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Editorial

New Frontiers in Cementitious and Lime-Based Materials and Composites

Cesare Signorini [1,*], Antonella Sola [2], Sumit Chakraborty [3] and Valentina Volpini [4]

[1] Institute of Construction Materials, Technical University of Dresden, Georg-Schumann-Straße 7, 01187 Dresden, Germany
[2] Manufacturing Business Unit, Commonwealth Scientific and Industrial Research Organization (CSIRO), Research Way, Clayton, VIC 3168, Australia; antonella.sola@csiro.au
[3] Department of Civil and Structural Engineering, University of Sheffield, Sheffield S1 3JD, UK; sumit.chakraborty@sheffield.ac.uk
[4] Interdepartmental Research Centre "En&Tech", University of Modena and Reggio Emilia, P.le Europa 1, 42124 Reggio Emilia, Italy; valentina.volpini@unimore.it
* Correspondence: cesare.signorini@tu-dresden.de; Tel.: +49-351-46336565

Abstract: Cement and lime currently are the most common binders in building materials. However, alternative materials and methods are needed to overcome the functional limitations and environmental footprint of conventional products. This Special Issue is entirely dedicated to "New frontiers in cementitious and lime-based materials and composites" and gathers selected reviews and experimental articles that showcase the most recent trends in this multidisciplinary field. Authoritative contributions from all around the world provide important insights into all areas of research related to cementitious and lime-based materials and composites, spanning from structural engineering to geotechnics, including materials science and processing technology. This topical cross-disciplinary collection is intended to foster innovation and help researchers and developers to identify new solutions for a more sustainable and functional built environment.

Keywords: cement; lime; sustainable materials; fibre-reinforced composite; recycled aggregates

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Citation: Signorini, C.; Sola, A.; Chakraborty, S.; Volpini, V. New Frontiers in Cementitious and Lime-Based Materials and Composites. *Crystals* **2022**, *12*, 61. https://doi.org/10.3390/cryst12010061

Received: 9 December 2021
Accepted: 21 December 2021
Published: 4 January 2022

Cement and lime have been the predominant binders in the construction sector since ancient times, owing to their worldwide abundance, affordability, and well-established physical and mechanical performance. By tuning the relative amounts of binders with aggregates, water, and additives, a variety of conglomerates can be designed to address specific service requirements. Cement and lime-based conglomerates range from fine-grained mortars for plasters to structural concrete with or without fibre reinforcement for buildings, bridges, tunnels, pavements, girders, precast members, walls, screeds, etc.

Prompted by the necessity of developing smart and reliable infrastructures and more energy-efficient urbanised areas, new frontiers are opening to identify viable materials and methods with the inclusion of industrial by-products, alternative aggregates, and natural reinforcements [1]. The partial or total replacement of conventional cement and virgin mineral aggregates is pivotal to reducing the environmental issues and carbon footprint of customary conglomerates, since the conventional manufacturing chain is known to require a substantial amount of energy and resources. Further, intensive investigation is under-way to formulate novel inorganic composite materials for lightweight precast elements and for strengthening laminates, which are expected to transform present-day approaches to the preservation and restoration of historical buildings and architectural heritage [2–4]. As new materials with embedded functionalities are being proposed every day, scientists gain a deeper understanding of the relationship existing between composition, manufacturing, and in-service behaviour of cementitious and lime-based materials and composites.

This Special Issue aims to shed light on the latest research outcomes in this multidisciplinary field, spanning through the vast areas of structural, geotechnical, and environmental engineering, mineralogy and materials science, nanotechnology, fibre and textile technology, and design criteria. The high-quality peer-reviewed contributions gathered in this Special

Issue include both experimental papers, which discuss lab-based activities and/or theoretical modelling, as well as review articles that extensively analyse the state-of-the-art within specific fields of interest. The topics covered in this Special Issue include fibre-reinforced composites (e.g., textile-reinforced mortar/concrete (TRM/TRC) [5,6] and fibre-reinforced concrete (FRC) [7,8]), sustainable cementitious conglomerates where the ordinary Portland cement (OPC) binder is replaced by recycled by-products [9] (silica fume, kiln ashes, biochar, slag, biomass ashes, geopolymers, alkali-activated concrete, etc.), with the possible implementation of self-healing properties. In addition, studies regarding the incorporation of recycled aggregates providing concrete with increased eco-compatibility and additional functional properties, such as thermal and acoustic insulation, are also presented [10,11]. Moreover, durability is a key issue, especially for emerging materials whose behaviour in the long run is still unknown. Long-term stability is still the subject of debate for some of the recycled constituents, such as plastic fibres coming from low-grade sources, and also for composite systems in which the unoptimised interphase between the reinforcement and the surrounding inorganic matrix may represent the weakest link [12,13]. Reliability becomes critical in harsh environmental conditions, e.g., in coastal areas or underground applications [14]. Therefore, updated guidelines are sought to regulate the safe usage of these structural materials.

