Editorial

Special Issue: New Trends in Recycled Aggregate Concrete

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1. Introduction

Concrete is the most used manufactured material in the world and certainly one of those having the most impact on the environment. However, there is no foreseen alternative to this material within a developing world context. Therefore, a pressing need exists to promote the reduction of the environmental impacts of concrete, guaranteeing at the same time that its technological and economic advantages remain valid.

One of the ways to achieve this objective is by replacing part or all of the natural aggregates with alternatives resulting from recycled materials or various types of waste/by-products from several industries, including construction. Many of the consequences on the technical, economic, and environmental performance of recycled aggregate concrete have been established by the very dynamic research on this subject. Nevertheless, there is both a lag between research and industry practical applications and a number of subjects that must still be explored, which represent new trends in the search for sustainable recycled aggregate concrete.

This Special Issue is therefore dedicated to "New Trends in Recycled Aggregate Concrete" and contributions on, but not limited to, the following subjects were encouraged: Upscaling the use of recycled aggregate concrete in structural design; Large-scale applications of recycled aggregate concrete; Long-term behavior of recycled aggregate concrete; Performance of recycled aggregate concrete in very aggressive environments; Reliability of recycled aggregate concrete structures; Life cycle assessment of recycled aggregate concrete; Mesostructure analysis of recycled aggregate concrete.

So far, 16 papers have been published in the Special Issue of a total of 25 submitted. The next sections provide a brief summary of each of the papers published.

2. Upscaling the Use of Recycled Aggregate Concrete in Structural Design

In their study, Wang et al. [1] evaluated the performance of reinforced recycled aggregate concrete (RRC) columns under cyclic loading, using a fiber-based numerical model. With this model, they performed a comprehensive parametric study to examine the effects of a range of variables on the hysteretic characteristics of RRC columns. A grey relational analysis was also conducted to establish quantifiable evidence of key variable sensitivities. They concluded that the use of the additional water method (AWM) for manufacturing recycled aggregate concrete was likely to reduce the lateral load-carrying capacity of the RRC columns (up to 10%), whereas the opposite would occur if a conventional mixing procedure was adopted. Moreover, compared with other factors such as steel area ratio, the content of natural aggregates replacement had a less remarkable effect on the seismic performance of the RRC columns. In general, the RRC columns have acceptable seismic-resistant properties, and they can be used in earthquake-prone regions with confidence.

Choi et al. [2] developed an experimental study on the flexural behavior of reinforced concrete members with heavyweight waste glass as fine aggregate under cyclic loading. They concluded that, for full replacement, the crack patterns were affected, and there was an increased possibility of sudden failure owing to concrete crushing. Additionally, the load capacity and flexural rigidity were affected by the content of heavyweight waste glass, but the flexural performance improved when mineral admixture as a binder or a low water-binder ratio were used.

Another experimental study was developed by Wu et al. [3] on the dynamic mechanical properties of fiber-reinforced concrete (FRC) under different strain rates. Dynamic uniaxial compression and splitting tensile experiments of FRC with polyvinyl alcohol (PVA) fibers were carried out for two matrix strengths. PVA fibers enhance and toughen concrete, improving its brittle properties and residual strength. With increasing strain rate, the compressive strength, splitting tensile strength, and elastic modulus increase to a certain extent, whereas the toughness index and the peak strain decrease to a certain degree. The post-peak deformation characteristics change from a brittle to a ductile failure with dense cracking. These effects depend on the matrix strength.

Yanweerasak et al. [4] studied the effect of recycled aggregate quality on the bond behavior and shear strength of reinforced concrete members. They concluded that the bond strength of both natural and recycled concrete increased with a decrease in water-to-cement ratio but not for the full spectrum of ratio values. Furthermore, the shear behavior of reinforced concrete beams with natural and recycled concrete is very similar, but the results depend on the size of the beams.

De Brito et al. [5] questioned the validity of concrete compressive strength predictions without knowing the properties of the aggregates. For the same mix composition (with similar cement paste quality), there was a significant difference between the results when natural aggregates of various geological nature were used in concrete. The same was true when different qualities of aggregates were used. However, the scatters significantly decreased when the mixes were classified based on the geological nature of the aggregates or on their quality. The influence of the aggregates on the compressive strength of concrete became much more discernible when recycled aggregates were used mainly due to their more heterogeneous characteristics.

3. Large-Scale Applications of Recycled Aggregate Concrete

In their research, Kim et al. [6] performed a study on the properties of recycled aggregate concrete and its production facilities. Equipment was developed to improve the quality of recycled aggregate to increase the use of that aggregate for environmental improvement purposes. The results showed improvements in the air volume, slump, compressive strength, freezing and thawing resistance, and drying shrinkage.

An investigation on the use of recycled concrete aggregates originating from a single ready-mix concrete plant was performed by Anastasiou et al. [7]. Crushed hardened concrete from test specimens (HR) and from returned concrete (CR) were tested for their suitability as concrete aggregates, and cement sludge fines (CSF) originating from the washing of concrete trucks were tested as filler. Both HR and CR can be considered good-quality recycled aggregates, especially when the coarse fraction is used. Furthermore, HR performs considerably better than CR both as coarse and as fine aggregate. CSF seems to be a fine material with good properties as a filler, provided that it is properly crushed and sieved through a 75 µm sieve.

