

Popular science project summary

The civilizational progress of the past two centuries has brought humanity numerous benefits, including an improved standard of living, but also new threats to the environment and future generations. Among the most important challenges associated with economic development is the increasing consumption of natural resources, access to which, especially high-quality deposits, is becoming more limited due to intensive exploitation. For this reason, it is crucial to seek solutions that enable the reuse of waste materials (recycling) and their conversion into higher-value, functional products (upcycling). One example of an underappreciated waste resource is lignin, produced in pulp and paper mills as well as biorefineries. Most commonly, lignin is burned on site as a fuel to generate the energy required for industrial processes. However, lignin is a biopolymer with significant potential, which can be successfully applied in other fields. In this project, it will serve as the organic component of innovative hybrid admixtures for sustainable cementitious composites.

A second key challenge is the growing problem of air pollution. According to the World Health Organization, as much as 99% of the world's population breathes air in which pollutant levels exceed recommended standards. Residents of low- and middle-income countries are particularly vulnerable, where concentrations of harmful substances such as particulate matter, ozone, carbon and nitrogen oxides, sulfur dioxide, and volatile organic compounds are especially high. These pollutants can cause serious respiratory and cardiovascular diseases. The air pollution problem requires actions in two main areas: (i) reducing emissions to the atmosphere through modern technologies, reduced consumption of resources and energy, and the use of pollutant capture systems; (ii) removing contaminants already present in the environment, for example by decomposing them into substances safe for humans and the environment. The project focuses on construction materials, as the production of Portland cement involves enormous energy consumption and is responsible for about 8% of global CO₂ emissions related to human activities. The project thus aims to develop more durable building materials with new, desirable properties.

To achieve this, lignin obtained directly from pulp and paper mills and biorefineries will be appropriately modified to enhance its function as a plasticizing admixture for cement mortars, as well as to improve its ability to interact with the inorganic component in the hybrid system. This inorganic component will be nanometric titanium(IV) oxide, specially modified to achieve photocatalytic activity in both the ultraviolet and visible light ranges. The combination of TiO₂ and lignin in the hybrid material will be carried out using an environmentally friendly mechanochemical method. This will also address the issue of nanoparticle aggregation and agglomeration, which typically deteriorate the properties of cement composites. The obtained hybrid materials will undergo comprehensive characterization using available research methods and measurement techniques, such as Fourier-transform infrared spectroscopy, scanning electron microscopy, thermogravimetric analysis, particle size measurement, and zeta potential analysis as a function of pH.

In the next stage, the developed lignin-based hybrid admixtures will be used in cementitious composites, including those with reduced carbon footprint, where a portion of Portland clinker is replaced with mineral additives (fly ash, blast furnace slag, silica fume). The aim will be to evaluate the impact of these admixtures on the properties of both fresh and hardened cement mortars, including rheology (e.g., workability), compressive and flexural strength, microstructure, and porosity. Special attention will be given to the functional characteristics of the new materials, such as their ability to remove air and water pollutants and to inhibit the growth of microorganisms, which translates into improved resistance to microbiological corrosion. Durability tests of the obtained composites will also be carried out, focusing on their long-term performance under environmental factors, including freeze-thaw cycles, CO₂ exposure (carbonation), and ultraviolet radiation.

As a result, the project will deliver sustainable cementitious composites with new functional properties, achieved through innovative hybrid admixtures containing waste lignin. These advanced materials may significantly contribute to the development of sustainable construction, with the resulting structures serving many generations while reducing their environmental impact. The project will be conducted at Poznan University of Technology, within the Faculty of Chemical Technology and the Faculty of Civil and Transport Engineering, as well as in international collaboration with the Czech Technical University in Prague. Thanks to access to state-of-the-art research facilities and the extensive experience of the scientific team, the project is guaranteed to be implemented on time and at the highest scientific level.