Eco-efficient binders obtained from the thermal activation of cementitious materials

Summary

In the move toward sustainable construction, research has been carried out in recent years with the aim of reducing the economic and environmental impact of the sector. Concrete, still the most common structural option, accounts for an excessive amount of CO_2 emissions from its mainstream binder, cement, extensive resource depletion, and generation of large volumes of construction and demolition waste. Since cement manufacture represents more than 80 % of CO_2 emissions in concrete production, more sustainable solutions must involve the development of new low-carbon binders. The binders developed in this PhD thesis explore the possibility of recovering the hydraulic properties of existing hydrated cementitious products by re-applying a thermal load at much lower temperatures than those employed in the sintering of clinker from natural raw materials. In fact, by keeping reactivation temperatures below 700 ºC, decarbonation of limestone (a stage responsible for over 60% of total emissions) is thus avoided. Therefore, recycled thermoactivated cement (RC) can simultaneously tackle the main issues faced by the concrete industry, which other low-carbon binders cannot.

The cementitious fraction was extracted from concrete waste using a novel magnetic separation method. Afterwards, RC was thoroughly characterised to determine optimal thermal activation conditions, including phase evolution and microstructural development. Pastes and mortars containing RC were assessed in both fresh and hardened states. Concrete with RC was characterised in terms of mechanical properties (compressive strength, splitting tensile strength, elasticity modulus, shrinkage) and durability factors (main transport properties, the carbonation resistance and the chloride penetration resistance). Following technical validation, the eco-efficiency of RC production was assessed. The magnetic separation yielded an 80% pure cementitious fraction and high-quality recycled sand with under 3% adhered paste. RC is primarily composed of α'_H-C_2S and reacts mainly within 1-3 days. Upon hydration, it forms a dual microstructure, yielding a finer texture than comparable CEM I 52,5 pastes. While RC's porous nature and high surface area require more water, workability is not much affected, up to 30% RC in mortars and 15% RC in concrete. Composite cements mixing CEM I 52,5 with 20% and 50% RC meet EN 197-1 strength classes 52.5 and 32.5, respectively. Concrete retains mechanical performance with up to 40% RC. Chloride and carbonation rates in concrete are mostly unaffected with RC, while capillary absorption and oxygen permeability are reduced beyond 30% RC. RC production can be 30% less energy-intensive, emit only 20% of CO_2 compared to clinker, and show a 50% reduction in most environmental impact categories in a cradle-to-gate analysis.

Outputs: 12 papers in ISI journals; 3 papers in international conferences; 1 paper in a national journal; 6 papers in national conferences; 2 book sections and 1 webinar.

Keywords

Eco-efficient binders, recycled thermoactivated cement, eco-efficient concrete, low-carbon.

Recycled cement production and use in a closed-circular economy cycle that tackles the main issues faced by the construction and concrete industries.

PhD student
Ana Chambel da Silva Carriço

PhD program
Civil Engineering (IST, University of Lisbon)

Supervisor
José Bogas (CERIS, IST, University of Lisbon)

Co-supervisor
Mafalda Guedes (IPS, Polytechnic Institute of Setúbal)

Period
2019-2024

Funding
FCT scholarship (SFRH/BD/146033/2019)