RHEOLOGY-BASED MIXING PROCESS TO ENSURE UNIFORM WORKABILITY OF DEMANDING CONCRETE MIXES

RHEOLOGIEGESTÜTZTE MISCHPROZESSFÜHRUNG ZUR SICHER-STELLUNG EINER GLEICHFÖRMIGEN VERARBEITBARKEIT VON ANSPRUCHSVOLLEN BETONGEMISCHEN

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SUMMARY

In current research approaches a combined two-stage mixing concept is developed, to produce fresh concrete with continuously high quality in respect of its workability and robustness. In practice, there is a strong demand to ensure an excellent pumping of the fresh concrete mixture. Normally, for standard vibrated concretes problems are rare on construction site. But in respect to the increase of usage of more complex concretes like SCC and HPC a higher sensitivity of the behavior of the fresh concrete can be observed caused by a higher amount of admixtures and additives. For this reason, problems of pumping large quantities of concrete are to be solved, especially when the concrete is pumped over large distances with large differences in height. Moreover, the environmental conditions as well as the moisture of the finer aggregates influence the workability of the fresh concrete. Therefore, the mixing of concrete plays is an important role, to ensure defined rheological properties of the fresh concrete after the mixing process, to guaranty a problem-free pumpability and good storage stability with low tendency for separation. For this purpose, the yield point and viscosity of the concrete should be kept within an acceptance range in order to counter segregation or even the loss of the flow or self-compacting properties.

ZUSAMMENFASSUNG

In aktuellen Forschungsansätzen wird ein kombiniertes zweistufiges Misch-konzept erforscht und weiterentwickelt, um Frischbeton mit gleichförmiger hoher Qualität mit Blick auf die Verarbeitbarkeit und Robustheit herzustellen. Ziel ist es, anspruchsvolle Hochleistungsbetone in einem kontinuierlichen Mischprozess

zielsicher herzustellen und auf der Baustelle nach der Übergabe bis zum Einbau in die Schalung zuverlässig pumpen zu können. Bei der Verarbeitung von klassischem Rüttelbeton kommt es nur selten zu Problemen. Doch beim Einsatz der anspruchsvolleren Betongemische wie SVB und HLB zeigt sich ein deutlich sensibleres Frischbetonverhalten abhängig von den Schwankungen der Gehalte und Eigenschaften der verwendeten hochwirksamen Betonzusatzmittel und Betonzusatzstoffe wie auch den aktuellen Witterungsverhältnissen. Folglich bedarf es geeigneter Lösungsansätze, um auch anspruchsvollere Betongemische über große Distanzen und Förderhöhen vom Fahrmischer bis zum Einbauort zielsicher pumpen zu können. Entscheidend ist die Einhaltung des für das Pumpen und den Einbauprozess erforderlichen rheologischen Frischbetonverhaltens. Daher kommt dem Mischen von Beton eine entscheidende Rolle zu, um definierte rheologische Eigenschaften des Frischbetons nach dem Mischprozess sicherzustellen, die ein problemloses Pumpen erlauben, ohne dass es zu Entmischungen, Konsistenzveränderungen etc. bei der Pumpförderung kommt. Zu diesem Zweck müssen die Fließgrenze und die Viskosität des Betons im geforderten Akzeptanzbereich gehalten bleiben, um einer Entmischung oder gar dem Verlust der Fließ- oder Selbstverdichtungseigenschaften entgegenzuwirken.

KEYWORDS: Rheology based mixing, packing density, high performance mixers, mixing and pumping of concrete

1.   INTRODUCTION

High-performance concretes are characterized by excellent durability and mechanical behavior for example very high strength. For this purpose, a high packing density is aimed for, in which the fine- and finest-grained additives fill the coarse grain skeleton while observing the respective grading curves. If low water-cement-ratio (w/c) or low water-binder-ratio (w/b) is achieved, capillary porosity can be minimized. As a result, structural elements are showing properties like high strength capabilities and impermeability to gases and liquids. Furthermore, strength increases can be achieved by the targeted selection of additives with pozzolanic or latent hydraulic reaction characteristics. Ecological aspects can also be taken into account by using e.g. inert additives as cement substitute. High quantities of superplasticizer are generally used to ensure that the fresh concrete of the mixture, which is rich in fines and low in water, can be processed easily.

These cause a considerable increase in costs and often result in a pronounced viscoelastic behavior when larger quantities of superplasticizer are used.

The highly viscous mixing behavior leads to considerably longer mixing times, which increases energy consumption. In the case of minor fluctuations in the quality of the starting materials and in the accuracy of their dosing, the fresh concrete behavior also changes. In order to ensure a high uniformity of the properties of the fresh concrete, a mixing system and a mixing process is required which allows a homogenization of all components and a deagglomeration of all fine particles of the mix. Moreover there is an interest to be able to characterize the rheological properties of the fresh concrete during mixing inside the mixer [1, 2]. For this, a rheology-based mixing process is of interest, to ensure a high uniformity of the fresh concrete properties from batch to batch.

