MIXING SELF COMPACTING CONCRETE: MIXERS, MIXING METHODS, MIXING TIME

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ABSTRACT

Some main specificities of SCC manufacturing are detailed, mainly the proportion of non-compliant industrial batches, the influence of the mixer, mixing time and mixing method on the SCC characteristics.

Special attention is given to correctly define the mixing evolution description, i.e. the homogenization time, the stabilization time, the fluidity time and the characteristic time of the paste rheology evolution. Also, mixing systems principles are summarized and some important adimensional mixing numbers are specified: the number of turns and the Metzner and Otto constant K_S.

Besides, on the bases of literature data and experimental results it is shown, on the one hand, that the proportion of non-compliant batches in industrial conditions is significant for normal utilization of current equipments, and on the other hand, that the mixing method can alter or, at contrary, improve the concrete flow abilities.

Keywords: production; robustness; loading sequence; two-stage mixing

INTRODUCTION

It is undoubtedly that self compacting concrete is more complex to produce than ordinary concrete. A complete discussion on SCC manufacturing is huge and this paper details only some main specificities. Mixing related problems are particularly discussed, on the bases of literature data and experimental results. Some tips in choosing the appropriate mixer and mixing method for SCC manufacturing are given in this paper, based on some concepts developed for the understanding of the mechanism of paste formation during mixing. These concepts are briefly presented in the first part of the paper.

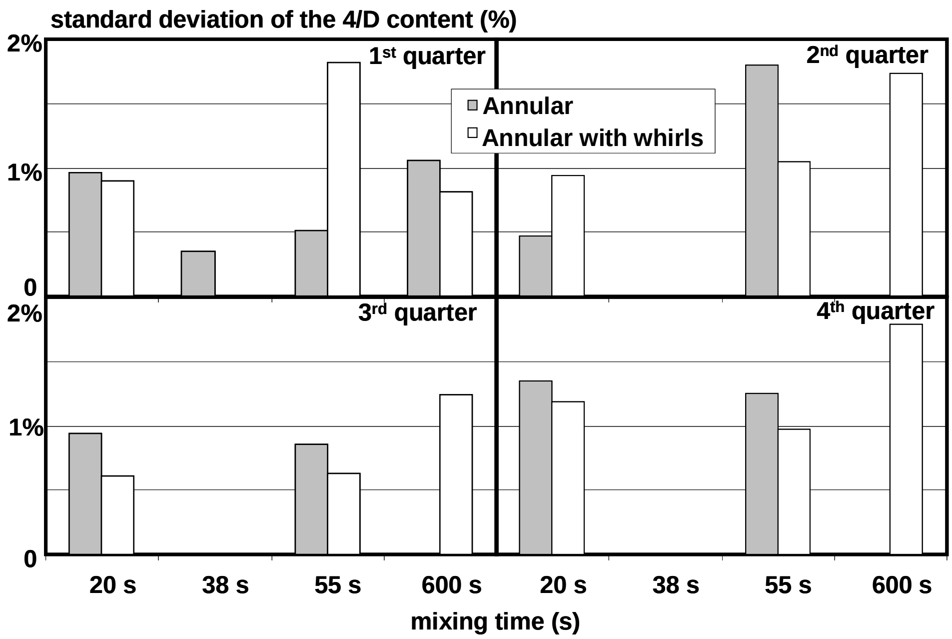
MIXTURE EVOLUTION WITH MIXING TIME

As the mixing time of concrete increases with the powder content[6], SCC involves longer mixing time than regular concrete[1,3]. However, more detailed analysis of the mixing effect needs first to better clarify the concept of "mixing time needed". A theoretical mechanism of concrete paste texturation[7-9] supposes that: i) at the early stage of the liquid introduction on the agitated powder loose clusters of solid particles forms, including liquid bridges which give the clusters cohesion; ii) the mixing shear consolidate the clusters and liquid is squeezed out of them assuring the growth of the clusters size, by coagulation with still dry powder elements or other clusters; iii) zones of paste are formed when liquid bridges unite and the continuum liquid formed coats several solid particles; and iv) once the paste formed at a time designated as "fluidity mixing time", fine particle agglomerates still present in the paste are gradually broken up by admixture effect under shear. The different transitory stages in concrete mixing are also described in newer researches[10,11].

