Mixing concrete – a constant challenge

Good mixer, good concrete: the first step on the road to success

Concrete is a material that for decades has been the subject of research and development at a variety of institutions and universities throughout the world, and will probably remain so for a long time to come. New improved concretes are regularly presented at congresses and conferences. And we regularly hear the speakers say that a particular concrete is difficult to mix, and that it should be mixed for a longer period of time. Some speak merely of more mixing without actually putting any numbers on it. The fact is: premium concretes are still mixed according to "feel" as there are no objective rules laid down for the mixing procedure. Mixing means introducing energy to a system. The purpose of this contribution is to make mixing understandable as a rational process involving energy. The mixing systems available on the market will also be presented.

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Mixing concrete

Today's concrete is simultaneously a mass building material and a high performance material, writes Professor Dr.-Ing. Bernd Hillemeier [1]. "Until now, concrete has been considered as a simple ternary system of cement, water and aggregate. But today there is a push to create new and innovative concretes. High-tech concrete is treated as a six phase system, consisting of cement, aggregates, water, fluid and solid additives, and air." [1].

The characteristics of the cements, aggregates, mixing water, fluid and solid additives are described in standards and specified to the user. However there are no binding guidelines or standards for the procedure, with which these materials are all united: mixing the concrete.

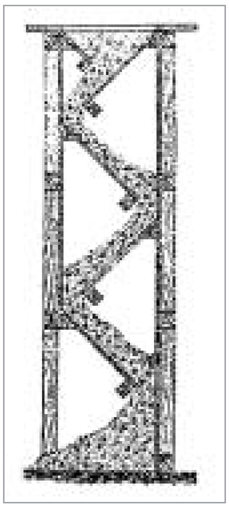

Figure 1: Gravity mixer made of wooden boards, around 1860 [13]

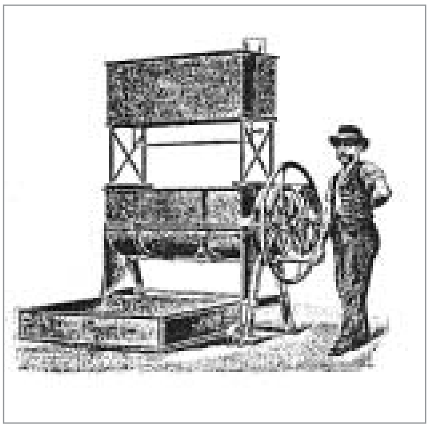

Figure 2: Hand operated trough-mixing machine, Tietze design, around 1870 [13]

Here both the regulations and the cement manufacturers themselves trust in the feel of the user. DIN EN 206-1 only requires uniformity from the mixer: "9.6.2.3 Mixers: The mixer must be able, with their available capacity, to achieve an even distribution of the raw materials and an even workability of the concrete within the mixing time" [2]. The mixing process itself cannot be tested in any way and is completely subjective: "9.8 Mixing the concrete: Mixing the raw materials must take place in a mixer according to 9.6.2.3 and take such a time needed for the mixture to appear homogeneous" [2]. The standard does not recognise a definition of uniformity.

The guidelines from the cement manufacturers are going in the same direction. "Mixing must take place in a mechanical mixer and be continued until the mixture appears uniform. This period of time is the mixing time. Experience suggests that with normal concrete it is a minimum of 30 seconds, and 90 seconds with lightweight concrete. When producing concretes with special requirements, for example self-compacting concrete, fair faced concrete or when using air entraining agents, longer mixing times may be necessary" [3]

What is a "longer" mixing time? And what happens, if the mixing time is too short or too long? When making whipped cream, the housewife knows when she must stop "mixing". Who knows this for concrete? The housewife also knows that she must carry out her mixing tasks at a particular minimum speed. Who today knows what the minimum speed is for mixing of concrete?