2. MIX DESIGN

2.1 INFLUENCE OF PACKING DENSITY ON CONCRETE PROPERTIES

The fresh and hardened concrete behavior is largely determined by the packing density of the solid particles of all components of the mix [3]. The packing density is calculated from the volume of the solids in relation to the total volume. It is influenced by the particle size distribution and particle shape [4]. A high packing density is generally associated with favorable fresh and hardened concrete properties [5], since fine particles fill the cavities of the coarser particles. If the proportion of coarse particles is high, large quantities of fine particles are required. If the fines content is high, these particles occupy a large specific surface area and require a large amount of water. Therefore, a particle composition should be sought that reduces the amount of water required. In [6], the increase in strength is explained by the porosity of the cement paste, since very small pores are formed if the grading curves of all components of the mix are fitted together to an optimum. In [7] the influence of the particle shape was analyzed. Edged particles cause a lower packing density and larger cavities are formed in which mixing water collects. At the particle surfaces no sufficient sliding film is formed, which impairs the processability [8]. A higher packing density can be achieved with limestone powder than with quartz powder [5]. It is known that not only the reactivity but also the granulometry of all components of the mix determine the development of the concrete structure and thus the properties of the concretes in their fresh and solid state.

2.2   CONCRETE MIXTURES WITH OPTIMIZED PACKING DENSITY

The grading curve has a direct influence on the fresh and hardened concrete properties. The modified Andreassen model [9] is used to optimize these properties. Here, a target grading curve is used, to which the grading curve of the concrete is to be adjusted in order to increase the packing density. The sieve passage of the individual fractions is calculated depending on the maximum and minimum particle size of the mixture. The formation of the grading curve is influenced by a distribution module q. The lower the modulus, the higher the proportion of fines in the mixture.

Self-compacting concretes should have a distribution modulus of $0.22 < q < 0.25$ and earth-moist concretes a distribution modulus of $0.35 < q < 0.40$ [10]. The green strength increases with decreasing water demand. According to [11], the maximum packing density is reached with a distribution modulus of 0.28. The maximum packing density is reached with a distribution modulus of 0.28. [12] also takes the particle shape into account. For this, the particle index, which shows the ratio of length to width of the particles, is considered. As the particle index increases, a lower distribution modulus is recommended in order to fill the cavities with the higher amount of cement paste.

2.3   MIX DESIGN WITH BÉTONLABPRO

Using the BétonlabPro software developed at the Laboratoire Central des Ponts et Chaussées, which links various models to form the Compressible Packing Model (CPM), it is possible to derive a relationship between the composition of the mix and the properties of the concrete [13]. An essential element of the software is a database in which important characteristics of all components of mix are stored, such as water demand, superplasticizer requirement and compactability. The packing density of the particle fraction can then be calculated with these quantities to be determined experimentally. The higher the packing density of a fraction, the stronger it is represented in the ideal mixture [6]. Concrete additives make a considerable contribution to increasing the packing density and thus to considerably increasing the performance of the concrete in the fresh and solid state.

3. MIXING PROCESS CONTROL – LAB SCALE ANALYSIS

3.1 EXPERIMENTAL INVESTIGATIONS IN STANDARD OR HIGH-PERFORMANCE MIXERS

Extensive experimental investigations have shown [1, 2] that for HPC, which are rich in fines and superplasticizers and low in water, the mixing process has a decisive influence on the uniformity and quality of the workability of the fresh concrete and the properties of the solid concrete. The subject of current investigations is the analysis of the dependence of the fresh concrete properties on energy input, dosage sequence and dosage rate of all components of the mixture. In addition, optimum tool speeds and the advantageous design of the mixing tools are sought in order to achieve fast and complete disintegration of all fines and thus the best possible homogenization of all components. A further research interest is the question of when, in which rates and in which quantities the superplasticizers are to be added to optimize the fresh concrete properties.

A single-shaft compulsory mixer (EMS 60 C) from Elba is used as a representative of standard single- and twin-shaft mixers preferred in the construction industry for the production of fresh concrete. A conical mixer (KKM-R 30) from Kniele Baumaschinen GmbH was used as a high-performance or intensive mixer within the scope of the investigations presented here. Further investigations to improve the fresh and hardened concrete properties of high-performance concretes by means of intensive mixing systems are presented in [1].

The main differences between the two concrete mixers mentioned above can be summarized as follows. The EMS 60 C has a frequency converter with the possibility of setting a specific speed. The speed specification is implemented by an asynchronous motor with an output of 3 kW. In contrast, the KKM-R 30 is equipped with direct torque control, so that the speed or torque can be specified via the frequency inverter. These specifications are implemented by a synchronous motor with significantly higher accuracy. This motor has an output of 15 kW.