One can conclude that at least two different mixing stages should be considered to analyse the concrete mixing: firstly the formation of the granular paste and secondly the softening of the paste. These two phenomena should be added to the ordinary meaning of mixing which is the homogenisation. In principle, the homogenisation concerns at least two compositional parameters: i) the standard deviation of the aggregate content in the mixture, and ii) the standard deviation of the proportion between the water and powder contents in the mixed volume. Homogenisation means basically the decreasing of the standard deviation of the mixture characteristics in the mixed volume. So, from a compositional point of view, at least two homogenisation times could be considered: the aggregates homogenization time and the homogenisation of the water to powder ratio.

An extensive research on the homogenisation of aggregates was conducted in the 1980's[12] on regular concrete mixtures. More recently the heterogeneity of SCC samples after different periods of mixing was experimentally studied as well. A SCC mixture (water to powder ratio 0.36, CEM I 52.5 content of 388 kg/m³, 166 kg/m³ of limestone filler, sand to coarse aggregates ratio 0.85, melamine superplasticizer to powder ratio 2.7%) was mixed in two different 1m³ mixers. The first one is an annular mixer, with 8 blades having a simple rotational movement of 19 rpm. The second one has similar geometry with two extra whirls which planetary movement velocity was about 2.7 times higher than the principal rotational velocity. 4 samples were taken from each quarter of the SCC discharge after different mixing times (20, 38, 55 and 600 seconds). As shown in Figure 1, no statistically relevant evolution of the standard deviation in each quarter of the discharge was observed with the mixing time. So, as for the regular concrete, it may be considered that the coarse aggregates homogenisation is finished at short mixing time (at least after 20 seconds).

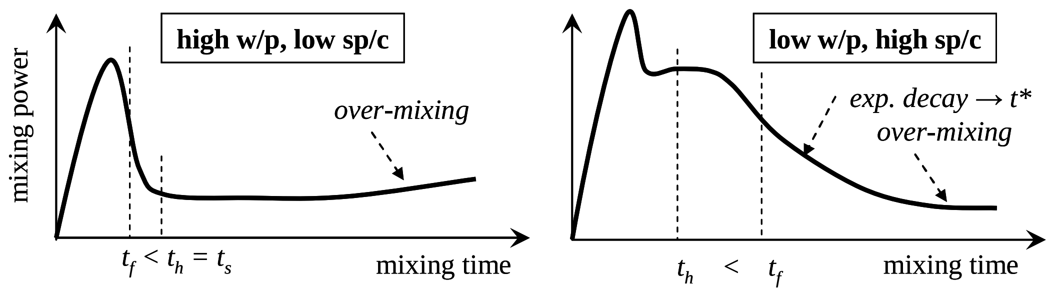
Figure 1. Evolution of the standard deviation of the content in aggregates larger than 4 mm, in samples of 1 kg of concrete at different mixing times in each of the quarter of the discharge



The homogenization of the water and powder content needs longer mixing time. Subsequently, the homogenisation time should generally be considered as the mixing time needed to obtain an as reduced as possible standard deviation of the water to powder ratio.

High water to powder ratio is usually designed in regular concrete. As a consequence, even for important w/p heterogeneities the paste formation is fast in all mixture. The mixing problem becomes a granular paste homogenisation and the operation finishes at a state usually called "uniform concrete". Once the uniform concrete obtained in regular concrete, only slight further evolution of the mixture could be observed. This can be confirmed by the time evolution of the mixing power which becomes constant. The corresponding mixing time, commonly called stabilisation time, is generally admitted as the mixing time needed for the regular concrete.

Figure 2. Schematic representation of the evolution of the mixture during mixing, by using the mixing power evolution in time; t_f –fluidity time, t_h – homogenization time, t – half-life time of consistency evolution after fluidity.*



