

Determination of the mechanical properties and gamma-neutron shielding effectiveness of ultra-high performance dense concrete (UHPdC) exposed to high temperatures

Abstract

Nuclear energy is integral in producing energy with net-zero emissions but widening its adoption requires advanced radiation shielding material. While concrete is widely used as radiation shielding material, there is a lack of study on shielding using ultra-high-performance concrete (UHPC) despite it being the most advanced concrete material to-date. This study delves into the mechanical properties and the shielding capabilities of denser UHPC (ultra-high-performance dense concrete, UHPdC) against both gamma-rays and neutron radiation, particularly under high-temperature scenarios. Three mixtures of UHPdC are composed of sand, barite, and magnetite, separately, with a common incorporation of colemanite, steel and polyvinyl alcohol (PVA) fibers. These mixtures are subjected to temperatures of 400 and 800 °C, assessing their microstructural changes via X-ray μ -CT analysis, mechanical strength, and their gamma-rays and neutron shielding properties. Key findings revealed that sand UHPdC exhibited the highest compressive strength of 131.0 MPa, while magnetite UHPdC showed superior shielding against neutron radiation and gamma-rays emitted by Co-60, demonstrating enhanced effectiveness of more than 17 % and 12 %, respectively, compared to other types. The durability of magnetite UHPdC was notably robust up to 400°C, attributed to the thermal stability of its iron oxide content. However, at 800°C, all variants exhibited diminished shielding properties, likely due to degradation of neutron moderators and absorbers at the lower temperature. This research underscores the potential of UHPdC, especially magnetite-based, as a formidable material in nuclear infrastructure, capable of withstanding extreme conditions while providing effective radiation shielding. In addition, future studies should focus on the optimizing mix designs of UHPdC to mitigate the impacts of high temperatures, thereby enhancing the structural integrity and longevity of nuclear facilities.

Keywords

Gamma-rays; Heavyweight aggregates; High temperatures; Neutrons; Radiation shielding; Ultra-high-performance concrete (UHPC)