Since the production of self-compacting concretes with reproducible properties with standard mixing systems is still considered problematic at present, the influences of the mixing energy input on the mixing duration in the case of the use of a single-shaft compulsory mixer (EMS 60 C) should be worked out within the framework of the investigations shown. The formulation of a self-compacting

concrete according to [1] was chosen for this purpose. The mixing time was recorded analogously to the theoretical investigations with BétonLAB Pro over the stabilization time. Afterwards an optimum of the mixing time is reached, if the engine power strives asymptotically against a minimum over time. As the illustration on the left in Fig. 1 shows, mixing the self-compacting concrete requires a mixing time of about 180 s when using the full engine power with a tool speed of 50 min^{-1}. By modifying the frequency inverter, the originally low motor power of 3 kW could be increased by a factor of two, so that the mixing time could be halved at a speed of 75 min^{-1} (see Fig. 1, left).
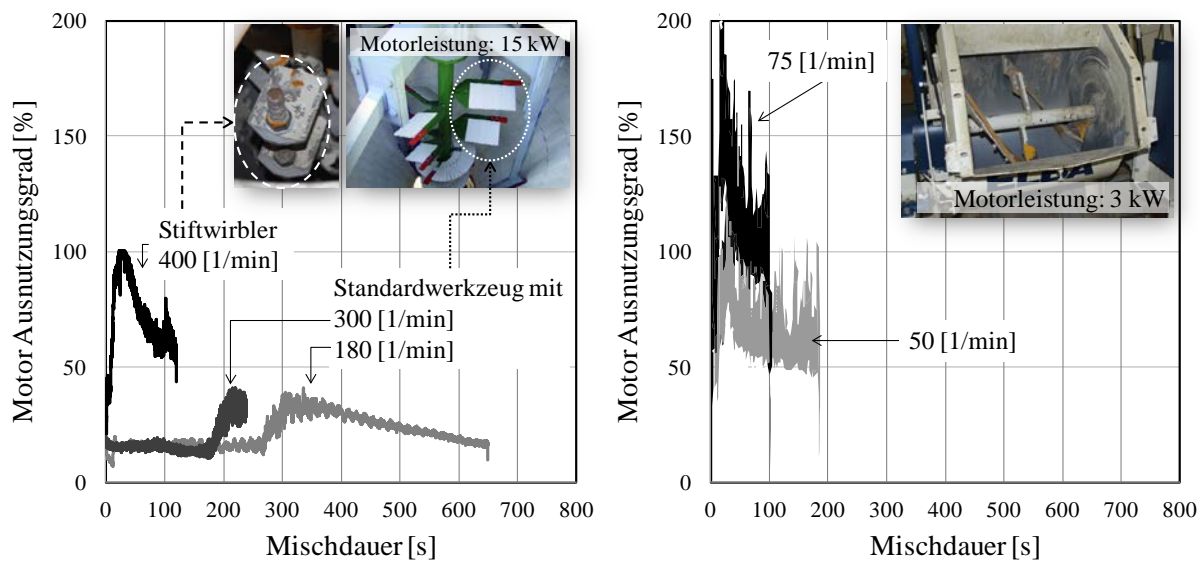

Fig. 1: Influence of drive power and tool speed (left) as well as the design of the mixing tool (right) on the mixing time; left: self-compacted concrete in EMS 60 C; right: ultra-high-strength concrete in KKM-R 30

For the use of the intensive mixer, the influence of tool speed, energy input and tool arrangement and geometry for an UHPC was investigated, as it was used in the priority program of the German Research Foundation [4]. As a result, it was found, that the available engine power could not be optimally used with the mixing tool used in the standard mixing system. With a tool speed of 180 min^{-1}, a mixing time of more than 6 minutes is required. If the engine speed is increased to 300 min^{-1}, the mixing time is reduced to 4 minutes. A significant improvement can be achieved by optimizing the mixing tool. In one variant of the tool redesign, pin whirlers were used, as shown in the right illustration of Fig. 1. With the pin whirlers, the available motor power could be fully utilized by increasing the tool speed to 400 min^{-1}, so that the mixing time could be reduced to 2 minutes. Despite the higher engine power, the overall energy consumption is significantly reduced

as a result of the shorter mixing time. In addition, the tool equipped with additional pins supports the vertical movement of the mix and thus contributes to optimizing the mixing process, resulting in better fresh and hardened concrete quality.

3.2 PUMPING OF SCC AND HPC

The pumping of concrete is fundamentally different from that of a viscous liquid such as water. The flow of concrete only begins after the yield point has been exceeded. In the literature, the rheological models according to Bingham or Herschel Buckley are used. In vibrated concretes, the yield point is usually higher than the shear stress at the wall of the pump line [15]. As a consequence, there is no shearing of the vibrated concrete inside the pipe, where the shear stress is zero. In this "plug-flow" process, the vibrated concrete is transported through the pump on a layer of cement paste a few millimeters thick [16] (see Fig. 2, top). The concentration of aggregates in the immediate vicinity of the wall of the pumping hose is significantly lower than in the center of the cross-section. This phenomenon is called the wall effect and describes the influence of the wall on the distribution of the aggregate.

