Fourth International Conference on Sustainable Construction Materials and Technologies
http://www.claisse.info/Proceedings.htm

SCMT4
Las Vegas, USA, August 7-11, 2016

Sustainability and Its Consequences on Mix Design, Workability and Casting of Concrete

Nicolas Roussel[1]

[1]SIÈGE IFSTTAR, POINT 41, 14-20 BOULEVARD NEWTON, CITÉ DESCARTES, CHAMPS SUR MARNE, F-77447 MARNE LA VALLÉE CEDEX 2, FRANCE. Nicolas.roussel@ifsttar.fr

ABSTRACT

Concrete is the largest volume material used by man and is irreplaceable for innumerable large infrastructure developments. From the point of view of natural resources, ecology and economy, it is virtually impossible to imagine substituting concrete by any other material. However, because of the large volumes used, its energy and CO_2 footprint are important. This review paper examines some of the routes that may be followed to further reduce the environmental impact of concrete and focuses on the consequences from a fresh properties and casting processes point of view. The approach consists in extracting from life cycle assessment data the anticipated changes in mix design of concrete and derive from these the expected changes in terms of rheology and processing technologies along with the upcoming trends that shall allow for these change to become real. The questions of short-term perspective or long-term perspective alternative binders, new admixtures, crushed and recycled aggregates and emerging casting processes such as 3D printing are covered.

INTRODUCTION

The industrial sector is responsible for approximately 25% of global carbon dioxide (CO2) emissions among which CO_2 emissions from cement plants represent no less than 5% of total anthropogenic emissions (Hendricks *et al.*) despite the efforts of the cement industry. Recent studies on the Life Cycle Assessment for concrete structures show that 85% of the CO_2 emissions come from the cement (Parrot). Moreover, life Cycle Assessment for cement shows that 95% of the CO_2 is produced during the fabrication of the cement powder, compared to the low energy consumption of the transport of raw materials and finished products (Teller *et al.*). Therefore it seems obvious that the necessary effort in the building and construction sector in term of CO_2 reduction has to be made on the type and amount of cement used in concrete, at least as a first step.

In parallel, as noted by Dixit et al. (2010), the construction industry accounts for two-fifths of the raw stone, gravel and sand consumption. It is also accountable for 40% of total energy and 16% of annual water consumption (Langston, 2008; Tommerup et al., 2007; Lippiatt, 1999). These figures are more or less similar in any developed country. In Europe, for example, more than 50% of the material flows are used in built environment (IFEN, 2006; EU, 2004) and concrete, as the second sold manufactured materials after water, contributes for a large part.

The construction industry is also a major waste producer. In France, building construction and civil engineering works produce 40% of all waste (IFEN, 2006) without considering earth transportation and disposal during site works preparation. In European Union, 450 millions tons of construction and demolition (C&D) wastes are generated each year and the amount of inert materials such as brick and concrete is estimated at 180 million tons, which represent 480 kg per capita (Rao et al., 2007).

Concrete recycling has therefore the potential to reduce simultaneously the amount of landfilled C&D waste and to preserve natural mineral resources. Making use of recycled concrete aggregates (RCA) has thus been a subject of investigation for a long time (Ravindrarajah et al., 1985; Nixon, 1978; Frondistou-Yannas, 1977). These studies often conclude on the fact that concretes produced with RCA had lower compressive strength and elastic modulus than normal concrete (Frondistou-Yannas, 1977). Furthermore, the mixture needs 10% more water and workability shows a very fast slump loss (Nealen and Schenk, 1998; Barra de Oliveira and Vasquez, 1996). As a consequence, even if using RCA can bypass the need to consume virgin natural aggregate and simultaneously preserve landfill space, this potential is not fully used and RCA are still primarily used as granular base in road works (Ramachandran, 1981 ; Dhir et al., 2000). The main reason for that open recycling, or down cycling loop, lies in the fact that RCA contain a non-negligible amount of cement paste from the original concrete attached to the natural original aggregate.

EXPECTED CHANGES IN MIX DESIGN AND THEIR CONSEQUENCES

We can expect from the above that we will see an evolution in mix design following the three following axis. First, a decrease in clinker dosage in concrete and an increase in the use of alternative powders, which often lead to a decrease in the W/P ratio, can be expected. Then, a decrease in the pressure on natural aggregates resources by using more crushed aggregates is needed. Finally, an increase in the use of recycled crushed demolished concrete is non avoidable.

These changes will affect workability, rheological parameters and casting process, which do correlate as shown in in Tab.1.