4. Long-Term Behavior of Recycled Aggregate Concrete

Yang [8] analyzed the effect of different types of recycled concrete aggregates (RCAs) on the equivalent concrete strength and drying shrinkage properties. A total of six mixes were proportioned using the modified equivalent mortar volume (EMV) method with three RCAs. The test results show that the concrete with RCAs produced from concrete sleepers exhibited compressive strength, Young's modulus, and flexural strength values equivalent, within 2% variation, to those values of the companion natural aggregate concrete. In other mixes, compressive strength was found to decrease to

11–20%. For 100% replacement, the Young's modulus increased up to 10% and the drying shrinkage increased up to 8%, while for 50% replacement, the Young's modulus decreased up to 8% and the drying shrinkage dropped up to 4%.

Chen et al. [9] performed an analysis and modelling of the shrinkage and creep of reactive powder concrete (RPC) with various steel fiber contents. It was revealed that the compressive strength and modulus of elasticity increased with increasing steel fiber content, contrary to shrinkage and creep. A good linear relationship was found between the axial stress ratios and creep strain. All four existing models were unable to accurately predict the shrinkage and creep of RPC. However, a good agreement between the experimental results and the proposed shrinkage and creep numerical models was observed.

5. Performance of Recycled Aggregate Concrete in Very Aggressive Environments

Chen et al. [10] analyzed the residual properties of steel-reinforced recycled aggregate concrete (RAC) components after exposure to elevated temperatures. Significant physical phenomena occurred on the surface of RAC and steel-reinforced recycled aggregate concrete (SRRAC) components after exposure to elevated temperatures. The mechanical properties deteriorated significantly with the increase of temperature, namely, the strength of the RAC, and compressive capacity, bending capacity, shear capacity, and stiffness of the SRRAC. The ductility and energy dissipation of SRRAC components were insignificantly affected by the elevated temperatures. Mass loss ratio, peak deformation, and bearing capacity showed a slight increase trend with the increase of replacement ratio. However, the stiffness showed significant fluctuation for high replacement ratios. The ductility and energy dissipation showed significant fluctuation for intermediate replacement ratios.

6. Reliability of Recycled Aggregate Concrete Structures

Duan et al. [11] used artificial neural networks (ANNs) to determine the significance of aggregate characteristics on the mechanical properties of recycled aggregate concrete (RAC). The results show that water absorption has the most important effect on aggregate characteristics, further affecting the compressive strength of RAC, and that combined factors including concrete mixes, curing age, specific gravity, water absorption, and impurity content can reduce the prediction error of ANNs to 5.43%. Moreover, for elastic modulus, water absorption, and specific gravity, they are the most influential, and the network error with a combination of mixes, curing age, specific gravity, and water absorption is only 3.89%.

7. Life Cycle Assessment of Recycled Aggregate Concrete

Park et al. [12] performed an analysis of the life-cycle environmental impact of recycled aggregate. The environmental impact of recycled aggregate (wet) was up to 16–40% higher than that of recycled aggregate (dry), mostly due to the amount of energy used by impact crushers. The environmental impact of using recycled aggregate was found to be up to twice as high as that of using natural aggregate, largely due to the greater simplicity of production of natural aggregate requiring less energy. However, the abiotic depletion potential was approximately 20 times higher when using natural aggregate because its use depletes natural resources, whereas recycled aggregate is recycled from existing construction waste. Among the life-cycle impacts determined from the assessment of recycled aggregate, global warming potential was lower than for artificial lightweight aggregate but greater than for slag aggregate.

8. New Applications of Recycled Aggregate Concrete

Foti et al. [13] studied the mechanical characteristics and water absorption properties of blast-furnace slag concrete with fly ash or micro silica additions. The results show the following: (i) the use of fly ashes, and especially silica fume, together with slag in concrete enhances the compressive strength of concrete mixes and shows very high water/cement ratios; (ii) micro silica concrete shows a

specific weight lower than slag and fly ash concrete; (iii) for both types of concrete, the splitting tensile strength is consistent with the compressive strength, whereas flexural tensile strength is rather low, especially for slag and silica fume concrete; and (iv) compared to an ordinary concrete, the types of concrete examined in this research have a lower water absorption value, especially silica fume concrete.

Wang et al. [14] presented a material characterization for sustainable concrete paving blocks. Five types of waste materials were used in this project, including recycled concrete coarse aggregate (RCCA), recycled concrete fine aggregate (RCFA), crushed glass (CG), crumb rubber (CB), and ground granulated blast-furnace slag (GGBS). Using either RCCA or RCFA can decrease the blocks' strength and increase their water absorption. The suggested incorporation levels of RCCA and RCFA are 60% and 20%, respectively. Adding CG to the concrete paving blocks as a type of coarse aggregate can improve their strength and decrease their water absorption. The addition of CR causes a significant deterioration of the blocks' properties, except for their slip resistance.

Song and Lange [15] analyzed the crushing performance of ultra-lightweight foam concrete with fine particle incorporation. The results indicate that the use of fine-graded sand particles in a small content simultaneously reduces the cement content and enhances the crushing performance. However, poor performance is observed for a high sand content. The cellular structure of the foam–sand composite, and thus its mechanical behavior, can be substantially weakened by larger sand particles, especially when the particle size is larger than the voids in the foam.

The effect of the addition of nylon fibers (NFs) on the performance of recycled aggregate concrete (RAC) was studied by Lee [16]. RAC showed a lower performance than crushed stone aggregate concrete (CAC) because of the adhered mortars in the recycled aggregates. However, it was obvious that the addition of NFs in RAC mixes was much more effective in enhancing the performance of concrete, due to the crack bridging effect from NFs. In particular, a high content of NFs (1.2 kg/m^3) led to a beneficial effect on the concrete properties compared to a low content of NFs (0.6 kg/m^3) with respect to mechanical properties and permeability, especially for RAC mixes.

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

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