sustainability

Editorial

Advanced Concrete and Construction Materials for Sustainable Structures

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1. Introduction

Innovation in structural engineering has sparked remarkable advancements in the building materials sector and the construction industry in general [1,2]. Within this dynamic landscape, the traditional perception of concrete as a static, unchanging material has given way to a dynamic field marked by continuous innovation. The definition of durable and sustainable concrete has evolved over time, mirroring the shifting paradigms in modern construction. Today, sustainability is at the forefront of concrete science [3], driving the search for materials that not only meet the demands of construction but also tread lightly on our environment [4].

The sustainability of cementitious construction materials has emerged as a paramount concern, commanding the attention of researchers, engineers, and industry experts alike [5]. The production of cement accounts for approximately 8–10% of CO_2 emissions, thereby contributing to the global rise in environmental temperatures [6,7]. The imperative to reconcile the immense benefits of concrete structures with the pressing need to reduce their environmental footprint has catalyzed a wave of exploration into advanced concrete materials. These materials, collectively referred to as “advanced concretes”, are characterized by their transformative microstructures, alternative binders to traditional Portland cement, and innovative additives designed to enhance durability and safety and minimize environmental impact throughout the life cycle of structures [8].

Among the noteworthy innovations are sustainable cementitious materials like alkali-activated binders and calcium sulphoaluminate cement, which hold the potential to revolutionize construction practices by reducing the carbon footprint of concrete [9]. However, as these novel materials emerge, the imperative for further research persists. The journey towards their full potential necessitates the optimization and standardization of mix designs, grounded in precise specifications that can guide the construction industry toward sustainable solutions.

This Special Issue, titled “Advanced Concrete and Construction Materials”, aspired to provide a platform for groundbreaking research and critical reviews that transcend existing boundaries of knowledge in the field of advanced concrete construction materials. Embarking on this journey into the realm of advanced concrete and construction materials, we invited researchers, scholars, and industry professionals to contribute their expertise and insights. Our objective was to collect original research contributions that not only extend the frontiers of understanding but also pave the way for practical applications in the construction industry. Together, we aimed to shape the future of construction by harnessing the transformative potential of advanced materials and fostering a sustainable, resilient, and innovative built environment.

The scope of this collection of papers spans a wide spectrum of topics, offering a comprehensive exploration of cutting-edge developments in the field of construction materials. The studies delve into diverse facets of advanced concrete technology, addressing

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critical issues of sustainability, durability, and innovation. From enhancing the strength and durability of fly ash aggregate concrete through nanosilica incorporation to investigating the use of waste tires for reinforcing concrete columns under axial loads, these studies showcase innovative approaches that are reshaping the construction industry. Additionally, the collection delves into the world of numerical modeling and design methods for specialized cementitious composites, such as Polyvinyl-Alcohol-engineered cementitious composite beams. It evaluates the potential of water treatment sludge as a sustainable replacement for clay in fired clay bricks. Furthermore, topics like corrosion resistance, plant-based cementitious composites, the durability of alkali-activated slag concrete, and the use of biological agents like *Sporosarcina pasteurii* for sustainable construction materials expand the horizons of what is possible in construction technology.

The papers collectively highlight the urgency of advancing construction materials to meet the evolving demands of sustainability, resilience, and environmental responsibility in the construction industry. The research work presented in this collection paves the way for a more sustainable and efficient future in construction, addressing contemporary challenges while envisioning a more resilient and eco-friendly built environment. In the following section, we present a brief description of each of the ten articles in the collection.

2. Contributions

Azimi and Toufigh (Contribution 1) investigate the impact of incorporating slag into alkali-activated fly ash slag (AAFS) concrete. The study explores the mechanical properties, pore structure, and transport characteristics of AAFS concrete with varying slag content. Through unconfined compression and ultrasonic pulse velocity tests, it is observed that an increasing slag content improves the compressive strength, with the most significant enhancement occurring at a 20% slag replacement. The inclusion of slag leads to a noteworthy reduction in pore volume, particularly in gel pores, and an increase in surface area, indicating the presence of more geopolymeric products in AAFS gel. The microstructure of the AAFS gel is found to be more tortuous than the AAS gel, and the SEM/EDX analysis reveals the role of Ca ions in forming a highly compacted gel structure. Additionally, a higher slag content (up to 30%) significantly decreases transport properties due to microstructural changes. The study establishes an exponential relationship between ultrasonic pulse velocity (UPV) and compressive strength, highlighting the sensitivity of UPV to changes in compressive strength. Moreover, the research demonstrates that AAFS with equivalent strength levels exhibits a significantly lower water permeability compared to conventional concrete, emphasizing the influence of slag on pore structure modification. This paper offers valuable insights into the optimization of AAFS concrete by tailoring its composition to enhance both mechanical and transport properties.

