

Special Issue Advances in High-Performance of Eco-Efficient Concrete

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1. Introduction

The benefits of recycling in the construction sector have been widely demonstrated and are unquestionable. The advances in the use of recycled aggregates, steel slags and low-impact cements imply an important reduction in the environmental footprint, and eco-efficient concretes made with them must be a priority. However, these materials show, in some cases, losses of mechanical and durability behavior compared with natural materials. This is why we must invest our efforts in finding high-performance eco-efficient concretes that can compete or even surpass traditional concrete. To achieve this, research and dissemination of results are essential. The objective of this Special Issue is to group together the most recent and relevant research in relation to high-performance eco-efficient concrete. Subsequently, the possibility of publishing a book with the contributions of all authors will be assessed.

Thus far, 13 papers have been published in the Special Issue of a total 25 submitted. The next sections provide a brief summary of each of the papers published.

2. Resonance Fatigue Behaviour of Concretes with Recycled Cement and Aggregate

Cantero et al. [1] show that the huge increase in production of construction and demolition waste (CDW) worldwide is leading to the valorization of it as recycled aggregates. One of the most promising alternatives is its use as a recycled aggregate in the manufacture of structural concrete, which motivates the study of the dynamic behavior of these materials in order to ensure their suitability for use in elements subjected to dynamic loads. This work evaluated the resonant compressive fatigue behavior of structural concretes with 25% or 50% recycled mixed aggregates, either individually or in combination with 25% recycled cement of clay-based materials, both from CDW. All mixes were subjected to compressive fatigue tests using the accelerated Locati method. Regarding the fatigue limit, the results showed that for all mixes, it was between 30% and 45% of the compressive strength. In addition, a correlation was also found between the resonance frequency of the test and the deformation suffered by the specimen. This correlation enabled the estimation of the fatigue limit through a more stable parameter than the strain measured by strain gauges, namely, the resonance frequency. In addition, it was found that the resonance frequency of the test changed as the specimen damage increased. This observation enabled the estimation of the fatigue limit through a more stable parameter than the strain measured by strain gauges, namely, the resonance frequency.

3. Thermal Inertia Characterization of Multilayer Lightweight Walls: Numerical Analysis and Experimental Validation

Del Coz-Díaz et al. [2] show that thermal inertia properties of construction elements have gained a great deal of importance in building design over the last few years. Many



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investigations have shown that this is the key factor to improve energy efficiency and obtain optimal comfort conditions in buildings. However, experimental tests are expensive and time consuming, and the development of new products requires shorter analysis times. In this sense, the goal of this research is to analyze the thermal behavior of a wall made up of lightweight concrete blocks covered with layers of insulating materials in steady- and transient-state conditions. For this, numerical and experimental studies are carried out, taking outdoor temperature and relative humidity as a function of time into account. Furthermore, multicriteria optimization based on the design of the experimental methodology is used to minimize errors in thermal material properties and to understand the main parameters that influence the numerical simulation of thermal inertia. Numerical Finite Element Models (FEMs) take conduction, convection and radiation phenomena in the recesses of lightweight concrete blocks into account, as well as the film conditions established in the UNE-EN ISO 6946 standard. Finally, the numerical ISO-13786 standard and the experimental results are compared in terms of wall thermal transmittance, thermal flux and temperature evolution, as well as in terms of the dynamic thermal inertia parameters, showing a good agreement in some cases and allowing builders, architects, and engineers to develop new construction elements in a short time with the new proposed methodology.

4. Development and Evaluation of Nano-Silica Sustainable Concrete

Habib H. Alqamish and Adil K. Al-Tamimi [3] show that over the last decade, nano-materials made a major breakthrough in the concrete industry by providing the concrete with unique properties. Earlier studies have shown improvements in the early strength of concrete that can accelerate the construction process. In this study, 1% and 2% of nano-silica were added to concrete mixtures that contain 30% and 70% ground granulated blast-furnace slag (GGBS). Adding 1% of nano-silica to the 30% GGBS mixture showed an increase in the compressive strength by 13.5%, 7.8%, 8.1% and 2.2% at one day, three days, seven days and twenty-eight days, respectively. The 2% of nano-silica increased the 30% GGBS mixture's compressive strength less effectively, increasing by 4.3%, 7.6% and 4.9% at three days, seven days and 28 days, respectively, when compared to the 1%. On the other hand, adding 1% and 2% of nano-silica reduced the 70% GGBS mixtures' compressive strength. Moreover, nano-silica reduced the deformability of the mixtures significantly, which caused the increase in the Young's modulus. The flexural strength of the 30% GGBS mixtures had similar behavior as the 28-day compressive strength one. On the other hand, the flexural strength of the 70% GGBS mixtures increased as the nano-silica increased. The nano-silica addition improved the microstructure and the interface structure of the mixtures due to its high pozzolanic activity and the nanofiller effect, which is confirmed by RCPT results and SEM images.

