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Synthetic Aggregates: Their Role in the Production of Smart Infrastructures

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Abstract

This study is regarding the review of the production, evolution and potential uses of advanced aggregates based on waste and/or industrial by-products for the construction field, in order to promote the conservation of the environment from pollution and prevent natural resources from depletion; thereby giving way to sustainable development. Additionally, a review of smart aggregates was made in order to understand their potential contribution for the generation of smart infrastructures. The current research indicates that there is a potential niche associated with smart lightweight aggregates development that could be part of future investigations.

Keywords: Concrete; Lightweight aggregates; Piezoelectric; Glass-ceramics; Smart infrastructures

Introduction

In the construction world, concrete is the primary and universal material used to build almost all types of infrastructures such as: bridges, dams, buildings, swimming pools, homes, streets, patios, basements, pavement blocks, lamp-posts, drain covers, benches, and various others. Concrete generally consists of cement, water, aggregate, and admixtures where, through the process of hydration, it hardens after it has been placed. In the last decade, a growing interest in the production of advanced aggregates has been developed for several industries in the construction field. The goal is to look for a generation of smart construction materials that can respond to changes in their condition or the environment in which they are exposed, in a useful and controlled manner.

On the other hand, there are a huge number of synthetic aggregates. Some of these have been used in construction of infrastructures as substitutes for natural aggregates or in direct competition with them. Additionally, there are substantial quantities of lightweight aggregates produced by expansion or sintering of clays, shales, or fly ash, and both lightweight and dense aggregates produced from blast-furnace slag, etc [1]. Their unique properties such as absorption, porosity, permeability, strength, elasticity, density, specific gravity, hardness, particle shape, surface texture, also their chemical composition and potential reactions with systems like asphalts and cements make them a crucial materials in many fields of engineering and sciences. Therefore, these are used in civil engineering projects and contribute to increasing performance, comfortability, and energy efficiency of structure. In addition, the last tendencies in researches related to the production of smart lightweight aggregates (SLAs) and environmental conservation have been focused on

a. An increasing effort for the conversion of waste or industrial by-products into useful building materials [2,3], also

b. In the replacement of sand in concrete structures in order to reduce the natural exploitation of this kind of resource [4,5], and

c. To make a great contribution in the reduction of the environmental pollution [6].

Currently, societies are requiring a better process of implementing a damage detection and characterization strategy of infrastructures, based on concrete, where the structural health monitoring (SHM) of structures could play a key role in public safety. However, a bigger effort has to be made for lightweight concretes where the future studies have to be focused on the input that causes the change in smart material properties (may be in the form of electrical/magnetic field, mechanical stress/strain or changes in temperature, pH, moisture and/or light) in order to produce advanced aggregates that will be the master-key of the future smart infrastructures.

Discussion

A new generation of synthetic aggregates have been developed in recent years making them of various waste and industrial by-products like fly ash, paper pulp, municipal solid waste, power plant solid waste, saw dust, rice husk ash, granite powder iron ore dust, etc. These are the new raw materials for the innovation in the production of SLAs trough their physicochemical conversion into useful products with a direct application in the construction field. For instance, Srinivasan et al. [6] have produced synthetic aggregate based on fly ash, rice husk ash, and iron ore dust that were mixed with cement in order to produce a final synthetic aggregate. The evaluation of mechanical properties like compressive strength, weight loss and reduction in strength was monitored up to 56 days, and durability test was conducted on normal cured specimens, for a 28-days continuous immersion in NaCl solution. The results showed that synthetic aggregate has 31.8% lower value than the natural aggregate for crushing and 26.4% higher impact value. Concrete with density 2151kg/m^3 can be achieved using those synthetic aggregates while density of normal concrete mix goes up to 2498kg/m^3. The water absorption of synthetic aggregate is 9 times higher than that of natural gravel which is the major disadvantage which can be eliminated by various treatment methods that are available, such as treating with water-glass. Finally, those new pozzolanic aggregates can be considered for various applications such as wall panels, masonry blocks, roof insulation material, and structural load bearing elements, etc.

Furthermore, synthetic lightweight aggregates have been also produced using fine sediments from reservoirs as How-Ji Chen et al. [7] indicated in their research. Those synthetic aggregates were manufactured in a newly developed rotary kiln. The new aggregates have a hard-ceramic shell, with a porous core, and a relative density ranging from 1.01g/cm^3 to 1.38g/cm^3, which is significantly lower than normal density of aggregates. The produced aggregates also meet the requirements of ASTM C330 with bulk density less than 880kg/m^3 for light course aggregates and were verified as qualified LWA for structural concrete. Further, the engineering properties of the concrete made from the produced aggregates covers the requirements of structural lightweight concrete.