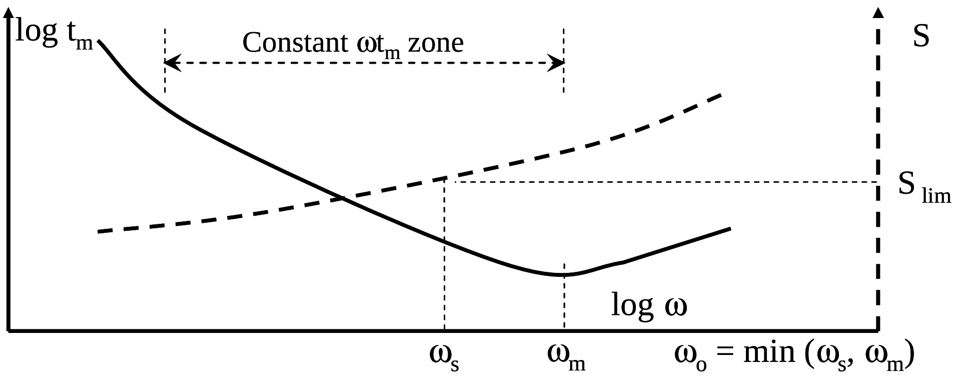
A different approach should be considered for lower water to powder ratio concrete, as SCC. For these mixtures, the compositional homogenisation arrives before the structuring of the mixture in a granular paste. A first mixing efficiency characterisation is provided by the fluidity time in place of the stabilisation time. Once the granular paste is formed, the consistency of the mixture continues to evolve due to the broken up of fine particles agglomerates. The fine particles released by agglomerates serve to increase granular skeleton compactibility, thereby decreasing paste viscosity[13]. So, a quasi exponential consistency evolution or, alternatively, a hyperbolic decay should be defined to complete the SCC mixing characterisation[7]. A characteristic unit of this decay equation could be defined by the half-life time which characterizes the behaviour after the fluidity time. Over-mixing phenomena like increasing temperature and attrition effects perplex the behaviour after the fluidity time and complete the time evolution of the mixture description. The Figure 2 summarizes the discussion above.

MIXERS

A large variety of mixers are used in the concrete industry[3,14,15]. Methods for the evaluation of concrete mixers efficiency are proposed by standards and recommendations (ASTM C94, NF ISO 18650, RILEM TC-150). It is however difficult to obtain an objective comparison between the efficiency of mixers commercially available as the different mixing systems can not be dissociated from the mixing method, mixer size, filling level and tool wear. Also, the mixing efficiency may act dissimilarly for different concrete mix-designs. At this stage, the discussion is limited to the principles of mixing and to the adequacy to the SCC manufacturing.

For Newtonian fluids in laminar flow the agitator can achieve two functions. The first is to introduce movement into the fluid (pumping). The second function is to separate the flow, aiming to increase the fluid distribution (dispersing). In Bingham fluids these functions should be assured by different agitation tools. Efficient interaction between the tools in laminar flow firstly depends on the mixer geometry but also depends on the tools velocities. Too low mixing speed induces localised mixture kinematics and large dead volume diminishes mixing efficiency. Too high mixing speed produces plug-flow zones, with similar effects.

Figure 3. The mixing time needed (t_m*) and the standard deviation of the coarse aggregates content (*S*) evolutions with the mixing rotational speed –* ω*;* ω_s *corresponds to the accepted limit for* S *and* ω_m *corresponds to the upper limit of the constant number of turns (*ωt_m*) zone;* ω_o *is the upper limit of the mixer rotational speed.*



The favourable mixing speed range is different from one mixture rheology to another, and could be very different between a regular concrete and a SCC. In this favourable mixing speed range, the characteristic time of the mixture evolution seems proportional to the mixing speed. It results that the number of turns (product of the angular velocity and the mixing time) to obtain the desired mixture is a mixing constant. To optimise the mixing time the mixing speed should be chosen as high as possible to keep constant the number of turns needed (Figure 3). Meanwhile, the mixing speed should also be limited to avoid the segregation in the granular phase, as higher velocity in the mixed granular media induces higher segregation of coarser particles. The rotational mixer speed should be lower than that producing the accepted limit of segregation (Figure 3).