5. Rheology, Hydration, and Microstructure of Portland Cement Pastes Produced with Ground Açai Fibers

Azevedo et al. [4] show that the açai (*Euterpe oleracea*) is a typical Brazilian fruit that is enveloped by natural fibers. This work investigated the effect of incorporating ground açai fibers (in natura and chemically treated with NaOH and HCl) in a 5–10 wt.% replacement of Portland cement on the rheology, hydration and microstructure of pastes. Rotational rheometry, isothermal calorimetry, X-Ray diffraction (XRD) and scanning electron microscopy (SEM) were performed to evaluate the cement pastes, in addition to SEM-EDS, FTIR, zeta potential, and XRD for fiber characterization. The results showed that the chemical treatment reduced the cellulose and lignin contents in açai fibers while increasing its surface roughness. The addition of 5% of fiber slightly increased the yield stress and viscosity of paste, whereas a 10% addition drastically increased these properties, reaching yield stress and viscosity values 40 and 8 times higher than those of plain paste, respectively. The incorporation of 5% in natura fibers delayed the cement hydration by about 2.5 days, whereas 10% in natura fibers delayed it by over 160 h. The chemical treatment significantly reduced this retarding effect, leading to a 3 h delay when 5% treated

fibers were incorporated. Overall, the combined NaOH/HCl treatment was effective for açai fibers' functionalization, and these fibers can be used in cementitious composites.

6. Effect of Freeze–Thaw Cycles on Carbonation Behavior of Three Generations of Repeatedly Recycled Aggregate Concrete

Liu et al. [5] show in their paper that multiple recyclings of waste concrete has attracted widespread attention. This study presented the carbonation behavior of repeatedly recycled aggregate concrete (RRAC) used in a microfrozen region. The effects of freeze–thaw cycles on the carbonation depth of three generations of RRAC with a 25%, 75% and 100% replacement rate were evaluated. All RRAC specimens after different numbers of freeze–thaw cycles were rapidly carbonated for 28 d indoors to test the carbonation resistance of concrete. The results suggested that the carbonation depth of RRAC subjected to freeze–thaw cycles is higher than that in the non-freeze–thaw condition. This is because the freeze–thaw damages cause the internal structure of RRAC to become porous and prone to cracking, thus providing convenient channels for CO₂ to react with the alkali in the cementitious materials. With the growth of the replacement rate or recycling number, RRAC reveals serious freeze–thaw damage and inferior carbonation resistance, which is due to the continuous deterioration of repeatedly recycled concrete aggregate (RRCA) quality. However, when the replacement rate was 25%, the carbonation depth for the third generation of RAC was comparable to the second generation of RAC at a 75% replacement rate, and even the first generation of 100% RAC. To ensure better carbonation resistance durability of RRAC, the low replacement rate of RRCA should be considered. For the third generation of RAC with the 100% replacement rate, its highest carbonation depth after freeze–thaw cycles was 9.16 mm, which still met the design requirements for structural use in a microfrozen region. This indicates that it is feasible for three generations of RRAC to be used in the microfrozen environment and that RRAC has great engineering application potential and promotional value.

7. Investigation of Mechanical Properties, Durability and Microstructure of Low-Clinker High-Performance Concretes Incorporating Ground Granulated Blast Furnace Slag, Siliceous Fly Ash and Silica Fume

Katarzyna Konieczna, Karol Chilmon and Wioletta Jackiewicz-Rek [6] show that the main assumption of eco-efficient High-Performance Concrete (HPC) design is the reduction in Portland cement clinker content without negatively affecting the composite's mechanical and durability properties. In this paper, three low-clinker HPC mixtures incorporating slag cement (CEM III/B as per EN 197-1) and Supplementary Cementitious Materials (SCMs)—Ground Granulated Blast-Furnace Slag (GGBFS), Siliceous Fly Ash (SFA) and Silica Fume (SF)—were designed. The maximum amount of Portland cement clinker from CEM III/B varied from 64 to 116 kg in 1 m³ of concrete mix. The compressive strength of HPC at 2, 7, 14, 28, 56, 90 days, and 2 years after casting, as well as the modulus of elasticity on 2-year-old specimens, was tested. The depth of water penetration under pressure and internal frost resistance in freeze–thaw tests were evaluated after 56 days of curing. Additionally, the concrete pH value tests were performed. The microstructure of 2-year-old HPC specimens was analyzed using scanning electron microscopy (SEM). The research proved that it is possible to obtain low-clinker HPCs that reach a compressive strength of 76–92 MPa after 28 days of curing and show high values of modulus of elasticity (49–52 GPa), as well as increased resistance to frost and water penetration under pressure.