The study of Peng et al. (Contribution 2) explores the enhancement of the strength and durability of cold-bonded fly ash aggregate (CFAA) concrete through the incorporation of nanosilica (NS). The study conducts various tests and analyses, revealing that the optimal NS dosage is 2 wt%, resulting in improved compressive and splitting tensile strength as well as early-age strength. NS's positive impact on the cementitious matrix reduces porosity but should be carefully dosed to avoid microscale deficiencies. Furthermore, the research demonstrates that CFAA concrete exhibits better resistance to carbonates than sulfates during dry–wet cycles, with NS mitigating deterioration in later cycles. Under freeze–thaw conditions, NS-modified CFAA concrete displays desirable spallation resistance and internal frost resistance but limited effectiveness against sulfate attacks. This study offers valuable insights for enhancing CFAA concrete's performance in harsh environments, encouraging future research into damage models and long-term performance under varying conditions.

Teymouri et al. (Contribution 3) experimentally investigate the durability of alkali-activated slag concrete (AASC) in a hydrochloric acid (HCl) environment, aiming to assess its potential as an eco-friendly alternative to conventional concrete. Thirteen distinct mix designs were explored, considering various parameters, including the type of alkaline solution, molarity, weight ratios, and alkali solution to slag ratios. After subjecting the samples to a six-month exposure in a HCl solution with pH = 3, visual inspections revealed that AASC had remarkable durability, contrasting with the substantial deterioration observed in ordinary Portland cement (OPC) concrete. The results underscored the superiority of AASC over OPC concrete in terms of HCl acid resistance, with AASC exhibiting minimal strength reduction and weight loss (one-tenth and one-fifth, respectively). Notably, samples activated with potassium hydroxide showed more pronounced strength reduction and weight loss than those with sodium hydroxide. The lower molarity of sodium hydroxide contributed to AASC's enhanced performance against acid attacks. Moreover, AASC samples with a $NaOH/Na_2SiO_3$ ratio of 1 demonstrated favorable durability compared to those with a ratio of three. The higher ratios of alkali solution to slag (0.6 compared to 0.4) resulted in increased strength reduction and weight loss. This study sheds light on essential mix design parameters for AASC in acidic environments, showcasing its potential as a durable and environmentally friendly alternative to traditional concrete.

Juárez-Alvarado et al. (Contribution 4) conducted a study on sustainable cementitious composites incorporating plant fibers and bio-aggregates to reduce environmental impacts. Four composites were examined: lechuguilla, flax-fiber-reinforced matrices, and wood and hemp shavings as bio-aggregates. The research encompassed nineteen mixtures, including control specimens, and evaluated the composites' hygrothermal, mechanical, and durability properties. Key findings include the adverse effect of fiber treatment on flexural strength in the lechuguilla and flax fiber composites, whereas untreated fibers and those with accelerated deterioration exhibited improved mechanical behavior. The presence of fibers increased porosity and reduced density, with flax fiber composites showing higher porosity due to the uneven fiber distribution. In addition, micrographs demonstrated no fiber embrittlement, with failure modes varying between untreated and treated fibers, impacting flexural and compressive behavior. Wood and hemp shavings' microstructures significantly affected the composites' physical and mechanical properties, with their high porosity reducing the overall compressive strength and bulk density. However, incorporating shavings improved hygrothermal properties, notably reducing thermal conductivity and achieving classification as moderate for moisture regulation efficiency.

The work of Ahmadi et al. (Contribution 5) explores the potential of using water treatment sludge (WTS) as a partial replacement for clay in fired clay brick production, aiming to address environmental concerns associated with traditional brick manufacturing processes. Various mixtures with WTS replacing clay in ratios ranging from 0% to 80% were investigated. The study revealed that an increase in WTS content led to improved plasticity and water absorption in the mixtures but resulted in decreased dry density and strength, particularly in unconfined compression strength. Higher WTS ratios also correlated with increased porosity and reduced bulk density. However, bricks containing up to 20% WTS and fired at 1000 °C exhibited enhanced properties suitable for moderate and severe exposure conditions. Efflorescence was primarily influenced by WTS content, and surprisingly, the firing temperature had minimal impact. Despite some reductions in strength, the research suggests that finding the right balance between WTS content and firing temperature holds promise for producing environmentally friendly bricks.

