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Temat rozprawy doktorskiej: „Opracowanie materiału na bazie spoiw o obniżonym śladzie węglowym o odpowiednich właściwościach reologicznych umożliwiających drukowanie prefabrykowanych elementów budowlanych metodą addytywną"

Title of the doctoral dissertation: "Development of a binder-based material with reduced carbon footprint and suitable rheological properties to printing of prefabricated building components"

Streszczenie/ Summary

Amid steadily rising demand for concrete and mounting pressure to reduce greenhouse gas emissions- driven primarily by the energy-intensive production of Portland cement- there has been a marked intensification of research into material and process solutions with a reduced carbon footprint. One development pathway is 3D Concrete Printing (3DCP), which shows potential to shorten construction timelines, minimize waste, and enable the freeform shaping of complex geometries. However, mixes used in 3DCP are typically highly emissive due to the dominant share of Portland cement in their composition.

The aim of this study was to develop and assess a baseline concrete mix for 3DCP based on Portland cement, and subsequently to verify the feasibility of modifying it with secondary raw materials in order to improve both environmental metrics and functional performance.

The research methodology comprised three stages: (I) development and validation of the baseline mix design and fresh-state characteristics, selection of process parameters (extrusion efficiency, print speed, nozzle diameter), and the design of a printhead and test stand; (II) comparison of the mechanical and physical properties of elements produced by 3D printing with conventionally cast specimens, including analysis of anisotropy and the influence of printing strategy on mechanical parameters of the printed elements; (III) verification of composition modifications through the addition of waste-derived raw materials and lightweight aggregates, along with an assessment of the potential environmental benefits of such solutions.

The study yielded a reference mix for 3DCP and process parameters that ensured high repeatability of results. Comparative analysis showed that printed elements exhibited lower mechanical strength than traditionally cast specimens, with anisotropy particularly pronounced in flexural strength and exacerbated by prolonged interlayer intervals. The designed wall assemblies enabled enhanced thermal insulation by controlling the fraction of load-bearing material. Introducing recycled constituents allowed the rheological properties to be maintained at a level ensuring printability, but led to reductions in mechanical performance (especially flexural strength). The use of

lightweight aggregates decreased the thermal conductivity of the elements by up to 70% compared to the reference values. Material modifications also enabled a reduction in the carbon footprint by approximately 50% relative to the baseline mixture.

The results confirm the technical feasibility of producing precast components via 3DCP using mixes modified with secondary raw materials, while highlighting their considerable potential for decarbonizing construction. At the same time, the need to account for reduced load-bearing capacity and heightened anisotropy in structural design was identified. Optimization of process parameters (print speed, nozzle diameter, interlayer waiting time and mix constituents (recycled materials, lightweight aggregates) should therefore be tailored to the intended function of the element (load-bearing versus insulating), to balance mechanical requirements with environmental objectives.

The developed research infrastructure and the set of established metrics provide a foundation for further work on low-emission 3D concrete printing technologies.