The second mechanism known is shear-induced particle migration [17, 18]. Particles within the suspension flow from areas of high shear stress into areas with a lower shear stress. During pumping, the shear stress on the wall is maximum and decreases linearly towards the center of the pipe. As a result of this shear stress distribution, the particles (binders, additives, sand and aggregates) migrate to the center of the pumping hose. The cement paste layer on the pipe wall, which is poor in particles, has a significantly lower yield point and plastic viscosity than the rest of the material and forms the so-called lubrication layer. Due to the increasing particle concentration as a result of particle migration from the wall area, the yield point and viscosity increase outside the edge area, which counteracts particle migration.

An increase in shear stress with increasing pump pressure is not necessarily associated with increased particle migration [17]. The also increased viscosity counteracts this. In pump tests it was found that the flow rate is almost linearly dependent on the level of the pump pressure. As the pump pressure increases, the shear stress on the inner wall of the pump line also increases. It can therefore be assumed that the thickness and rheological properties of the cement paste on the wall of the pumping hose are only slightly influenced by the pump pressure.
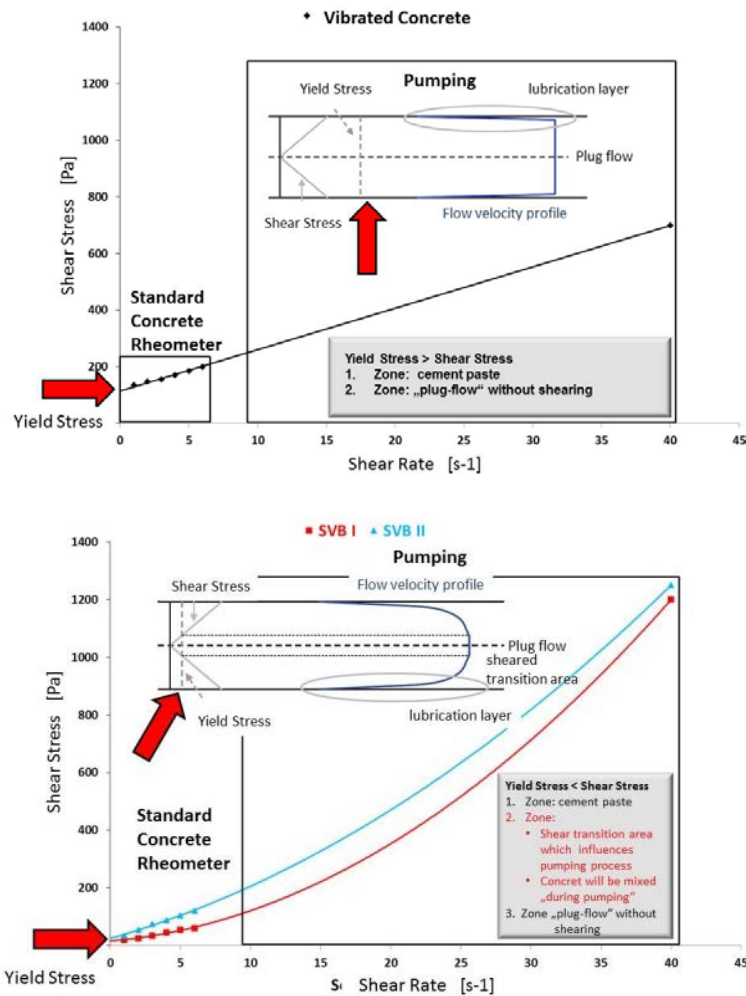
Fig. 2: Influence of pumping on the rheological behaviour of concrete; Vibrated Concrete (top) and Self Compacting Concrete (SCC or SVB in German language) (bottom)

Despite the excellent flowability of SCC, its pumping requires considerably higher pump pressures than with conventional vibrated concretes. This is due to the shear thickening observed during mixing and pumping [19]. If the "plug flow" in vibrated concrete can be explained by the formation of a paste layer, the SCC model must be extended (see Fig. 2, bottom). Thus, the shear load during pumping is above the low yield point of an SCC and the mixture is sheared over a large part of the cross-section. A "plug flow" with a maximum calculated diameter of 74 mm could be observed at 17 SCC's in the middle of the pipe (un-sheared area) in [15]. According to [15, 20], the speed profile of an SCC consists of a small "plug flow" in the middle of the pipe, a low-particle paste layer on the wall (lubrication layer) and a sheared transition area.