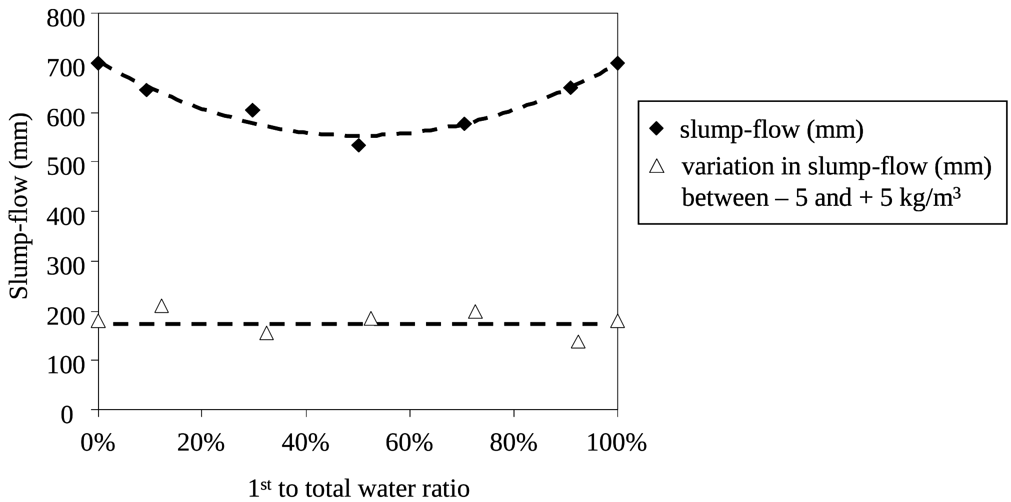
It is established[16] that the mixing in laminar flow highly depends on the flow strain rate. For efficient SCC manufacturing one should give priority to mixers which inseminate the highest strain rate at given mixing speed. The ratio between mean strain rate in the mixture volume and mixer rotational speed, generally called K_s[17], should be maximized. Metzner and Otto constant K_s is a mixer constant as is generally considered independent from the mixing speed for non-Newtonian fluids.

Other than that, concrete mixing is also a problem of granular micro-structuring. In the light of the previously detailed mechanism of concrete paste texturation, one can identify the importance of compression stress (including the spherical component of the stress tensor). Indeed, it is observed that mixers introducing high level of compaction into the mixture are most effective for mixing concrete with low w/p[18]. The efficiency of micro-structuring is improved further by applying cycles of compaction and loosening into the mixture. This mechanism is generally implemented by raising the mixture (loosening) then dropping it and producing densification. This kind of mixer, with high densification combined with large cycles of loosening should be privileged for the mixing of low w/p concrete as SCC.

MIXING METHODS

The nowadays way of mixing by a forced paddle mixers is feeding all the ingredients simultaneously at constant mixing speed, except for some portions of admixture and water to be mixed at a later stage. Laboratory studies show that the dry mixing has no influence on the concrete characteristics[19]. In practice this conclusion is more uncertain as natural aggregates are generally wet and the so called “dry mixing” is a way to introduce water into the mixer in two steps.

Figure 4. Evolution of the slump-flow for a given mix-design with the ratio between the first and total water



The two steps water loading can be unfavourable to the SCC workability. Tests were conducted on a SCC (water to cement ratio 0.45, CEM I 52,5 content of 400 kg/m³, sand to coarse aggregates ration 0.91, polycarboxylate superplasticizer to cement ratio 0.90%) mixed in a laboratory planetary mixer (cf. Figure 4a). The added water is loaded in two stages, with a delay of 1 minute on a total mixing time of 6 minutes. A significant loss of slump-flow is observed when water is added by half, compared with the one stage water loading. The difference in slump-flow is equivalent to a decrease in the water content of 10 kg/m³. Similar trends are presented by Bonen et al.[3], in a literature review on the effect of aggregates natural moisture content. However, water absorption by aggregates during mixing is only a part of the explanation of the results in Figure 4. Indeed, the cement paste rheology mixed without aggregates is also sensitive to water loading sequence[20]. This phenomenon is more complex to explain and highly depends on type and proportion of superplasticizer in the cement paste.

When concrete is mixed in a drum mixer, more complex mixing methods are recommended. More generally, various sequences of components loading are proposed in concrete mixing to improve different concrete characteristics.

CONCLUSION

Manufacturing process interacts with concrete characteristics in various ways. Some aspects related to SCC are developed here. Firstly, a rough comparison between the robustness of SCC mixtures and the industrial batch to batch variation demonstrates the important proportion of non-compliant batches inherent to current industrial equipments. Secondly, the different objectives when mixing high-slump or regular concrete are highlighted. For regular concrete the granular paste is rapidly obtained and the role of mixing is to obtain a uniform concrete. For SCC, the function of the mixing is sequentially to homogenise the unsaturated powder, to structure it by forming the granular paste and to disperse powder agglomerates to obtain the targeted rheology. The adequacy of the mixing system to the SCC manufacturing is the third aspect taken into account. Should be privileged mixers maximising the ratio between mean strain rate and mixer rotational speed and, also, introducing high level of compaction into the mixture. Finally, it is shown that the mixing method could significantly change the workability of the concrete. The classical method which consists on feeding all the ingredients simultaneously seems better than a two-step water loading method, but could be less effective than a method mixing the cement slurry in a first stage.

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