Khoshtina's review article (Contribution 6) explores the use of Sporosarcina pasteurii in sustainable construction through bio-cementation, inspired by natural calcium carbonate precipitation. While laboratory experiments demonstrate this process's potential, its practical application faces challenges due to process complexity and variable sensitivity. The review highlights bio-cementation's benefits in improving mechanical properties, reducing energy consumption, and lowering carbon footprint. Factors influencing bio-cementation include urease activity, environmental conditions, and application methods. Sporosarcina pasteurii shows robust performance, with enzymatic-induced calcium carbonate precipitation (EICP) proving superior to microbially induced precipitation (MICP) in some areas. However, MICP remains cost-effective. Particle granularity impacts bio-cementation outcomes. Promising research directions include repairing existing structures, interdisciplinary approaches, and employing numerical simulation models to advance this eco-friendly construction technique for a more durable and environmentally friendly industry.

The work of Mahat et al. (Contribution 7) explores a novel approach to tackling the environmental issue of waste tires by repurposing them in concrete columns. Recycled rubber tires are used as external reinforcements and formworks during concrete column construction, serving confinement functions. The experimental results show that these columns exhibit greater resistance to axial loads compared to traditional ones. Additionally, they display unique strain-softening behavior post-concrete failure. This innovative technique has the potential to enhance the structural performance of columns, making it a sustainable solution for retrofitting existing structures and constructing new ones.

Shi et al. (Contribution 8) aimed to assess and enhance the durability of concrete structures with fractures by investigating their seepage characteristics and the deterioration of their mechanical properties. Triaxial tests pre- and post-water penetration revealed significant impacts of fracture–seepage coupling on permeability and strength, with up to 32.8% decreased strength with increased fracture angle. Fracture–seepage–stress coupling further reduces strength, doubling the rate of decrease compared to intact concrete. Different fracture angles alter fracture expansion and damage modes, exacerbating concrete fragmentation. According to the research, enhancing concrete's seepage and fracture resistance is critical for extending structure lifespan.

Gil-Martín et al. (Contribution 9) discuss the limitations of the new Eurocode 2's guidance on concrete cover for reinforcement protection against carbonation-induced corrosion. While Eurocode 2 offers insights for 50- and 100-year service life designs, this article introduces a novel "square root of time" relationship, allowing for long-term structural designs and assessments. The newly proposed function adjusts carbonation front evolution to align with Eurocode 2 standards, enhancing the ability to design exceptionally durable structures and assess existing ones. The key revelation lies in the approximation of carbonation front evolution and a structure's expected service life using Eurocode 2 while disregarding resistance class against carbonation-induced corrosion. Instead, this method relies solely on concrete strength resistance and exposure class. The article's conclusions highlight a continuous formulation for the carbonation front based on the "square root of time" principle and in accordance with prEN 1992's minimum cover recommendations. This formulation, related to concrete compressive strength, aids in determining the requisite cover for carbonation protection, even considering indicative strength classes against carbonation-induced corrosion. Ultimately, this innovative expression is a valuable tool for designing exceptionally durable structures.

Fu et al. (Contribution 10) focus on the application of Polyvinyl-Alcohol-engineered cementitious composites (PVA-ECCs) in reinforced beams subjected to bending loads. A nonlinear finite element model is developed to simulate the behavior of PVA-ECC beams, incorporating constitutive models for PVA-ECCs, bond–slip behavior with reinforcing bars, and various design parameters. The study demonstrates that the numerical model accurately predicts the load–deflection curves and failure modes of PVA-ECC beams, offering a more precise estimation of ultimate loads and deformation capacities. Parameter analysis reveals the significant influence of the reinforcement ratio on the stiffness and ultimate load, while considering the tensile strength of PVA-ECCs in the tension zone yields more accurate results than existing design methods. Overall, the research contributes valuable insights into the behavior and design of reinforced PVA-ECC beams, offering potential advancements in structural engineering practices.

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