On the other hand, Perera et al. [4] generated novel glass-ceramic porous spherical particles with chemical composition into the SiO_2-CaO-Al_2O_3-MgO quaternary system as replacement of sand aggregates in mortars. The crystalline blast furnace slags (c-BFS) without any hydraulic property was transformed into spherical particles with a porous semi-amorphous matrix with lower density than their precursor. The conversion occurs by the c-BFS projection into an oxygen/Liquefied Petroleum Gas (LPG) plume-flame. This new aggregate was used to replace the sand in conventional mortars formulations. The properties of the specimens such as density, compression strength, were evaluated at different aging times (7, 14 and 28 days). The results indicate that the pores of these materials determinate favorable thermal and acoustic insulation properties and permit an overall reduction of the self-weight of the final products.

In addition, Ibrahim et al. [5] developed a procedure to generate lightweight bubble aggregates (LBA) by mixing foam with ordinary Portland cement according to the composition which has been set. The evaluated properties of the LBA indicate that they can be successfully categorized into lightweight aggregate. The loose bulk density is obtained at 812.5kg/m^3 which can be categorized under lightweight aggregate group. For water absorption the value obtained is 9.7% which is slightly higher compared to normal aggregate. Meanwhile the average specific gravity obtained for the samples of LBA is 1.75. Compressive strength for the aggregates was 17.76MPa. Finally, the highest compressive strength for LBA foamed concrete was obtained at 25% replacement.

Smart Aggregates

Just a few researches were found related to the production and application of smart aggregates. Some of them are related with methodologies to measure signals emitted by smart materials. Thereby, the guided wave (GW) based testing techniques have been found to be very efficient for damage detection and health assessment of various infrastructures. In this regard, Zhao et al. [8] produced a smart aggregate based on a piezoceramic-based element that is an innovative multifunctional device. The smart aggregate has been successfully applied to the SHM of concrete structures under both static loading and seismic excitations. In those studies, several smart aggregates were mixed with the concrete structures and the health state of the concrete structures was evaluated by monitoring the signals recorded by the smart aggregates. The elastic wave generated by the smart aggregate can propagate a long distance along the beam as the guided wave for which the beam serves as the waveguide. This guided wave can be sensed by the piezoceramic patches mounted on the beam surface to monitor not only the surface damage near the patch but also internal damage. Likewise, Zhang et al. [9] used piezoelectric smart aggregates (SAs) to provide a useful way to assess damage in concrete structures. Those SA sensors were tested for monitoring stress using four identical lightweight concrete (LWC) cylinders with six SAs embedded in each specimen subjected to typical loading paths and load levels. The effects of the related meso-scale factors on the feasibility of monitoring were evaluated. Then the sensors' sensitivity curves and the extent of SA output randomness were quantified. Finally, this research indicates that SAs have potential for monitoring stress in LWC structures during the entire damage process.

A different way to obtain a signal back from concrete structures was developed by Wenhao et al. [10] who produced lightweight conductive aggregates (CA) loaded with modified agar gel and where their influence on the resistivity of conductive cement-based materials was evaluated. Results indicate that by impregnation treatment, agar gel was efficiently loaded in porous lightweight aggregates, thus CA with a resistivity of 0.5Ω·m was obtained. The prepared CA significantly improved the conductivity of cement-based materials, and the final got effect is

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due to the altered microstructure of cement matrix, and the new conductive network established by CA that can be characterized by GEM model. These research shows that the prepared CA have promising potential for applications related to cement-based composites.

Conclusion

In recent years, a huge amount of different waste and industrial by-product materials have been used as a precursor to produce advanced synthetic aggregates considering not only their physicochemical properties but also from the point of view of sustainability. Additionally, the environmental impact for those waste and industrial by-products could be reduced positively if are used in value-added applications. Therefore, the future uses of lightweight aggregate could be extraordinary regarding the utilization of them in smart modern infrastructures. In addition, some of the most recent research projects related to smart aggregates based on piezoelectric materials and their feasibility have been verified in normal weight concrete (NWC). Consequently, more efforts are needed to produce smart lightweight aggregates (SLAs) that must be focused on meso-scale factors because it is the key for smart aggregates (SA)-based monitoring. Finally, it is expected that the present article will likely inspire the international research community to make their own contributions in the usage of waste and by-products from different industries as raw materials in order to transform them into smart building materials able to cover the current niche related to the production of smart lightweight aggregates for the construction field.

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