In this Special Issue, readers will find a wealth of information regarding existing literature and emerging research in all areas of cementitious and lime-based materials and composites, as summarised in the following paragraphs.

- Glass-fibre reinforced cement (GRC) panels may be superimposed on existing precast concrete (PC) walls for decorative and structural purposes. However, the GRC layer is likely to crack and break off as a consequence of the different shrinkage that GRC and PC experience due to changes in temperature and humidity, especially in outdoor settings. As proven by Chen et al. [15], adjusting the formulation of the GRC is key to reducing the shrinkage mismatch, with the addition of rubber powder, expanding agent, and metakaolin being advantageous to minimise the internal porosity and improve the compactness of the mortar structure. Additionally, a smooth GRC-PC interface is is useful for increasing the crack resistance as compared to a rough interface;
- In principle, the addition of end-of-life tyre (ELT) rubber can improve the mechanical properties of concrete, thus offering a viable approach to valorising this type of waste material. Nonetheless, the actual reinforcing effect is often undermined by the weak cementitious matrix–rubber interaction. The contribution by García et al. [16] compares different surface treatments aimed at improving the performance of concrete–ELT rubber composites. The experimental outcomes identify hydration as the most favourable treatment, as it makes it possible to add up to 5% ELT rubber (with respect to the aggregate weight) without compromising the design strength. The adoption of a pozzolanic Portland cement, with local (Chilean) fly ash waste, also contributes to these promising results;
- The paper by Li et al. [17] investigates the structural behaviour of concrete joints, where an on-site cast concrete element is jointed with a precast wall. An extensive experimental activity accounts for the role played by (*i*) the strength grade of the concrete mixtures, (*ii*) the interface between precast and on-site cast concrete elements, and (*iii*) the storage time for the precast element. Remarkably, it is observed that the mechanical behaviour of the joints benefits from the higher strength of the on-site cast concrete. Moreover, interface roughness is beneficial to the mechanical behaviour of the whole joint. The paper is mainly centred on structural issues and provides some interesting design inputs that can be successfully implemented in the practice;
- The contribution by Yao et al. [18] presents an experimental research on hybrid fibre-reinforced concrete specifically designed to manufacture vertical shafts, which are frequently found in coal mining to create the load-bearing structure of tunnels for the movement of operators, ventilation, and drainage. As expected, these structural ele-

ments are exposed to extremely harsh environmental conditions, which may represent a challenge for the adoption of newly designed composite materials. For this reason, the paper by Yao et al. [18] thoroughly investigates the long-term performance of a new cement-based composite system based on the synergistic interaction of polyvinyl alcohol and polypropylene-steel hybrid fibres. It is found that the combination of these two kinds of fibres enhances the impermeability of the wall, thus bringing in superior resistance to corrosion and freeze-thaw cycles;

