ADMIXTURES, ESSENTIAL COMPONENTS OF SUSTAINABLE CONCRETE

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Abstract

Over the years concrete has remained the preferred material of choice of the construction industry; one of the reasons being its versatility. In the last decades its performance has been enhanced through the use of admixtures: essential components to obtain the desired characteristics in fresh and hardened states.
However, in recent times key trends are challenging the concrete industry to provide highly sophisticated materials guaranteeing a sustainable approach. Admixtures can be a powerful tool to enhance energy efficiency in concrete production and durability of structures minimizing their environmental impact. Admixtures can also allow the use of recycled and supplementary cementitious materials (SCM) ensuring the proper performance development and targeting a zero net waste concept.
In the next decades concrete is expected to be still one of the key materials and advanced technologies as ultra high performance concrete, obtainable by engineered admixtures, can be considered one of the great chance to innovate structures.
The present paper is an overview of the achieved admixtures' contribution to sustainability and an outlook into future opportunities to make concrete an even more sustainable material.
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Keywords

Admixtures, sustainability, energy efficiency, supplementary cementitious materials, ultra high performance concrete

Biographical notes

Roberta Magarotto has a synthetic organic chemistry education, University of Venice (Italy). Since 1993, she has been working in the field of concrete admixtures, focusing in the development of new polymeric superplasticizers and their interaction with cement. Additional key areas are concrete durability and new concrete technologies such as self compacting concrete, ultra high performance concrete.
From 2002 to 2007 she had been head of the Admixture Department of R&D at BASF Construction Chemicals Italy. Since 2008, she has been the Director of Development of the European Business Unit Admixture Systems of BASF Construction Chemicals.

1. INTRODUCTION

Sustainability, defined by the World Business Council for Sustainable Development (WBCSD) as: “Forms of progress that meet the needs of the present without compromising the ability of the new generations to meet their own needs” has lead to a deep concern about depletion of natural resources and emission of CO_2. The sustainable approach to construction has become the key innovation driver of concrete technology and it is expected in the 21st century to use more complex cementitious compositions and to contain more supplementary cementitious materials (SCM) in order to strive for energy efficiency in concrete production and to lead to a superior durability and enhancement of service life, thus providing an environmentally secure material for the future.

Complexity of concrete composition, fast changing regulations and high performance requirements are transforming the old, traditional, rough concrete into a sophisticated material where admixtures are an essential component to ensure sustainability without compromising on technology development and progress.

2. The Admixture contribution to sustainability

The contribution of admixtures to sustainability can be manifold, influencing various features:

- Allow use of more sustainable raw materials in concrete (clinker produced with secondary fuels, SCM, recycled aggregates)
- Ensure a more energy efficient concrete production (easiness of mixing and transportation, pumpability, placeability, compaction, finishing and curing)
- Ensure a better durability

In this paper the contribution of admixtures to sustainability is focused on their functional effect in concrete. Information on toxicological and leaching behaviour in recycled concrete of admixtures themselves was already provided by a specific paper presented by EFCA (1). The conclusion was that, due to their low dosage, concrete admixtures play a subordinate part in the multi- component system concrete and, moreover, based on existing data and estimates, the superplasticizers under consideration cannot be classified as ecologically hazardous from the point of view of environmental technology.

2.1 Use of more sustainable raw materials in concrete

Water reduction, which is one of the key functions required to admixtures, is obtained through synergistic mechanisms of action: a) induced electrostatic repulsion, b) induced steric hindrance preventing particle-particle contact, c) reduction of water surface tension, d) lubricating film between particles, e) releasing of water trapped within cement flocks, f) inhibition of the surface hydration of the cement particles, g) change in morphology of the hydration products.
The interactions in concrete (2, 3) are complex and interdependent. However, through a proper and balanced use of all these mechanisms, effectiveness of admixtures can be optimised according to the many variables which may be playing a role especially when different nature of materials are present in concrete as a consequence of the sustainability effort.
Among the different nature of materials we can mention are: the clinker obtained using alternative fuels, SCM composition and recycled aggregates.

Referring to alternative fuels in 2006, the European cement industry used an energy equivalent of about 26Mt of coal, a non renewable fossil fuel, for the production of 266Mt of cement. Alternative fuels constituted 18% of this across Europe, saving about 5Mt of coal and reducing the need for mining a non renewable resource.

Characteristics which may have an important role in the matrix of complex physico-chemical interactions are:

- the orthorhombic/cubic C_3A ratio influenced by the alternative fuel use in clinker production, the soluble sulphate content and their impact on initial workability and workability retention
- the fineness and, more precisely, the granulometric distribution of SCM
- the chemical composition of SCM only partially controllable as by product
- the chemical composition, granulometric characteristics and adsorption features of recycled aggregates

New generation superplasticizers, with their high degree of differentiation of chemical structure and thus performance customization, can provide fluidification, workability retention and viscosity control, otherwise not achievable, especially in presence of unfavourable C_3A ratio and high adsorption of materials.
One of the major technical barriers against the use of large quantities of SCM is the slower hydration process and its drawback in terms of early strength above all at low temperature. Accelerating agents can promote the kinetics of strength development thus allowing an optimised mix design reducing embodied carbon dioxide and fully exploiting the benefits of SCM at long term, as reported in Figure 1.