4.   RHEOLOGY-BASED MIXING PROCESS IN REAL SCALED MIXERS

4.1 FUNDAMENTALS

Concrete mixtures rich in fines and low in water require a higher energy input during mixing and significantly longer mixing times than normal vibrated concretes [21]. The increase in tool speed alone is not sufficient to supply the amount of energy required for perfect mixing and for homogenization of all fine components. What is needed is an appropriately equipped drive train with a digitally networked sensor-actuator concept that adapts the respective mixing energy input to the maximum amount of energy that can be absorbed by the fresh concrete. By adjusting the tool speed and nominal motor torque as required, mixing and homogenization are to be accelerated and the needed mixing time will be minimized. Last but not least, the powertrain concept can also be used for quality assurance evaluation of the rheological properties of the fresh concrete inside the mixer. The authors were able to demonstrate these relationships in laboratory mixing systems [1, 2], which are now being transferred to a real-scale concrete mixing plant in the project "Concrete roadway 4.0" [22] (cf. Fig. 3).

Fig. 3: Installation of a real-scale mobile concrete mixing plant type Liebherr DW 1,25 in the test hall Pfaffenwaldring 4d at the MPA University Stuttgart - pocket series silo with 4 rock grain chambers with externally mounted cement silo (left) and view of the mixing plant integrated into the hall (right) (source IWB)

Compared to the standard version, the mixing system is equipped with a new heavy-duty gearbox, a frequency converter control and a significantly more powerful motor on the drive side. The gearboxes are currently in production. They are

equipped with an electric drive with an output of 75 kW (see Fig. 4). The new drive train operates almost loss-free.

The drive concept allows the energy input to be continuously adjusted during the mixing process by controlling the nominal motor torque on the synchronized mixer shafts. The energy input into the mixture is handled by the mixing tools attached to the mixer shafts, whose geometry and arrangement offer further potential for optimization. The decisive factor, however, is the determination of the speed or torque specification, which depends on the mixing process itself. For this purpose, a control strategy was developed, tested and validated which uses the information of the measurement and control components integrated in the mixing system.
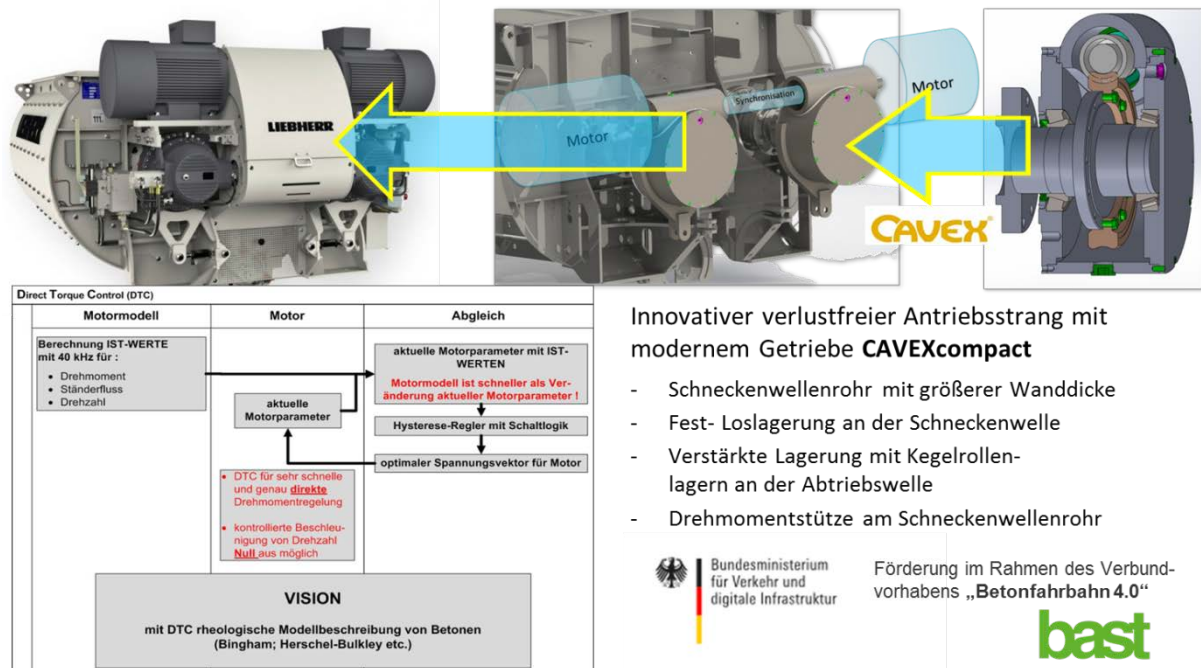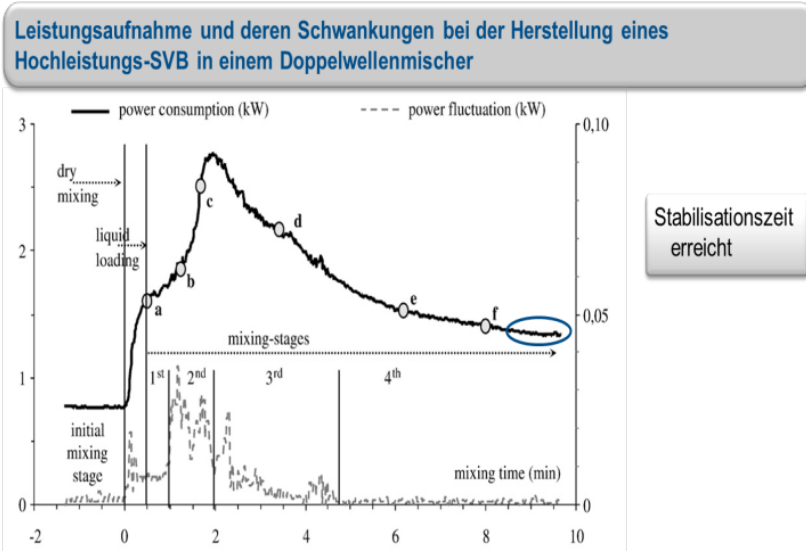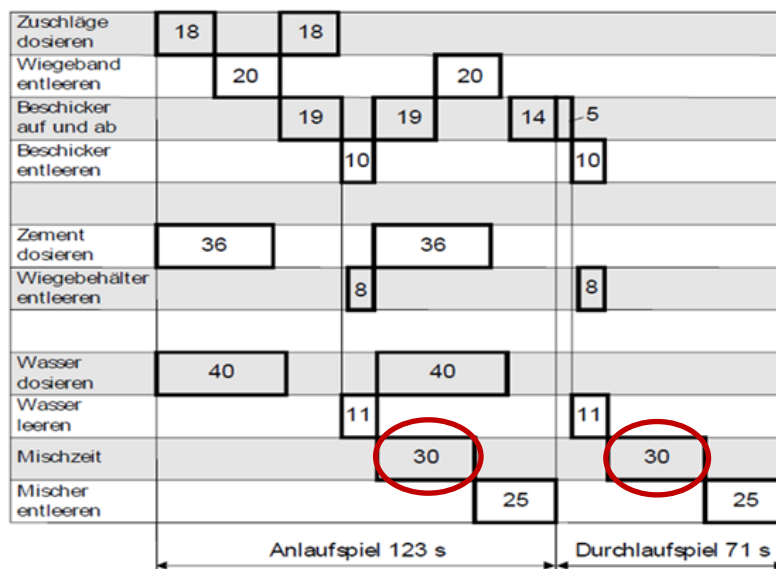

