Development of complex nanometric structures for tailoring the shielding and rheological properties of cement-based mixtures used in the 3D printing technology

3D printing, also referred to as Additive Manufacturing (AM), is a technology which builds the physical components of a three-dimensional object in a layer-by-layer manner, without any formwork support or vibrational processes. Complex geometries, such as three-dimensional structures with undercuts or cavities, are typically impossible to manufacture with conventional technologies like milling, turning or casting, or are only possible at disproportionately high costs. Now, any shape that can be constructed in a 3D CAD program can be produced with additive manufacturing technology. . In recent years, there has been a substantial interest in 3D printing with cement-based composites, with particular interest focusing on special applications such as the production of heat-resistant and shielding elements for hospitals, safety, protective and nuclear facilities.

Concretes for AM technologies differ noticeably from castable concretes due to significant contribution of fine fractions of materials and lack of coarse aggregate. The rheological properties of 3D concrete mixtures are critical aspects of 3D printable composites, such that even a small modification in the mixture can cause extrusion problems for a 3D printer. Nanomaterials, due to their spectacular chemical reactivity and beneficial effects on rheological properties, were found to be extremely suitable to be used in printable mixture formulations.

To produce radiation shielding elements incorporation of nanosized admixtures was found to have spectacular effects. However, most of the heavy-weight additives have extremely low binding ability with cement matrix and affect negatively the rheological properties of composites. Therefore, an important question arise:

How can one improve the immobilization of nanoparticles used for radiation shielding, within the cement matrix, to make them suitable for 3D printing applications?

The solution to this problem is the introduction of novel additives to cementitious composites, such as molecular hybrids (complex nanostructures), which make it possible to tailor (control) the properties of printable composites. To date, there exists no knowledge regarding additives for improving the radiation shielding properties of 3D printable concrete. This project is therefore the first of its kind in the field.

The aim of this project is to develop a lead-free complex nanostructure, for tailoring the shielding (gamma and neutron) attenuation and rheological properties of cement-based mixtures suitable for 3D printing. To achieve this goal through a bottom-up approach, a nanostructure composed of bismuth oxide (Bi_2O_3), gadolinium oxide (Gd_2O_3) and silicon oxide (SiO_2) will be developed.

The overall objective of this work is to combine materials containing the high electron density (high Z) needed for gamma attenuation (Bi_2O_3) and the high interaction probability required to slow neutrons (Gd_2O_3), with a material which will improve their immobilization within the cementitious matrix (SiO_2). By adjusting the nano-SiO_2 content (layer thickness) in the nanostructure, the rheological properties of a printable mixture can be optimized (controlled).

To understand the effects of synthesized complex nanostructures extensive research plan will be implemented including hydration, rheological, mechanical and thermal resistance studies of printable material. Moreover, 2D and 3D imagining techniques such as X-ray micro-computed tomography will be applied in order to understand the effect of produced nanostructures on the microstructural characteristics of the printed elements. This will allow to understand how nanoparticles modifies the microstructure of composite and affects the pore structure inside the specimen. At the end comprehensive experimental and theoretical evaluations of the gamma-ray and neutron attenuation of printed elements will be performed. Based on the obtained results it will be possible to understand what is the most optimal synthesis process of nanostructure as well as what is the optimal content of nanostructure which is beneficial for improving the radiation shielding and thermal resistance of printable composites.

A fundamental scientific understanding of the relationships between design, materials, processes and the printable material will be established through the proposed research plan. As such, one of the outcomes of the project will be the development of a complex multifunctional additive for 3D printable cementitious composites.

Proposed research project will be implemented by an interdisciplinary and international research group composed of experts in the fields of rheology (Germany), radiation shielding (Saudi Arabia) and micro-computed tomography (South Korea).