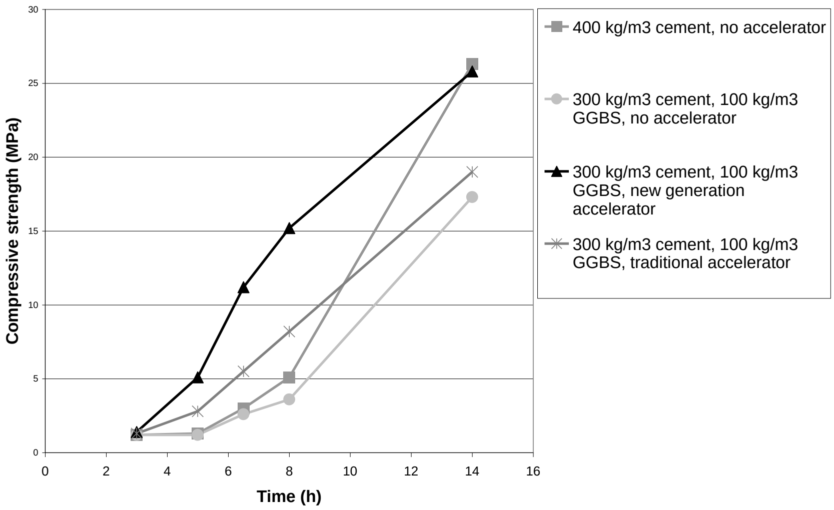

Figure 1 Example of strength development acceleration through the use of traditional and new generation accelerators in pure OPC and OPC+GGBS concrete at the same W/C

The use of recycled aggregates (RA) in concrete is expected to be a sustainable approach from the waste perspective although it is in clear conflict with the increasing requirements in terms of quality and engineering properties. The high water demand of these type of aggregates, which is related to their huge pore volume, leads to a notable reduction in the compressive strength and, consequently, several codes and standards limit their use in concrete. The use of very effective high-range water reducing admixtures is, therefore, essential. Nevertheless, due to the magnitude of the water demand of recycled aggregates, the use of superplasticizers should be combined with the use of chemicals able to control the adsorption of superplasticizer. This will enable the offset of the smallest pores of the recycled aggregates and, consequently, further reduce their water demand as to allow the use of higher amount of recycled aggregates without significant detriment to the compressive strength (Figure 2).

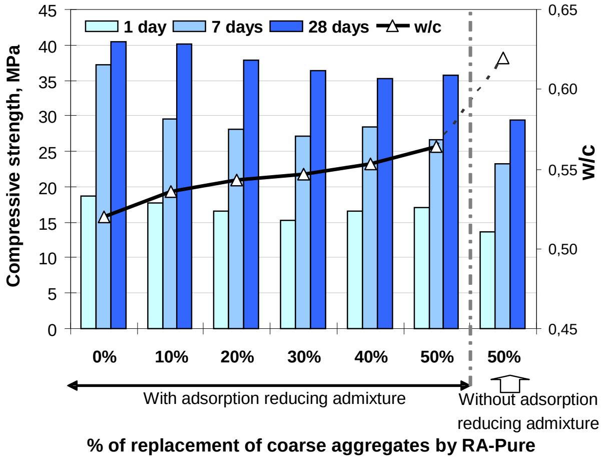

Figure 2 The effect of adsorption reducing admixtures on water request and compressive strength of concrete with recycled concrete aggregate

2.2 Energy Efficiency

Considering the energy involved in the various steps of production and curing of concrete we can list the following: 1) mixing, 2) transportation, 3) pumpability, 4) placeability/compaction 5) finishing and 6) curing.

Throughout the process and time of placing, workability retaining water reducers can ensure a high fluidity and therefore low energy required in the mixing and transportation process, which can be seen as a contribution to sustainability both in terms of lower mixing energy required but also in terms of much better possibility to optimise the mix design without compromising on strength development and rheological properties over time.

Rheological modifiers, to reduce or increase the viscosity according to the needs of the mix design used, can be a valid tool to enable an easier pumpability of concrete thus a lower energy required, as well as a lower wear and tear of the pump.

Table 1 - Indication of the comparable effectiveness of the VMA in pumped concrete. (4)

Application / Customer requirements	Effectiveness
Reduced segregation and blockages in the pump lines	++++
Overcoming lack of fines in the mix	++++
Reduced pump pressure	+++
Reduction on wear	+
Reduction in pump energy used	+
Improved pumping with crushed aggregate	+++
Long pumping distances	+++
Greater pumping heights	+++
General improvement in pumpability	+
Stabilizing entrained air during pumping	++
Pumping light weight aggregate concrete	+++

+ low effectiveness ++++ high effectiveness

A technology that has gained widespread use in the precast industry where its advantages are easily verified and put to a profitable use is Self Compacting concrete (SCC). Use of SCC significantly enhances the aesthetics and the durability of the precast elements. It is estimated that more than 50% of the concrete used for structural precast elements is now self compacting.