Fig. 4: Rheology-based mixing with loss-free and digitally networked drive train (source: IWB & CAVEX)

4.2   FROM STATUS QUO TO RHEOLOGY-BASED MIXING PROCESS MANAGEMENT

Usually, the control concept of concrete mixing plants is based on a process schedule (cf. upper illustration in Fig. 5). In newer mixing plants, the current consumed by the drive during mixing or the power requirement of the electric drive required for mixing and maintaining a certain tool speed is also recorded and graphically visualized (lower illustration in Fig. 5). In comparison with the process schedule, which generally stops the mixing process after 45 seconds, the end of the mixing process can be determined much more reliably by recording and

evaluating the power consumption of the drive. If the drive power approaches a lower limit value, a complete mixing and homogenization of the fresh concrete is assumed [23]. The achievement of this mixing process phase is referred to as stabilization time.

However, from the point of view of the authors, this information is not sufficient to reliably determine the end of the mixing process for demanding concrete mixtures, such as SCC, HPC, UHPC and road concretes. Rather, the rheological properties of the fresh concrete would have to be determined after reaching the stabilization time, as would be expedient with a characterization of the viscoelastic behavior of the mixture in the mixer.

Zuschläge dosieren	18		18				
Wiegeband entleeren		20			20		
Beschicker auf und ab			19		19	14	5
Beschicker entleeren				10			10
Zement dosieren		36			36		
Wiegebehälter entleeren				8			8
Wasser dosieren		40			40		
Wasser leeren				11			11
Mischzeit					30		30
Mischer entleeren						25	25

Anlaufspiel 123 s   Durchlaufspiel 71 s

Leistungsaufnahme und deren Schwankungen bei der Herstellung eines Hochleistungs-SVB in einem Doppelwellenmischer

Quelle: Cazacliu, B.; Roquet, N.: Concrete mixing kinetics by means of power measurement. Cement and Concrete Research, 39 (2009), p. 182–194

Fig. 5: Potentials of Innovative Mixing Process Management - Schedule (top), Determination of the Mixing End (bottom)

4.3 RHEOLOGICAL CHARACTERIZATION OF THE FRESH CONCRETE IN THE MIXER

The methods and concepts for characterizing the rheological properties of fresh concretes developed and tested on laboratory mixers have been converted into a patent application with the international publication number WO 2017/103067 A1 [24]. The grant was decided on 2.10.2019. The novelty value lies in the determination of the breakaway behavior of the fresh concrete at the point in time at which a first indication of sufficient mixing from the power consumption curve or the torque required for the operation of the mixer shaft is assumed when the stabilization time is reached (cf. Section 4.2).

In rheology [25], the breakaway force is defined as the force which is used to set the static friction of the mixture in the mixer shaft at rest in motion again. In the case of rotary drives, the term breakaway torque is used instead of breakaway force. In order to be able to record the breakaway behavior, measurements must be possible at very low speeds. Very low torques can therefore be achieved with the frequency inverter-controlled drive in order to determine the yield point of the fresh concrete. In order to obtain measurement data as accurate as possible on the effective torque and rotational behavior of the mixer shaft in the lower speed range, an almost loss-free drive train is required, which is why a corresponding heavy-duty gearbox was developed by the company partner CAVEX [22].

In order to achieve a rapid end of mixing in mixing stage I, i.e. to achieve the stabilization time with the shortest possible mixing time, the energy input is maximized from the start of mixing. If the mixing energy requirement at the start of mixing is at its highest, the torque required for the mixing process gradually decreases as the mixing and homogenization of all the components of the concrete progresses. If too high a torque is provided at the mixing tools, the mixing energy can no longer be absorbed by the mixture. Parts of the mixture are torn out of the compound around the mixing tools and thrown outwards. The power supply must be adapted accordingly by slightly reducing the nominal motor torque.

In principle, shear rate or shear stress controlled mixing processes can be realized with the drive concept. Shear rate-guided mixing processes are carried out via a deformation specification and may be suitable for flowable fresh concrete mixes. Not only for pasty to stiff concrete mixes, such as for pavement concretes, a torque specification and thus shear stress-guided mixing operation seemed to be the best solution.

If the stabilization time and thus the end of mixing stage I is reached, it must be checked whether all components of the concrete mix have actually been completely disintegrated and sufficiently homogenized. Accordingly, in a second step the rheological behavior of the mixture is characterized inside the mixer. Such an examination should not be carried out after each mixing batch, but should be carried out randomly for quality assurance purposes. However, the rheological characterization of the mixture is always recommended if there are major fluctuations in the properties of the starting materials and if there are any abnormalities or deviations in the first mixing stage until the stabilization time has been reached, and if the fresh concrete consistency needs to be adjusted.

For rheological characterization of the viscoelastic flow and deformation behavior, the mixer shaft is first brought to a standstill after reaching the stabilization time. The breakaway torque is then determined. Further series of measurements can now be carried out to determine the corresponding value pairs of torque and speed in the range of low shear rates between two and five.

The mixing process of a mixing batch can be summarized as follows:

I. Mixing Phase I – determination of reaching stabilization time

   a) Raw materials shall be fed into the mixer in appropriate order and according to dosing instructions

   b) Mixing tools shall be put into operation by means of the drive train specific to the mixing system.

   c) The drive power and speed of the mixing tools are already optimized during the addition of the individual components of the mixture by continuous recording and evaluation of speed and torque in real time in order to make maximum use of the nominal motor power and to reach the end of mixing, which can be derived from the stabilization time, as quickly as possible.

   d) Recording of the temporal course of the engine power, which approaches a lower limit value towards the end of the mixing process by an asymptotic approximation.

   e) If the engine power approaches the lower limit value, the stabilization time is reached and indicates a possible end of mixing.

   f) Mixer shaft stop and end of mixing phase I.

II. Mixing Phase II - rheological characterization of the fresh concrete properties

    a) The stopped mixer shaft is subjected to a linear torque increasing with time until the mixer shaft just begins to rotate. At this moment the breakaway occurs. The effective torque is referred to as the breakaway torque.

    b) With this constant torque, the speed set after stabilization is recorded.

    c) After speed stabilization, the torque is increased abruptly to a specific amount and then the stabilization of the speed setting is waited for and recorded again.

    d) Multiple repetition of the process shown under II.b of a gradual increase in the torque and of waiting for the stabilization of the speed occurring as a function of the torque shown under II.c. The respective increase in torque is always in the range of small shear rates. The maximum torque to be applied should not exceed 25% of the torque applied during mixing to achieve rapid mixing.

    e) The number of torque increases, i.e. repetitions, should be between 3 and 5. As a rule, the quality of the statement can be improved by increasing the number of repetitions. However, the residence time of the concrete in the mixer also increases with the number of repetitions, which is why a limitation of the number of repetitions is indispensable for construction practice.

The course of the Mixing Phase II is shown schematically in Fig. 6. In the graph on the left, the torque is continuously increased in small steps from the stationary mixer shaft until the mixer shaft starts to move. This indicates the breakaway torque and the associated breakaway torque. The breakaway torque is kept constant until the mixer shaft moves at a stable speed and the first pair of values of torque and speed can be formed. This is followed by the first increase in torque at a low shear rate as described in e). Wait again until the mixer shaft adjusts to a constant speed with the torque held constant. Fig. 6 shows a further increase in torque at a low shear rate. In addition to the breakaway torque, there are therefore three value pairs of torque and associated speed from which the shear stresses and shear speeds shown in the diagram on the right have been derived.
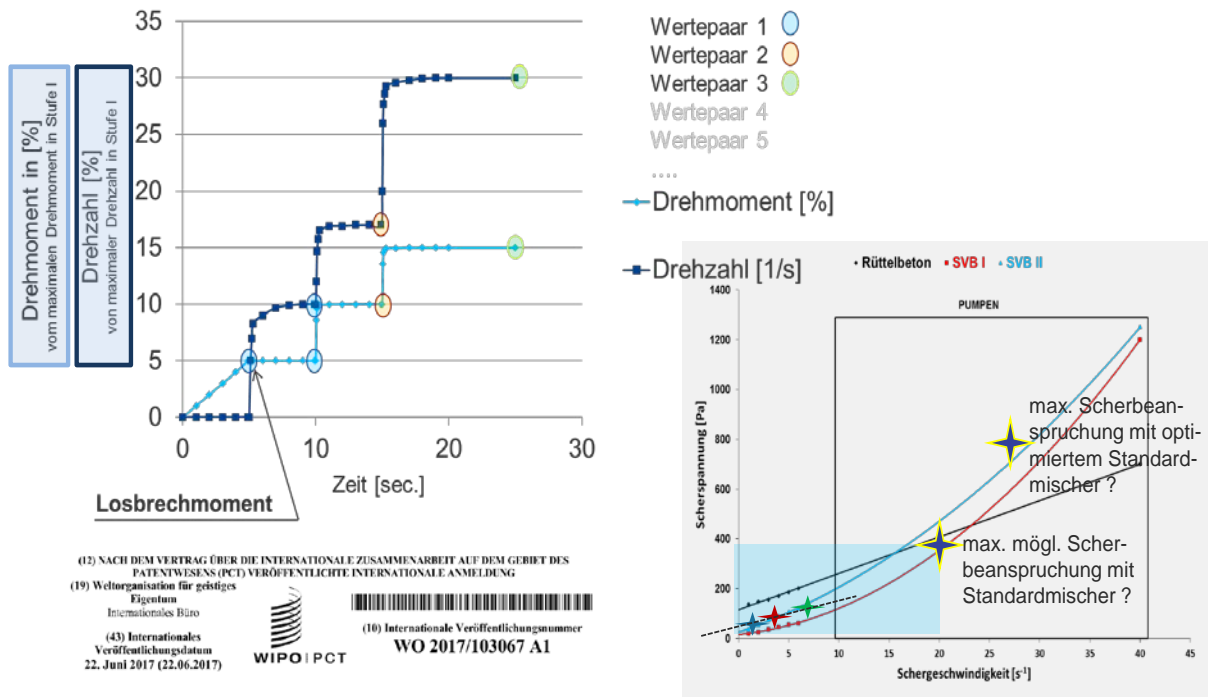
Fig. 6: Schematic representation of the "concrete production" process chain as it is to be used in the previous version "concrete roadway 4.0" (source: IWB)

The three value pairs can be represented with a compensating straight line in the range of low shear rates. Its intersection point with the ordinate allows a statement to be made about the yield point. The slope of the straight line corresponds to the viscosity of the fresh concrete. Although the values for yield point and viscosity determined in this way do not represent absolute measured variables, they are always constant, at least for the mixer and the specific concrete composition. The method thus offers the possibility of evaluating fresh concretes with regard to their rheological behavior in the mixer.

If the two rheological parameters are outside the required acceptance range, the mixing process must be continued despite reaching the stabilization time in order to bring about a consistency adjustment. In addition to extending the mixing time, suitable concrete additives (additives and/or admixtures) can also be added [1, 2].

5. OUTLOOK

The aim of the authors is to determine the fresh concrete properties of an SCC, HPC, UHPC or of a pavement concrete either immediately after mixing in order to check compliance with the rheological parameters yield point and viscosity required for the stability and robustness of such an ambitious concrete before

the pumping or pavement process. During pumping, especially SCC or HPC experiences shear loads that are significantly higher than those in conventional mixers. As a result, the plastic viscosity decreases over the pumping distance.

Based on these findings, technological solutions are therefore being developed in the current work to prevent a negative influence on the rheological properties during pumping, placement or pavement processes. Thus, the proportion of past relevant for the rheological properties must be subjected to a higher shear load during the mixing process.

ACKNOWLEDGEMENTS

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