Innovative smart composite coatings endowing antimicrobial properties to several materials

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The issue of bacterial colonization and proliferation has consistently attracted research attention, especially with the ongoing development and spread of bacteria and microorganisms resistant to traditional therapies or antibiotics. This concern impacts various aspects of human life, as well as environmental safety.

The aim of this thesis is to develop a ceramic/glass matrix composite coatings containing silver nanoparticles (AgNps), that exhibit antibacterial properties suitable for diverse applications in numerous fields. The radio-frequency (RF) magnetron sputtering technique was utilized for depositing these coatings, offering the advantage of applying thin layers on a wide range of substrates, from metallic to polymeric materials, without causing damage. Furthermore, the process parameters can be easily optimized to obtain coatings with varied compositions and properties tailored to specific application requirements.

This research focused on developing antibacterial composite coatings intended for three primary applications: air filtration systems, water filtration systems, and textiles in the automotive sector.

The employment of antibacterial composite coating in air filtration systems aims to reduce or prevent the growth of microorganisms and bacteria on filter surfaces, which could be promoted under specific temperature and humidity conditions. The developed coatings, constituted by silica or zirconia matrix embedding silver nanoclusters, as antibacterial agents, were applied onto metallic, glass fibre-based, and polymeric air filters. They were comprehensively characterized in terms of composition, morphology, and structure.
Antibacterial analyses, performed against *S. epidermidis* and *E. coli*, Gram-positive and Gram-negative bacterial strains, and against *C. albicans,* a fungal species, revealed strong bactericidal and fungicidal properties of the coatings. Moreover, the coatings retained their bactericidal effectiveness even after thermal regeneration treatments, allowing for potential reuse following sterilization processes.
In collaboration with Università di Torino, antiviral tests were carried out, revealing that the coatings effectively inactivate strains of Human Coronavirus (HCoV-OC43), Human Rotavirus (HRoV), Influenza A virus (Flu A H1N1), Human rhinovirus (HRhV A1), and Respiratory Syncytial Virus (RSV A2).

In addition, composite coatings with a silica matrix containing copper or zinc nanoparticles as antibacterial agents were studied, which did not demonstrate antibacterial efficacy.

Bactericidal composite coatings could be also involved in water filtration systems, aiming to reduce the use of chemical products and minimize waste. To achieve this goal, ZrO2-based coatings with embedded silver nanoparticles were developed for deposition on highly thermosensitive polymeric filter membranes. The process parameters and deposition time were optimized specifically for this application to prevent substrate damage and ensure robust antibacterial properties.
The coatings successfully inhibited the proliferation of *S. epidermidis* bacteria. However, their hydrophobic nature was found to slow down the filtration processes.

In collaboration with the CRF-FCA company, an attempt was made to develop antibacterial transparent composite coatings for use in automotive textile applications. The objective was to create coatings that maintain the original color of the substrate while providing antibacterial activity. Process parameters were optimized, and deposition times were minimized.
The resulting coatings, despite containing low silver content, successfully inhibited the proliferation of *S. epidermidis* bacteria. However, they did not meet the project's requirement for complete transparency.

This thesis aims to explore alternative technologies to magnetron sputtering for developing antibacterial composite coatings consisting of a silica matrix embedded with silver nanoparticles. To achieve this, a study involving a silica coating derived from the transformation of a pre-ceramic polymer, perhydropolysilazane (PHPS), is proposed. The kinetics and mechanisms of polymer transformation were investigated using FT-IR analysis under various conditions.

Silver nanoparticles were synthesized in situ by reducing silver nitrate through UV light irradiation. Morphological analyses indicated that the resulting coating exhibited a dense and compact structure. However, this structure hindered the release of silver ions, which consequently rendered the coating ineffective in inhibiting bacterial proliferation.