The picture is quite different in the ready mixed concrete industry though advantages of placeability, self compaction, easier finishing and durability in the structure are present and even more desirable when, as in ready mix, a high diversification of structure design and application conditions may result in difficult compaction.
The viscosity type Self Compacting concrete is proportioned to provide self compaction by the use of a viscosity modifying admixture which ensure segregation resistance without the need of a much higher cementitious content with respect to traditional concrete thus providing a more efficient use of materials and energy.
Finishibility is an additional feature of rheology which may play an important role especially nowadays that water / cement ratios are lower and can require higher energy. Dealing with this parameter requires reliable methods for the quantification of this value: parameters such as viscosity and yield can be controlled by tailored superplasticizers and, in general, rheological modifiers. (5)

2.3 Durability

Major savings in natural resources and energy could result if the concrete structure were more durable prolonging the service life beyond the conventional 50 years.
It is well know that admixtures can provide several advantages with respect to durability: low permeability, proper freeze-thaw resistance, shrinkage reduction, crack reduction, alkali aggregate reaction protection , etc.
Furthermore, in order to obtain the next level of concrete durability, we have to consider that performance of cementitious materials is controlled by physical and chemical processes occurring at a nanolevel. In the area of admixtures, structural design of polymer is already happening at this level. More recent approaches of nanotechnology in concrete are related to the design of C–S–H of nanostructure which could generate a quantum leap innovation not only in terms of strength acceleration but also in terms of overall mechanical and durability properties. New generation inorganic admixtures can have a profound impact on the dissolution process of cement and on the seeding of hydrates crystallisation thus driving the C–S–H structure to an higher level of packing.

3. Emerging Technologies

Interesting technologies which could provide a further contribution to sustainability are emerging requiring suitable admixtures to ensure the optimisation of the overall performance.

3.1 Ultra High Performance Concrete

The last few years have shown revolutionary developments of fibre reinforced concrete and ultra high performance concrete (UHPC) whose applications are still in the very preliminary stages. The extraordinary properties of UHPC makes it an excellent alternative to steel as a construction material and allows the construction of more sustainable and cost effective structures allowing innovative concepts of structural design. The very low water/cement ratio, particular to this type of mix design, requires the control of rheology through the use of specific water reducers tailored for this new material.
Nanotechnology has brought new light into the admixture science. It is now possible that chemicals or polymers can be engineered to bring together functional groups aimed at targeted performance. Polymers are therefore built for strong or weak adsorption onto the cement particles for dispersion effectiveness and for hydration control. The selection of the superplasticisers is very important as it will determine the rheological characteristics for transportation and placing of UHPC, making this new concrete material an important opportunity for the future of concrete. (6)
As can be seen in Figure 3, through the use of UHPC, technology thickness of elements can be extremely reduced even improving the overall mechanical characteristics and having a suitable rheology imparted by new generation superplasticizers. (7)

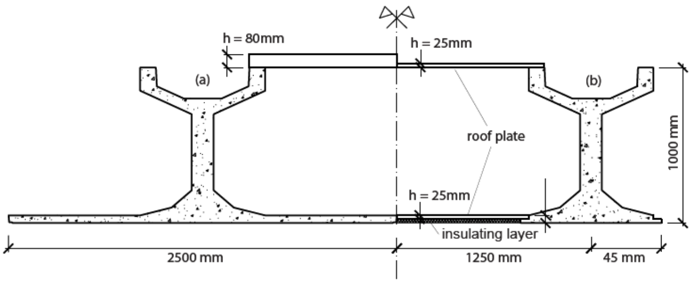

Figure 3 Thickness reduction of a roofing system designed with UHPC vs. traditional concrete

In this way high performance can be obtained so to allow a new structural design concept which provides a reduction of natural resources and primary energy consumption in addition to a reduction of global warming and ozone depletion potential.

3.2 Self-Healing Concrete

Besides its many advantages, unfortunately, concrete is susceptible to many sources of damage. Mitigating microscale damage through an autonomous method that senses and repairs cracks in a target way has become object of studies in the last years. Capsules, glass pipes, hollow glass fibers can be used as a reservoir of specific chemicals able to act when fracture induced by cracks produces a timely release of healing agent able to reduce porosity and passivate metal reinforcement bars. Research on healing chemicals, often selected among the categories of monomers and hydration accelerating agents, is key to ensuring an optimised and effective mechanism thus providing a smart durability concept.

4. Conclusion

Concrete can still be considered a very attractive material and, through an intelligent exploitation of admixtures, and in general of existing and emerging chemical technologies, it can be further improved both in terms of performance and sustainability, enhancing the possibility to save natural resources, energy, reducing CO_2 emissions and protect the environment.

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