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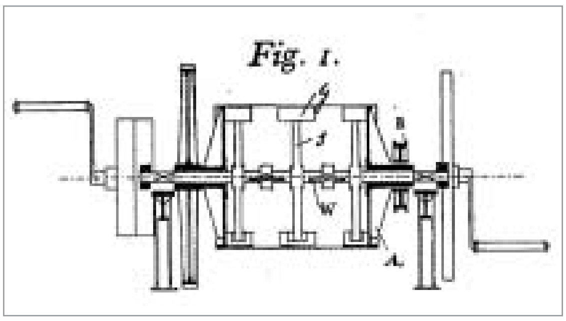

Figure 3: Trough mixer from patent specification No. 71321 Imperial Patent Office, Germany 1893

The fact that the mixing process can be formative for concrete is becoming ever more apparent. Chiara F. Ferraris, of the National Institute of Standards and Technology in the USA, writes in his article “Concrete Mixing Methods and Concrete Mixers: The State of the Art” [4]: “As for all materials, the performance of concrete is determined by its microstructure. Its microstructure is determined by its composition, its curing conditions, and also by the mixing method and mixer conditions used to process the concrete.”

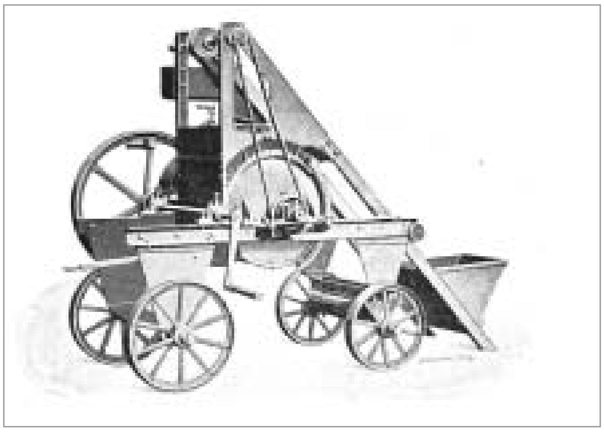

Figure 4: Concrete mixing machine, patent Kunz, 1910 [16]

What our fathers knew

What appears to the reader as a new problem, is not by any means new. Back in 1967 the following appeared: “ the characteristics of concrete is not only determined by well-known factors such as the cement content, the grain structure, the inherent strength and particle shape of the aggregate, the compacting method and subsequent treatment, the water cement ratio etc. but also the type of mixing process that has been carried out, for example the intensity of the scrambling process” [5]. Investigations are quoted, which show that increasing the mixing time raises the strength of the concrete [6].

One of the effects of an “intensive preparation of concrete” made possible by special mixing technology was described as “an improvement of the strength development, a reduction in cement usage, the use of cheaper types of cement, an improvement in workability, an increase in the dispersion of strength measurements and less water separation” [5]. The comparison was made between “normally” mixed concretes with an energy consumption of 1.0 kWh per cubic metre of hardened concrete compared to “intensively” mixed concretes with an energy requirement of 2.5 kWh per cubic metre of hardened concrete; the extra costs for electrical energy were, at the time, 10 times greater than the saving in cement.

Figure 6:
Funnel shaped mixing machine, around 1908 [19]

In 1973 there were reports on investigations carried out with Eirich mixing technology, which at the time was new, using an intensive mixer that had an inclined mixing vessel [7]. The mixing, carried out with 200 kilograms of cement in 60 seconds, amounted to three kilowatt-hours per cubic metre of finished consolidated concrete. Compared with a mixer, which required 0.75 kilowatt-hours per cubic metre in the same period of time for a mixture with 300 kilograms of cement, the intensive mixing resulted in strength increases of more than 20% - in spite of having 100 kilograms less cement [7].

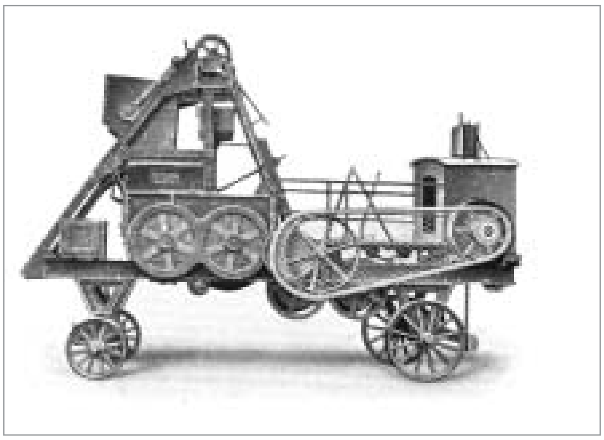

Figure 5: Trough mixer with a twin shaft system [18]

Without exception, in the opinion forming committees, the cement producers did not vote against setting minimum cement quantities in the standards for construction concrete. Because of the guidelines in the standards, the entire cement using industry was unable to push the use of intensive mixing technology. As a result, Eirich withdrew from the mass concrete market and limited themselves to the production of fine grain concretes such as roof tile concrete, face concrete and similar.

The knowledge of how to mix concretes was lost over the course of the decades. Of course the concretes themselves have changed, and knowledge gained in 1973 regarding intensive mixing could not simply be transferred to today’s concretes. Today almost every mixer manufacturer calls his product an “intensive mixer”. And in their brochures, many mixer manufacturers speak of the possibility of saving cement with their mixing system. However, no examples or investigations are quoted. For example, a 5% saving on cement would have resulted in more than 100,000 tonnes being saved in Germany’s 20,473,000 tonnes of concrete products used in 2002 for road construction, gardening and landscaping [8] .

Regarding the durability of concrete

In recent years the durability of concrete as a material is talked about more and more. Durability means that the required performance characteristics remain during a fixed length of time (service life, life span) under the regular operational conditions and taking account of costs (fair manufacturing and maintenance costs) [9].

No investigations have been published concerning how the mixing process affects the durability of concrete. Nevertheless it is known to the authors that universities are working on it.

Mixing technology development - mixing systems

The Verein Deutscher Zementwerke [Association of German Cement Plants], of Düsseldorf, Germany, says: "machine mixing is carried out in charge is in a drum, pan or trough mixer or in continuous mixers. Drum mixers are less suitable for stiff mixtures and those that are very cement-rich" [10].

Drum mixers are gravity mixers. They are not considered here. Pan and trough mixers are forced action mixers. An explanation on the Internet says [11]:

"Forced action mixers:
The mix is forced through turning mixing tools and mixed. Forced action in mixers considered to produce good mix quality, but this is substantially affected by the position of the blades.

Pan mixers:
Forced action mixer for the mixing of

Figure 7: Annular trough mixer, 1903

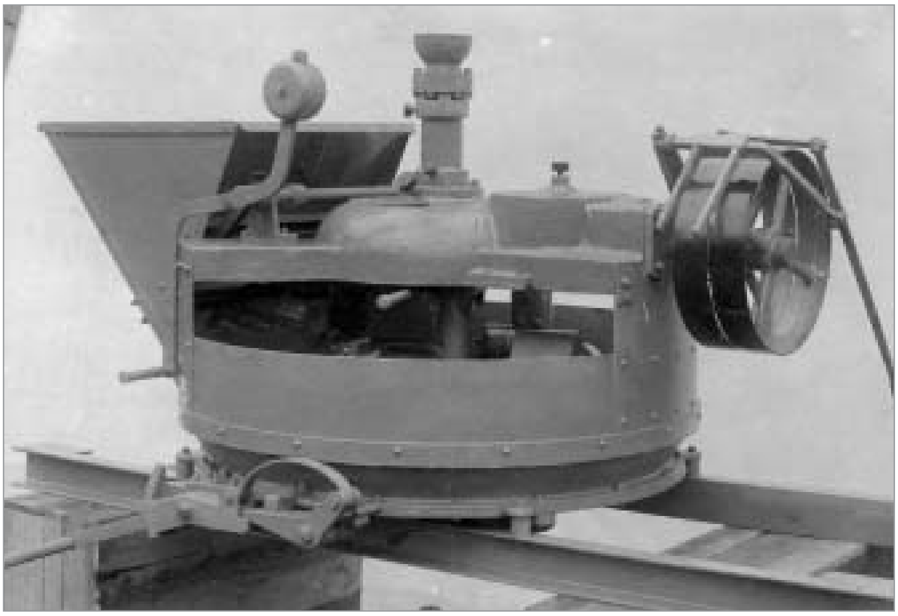

Figure 8: Planetary mixer, around 1910

concrete in which fixed or rotating mixing blades are arranged on a fixed or rotating circular mixing pan.

Trough mixer
Forced action mixer for mixing concrete, where one or two horizontal mixing shafts are arranged on a fixed or tiltable mixing trough."
Grouped together with pan mixers are annular trough mixers, planetary mixers, cone mixers and Eirich mixers. Grouped together with trough mixers are shaft mixers and double shaft mixers

Gravity mixers
In the early days of concrete, earth-moist concretes, which were compacted by tamping, were common, and were used in hydraulic and civil engineering. Since the beginning of the 19th century concrete products such as sewerage pipes, roof and floor slabs, moulded figures and reliefs have been produced, later followed by local concrete constructions such as bridges, water tanks, foundations and cellars made of waterproof concrete. [12].

These concretes could be mixed with

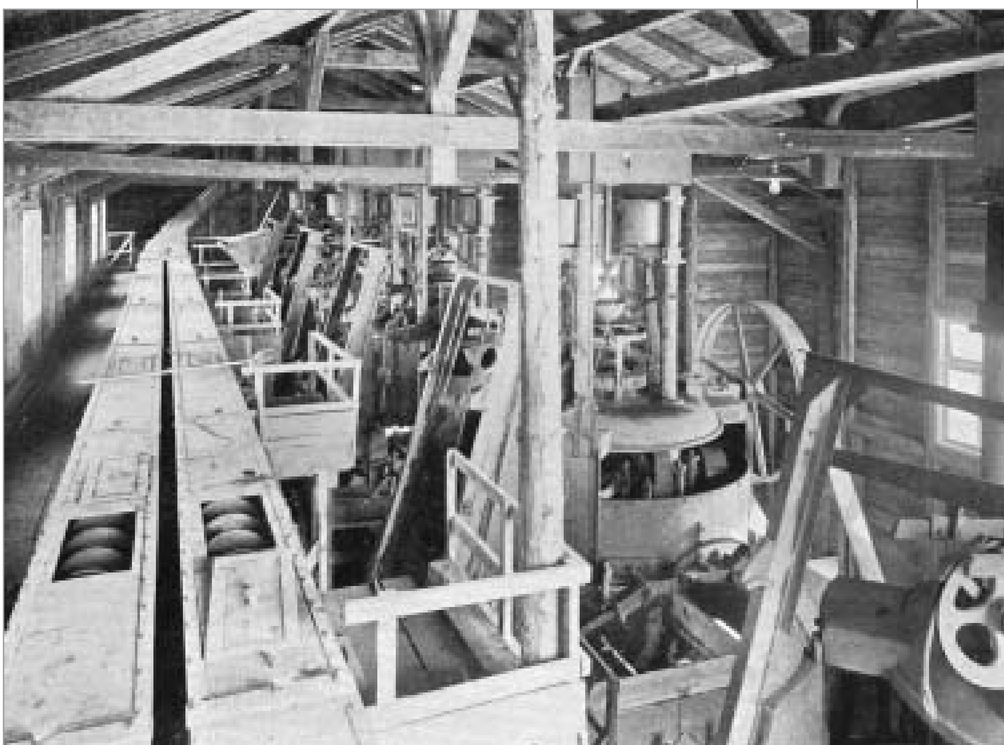

**Figure 9:
Mixing station in the construction of the Kiel Canal (1907 to 1914)**

a hand shovel and later on, with special gravity mixers made of wood or metal, which were filled with a shovel.

Single and twin shaft mixers

The break-through in building techniques with concrete came with the production of "iron reinforced concrete" (later referred to as "steel reinforced concrete") a star based on the J. Monier's patents of 1867 and 1878 [14]. Now concretes were necessary in order to completely in close the reinforcing bars with cement. Accordingly the mixing technology had to be better. In the first forced action mixers were developed, mainly based on the principle of the single shaft mixer (trough mixers or inline blenders).

Figure 2 shows a trough mixing machine with an emptying flap, around 1870, Figure 3 a trough mixer where the outer shell could be tilted for emptying [15].

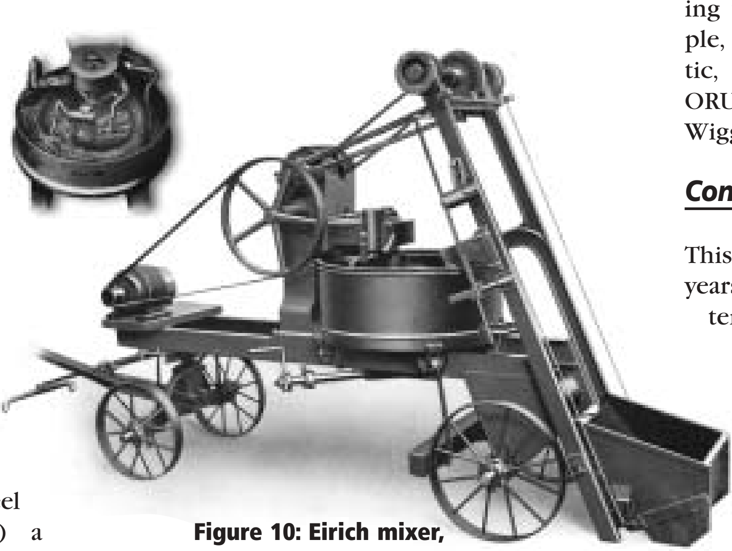

Figure 10: Eirich mixer, at the stage of development in 1924

Figure 11: Announcement, around 1930

Around 1900, mixers of different sizes and types became available, based on this patent by Alfred Kunz of Kempten, Bavaria (Figure 4). However, these mixers were not accepted in the market without some reservations. Single shaft mixers produced a mix of limited quality, in particular when mixing fine grain concretes. In the case of coarse aggregates there was very high wear around the walls. Furthermore, the shaft supports lay in the mix.

Twin shaft mixers developed out of the single shaft mixer. The mix to some extent can avoid the shaft, reducing wear; only around 30 per cent of the revolution of a mixer tool results in wear on the floor of the trough [17]. In 1930, the Bayer. Berg-, Hütten- und Salzwerke AG, Zweigniederlassung Hüttenwerk Sonthofen [Bavarian Mining, Smelting and Salt Works, Sonthofen Metallurgical Plant] offered both single and twin shaft mixers [18] (Figure 5). The company that grew out of this, BHS Sonthofen, still produces twin shaft mixers.

Today, suppliers of single shaft mixers include, for example, Elba und Reich. Those companies offering twin shaft mixers are, for example, Amman, Arcen, BHS, Elba, Elematic, Liebherr, Lintec, OMG Sicoma, ORU, Reich, Simem, Stetter, Teka and Wiggert.

Conical mixers

This mixing system is also around 100 years old as shown in Figure 6. The system did not become generally accepted in the market for processing concrete, although it possesses the advantage of simple emptying.

The designation "conical mixing machine" was already assigned in 1910 [20]. Conical mixers are very common in the chemical, pharmaceutical and food industries. One or two stirring tools are arranged in a conical mixing trough; where the mixer has two tools, in these can counter rotate. Manufacturers of such mixers found on the Internet include companies such as Amixon, Coperion Waeschle, Fryma Koruma, AVA-Huep, EMT Euro-Misch-Technik, BOLZ-SUMMIX, Glatt, and Hosokawa.

The cone mixer was reinvented for concrete. Kniele was awarded the German Precast Concrete Element Suppliers Innovation Prize 2003 at the Ulmer Beton- und Fertigteil-Tage [Ulm Concrete And Precast Element Conference]. Two contra rotating stirring tools run in the Kniele conical mixer, whose speed, according to the brochure folder, is infinitely variable. However at the same time Kniele writes "the low number of revolutions of the external stirring tool means less wear on the external wall and scrapers". Thus the tool speeds here are quite low, according to the manufacturer.

Suppliers of cone mixers and truncated cone mixers for concrete include Kniele and Pemat.

Annular trough mixer

The market for a good mixing system was very open in 1900, as demonstrated by some remarks recorded in the memories of Willi Eirich (1900 – 1985). In 1968 he wrote in a chronicle of the company [21] " The beginning of mixing machine construction at Eirich in Hardheim in the year

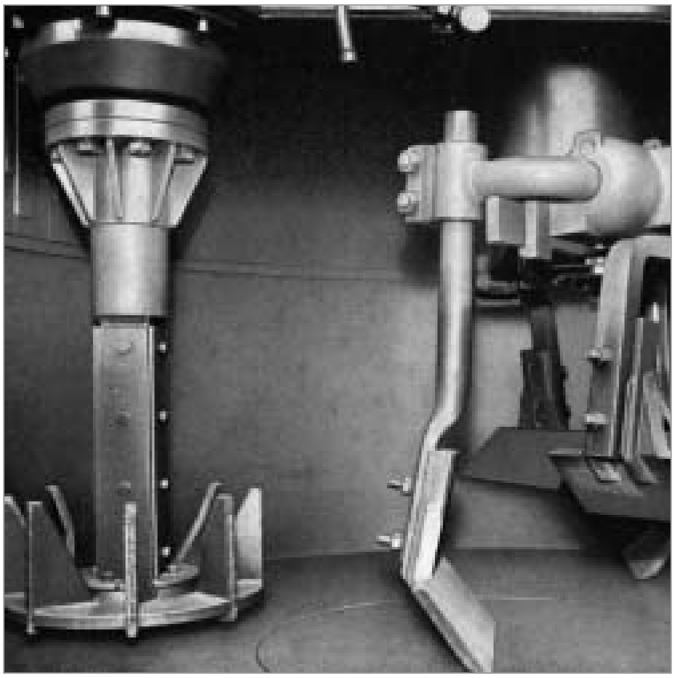

Figure 12: Eirich mixer with agitators, at the stage of development in 1960

1903”: “As far as I was aware, it was in the year 1903 when Uncle Ludwig first met a manufacturer of concrete block moulds, known as artificial stone in those days, when visiting an exhibition in Düsseldorf. In this exhibitor was showing moulds for small hand tamped concrete pipes, a manually operated forming table for concrete roofing tiles and a device for the hand manufacturing of small concrete blocks and slabs”. And “ the exhibitor was complaining and that there was no suitable machine available for mixing the concrete required for his forming equipment”.

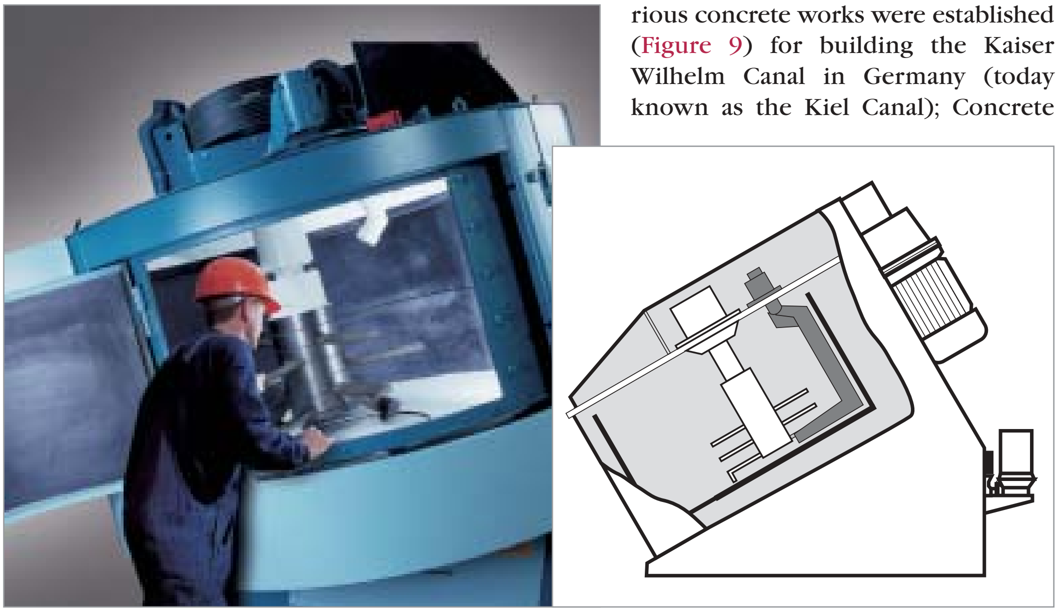

Figure 14: Eirich mixer with an inclined mixing container

Whereupon the two brothers Ludwig and Josef Eirich thought about how to help this man out. The result of this was the first annular trough mixer in 1903 (Figure 7). In particular the developing concrete product industry took on these mixers with enthusiasm.

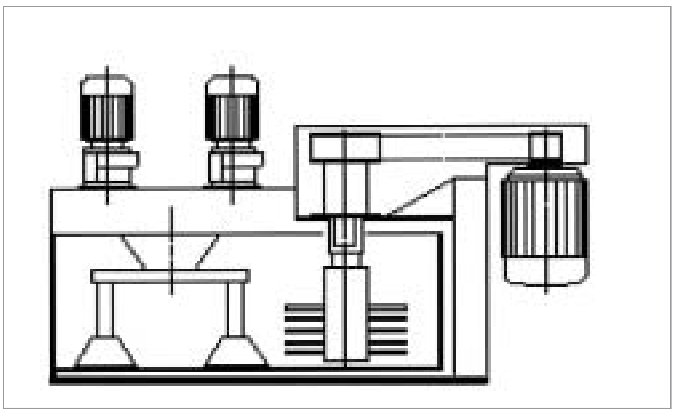

Figure 13: Eirich mixer with agitators, diagrammatic sketch

When, in the middle of the last century, Eirich withdrew from the business of processing mass concrete, several mixture manufacturers discovered the old mixing principle. Suppliers of annular trough mixers today include Kniele, Liebherr, Masa, OMG Sicoma, Pemat und Teka.

Planetary mixers

In 1906 Eirich considered that the annular trough mixer was outdated, and the planetary mixer was invented (Figure 8).

The planetary mixer gave better mixing results compared to the ring trough mixer. Numerous large bridge and lock construction projects were carried out using this mixer with its fixed mixing vessel in the first decades of the 20th century. For example, various concrete works were established (Figure 9) for building the Kaiser Wilhelm Canal in Germany (today known as the Kiel Canal); Concrete Works I at the lock building site Brunsbuettelkoog used five mixers to produce “2000 cubic metres of concrete 20 hours”, and Concrete Works II had an output of 250 cubic metres of concrete per hour [22].

Planetary mixers succeeded for the first time in manufacturing what at the time were considered to be very high-quality mixtures; the mixers were used as “concrete and mortar mixing machines” and “were unsurpassed in their use as mixers for cast stone, ready-mix mortar, moulding sand, xylolite, rendering, Terrazzo, tar macadam, aniline, powder, artificial fertilizer and so on”. [22]. Compared to other mixing units (tube mixers) there were savings on cement when producing concrete. The mixers were used throughout the world. The manufacturer was so confident, that even back in 1913, he lent the mixers out for one month's trial. No mixers were returned, all the customers bought one.

In 1912 Eirich developed the first planetary mixer that worked continuously [23]. At that time the only continuous mixers available on the market were trough mixers, developed from tube mixers; the patent application described how "there is however no thorough mixing of the individual components of the mix".

When in the middle of the last century Eirich withdrew from the production of mass concrete, several mixture manufacturers discovered the old mixing principle. