EFFECT OF MIXING ENERGY ON FRESH PROPERTIES OF SCC

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INTRODUCTION

While for the composition and properties of concrete and its raw materials numerous publications of rules and guidelines are available, the actual process of concrete producing, the mixing, is largely left to the user. The raw materials are to be mixed in such a way during mixing that the mixture appears to be uniform. As a matter of principle, the mixing duration is to be selected in such a way that sufficient mixing of the raw materials takes place. It is important that water and superplasticizer are evenly distributed and sufficiently disintegrated. If mixing energy is insufficient, the properties will not be achieved, which could be possible, according to the mixture proportion of the concrete. The necessary mixing duration depends mainly on the mixer design, as well as the mixture proportion. Due to the low water contents relative to the powder contents and high additive dosages, more energy is required for the production of self-compacting concrete to distribute the raw materials evenly. Mixing times of 240 s are not rare in a ready mixed concrete plant. This limits the concrete output in the plant significantly compared with common vibrated concrete and is, therefore, a substantial cost factor.

INVESTIGATIONS

First investigations at the cbm of Munich TU revealed a large optimising potential. Initially, the influence of mixing energy on the initial consistency, as well as the time-depending development of the fresh concrete properties of self-compacting concretes was systematically investigated. Based on these results, the mixing procedure could be optimised and the mixing time significantly reduced. An intensive mixer of the machine factory Gustav Eirich [3] with controllable tool velocity was made available to cbm for these examinations. It was also possible, to record the power input at the mixing tool and the mixing plate during the mixing process.

Investigations of two self-compacting concretes with usual composition and mixing time (SCC.A and SCC.B) were carried out. The compositions of these concrete types, as well as the fresh concrete properties are shown in Table 1. The concrete types SCC.A and SCC.B differ, essentially, in the coarse aggregate content ‘g’, as well as the ratio of water to powder volume ‘Vw/Vp’. In order to clarify the optimising potential of the mixing process, also a concrete was used, which is characterised by a high energy requirement to achieve its optimal fresh concrete properties (SCC.C). This concrete differs from SCC.B only by higher additive contents. It was possible to determine the effects of the various influencing factors during mixing more detailed due to the longer mixing times for producing SCC.C.

MIXING

The particle movements during mixing can be divided according to Stieß [2], in principle, into a convective and dispersive transport. Convective transport is a forced, directed movement of larger portions of the mix, e. g. by the mixing tool (coarse dispersion,
This is superimposed by the dispersive transport. Dispersive transport is the random movement of individual particles due to collisions between the particles. This leads to a mixing in small areas (fine dispersion), as well as a disintegration of agglomerates. The degree of homogenisation of the mix achieved in the concrete production influences the properties of the fresh, as well as the hardened concrete. The mixing quality depends, besides the mixture proportion of the concrete, essentially on the mixing time, the velocity of the mixing tool (or the mixing container), the geometry of the mixing tool and the mixing sequence.

**MIXING TIME**

At first, the influence of the mixing time on the fresh concrete properties of the self-compacting concretes was examined. In Figure 3, the development of the slump flow with J-ring is drawn up in dependence from the mixing time by the example of the SCC.C. In addition, the recorded input power at the mixing tool is shown. Three phases can be distinguished by the progression of the slump flow measure and power.

**Phase 1 - Dispersing**

Water was added at the time \( t_0 \) within 10 s. Fluid bonds between the particles (Figure 2) are formed by adding and dispersing of water. Due to the surface tension of the water and the capillary pressure inside the fluid bond, the inter-particle forces increase. Therefore, the first phase is initially characterised by a significant power input increase at the mixing tool. With the progress of dispersion of water and superplasticizer, a transition takes place from a grain bulk to a suspension. As soon as the particles are in a liquid environment, the capillary forces omit. This is shown by the decrease in power, which then follows. During this first phase, the

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<td>Water-powder volume ratio</td>
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<td>Maximum slump flow with J-ring [mm]</td>
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<td>V-funnel time [s]</td>
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<td>At mixing time [s]</td>
<td>( t_m )</td>
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<td>Mixing tool velocity 1.3 m/s</td>
<td>&gt; 480</td>
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**Table 1: Mixture proportions, basic characteristics and optimal fresh concrete properties**

**Figure 1: Processes during mixing**

**Figure 2: Fluid bond**
flowability clearly increases with increasing distribution of the raw materials.

**Phase 2 – Optimum**
The power at the mixing tool reduces asymptotic during the mixing process. As soon as a plateau is reached, a further homogenizing of the raw materials and a complete dispersion of the superplasticizer can be assumed. At this time, the flowability reaches its maximum.

**Phase 3 – Overmixing**
The further mixing energy leads to a decrease of the flowability of the concrete. Due to the convective and dispersive transport, further position changes between the particles take place. However, a significant improvement of the mixing quality is impossible. At the same time, further collisions between particles, as well as between particles and mixing tool continue occurring, so that the agglomerates are further disintegrated. It can also lead to a further enrichment of finest particles due to abrasion of the coarse aggregates. Abrasion of the first hydrate phases in the concrete is also possible, due to which new reaction areas appear (compare [3, 4]). These processes accompanied by a progressive increase of the surfaces and, due to this, an increase of the water and superplasticizer demand. Eventually, it leads to a decrease of flowability. Investigations of Wischers [4] of vibrating concretes also showed that surfaces are enlarged with increasing mixing time. He found that cement, getting finer by long mixing, makes the cement glue thicker and stickier and, eventually, leads to an increase in concrete strength.

In practice, especially the knowledge of the time ($t_1$) and the size of the time window ($t_2-t_1$) with optimum fresh concrete properties is of deciding importance for the concrete production. The dispersion phase should be rather short for an economical concrete production. However, it is also important that the period of optimal fresh concrete properties is not too short, to exclude an overmixing safely and by this, a reduction of the workability.

**MIXTURE PROPORTIONS**

The development of fresh concrete properties with progressing mixing time is, essentially, influenced by the composition of the concrete. This correlation is depicted in Figure 4 for the examined concretes at a tool speed of 1.3 m/s.

The mixing times are to be understood as including the time for water and additive addition. The mixing time is often defined as the duration of mixing after completed filling of raw material until the beginning of emptying. The homogenisation of the mixing material starts, however, during the addition of water and additives. As the addition times clearly vary plant-specific, a comparison of mixing times can only be made, if the filling time of water and additives is taken into account.
SCC.A reaches its maximum flowability in 120 s and, therefore, in a significantly shorter time than the SCC.B at 240 s. The SCC.C, especially developed for these examinations, needs even more than 480 s mixing time for this. Mainly the water content and the content of the, in this case, used viscosity agent on the basis of a synthetic Co-polymer seem to be responsible for the mixing time until reaching the maximum flowability. While an increase of the water content leads to a reduction of the mixing time, longer mixing times became necessary, when increasing the viscosity agent content.

The size of the window with optimal fresh concrete properties is essentially influenced by the coarse aggregate content. Therefore, SCC.A with higher coarse aggregate content shows a clearly shorter optimum phase than the other two concrete types. After 240 s mixing time, a clear reduction of the flowability is already evident, while the other concrete types SCC.B and SCC.C show hardly any decrease in the slump flow with J-ring up to a mixing time of 720 s. Due to the coarse particles, an increased disintegration of cement or filler agglomerates takes place - the coarse aggregates work as a grinding aid. The consequence is a faster enlargement of the surfaces. The demand of superplasticizer and water change and lead to a loss of the flow properties of the concrete.

However, the change in the mixture proportion presents only in very rare cases a sensible option shorting mixing times. The optimisation of the mixture proportion should serve, in the first place, ensuring the solid concrete properties, as well as improved workability. Here, one should think more of sufficient processing time and high segregation resistance. Possibilities reducing the mixing time should therefore be looked for by optimising the mixing technology and the mixing equipment.

**MIXING INTENSITY**

On the side of mixing technology, shortening the mixing time can be achieved by increasing the mixing tool velocity. Figure 5 shows the development of the slump flow with J-ring of SCC.C, in correlation to mixing time at different tool velocities. With increased tool velocity the dispersing phase shortens. The mixing time for reaching optimal flow properties can, therefore, be shortened significantly. While the maximum slump flow with J-ring is reached after 720 s at a tool speed of 1.3 m/s, SCC.C takes only 120 s at 8.7 m/s. At the same time, the duration of the phase with optimal flow properties shortens too. Therefore, overmixing is reached faster, combined with a decrease in flowability.