TECHNOLOGY	**Rheological and physical parameters**
Filling ability	Yield stress
Stickiness	Viscosity
Passing ability	Yield stress (and particle size)
Stability	Yield stress, viscosity and thixotropy (at the scale of the paste)
Specific processing issues	
Formwork pressure	Thixotropy
Cold joints	Thixotropy
Additive manufacturing	Enhanced thixotropy

Table1. Correlation between technological requirement and processing with rheological and physical parameters.

The change in binders will go along with a decrease in the water to powder ratio in order to guarantee the expected mechanical and durability requirements. This will lead to an increase in both yield stress and viscosity and, as it can be seen in Fig. 1, the increase in viscosity will be more drastic.

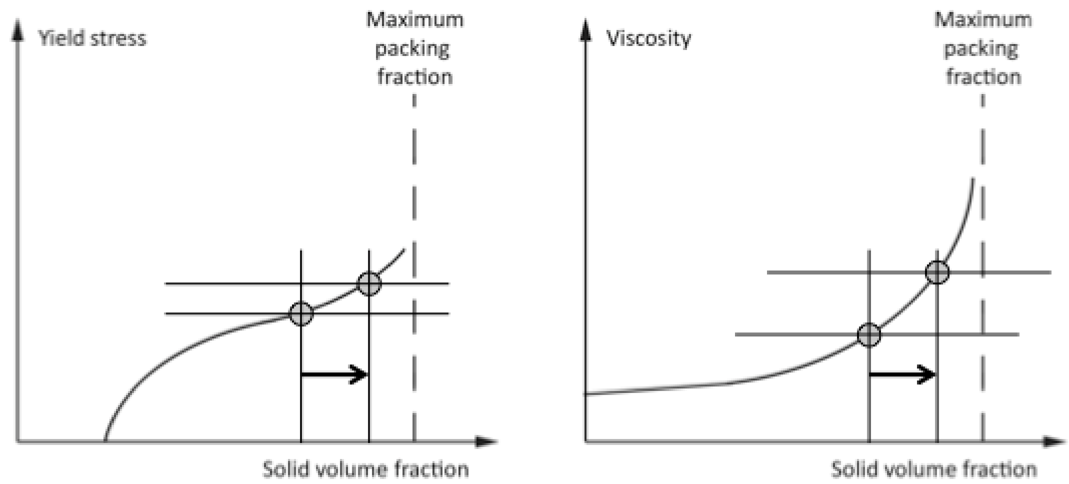

Figure 1. Change in yield stress and viscosity of a cementitious material for an decrease in the water to powder ratio

The replacement of natural round aggregates nu crushed or recycled aggregates will have similar consequences and, without an increase in matrix volume, an increase in both yield stress and viscosity is to be expected.

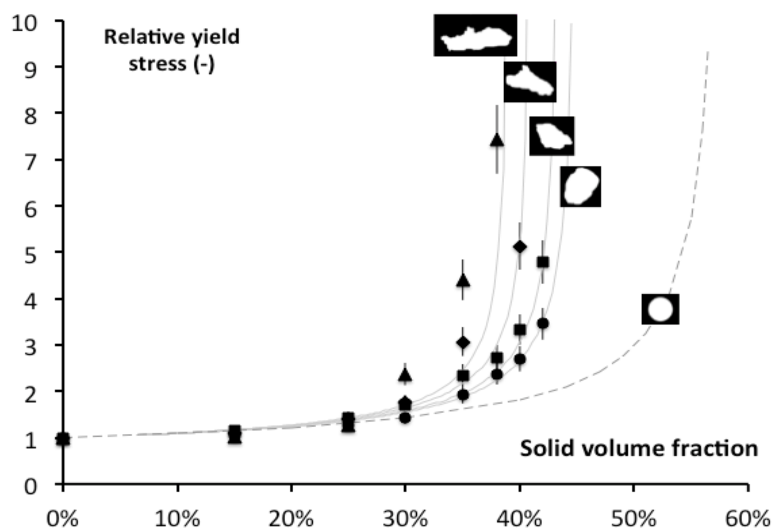

Figure 1. Yield stress of a mortar divided by the yield stress of the constitutive matrix as a function of volume fraction for particle with various morphologies.

The keynote will focus on the changes induced by sustainability and list the consequences of the expected decrease in clinker content, which lead to a decrease in Water/Powder ratio along with the incorporation of crushed aggregates and recycled concrete aggregates

It will be shown that these trends all lead to a yield stress increase, which requires the development of suitable admixtures for these new binders. It will be moreover shown that the decrease in Water/Powder along with r the incorporation of crushed aggregates and recycled concrete aggregates moreover lead to an increase in viscosity and a decrease in robustness, that will be more difficult to fight against. Finally, It will be pointed out that air entrainment for rheology purposes could become a key issue while concrete production plant shall improve the control of aggregates moisture.

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