8. Properties of a Lightweight Fly Ash–Slag Alkali-Activated Concrete with Three Strength Grades

Wang et al. [7] show in their paper that lightweight alkali-activated concrete (LAAC) is a type of highly environmentally friendly concrete, which can provide the benefits of both alkali-activated material and lightweight concrete. The study aimed to investigate the influence of different water/solid (W/S) ratios on the properties of normal-weight/lightweight fly ash–slag alkali-activated concrete manufactured at ambient temperature. The relative

performance of the alkali-activated concrete (AAC) mixed with limestone and sintered fly-ash lightweight aggregates as the coarse aggregates was also compared to the conventional ordinary Portland cement (OPC) concrete mix in terms of their compressive stress–strain relationship, splitting tensile strength and fracture parameters. The morphologies and microstructure of the four types of interfacial transition zones (ITZs) were characterized by scanning electron microscopy (SEM). Results indicated that the AAC had a higher tensile strength, stress intensity factor, brittleness and lower elastic modulus than its cement counterpart. With the decrease in the W/S ratio, the density, compressive and tensile strength, ultrasonic pulse velocity, fracture energy, brittleness and elastic modulus of the AAC increase. However, the influence of the W/S ratio on the mechanical properties of the LAAC with lightweight porous aggregates was less than that of the normal-weight AAC. Predictive models of the splitting tensile strength, fracture energy and elastic modulus of the AAC were also suggested, which were similar to those of the OPC concrete. Furthermore, the microstructure investigation showed that no wall effect occurred in the ITZ of the AAC. The ITZ structure of the hardened AAC was also more compact and uniform than that of the OPC concrete.

9. Evaluation of the Possibility of Replacing Fly Ash with Glass Powder in Lower-Strength Concrete Mixes

Robert Jurczak and Filip Szmatała [8] show in their paper the results of research on the possibility of replacing fly ash with recycled waste glass in lower-strength concrete mixes. The results of testing concrete mixes containing either waste-glass powder or fly ash are presented in the article. A standard C12/15 concrete mix was chosen for the tests based on its common use for producing concrete for footings to support road curbs and gutters along national roads in the Polish province of West Pomerania. In the first step of the testing procedure, reference mixes were prepared with 22.5% and 45% fly ash in relation to the content of cement. In the next step, mixes were prepared based on the same specification, except that glass powder was added in place of fly ash. The samples were then tested to determine the influence of waste-glass powder on the main properties of the prepared concrete mixes and on the performance of the concrete when hardened. All the samples were tested for 7- and 28-day compressive strength, water absorption, and freeze–thaw resistance in water. Next, the performance parameters of the samples containing waste-glass powder were compared to the reference mixes containing an equal amount of fly ash. The test results and their analysis allow us to conclude that mixes containing glass powder are not only equal to mixes containing fly ash, but even outperform them by a wide margin in terms of durability.

10. Mechanical Behavior of Steel Fiber-Reinforced Lightweight Concrete Exposed to High Temperatures

Wang et al. [9] show in their paper that the mechanical characteristics of steel fiber-reinforced lightweight concrete (SFLWC) under high temperatures are studied in this paper. Different concrete matrices, including all-lightweight concrete (ALWC) and semi-lightweight concrete (SLWC), and different steel fibers with hooked ends and crimped shapes, are considered as objects. In addition, normal-weight limestone aggregate concrete (NWC), no-fiber ALWC, and SLWC were tested after high-temperature treatment as a control group. The temperature effects on the splitting tensile strength, ultrasonic pulse velocity, compressive stress–strain curve, elastic module, peak strain and axial compressive strength of the SFLWC were investigated. The results showed that, with increasing exposure temperature, both the axial compressive strength and the elastic modulus decreased, whereas the axial peak strain has a certain increase, and hence, the stress–strain curves were gradually flattened. The toughness of all the concretes increased first and then reduced with increasing temperature, whereas the specific toughness of all the concretes increased with the increase in temperature. Compared with NWC and SLWC, ALWC had a better capacity to resist high temperatures, especially temperatures > 400 °C. Adding steel fibers can improve the capacity of energy absorption, specific toughness and residual

splitting tensile strength of lightweight concrete (LWC) before and after it is exposed to high temperatures. Based on a regression analysis, a segmented constitutive equation for LWC and SFLWC under uniaxial compression was derived from fitting the experimental findings, and the fitting curve agrees well with the test results.