![Figure 4: Effect of mixture proportion – mixing](image1)

![Figure 5: Effect of mixing tool velocity - SCC.C tool velocity 1.3 m/s](image2)
Furthermore, it could be observed that the maximum flowability decreases somewhat with increased tool speed. Temperature increase in the mix as a reason could be excluded. However, the kinetic energy of the particles increases to the second power with an increase of the mix velocity. In case of a collision between particles, also harder agglomerates can now be disintegrated. The surface and, by this, the water demand of the solid mixture increases compared with mixtures, which are mixed at lower velocities. The consequence is a lower flowability.

How much the mixing time can be shortened by increasing the tool velocity and in how far this is combined with a decrease in flowability, depends, again, on the mixture proportion (Figure 6). The decrease in flowability is influenced by the content of coarse aggregate. Therefore, the decrease in flowability of SCC.A with higher content of coarse aggregate was clearer than of SCC.B and SCC.C with lower coarse aggregate content. On the other hand, SCC.A needs lower tool velocities, compared with the other two concretes. The mixing time to reach maximum flowability of SCC.A could already at a mixing tool velocity of 2.6 m/s reduced to only 60 s. A further increase of the velocity was not sensible, as no further reduction of the mixing time could be achieved. In contrast, the mixing time for SCC.B could still clearly be reduced to 90 s by increasing the tool speed to 8.7 m/s.

According to this, the optimal velocity is, therefore, not a fixed value, but has to be determined for every type of concrete, depending on mixing time and maximum flowability. If high tool velocities are to be used, then, especially for high coarse aggregate contents, an increased water demand in the mixture proportion has, possibly, to be taken into account.

However, the reduction of mixing time, connected to an increase of the tool velocity, can significantly contribute to an increase of the capacity of a ready mixed concrete plant. At mixing times of 60 s, including time for water and superplasticizer addition, the mixing time of self-compacting concrete is in the range of common vibrating concrete types.

**HYBRID MIXING SEQUENCES**

For a further reduction of mixing times, tests were carried out with hybrid mixing sequences. In hybrid mixing sequences, mixing is carried out in several partial processes with varying mixing intensity. In previous investigations it was found that high tool ve-
locities accelerate, especially, dispersion of water and superplasticizer. After transition from grain bulk to suspension, a high energy input is not required any more. In hybrid mixing processes, the tool velocity is adjusted according to the respective requirements (Figure 7). By high tool velocities in the starting phase, especially, water and superplasticizer dispersion is to be intensified. In order to minimise the energy input and, by this, reduce a progressing desagglomeration, the final homogenising of the mix is then carried out at lower tool velocities. It was possible to produce the SCC.A with its maximal flow-ability ($d_{sj} = 744$ mm) in a mixing time of 60 s with such a hybrid mixing process. A period of 20 s with high tool velocity ($4.5$ m/s) proved to be optimal for this concrete. In the following, the tool velocity was lowered to $1.3$ m/s.

If the idea of a hybrid mixing process is transferred to the production of self-compacting concrete in the ready mixed concrete plant, it would be possible reducing the running time of the plant mixer still further. In this case, only the intensive water and superplasticizer dispersion takes place in the plant mixer; the final homogenising can take place at low mixing intensity in the vehicle concrete mixer. When using a hybrid mixing process according to Figure 7, the mixing time in the factory mixer could be reduced to 30 s for the SCC.A. First tests in a ready mixed concrete plant showed that the effective mixing time in the plant mixer can be clearly reduced by using hybrid mixing processes, also with compulsory mixers at low mixing tool velocities.

CONCLUSIONS

Without a doubt, numerous concrete technological and economical advantages are combined with the use of self-compacting concretes. However, long mixing times lead to a reduction of the capacity of the concrete plant and can cause, also, supply bottlenecks on site. It was possible, by increasing the mixing tool velocity, to reduce the mixing time to 60 s, including time for water and superplasticizer addition. Due to this, the mixing time for the production of self-compacting concretes lies in the range of common vibrating concrete. The productivity of the production can be considerably increased by this significant reduction of mixing time and, due to this, the production costs for self-compacting concrete can, eventually, be reduced.

Self-compacting concrete could be produced in a total mixing time of 60 s too by using hybrid mixing sequences. A separation of the mixing process into an intensive mixing phase in the plant mixer and following homogenising in the vehicle concrete mixer is conceivable for the production of ready mixed concrete. Thus, a reduction of the effective mixing times in the plant mixer down to 30 s can be achieved by respective tool velocities.

REFERENCES