- Al-Ameri et al. [19] discuss the residual strength to impact of concrete subjected to thermal ageing. This topic is of particular interest because the greatest part of the available literature elaborates on the resistance of concrete to fire and heat, whereas just a few papers address the resistance to high-rate loading, i.e., blast or impact. These loading conditions may be regarded as extraordinary, nonetheless the vulnerability of structures to dynamic loading is dramatically brought to light when disastrous events occur. Remarkably, according to the experimental work conducted by Al-Ameri et al. [19], thermal ageing has a deleterious effect on the capacity of concrete to withstand impact loading, especially for temperatures higher than 100 °C, as a consequence of the weight loss experienced by the conglomerate;
- The review by Almajed et al. [20] provides a detailed summary of the existing techniques for soil bio-stabilisation. As opposed to chemical and mechanical methods, bio-stabilisation techniques use either bacteria or enzymes to induce calcite precipitation and, hence, to bind and consolidate the soil grains. Bio-stabilisation is environmentally friendly, sustainable, and conducive to remediation of soil contamination. In addition to a survey of the published literature, the paper details practical guidelines for implementing different bio-stabilisation strategies in the field, according to specific site conditions;
- Pertaining to the geotechnical field, the review paper by Gudla et al. [21] explores the viability of granite dust as a soil stabiliser. Although granite dust comes from the processing of natural aggregates, disposing of this kind of industrial by-product is particularly challenging and poses severe issues for the environment. In addition, the pros and cons of using granite dust are thoroughly discussed, alongside some specific technological aspects, such as the interaction with weak soils and the choice of the optimal dosage in different applications;
- Song et al. [22] investigate the variability of the mechanical behaviour of coastal cemented soil for foundations as a result of the addition of iron tailings and nano-silica. Since nano-silica establishes a stable bond with clay, the addition of small amounts of nano-silica is sufficient to sharply increase the mechanical properties of cemented soils. On the other hand, the addition of iron tailings up to 20% improves the strength and stiffness of cemented soils. However, if the filler loading exceeds the 20% critical threshold, the material becomes extremely porous, with detrimental effects on the mechanical strength. This experimental study is particularly useful to foster understanding on how coastal cemented soils may attain satisfactory properties for real-scale applications;
- Zhang et al. [23] focus their attention on high-strength concrete and give an insight into its complex constitutive relations and failure behaviour under different stress states, both experimentally and numerically. Firstly, Zhang et al. [23] conduct conventional triaxial compressive tests on different high-strength concrete samples, and analyse the failure modes as a function of the applied confining pressure. Secondly, the experimental findings are discussed according to a statistical damage constitutive model based on the thermodynamic theory. The model accurately captures the stress-strain response of the tested samples and proves to be a useful tool to describe the performance of high-strength concrete;
- The substitution of natural coarse aggregates (NCAs) with recycled concrete aggregates (RCAs) in building materials represents a potential solution to improving the sustainability of the construction industry. Makul et al. [24] examine the state of the art on this subject and thoroughly analyse the performance of the composite material

as a function of source, type, or chemical and physical characteristics of the RCAs, as well as composition of the mixture, water content, curing conditions, and several other parameters. Makul et al. [24] also outline the open issues and future research that must be carried out to optimize the design of "green" composites. In conclusion, RCAs are a valuable resource that can be safely employed in traditional concrete, but their uptake to produce high-performance structural concrete, which must meet stringent mechanical standards, still requires additional efforts;

- As demonstrated by Vasovic et al. [25], the addition of cement to lime mortar makes it possible to effectively protect the cultural heritage, speeds up the restoration process, improves the materials' compatibility, and enhances the mechanical properties of mortar. Interestingly, Vasovic et al. [25] report that the presence of 20 wt% white Portland cement to replace lime and the reduction in the water-to-binder ratio, in combination with the incorporation of an air-entraining agent in air lime mortar, increase the strength of mortar without influencing the permeability. However, further research is sought to optimize the exact replacement of lime, evaluate the microstructural changes, and identify the compatibility of the blended cement-lime mortar in the masonry unit;
- Considering the climate emergence and and the increasing need to develop new cementitious materials, Landa-Ruiz et al. [26] put forward an interesting technical solution that uses sugarcane bagasse ash (SCBA) in combination with silica fume (SF) for the partial replacement of cement. Since several factors are relevant for developing new binder materials as an effective alternative to Portland cement, Landa-Ruiz et al. [26] consider three different variables, namely, (*i*) physical, mechanical, and durability properties of the concretes; (*ii*) CO_2 emissions; and (*iii*) recycling of waste materials. The use of eco-friendly ternary blend concretes prepared with 50% SCBA and SF leads to a resistance of 20.09 MPa at 180 days, significantly reduces the CO_2 emissions caused by Portland cement, and promotes a culture of waste recycling;
- Concrete cracking is an inevitable phenomenon and incorporating autogenous healing capability is a new branch of science that offers endless research scope. Luo et al. [27] consider the self-healing capacity of concrete prepared using several supplementary cementitious materials, such as fly ash (FA) and blast furnace slag (BFS), and cured in different conditions, reporting that the highest self-healing efficiency is found for water-incubated specimens. Additionally, BFS-based concrete shows better healing efficiency than FA-based concrete. The microstructural analysis demonstrates that the prime healing product, with and without supplementary cementitious materials, is micron-sized calcite crystals with a typical rhombohedral morphology. However, in-depth analysis is still needed to clarify the complete self-healing process.

Author Contributions: Conceptualization, C.S., A.S., S.C. and V.V.; resources, C.S.; writing—original draft preparation, C.S.; writing—review and editing, A.S., S.C. and V.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: A.S. is supported by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Research Office through the "Science Leader in Active Materials" grant.

Conflicts of Interest: The authors declare no conflict of interest.

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