POLITECNICO DI TORINO

ABSTRACT

DEPARTMENT OF APPLIED SCIENCE AND TECHNOLOGY

Thesis for the degree of Doctor Philosophy

DESIGN, PROCESS AND CHARACTERIZATION OF INNOVATIVE SMART COATINGS FOR HARSH ENVIRONMENTS

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The presented PhD dissertation refers, as summarized in the title, to the study and design of innovative "smart" coatings for devised applications in harsh environments, such as oil&gas industries, aerospace and marine. The "smart" feature relies on the fact that the coatings are equipped with sensors and sensing materials to foresee their degradation at an early stage. The coating materials investigated in this work have been Glass Fibre Reinforced Polymers (GFRPs), whereas optical fibre sensors (OFSs) have been the main type of sensor analysed, experimentally developed and tested.

The experimental activity carried out during has followed five research lines: (i) epoxy preparation and characterization (for subsequent fabrication of GFRPs), (ii) fabrication of optical fibre sensors (OFSs), (iii) degradation tests of epoxy and GFRPs samples containing embedded OFSs, (iv) study of chalcogenide optical fibre sensors, and (v) study of Carbon Nanotubes (CNTs) electrical-based sensors.

The thesis begins with a chapter (chapter 2) about the state-of-art on GFRP composites in oil & gas industries and the use of OFSs to detect the moisture diffusion in GFRPs. The state-of-art remarks the main features that sensors for GRFP must have. In particular, they must be non-destructive, and they must be able to operate remotely and in real-time. These requirements support the idea of developing new low-cost OFSs for monitoring the ageing of composites. The main features of OFSs, such as their immunity to radiofrequency interferences and intrinsic fire safety, are put into the context of oil&gas, where conventional electric-based sensors may give remarkable limitations in terms of remote operation, embedding and reliable operation in harsh environments.

Chapter 3 reports the details (materials, setups and methods) on the experimental activity on the different research lines. Subsequently, chapter 4 reports and summarize the outcome of several experiments that were performed for each research line.

In a material engineering science framework, epoxy samples were fabricated and characterized to develop and optimum curing procedure and asses mechanical/thermal/chemical properties. Meanwhile, novel OFSs were designed, fabricated and embedded in epoxy and GFRP samples. The OFSs were produced from commercial multimode fibres by etching the cladding - to make the fibre sensitive through the evanescent field and depositing a reflective silver surface on the fibre tip –to make the sensors working in reflection, so that they could be used as probes and reduce failures during the embedding process.

One issue of the OFSs based on silica is their employment at infrared wavelengths, which are a range of the electromagnetic spectrum very interesting for chemical sensing. Therefore, chalcogenide fibre sensors were investigated to overcome the limitations of silica glass fibres. Chalcogenide optical fibres were manufactured and used as sensors to monitor epoxy-curing reactions as well as diffusion of water and ethanol. This research has highlighted interesting features on the process of total polymer conversion.

Another activity focused on Carbon Nanotubes (CNTs), which were used as an alternative to OFSs to monitor the diffusion of water in epoxy and epoxy composites. As a proof-of-concept, the combined sensors were used to detect in situ and in real-time the diffusion of water in composites. Proof-of-concept experiments demonstrated that both types of sensors (CNTs and OFSs) were successfully able to detect the water diffusion through the epoxy matrix.

The last technical section, chapter 5, reports an outlook of the possible technology transfer of this research toward a commercial product or service. Market analysis, economical estimations and a tentative business plan for the industrialization and commercialization of OFSs and "smart" GFRPs are discussed.

In summary, this PhD thesis provides experimental hints on three different sensors that can be embedded in a GFRP composite to monitor its degradation caused by the diffusion of chemicals. This study opens up to the realization "smart" composites structures, such as pipelines and storage tanks used in the oil and gas sector, for effective and efficient maintenance routines.