11. Selection of the Optimum Carrier for Manufacturing Water-Repellent Concrete and Durability Evaluation of Cement Mortar Using It

Chang Bok Yoon and Han Seung Lee [10] show in their paper that the purpose of this experiment was to complement the shortcomings of existing surface treatment methods and to implement water repellency inside concrete to prevent water penetration and improve the durability of concrete. Carriers to provide water repellency were fabricated using fly ash (FA), silica fume (SF) and natural zeolite, which are used as admixtures for concrete. They were mixed with cement mortar, tested and evaluated. The compressive strength of the water-repellent impregnated natural zeolite (ZWR) specimen was 83% of that of ordinary Portland cement (OPC), and its contact angle was found to be 124° . The water penetration test and chloride ion penetration test confirmed that the water absorption and total passing charge were reduced, whereas the porosity and pore size were improved. For the other specimens, except ZWR, water repellency was judged to be insufficient due to the low fixing ability of the water-repellent's active ingredient. The results of evaluating the physical performance and durability of cement mortar for the selection of the optimum carrier revealed that powders other than ZWR are not suitable as a material for providing water repellency to concrete.

12. Crack Width and Propagation in Recycled Coarse Aggregate Concrete Beams Reinforced with Steel Fibres

Ghalehnovi et al. [11] show in their paper that reducing the crack width is a vital feature for protecting rebars from corrosion. In this investigation, the impact of steel fibers (SFs) on the cracking of recycled coarse aggregate reinforced concrete (RCARC) beams was investigated. Twenty-seven reinforced concrete (RC) experimental samples ($150\text{ mm} \times 200\text{ mm} \times 1500\text{ mm}$) were manufactured. Shear rebars were considered with different spacings. Specimens were tested under a four-point flexural setup. Recycled coarse aggregate (RCA) from a destroyed building was employed at 0%, 50% and 100% by weight. SFs were added at three contents (0%, 1% and 2%) in order to reduce the crack width. The mid-span load–displacement relationship and the crack propagation and width were measured during the tests. Therefore, this study intended to assess the impact of utilizing RCA and natural coarse aggregate on cracks' spacing and propagation in RC beams when SFs were employed. The obtained outcomes were compared with the requirements of CSA S474, NS 3473E, EC2-04, CEB-FIP and ACI 224R-01. It was found that enough shear rebars should be provided through the beams to control the crack width and propagation, but that SFs enhanced the bending performance of RCARC with no shear rebars.

13. Influence of Recycled Precast Concrete Aggregate on Durability of Concrete's Physical Processes

F. Fiol, C. Thomas, J. M. Manso and I. López [12] show in their paper that the research presented in this article analyzed the influence of incorporating precast concrete waste as an alternative to coarse aggregate in self-compacting concrete to generate new precast elements. The experimental study involved the characterization of recycled aggregate and the design of the mix of the new self-compacting concrete (SCC). The experimental study evaluates the physical processes that affect the durability of concrete with percentages of incorporation such as 20%, 50% and 100% of recycled aggregate. Two types of SCC were manufactured with a minimum compressive strength of 30 MPa and 45 MPa. The properties analyzed were the density of hardened SCC, shrinkage cracking, freeze–thaw resistance, resistance to ageing by thermal shock and abrasion resistance. The results obtained were compared with those of the control concrete, and it was observed that the

SCC under physical aggressions has a great capacity that affects durability. The results of this research show that it is possible to use the recycled aggregate coming from precast pieces in order to manufacture self-compacting recycled concrete in the same precast industry. However, a high loss of proprieties occurs for a 100% substitution, whereas for 20% and 50%, the variations with respect to the control concrete are smaller. In addition, taking advantage of this waste to incorporate it back into the production chain contributes to more sustainable construction.

14. Design Optimization of Rubber-Basalt Fiber- Modified Concrete Mix Ratios Based on a Response Surface Method

Gong et al. [13] show in their paper that rubber aggregates produced from waste rubber materials and environmentally friendly basalt fibers are excellent concrete modification materials, which significantly improve the working performance and mechanical properties of concrete. This paper studied the influences of the water-binder ratio, basalt fiber content and rubber content on the properties of rubber-basalt fiber-modified concrete (RBFC). Based on the response surface method (RSM), optimization schemes of three preparation parameters were designed. The results showed that all preparation parameters have significant impacts on the slump. The rubber content has a closer relationship with the compressive strength and the quadratic term of the basalt fiber content has a significant impact on the flexural strength. According to the analysis, the optimal mix ratio which possesses a reliable accuracy compared with experimental results includes a water-binder ratio of 0.39, a basalt fiber content of 4.56 kg/m³ and a rubber content of 10%.

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