coatings

Editorial

Progress in Sustainability and Durability of Concrete and Mortar Composites

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The origins of concrete as a construction material date back more than 2000 years ago, but the origins of the term itself are still under debate due to its many different interpretations throughout history. Concrete, in its generally accepted form by today's definition, is a hard rock-like man-made construction material that consists of aggregates, sand, water, and cement. The term "*concrete*" comes from the Latin word "*concretus*", meaning *compact* or *grown together*, and it was used for characterizing the materials obtained from the combination of two or more different materials. From this perspective, concrete can be considered to be among the first composite materials to be used by mankind.

As opposed to plastic, the facility with which concrete can be used to fill formworks or molds with any shape is one of its key advantages. At the same time, most of the constituent materials, with the exception of cement, can be found at very low cost, locally or at a very short distance from the construction site. Concrete compressive strength is high, which makes it suitable for members primarily subjected to compression such as columns and arches.

As with any other construction material, concrete has its disadvantages, too. The rheological, mechanical, and durability properties of concrete is highly dependent on the water/cement ratio. While higher values of the water/cement ratio results in a more workable concrete, the risk of segregation is also high. On the other hand, a too low value of the water/cement ratio, without the use of proper water reducing admixtures, may result in an improper binding of all aggregates within the cement paste [1,2]. Either way, the end result is a material that cannot fulfill its role for structural applications.

While concrete is very good in compression, it is also inherently weak in tension. The solution came from using materials that have a good behavior in tension, e.g., steel, to take over tensile stresses in concrete elements. The distribution of such materials could be in the form of individual reinforcing bar or as distributed reinforcement. Both reinforcing methods have their benefits, and sometimes they are used in combination. While "traditional" reinforcement is made almost entirely of steel, distributed fibers may have a variety of sources from natural [3] to man-made [4]. The advantage of using fibers in mortar or concrete resides in their ability to bridge small cracks and arrest their development. The scientific literature also highlights their contribution to increasing the toughness of mortar and concrete to repeated impact loads [5].

The European directive 2003/87/CE establishing a scheme for greenhouse emission allowance trading within the Community was the first international program of its kind in the world. The main objective was the reduction by 20% of the greenhouse emissions, by 2020, below the levels recorded in 1990. Despite this bold step towards reducing the environmental impact of modern society the UN Sustainable Development Goals (UN-SDG) project accounts that, globally, the greenhouse gas (GHG) emissions are 50% higher than in 1990. One major reason for this increase in the GHG emissions is the continuously increasing demand for new buildings due to a rapid expansion of urban areas. This put a tremendous pressure on the production of building materials, among which concrete is the leading material. According to the latest CEMBUREAU report, the production of cement in the European Union has risen from 175.1 million tons in 2017 to 182.1 million tons in 2019. Taking into account that cement represents 10% ~ 15% of the concrete volume one could only imagine the environmental burden the construction industry creates.

The depletion of natural resources is another factor of concern worldwide. Natural aggregates, constituting between 60% and 75% of concrete volume and which are recognized as the second source of CO_2 in concrete production, are quickly becoming a scarce "commodity".

However, one of the most important characteristics of cement based materials, e.g. mortar and concrete, is their ability to incorporate large amounts of wastes as partial or total replacement for cement and/or natural aggregates. Extensive research works were conducted to assess the suitability of various industrial by-products as supplementary cementitious materials (SCM) in mortar and concrete and their influence on the rheological, elastic, and mechanical properties of cement based materials [6,7]. Fly-ash (FA), a by-product of the coal-fired power plants, consisting mostly of glassy spherical particles has been long recognized as one of the SCMs with significant beneficial influence on the durability and long term mechanical properties of mortar and concrete when used in lower concentrations (less than 20% by weight of cement). On the other hand, one of the drawbacks of using fly ash resides in slow early strength development of cement based materials [8]. However, this effect could be mitigated by means of chemical activation or addition of nanomaterials. Another frequently used SCM is the ground granulated blast furnace slag (GGBS). The use of GGBS as partial replacement of cement in mortar or concrete leads to increased values of the mechanical properties, increased abrasion resistance, and lower permeability [9]. This has direct influence on the long-term durability of concrete which necessitates less maintenance works. Silica fume (SF), a by-product from the production process of silicon or alloys containing silicon, is another frequently used SCM with net benefits in terms of durability of cement based products [10]. Recent studies acknowledge the potential use of gypsum based by-products as SCMs in mortar and concrete [11,12]. Although less investigated compared to other SCMs, mortar and concrete made with gypsum-based SCM exhibited higher values of mechanical properties.

Thorough investigations were also conducted in the direction of natural aggregates substitution by recycled aggregates from various sources [1]. The benefits of using waste glass in mortar or concrete has been acknowledged not only from an environmental point of view but also from its contribution to the overall strength and durability properties [13] of the cementitious composites acting as a pozzolanic material [14]. At the same time, there is a growing concern related to the continuous increase in plastic wastes all around the world. It is estimated that plastic wastes exceed 25 million tons per year, worldwide. Studies revealed that the use of plastic waste in construction materials resulted in a decrease in mechanical properties, but the density and the thermal conductivity of the new material decreased [15,16]. This would make the use of plastic wastes more attractive for the construction industry provided more research effort is invested in this direction. Construction industry is not only one of the largest consumer of natural resources; it also generates a lot of wastes from the rehabilitation and demolition processes. The feasibility of using recycled aggregates from demolition wastes, in the context of the circular economy paradigm, resulted in many research works being published in the scientific literature. Their effect on the mechanical properties of mortar or concrete is hard to fully understand and quantify, given the large variety in the characteristics of the recycled aggregates depending mostly on their origin and initial composition [2,17,18]. The general consensus is that the mechanical and durability properties of mortar and concrete incorporating construction demolition wastes decrease, and new methodologies are investigated to improve the quality of recycled aggregates from these sources. Another pressing issue of the modern society is related to the increasing number of discarded worn tires. In view of ever stricter regulations in terms of landfills, tire components found their way in mortar and concrete mixes either in terms of distributed textile and steel fibers as reinforcement or as aggregates [19,20].

Water, the third component of a concrete mix, represents 15%–20% of the total mix. It also represents an invaluable resource for supporting all forms of life on earth. Research works were dedicated to using water from sources other than the fresh water. Studies on the use of wastewater from ready-mix concrete plants revealed that the solid content from the mixing water coupled with total amount of dissolved solids represent the main influencing factors on the mechanical properties of the resulting concrete [21]. The use of sea water, as an alternative to fresh water, in concrete mixes may have both negative and positive effects on alkali-activated slag cement and blast-furnace cement concrete. The former was identified in the form of lower initial compressive strength, increased open capillary porosity, and increased corrosion of steel reinforcement while the latter consists in higher values of the mechanical properties due to the combined effect of alkali metal compounds and salts [22].

A more recent alternative to cement based mortar and concrete is the geopolymer concrete. It is based on aluminosilicate precursors from either natural (metakaolin) or industrial by-products (fly ash, ground granulated blast furnace slag) sources. From the point of view of GHG emissions, geopolymer concrete has net benefits over Portland cement concrete, as it produces 80% less CO_2 during its production phase and requires 60% less energy to be produced [23–25].

We trust that the issues raised during this short editorial will help acknowledge the need for further research works in making mortar and concrete the construction materials of choice for future generations, especially in a way that significantly reduces these materials' environmental impact.

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