high temperature forming processes, offering guidance for more efficient, precise aluminium shaping in industrial applications. The aluminium COF study contributes to optimized hot-metal gas forming techniques, with broader relevance to high-temperature manufacturing.