Optimisation of concrete production

Innovative mixing concepts for the practicable manufacture of high performance concretes using standard mixing plants

At the WIB (Werkstoff im Bauwesen = Building Industry Materials) section of the Institute of Structural Concrete at the TU Darmstadt, plant and process-specific developments are ongoing with a view to adapting and expanding existing mixing plants to the requirements of the mixing task so that even the demanding mixtures for SCC, HPC and UHPC can be manufactured reliably with a retrofitted standard mixing plant. In the following article, the particular demands placed on the mixing process by mixture compositions that are rich in fines but with a low water content will be explained, and various innovative methods in terms of plant and process technology will be shown with which fines can be optimally solubilised and the entire mixture fully homogenised with a minimised mixing duration. To this end a pilot mixing plant with two different mixing systems was constructed in the research laboratory at the TUD. Hence, a conventional twin-shaft mixing system on the one hand and a conical mixing system on the other were procured. The laboratory was supplemented by a colloidal mixing system in order to accomplish particularly energy-intensive mixing processes. All appliances at the WIB were equipped with the latest generation of frequency converters and particularly powerful drive motors in order to be able to manufacture the very demanding concretes in an optimum manner. The technology which is henceforth available in the mixing laboratory is used to analyse in detail the demands on the mixing process and to develop suitable mixing regimes for the problems specific to concrete. The aim is to transfer the findings obtained in the mixing laboratory over to large mixing plants.

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Mixing effectiveness of concrete mixing systems

The testing of the mixing effectiveness of concrete mixers takes place using methods outlined in DIN 459-1:1995-11 'Building material machines – mixers for concrete and mortar' and in ISO 18650-2:2006-04 'Building and building material machines – concrete mixers – method for testing the mixing effectiveness'. Hence, according to DIN 459-2, the homogeneity of the concrete mixture is checked by means of a comparison of specified mixture constituents of the fresh concrete samples. To this end, the properties of reference mixtures are referred to. Fresh concrete compositions whose characteristics correspond to those of normal concretes are considered to be references. If modern high performance concretes conforming to DIN 459-2 are checked, their mixture compositions differ considerably from those of normal concretes.

In particular in the case of modern concretes, such as self-compacting concrete (SCC), high performance concrete (HPC) and ultra high performance concrete (UHPC), mixture compositions are used with a higher fines content and a lower water content compared to normal concretes, meaning that a considerably higher amount of mixing energy must be input in order to manufacture them. DIN EN 206 demands a homogeneous appearance of the fresh concrete. Since SCC, HPC and UHPC have a high fines content and since only very small amounts of mixing water are added to the mixture in conjunction with highly efficient concrete additives, particularly high demands are placed on the mixing process in order to ensure the complete solubilisation of all fines and their deep blending and homogenisation as well as the complete wetting of all solid surfaces with the mixing water and the liquid additives. By comparison, the coarser grain fractions are less critical with regard to the mixing process.

Due to the high input of mixing energy required for the manufacture of UHPC, most of the research institutes participating in the DFG (German Research Foundation) priority programme, SPP 1182 'Sustainable building with ultra high performance concrete (UHPC)', use an Eirich intensive mixing system. This mixer's high mixing tool speeds ensure a dispersive mixing process that allows both homogenisation of the fines and the separation of the fine mixture constituents.

Goal of the research work at the WIB

In the current research work at the WIB (Werkstoff im Bauwesen = Building Industry Materials) section of the Institute of Structural Concrete at the TU Darmstadt, plant and process-specific developments are ongoing with a view to adapting and expanding existing mixing plants to the requirements of the mixing task so that even the demanding mixtures for SCC, HPC and UHPC can be manufactured reliably with a retrofitted standard mixing plant. Accordingly, the research laboratory was equipped with a twin-shaft mixing system, a conical mixing system and a colloidal mixing system in order to be able to investigate any differences in the required mixing times for the manufacture of high performance concretes. The mixing quality in standard mixing systems is thereby essentially determined by the homogeneity of the raw materials, which are subject in practice to constant fluctuations.

In order to achieve optimum solubilisation of the fines, extensive investigations took place at the WIB using colloidal mixing systems, with which very high motor speeds and motor powers can be achieved. A two-stage mixing process can be implemented by supplementing a standard mixing plant by a comparatively inexpensive colloidal mixing system. Hence, the powder constituents are first solubilised with the water and the highly efficient concrete additives. The resulting suspension is fed to the standard mixing system and then mixed with the aggregates. Short mixing times with optimum mixing quality can be ensured in this manner. In order to control the three mixing systems used at the WIB, state of the art frequency converters are used which, in conjunction with the computer-assisted acquisition and evaluation of the motor data, allow optimum mixing operation.

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Requirements for mixing systems for the manufacture of high performance concretes

Today, high performance concretes are taken to mean concretes that exhibit the most diverse features of extraordinary capability. Whereas self-compacting concretes are developed for their special flowing characteristics, high performance mixtures are distinguished primarily by their considerably higher compressive strengths compared to normal concretes. If high durability is a priority, then puzzolanic concretes such as HVFAC (high volume fly ash concrete) offer interesting alternatives in terms of concrete technology.

Fundamentally, the compositions of high performance concretes differ considerably from those of normal concretes, depending on the intended characteristics. The recipes for high performance concretes are thus characterised by a (considerably) increased fines content, a water content that is mostly reduced compared to normal concretes and by the addition of increased quantities of superplasticisers. Besides the complete solubilisation and separation of the fines, great importance is also placed on the even distribution of the liquid components, i.e. the mixing water and the highly efficient chemical additives, since these must be fed to all surfaces of the added solid particles during mixing.

Mixing technology

The mixing effectiveness of a concrete mixer must be tested on the basis of three test concretes according to DIN 459-2. A specified number of samples must be taken from these three mixtures, for which, in addition to the water content and consistency, the solids contents are to be determined by means of a sieve analysis. The mixing quality achieved by a mixing system is assessed on the basis of variation coefficients, which must be determined for each component of the mixture composition. Fundamentally, the compositions of the test concretes, which are to be formulated as 3-component systems in accordance with DIN 459-2, differ significantly from the mixture compositions of modern high performance concretes due to their lower fines content, their high water/cement ratios and their lack of superplasticisers.

Whereas the solids in normal concretes, with their lower fines content, can be mixed and homogenised with no great effort, there are special points that need to be observed with regard to the movement of the mixture when mixing high performance concretes. According to [1], two different mixture movements arise when mixing compositions that are rich in fines. Whereas the coarse constituents can be mixed easily by convective mixture movements, the dispersive portion of the mixing process is accorded great importance in the case of a mixture composition that is rich in fines. This is characterised by a random collision of the fine particles (fine mixing), which enables the break up of agglomerates and, hence, the separation of the ultra-fine particles. Hence, not only the coarse constituents, but also the fines in the mixture can be distributed evenly.

A comparison of fresh concretes in accordance with DIN 459-2 allows statements to be made only about the evenness of the grain distribution. The extent to which the blending, homogenisation and separation of the fines in the mixture can be ensured cannot be assessed according to DIN 459-2. Accordingly, the proven method of testing the mixing effectiveness of mixing systems for normal concretes cannot be applied to high performance concretes, which are usually 5 or 6-component systems.

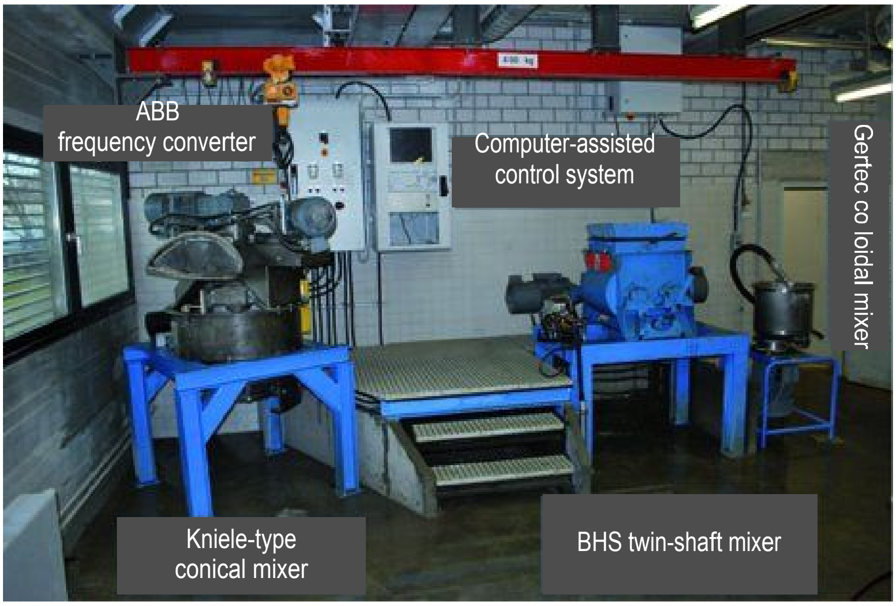


Fig. 1: Mixing plant at the Institute of Structural Concrete, TU Darmstadt

The mixtures for high performance concretes, which are richer in fines but have a lower water content, require an increased dispersive transport proportion in the mixing process in order to achieve the homogeneous appearance demanded by DIN EN 206. In return, the coarse distribution becomes less important. In most mixers, the mixing tools take care of both the transport of the mixture (coarse distribution) and the actual mixing (fine distribution). According to [2] and [3], the slow addition of water, a tool speed and mixing duration matched to the size of the mixing system, an optimum distance between the mixing tool and the wall of the mixer and an optimum tool width are required for trough and pan mixers in order to achieve a homogeneous, high mixture quality.

The manufacture of UHPC in particular requires a high quality mixing system, whose mixing tools are adapted, with regard to shape and arrangement, to the mixing requirements for the mixture. Within the context of the SPP 1182 priority programme (UHPC) sponsored by the DFG (German Research Foundation), the majority of the participating research institutes have decided on an intensive mixing system by Eirich. Here, the mixture is transported upwards by an inclined, rotating mixing vessel and falls back down due to gravity and the arranged scrapers. The mixture guided in this fashion in the interior of the mixing vessel is then fed to the actual mixing process, which is performed by a rapidly rotating, eccentrically mounted agitator.

As an alternative to the use of this specific intensive mixing system, developments are ongoing at the Building Industry Materials section of the Institute of Structural Concrete at the TU Darmstadt with the aim of also being able to manufacture demanding high performance concretes using conventional standard mixing systems. To this end, the most diverse adaptations and additions to the plant are required in order to also be able to reliably manufacture the compositions of high performance concretes, which are richer in fines but have a lower water content than normal concretes. The requirement here, besides achieving an optimum mixing quality, is the maintenance of the shortest possible mixing times in order to minimise energy consumption.

With regard to the plant, the emphasis of the research and development lies in the use of state of the art measuring and regulating systems in order to continuously measure and evaluate the rheological properties of the mixture, which is dependent on the addition of the individual components, over the entire course of the mixing process. The continuous adaptation of the use of the available mixing tools in the mixing system (selection, direction of rotation, speed of rotation) to suit the specific added substance leads to an optimum mixing of the mixture with regard to the homogenisation and mixing duration. However, only limited quantities of mixing energy can be input via the standard mixing tools in standard mixing systems. Accordingly, additions are made to the plants in the present investigations with which those parts of the mixture that are rich in fines can be optimally mixed and solubilised with the liquid components to be added. Using a two-stage method of manufacturing the fresh concrete, the dispersive mixing processes can initially be implemented in an inexpensive and energy-saving manner, because the fines can be solubilised and homogenised in an ideal way with the mixing water and the highly efficient concrete additives. The suspension prepared in this manner can then be fed to the standard mixing plant, in which the coarser aggregate fractions can be blended completely with the prepared fines suspension by means of convective mixture movement using the usual mixing duration for normal concretes.

Fig. 1 shows the mixing technologies available at the Institute of Structural Concrete. A twin-shaft mixing system and a colloidal mixing system can be seen on the right in the picture. The twin-shaft mixing system is representative of the wide range of mixing systems that can be found in standard mixing plants. The optimum solubilisation of the fines and the liquid components can be achieved using the colloidal mixer. Both mixing systems are controlled by the latest generation of frequency converters, which allow the performance data and rotary speeds of the externally ventilated drive motors to be read out continuously. A conical mixer (Kniele) can be seen on the left in the picture. On account of its special construction and its two independently usable mixing tools, this mixer can input high energy into the mixture. Therefore, high performance concretes can also be manufactured using the Kniele-type conical mixer without having to premix the fines with the liquid components.

Before explaining the two-stage manufacture of high performance concretes using the colloidal mixing system and the twin-shaft mixing system, the Kniele-type conical mixing system will first be explained below.

According to fig. 2, a vertical mixing shaft is situated in the centre of the vessel. Arranged on the vessel wall are outer scrapers that can be driven in the same or the opposite direction to the inner mixing shaft. The inner mixing shaft can be adapted to the specific requirements of the mixture by means of changing the number, size, spacing and inclination of the mixing tools. The rotary speeds of the inner mixing shaft and the outer scraper are arbitrarily controllable via frequency converters in the installation realised at the WIB, hence enabling the highly dispersive part of the mixture guidance that is required for high performance concretes. With the power and speed of the two motors for the inner mixing shaft and the outer scraper being continuously adaptable to the requirements of the high performance concrete to be manufactured, considerably shorter mixing times can be achieved whilst at the same time increasing the slump (acc. to DIN 1048 and DIN EN 12382) significantly.

A further optimisation of the mixing process can be achieved by means of the addition of the individual mixture components in steps. If the powder constituents (and the sand fraction, if applicable) are added to the mixing water and the superplasticiser and mixed at tool speeds of 6 - 8 m/s in the first step, then the suspension will be optimally solubilised. In the second step, the coarse aggregate fractions are then added and blended in using a considerably lower inner mixing shaft speed. Less motor power is required for the two-stage procedure than if a mixing process is used where all solid components are first homogenised in a dry state and subsequently have to be blended with the liquid components.

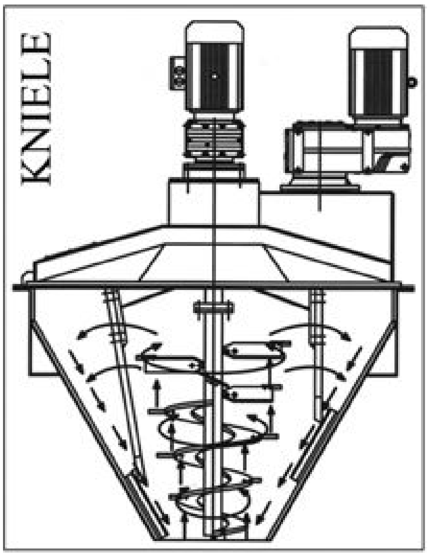


Fig. 2: Mixing principle of the Kniele-type conical mixer

A second interesting application of the Kniele-type conical mixing system has proven to be the gentle mixing of light aggregates into the premixed powder constituents and the mixing water/concrete additives, since the large gap between the inner mixing tool and the wall of the vessel prevents the destruction of the aggregate. Investigations by Thiel [4] show that up to 10 % of the light aggregates can be destroyed during the mixing process in standard mixing systems.

In order to demonstrate the possibilities of manufacturing high performance concretes using standard mixing systems, a twin-shaft mixer of type BHS was procured. Twin-shaft mixing systems have two axial mixing shafts and, with a market share of over 50 %, can be considered to be the standard systems for the manufacture of ready-mix concrete. Even though the remaining mixing systems used for the manufacture of concrete, e.g. planetary mixing systems, differ from twin-shaft mixing systems in their guidance of the mixture, it should be possible to transfer the following investigation results over to all standard mixing systems. For the manufacture of high performance concretes, a two-stage mixing process is fundamentally proposed in which the first mixing stage entails the dispersive solubilisation of the powdery and liquid constituents. The second mixing stage entails only the convective mixing process in which the suspension that has already been optimally solubilised and homogenised in the first stage is mixed with the coarser aggregate fractions.

If a twin-shaft mixing system is used for the manufacture of a high performance concrete, the mixing time of 30 seconds that is usual for normal concretes has to be extended considerably. If the tool speed is increased too much, this will lead in general to a considerably poorer mixing quality, since the mixture is merely thrown upwards by the faster rotary movements of the mixing tools (fig. 3). A controlled circulation of the mixture through the mixer cannot take place in this manner.

If the two-stage mixing process mentioned above is selected, in which the fines are solubilised in an optimum manner in the liquid constituents of mixing water and superplasticiser using a colloidal mixing system and the resulting suspension is then mixed with the coarse aggregates in the standard mixer, then high performance concretes can also be manufactured without problem in retrofitted and expanded standard mixing plants. The moderate investment costs for a colloidal mixing system adapted

Fig. 3: Twin-shaft mixer with a high tool speed

to the size of a standard mixing plant thereby enable standard mixing plants to be modernised economically, since this subsequently allows the operators to offer all concretes on the market. Alongside high mixing quality and uniformity of the fresh concretes, even demanding high performance concretes can be manufactured reliably in large quantities using comparatively short mixing times.

The essential elements of the two-stage concrete manufacturing method selected by WIB are:

1) Manufacture of the suspension containing the fines in the colloidal mixing system
2) Feeding the suspension to the standard mixing plant
3) Brief convective mixing of the suspension and aggregates in the standard mixing plant

High performance concretes can thus be manufactured using the same cycle times for the mixer feeding without reducing the production quantities familiar from normal concretes. This procedure pursues the rigorous separation of dispersive and convective mixture movements, which are indispensable for the reliable manufacture of high performance concretes with a high mixing quality.
By separating the convective and dispersive transport processes, considerable savings can also be made in the electrical energy required for the complete mixing process. If a standard mixing system is operated alone, for instance, a large amount of energy is input just for the much too large convective part of the mixture movement, without being able to ensure an optimum solubilisation of the fine constituents and an even distribution of the liquid components to the particle surfaces.

Whereas tool speeds of around 1.5 m/s are used in standard mixing plants, sporadic tool speeds of around 6 – 8 m/s are considered to be ideal in intensive mixing systems ([5] and [6]).
As opposed to this, the mixing tools mounted directly on the motor shaft in colloidal mixing systems (fig. 4) are operated at tool speeds of between 15 and 25 m/s. The wetting of the fine solid particles with water and concrete additives and the mechanical splitting of agglomerates is ensured by this dispersive mixing process; hence, it results in sedimentationally stable, colloidally dispersed mixtures that can be fed directly to the standard mixing system as a stable suspension when manufacturing high performance concretes. If larger quantities of concrete are to be produced, the suspensions manufactured using the colloidal mixing system can also be stored immediately in larger vessels in order to ensure a uniform production performance of the standard mixing plant at higher cycle rates if need be.

In order to demonstrate the effects of the two-stage mixing technology on the fresh concrete properties, an SCC with powder type according to Okamura was manufactured using the following mixing processes:

1) Use of the twin-shaft mixing system alone
2) Use of the Kniele-type conical mixing system alone
3) Two-stage manufacture using a combination of the colloidal mixing system and the twin-shaft mixing system

The results shown in fig. 5 prove that, as the dispersive proportion of the mixture move-

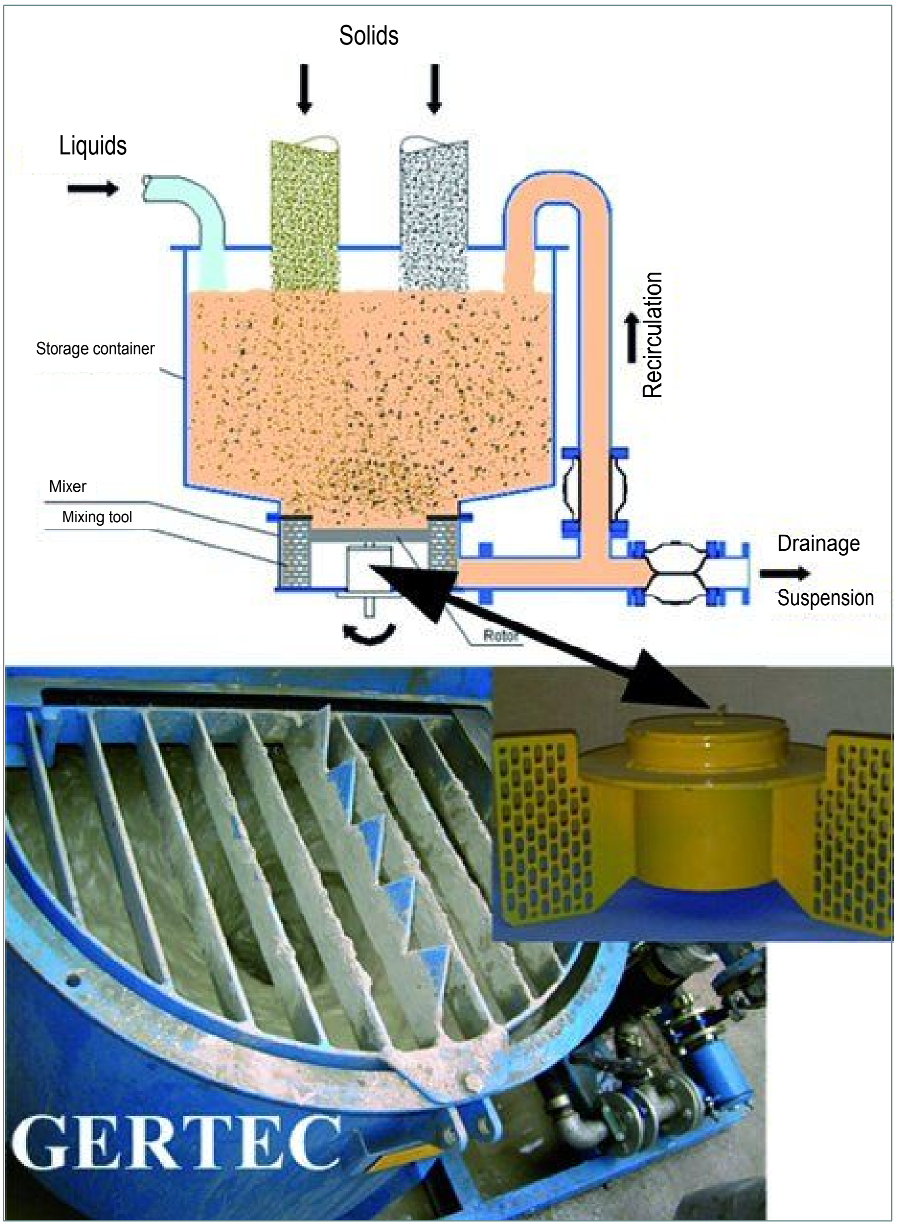
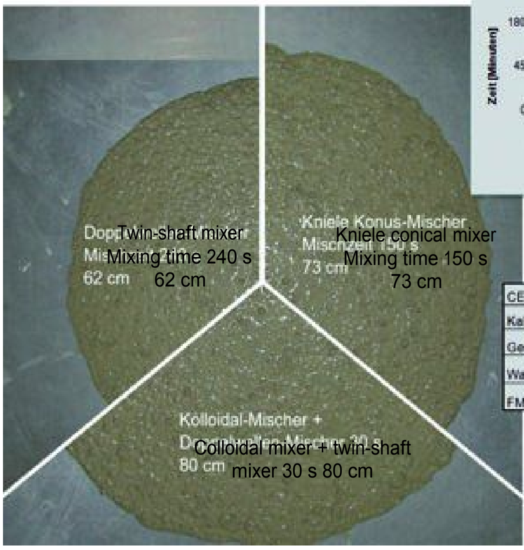


Fig. 4: Colloidal mixer

ment increases, the slump (acc. to DIN EN 12382. setting cone) of the SCC also increases significantly. In addition, the workability of the SCC can be maintained longest with the colloidal solubilisation of the powder constituents using the colloidal mixing system.

Mixing regime

Care was taken in the technical design of the laboratory mixing systems shown in fig. 1 that, as far as possible, all problems occurring in practice and in research and development can be investigated without restriction. For example, in order to be able to simulate the transport of concrete in mixer trucks, it is absolutely necessary to operate the mixing systems with very low tool speeds.
However, the inherent cooling of the three-phase motors is insufficient to prevent the inevitable motor damage resulting from continuous operation below 20 Hz. Accordingly, the higher power motors were equipped with external ventilation and can be operated over a wider range of rotary speeds using frequency converters of the latest generation.



CEMEX CEM III/A 42,5 N [kg/m³]	320
Kalksteinmehl Walhalla [kg/m³] / Limestone meal Walhalla [kg/m³]	290
Gesteinskörnung 0/16 [kg/m³] / Aggregate 0/16 [kg/m³]	1563
Wasser [kg/m³] / Water [kg/m³]	167
FM Sika 1035 [kg/m³] / Superplasticiser Sika 1035 [kg/m³]	5,53

Fig. 5: SCC using various mixing techniques

The frequency converters for the drive motors of all of the mixing systems used in the research laboratory can be coupled to a computer via an interface implemented at the WIB, so that it has been possible in the meantime to develop software solutions with which the mixing processes of normal and high performance concretes can not only be measured optimally, but also controlled in a suitable manner via user-friendly graphical user interfaces. Hence, the mixing regimes for the most diverse concretes can be optimised in such a way that the motor power and speed required for

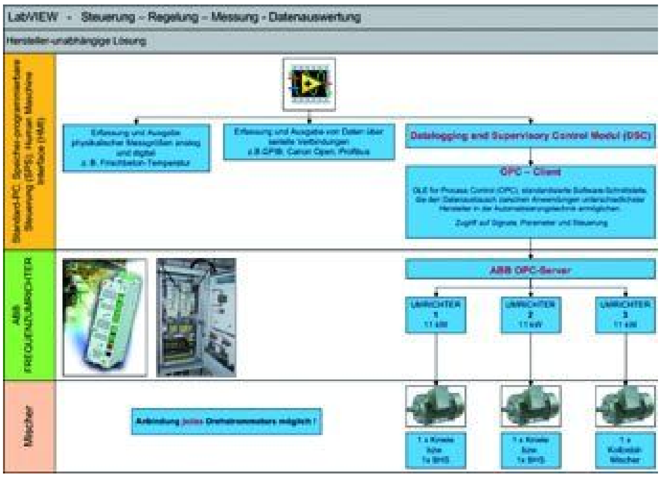


Fig. 6: Plant controller

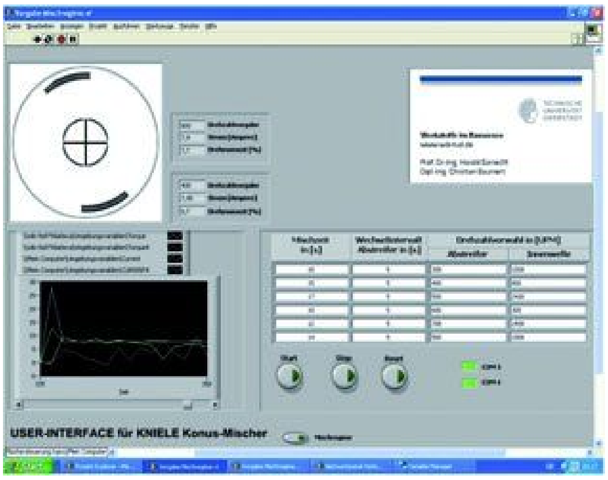


Fig. 7: Conical mixer mixing regime

coping with the mixing task are adapted to the type and dosing speed of the respective constituent of the concrete composition that is being added. This type of approach allows not only optimum mixing qualities to be achieved, but also the shortest possible mixing duration.

The software LabVIEW is used for the software-assisted monitoring and controlling of the mixing processes. The software enables the frequency converters to be integrated directly via the OPC (OLE for Process Control) software interface without additional hardware. The result of this is that, due to this open system, all three-phase motors can be operated and their motor data read out, independent of the make of the motor (fig. 6). According to [7], the actual mixing process can be subdivided into several phases. In the case of mixtures that are very rich in fines, mixing generally begins with a dry mixing phase and a large part of the mixing work is accomplished in a short time with the lowest expenditure of energy. With the subsequent addition of water, liquid bridges form between the particles that act like adhesive forces. These adhesive forces must be overcome by the mixing tools in order to be able to achieve an even homogenisation. To this end the motors must be driven with a higher torque in comparison with the dry mixing phase. With the addition of the superplasticiser, the power requirement of the drive motors decreases over the further course of the mixing process as the effect of the superplasticiser sets in. Once the torque of the motors reaches its minimum, the mixture – depending on the respective mixing technique being used – is optimally solubilised. Extending the mixing time will not achieve any further improvement in the fresh concrete properties. On the contrary, the particle abrasion caused by the continuing mixing operation increases the particle surface area and the further rubbing of the particles against one another raises the temperature of the mixture, resulting in poorer fresh concrete properties. The duration of the individual mixing phases and the associated tool speed can be freely specified via the graphical user interface provided by LabVIEW. All motor data that is of relevance for the user can be recorded, directly evaluated and visualised here. In addition, all data can be archived. In the course of the present research work, software is being developed at the WIB with which the adjustment of the power and speed of the mixing tool drive motors can be determined automatically by the host computer via the evaluation of the course of the mixing process. In addition, the duration of each mixing phase will be adapted individually to the course of the mixing process.

Accordingly, the mixing sequences can be optimised for the manufacture of even the most difficult recipes. If the suspension for the SCC illustrated above is manufactured in the colloidal mixing system at a constant tool speed (fig. 8) of 15 m/s, considerable differences in the drive motor power requirements are noticeable between the manual addition of cement and that of limestone meal, even though these have similar Blaine values. Hence, the motor torque was always less than 100 % when adding cement. When adding limestone meal, an immediate and significant overload of the drive occurs. In accordance with this observation, an increased tool speed (25 m/s) was selected for the first phase, in which the cement is added (fig. 9). In accordance with the higher tool speed, it was possible to increase the motor utilisation ratio considerably during the addition of the cement in order to ensure the high possible efficiency of the first mixing phase. In the second mixing phase, in which the limestone meal is added to the cement suspension, the tool speed is initially decreased significantly (8 m/s). As a result of this, the addition of the limestone meal can be performed in an ideal way without overloading the drive. On top of that, the reduced speed also results in the suspension being heated up by 2 Kelvin less, so that a higher slump (acc. to DIN EN 12382. setting cone) can also be achieved.

Work is currently ongoing with the object of automating the feeding of the raw materials in order to shorten the duration of the mixing process, minimise the mixing energy requirement and optimise the properties of the suspension. An effective mixing process has been achieved when the motor torque can be maintained continuously at virtually 100 % of the rated torque of the motor. To this end, the speed of the continuous addition of powder into the mixing vessel is controlled along with the speed of the motor in relation to the type of powder.

Rheological parameters

The measurement of the motor power during the mixing process enables the optimum end of the mixing process to be detected according to [5], [6] and [7]. The motor power decreases asymptotically during the mixing process and demonstrates the maximum homogenisation of the raw materials and even distribution of water and superplasticiser that is achievable with the mixing technique used.

Using the mixing technologies available at the WIB, the evaluation of the motor power and speed data over the course of the mixing process can be used to further the development of mixing process controllers, with which the tool speeds in the individual mixing phases, the optimum dosing of the substances to be added in liquid and solid form and the earliest possible end of the mixing phase can be actively and automa-

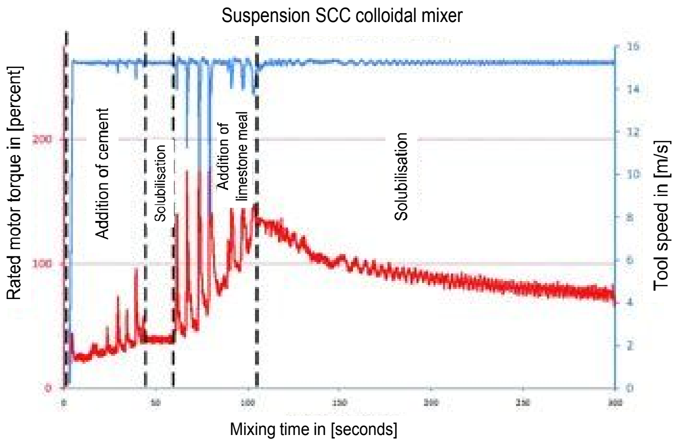


Fig. 8: Colloidal mixer – constant speed

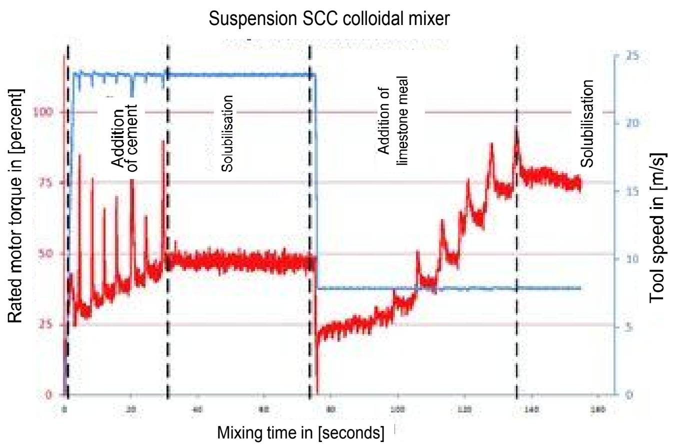


Fig. 9: Colloidal mixer – 2 speeds

tically determined and controlled. Last but not least, this provides a way of counteracting the numerous fluctuations in the composition and granulometry of the raw materials. Through the extremely sensitive measurement, evaluation and adaptation of the rated motor torque and the motor speed, it is possible to react very sensitively to changes of this kind. The same also applies to the problem of accounting for the moisture in the aggregate, which has a big influence on the fresh concrete properties, especially in the manufacture of high performance concretes.

The many well-known imponderabilities of the continuous measurement of moisture in materials, the influence on the mixing process and the mixing quality resulting from fluctuations in the composition and granulometry of cement and other fines, and the changing surface properties and granulometry of sands are, as has been described many times in literature, e.g. in [8], measurable only with great difficulty and can thus barely be accounted for when specifying the composition of the mixture. The increasing use of cement substitutes and new highly efficient concrete additives makes it even more difficult to ensure the uniform mixing quality of high performance concretes.

Consequently, it has so far only been possible to assess the mixing quality and the fresh concrete properties of high performance concretes after mixing is finished. As an alternative, it would be possible to analyse and evaluate rheological properties of the concrete mixture during the mixing process. The rheological behaviour of a mixture is usually characterised using a rheometer. To this end, a measuring tool is accelerated from a standstill to a specified rotary

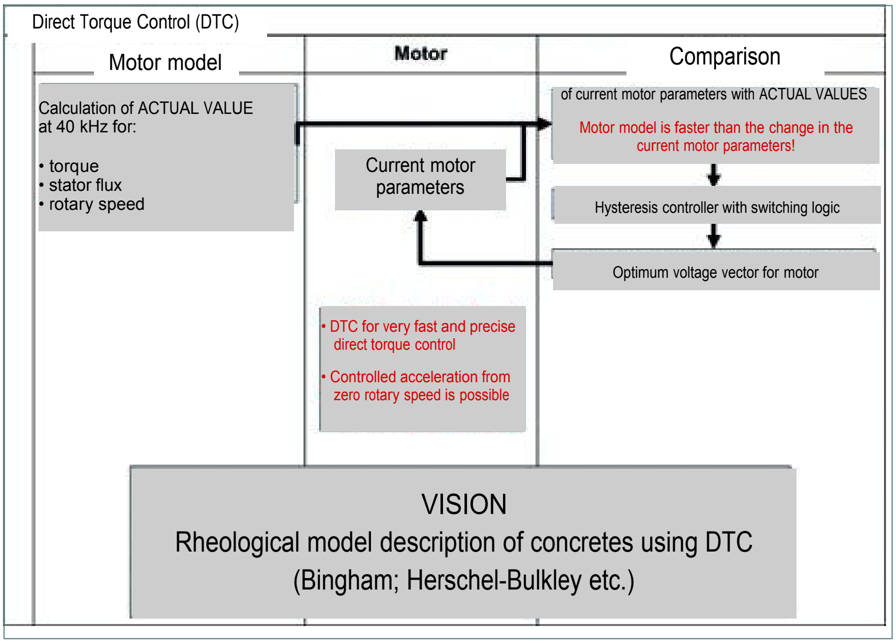


Fig. 10: Frequency converter with Direct Torque Control

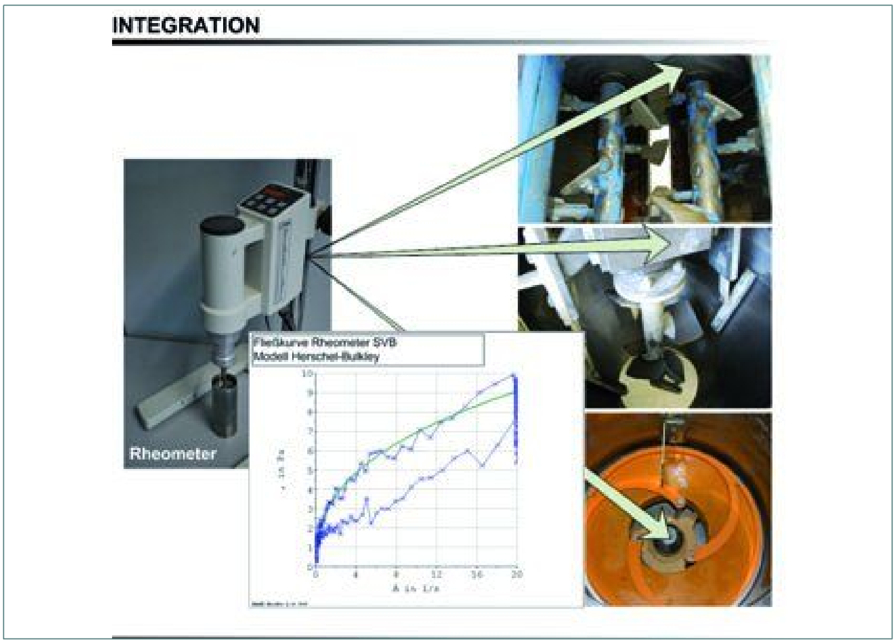


Fig. 11: Integration rheometer in the mixer

speed in a concrete sample and the torque is thereby measured. Very precise control of the rotary speed and a very reliable and sufficiently accurate measurement of the torque are required for this. If the mixing system itself is to be used as a rheometer, then the normal frequency converters with vector regulation, which represent the current state of the art in the infinite regulation of the speed of three-phase motors, allow corresponding use only with limitations. It has proven to be disadvantageous here that a minimum speed of approx. 2 – 3 Hz is required during operation in order to ensure the required high accuracy of the rotary encoders in the three-phase motors. Therefore, in assembling the laboratory mixing system at the WIB, frequency converters of the latest generation made by ABB were used. These operate with Direct Torque Control (DTC) and, even without rotary encoders, can achieve the same accuracy as vector-regulated systems, which require extra hardware for this. Besides direct control of the torque, the latest ABB frequency converter technology additionally allows a controlled ramp up of the drive motors from a standstill (0 Hz). To this end, the DTC method (fig. 10) uses a calculated motor model that calculates important parameters such as rotary speed, torque and stator flux every 0.025 ms and compares them to the currently measured motor data. Since the motor model can calculate the expected values faster than the current motor data actually changes, an extraordinarily high control accuracy is achieved. If the mixing tools in the mixer are accelerated from a standstill and the highly accurate motor data is measured, then software solutions using LabVIEW not only allow the recording of the measured values, but also the evaluation of rheological models according to Bingham, Herschel-Bulkley etc. (fig. 11). If the fresh concrete properties meet the requirements, then this rheological model can serve as a reference.

Each lot can then be checked for its rheological parameters without interrupting the production sequence. If the liquid limit of an SCC then proves to be higher than the reference, it can be corrected with an appropriate quantity of superplasticiser. If, on the other hand, the viscosity is too low, then viscosity modifiers enable a specific intervention. In conclusion, it was possible to manufacture even difficult to handle high performance concretes reliably and on an industrial scale using the illustrated upgrades and additions to mixing systems. The object here is not only to achieve the mixing quality more reliably than using the familiar mixing systems, but also to do so in a shorter time and with a better quality. In addition, the technically upgraded mixing systems react considerably less sensitively to manufacturing-related changes in the raw materials.

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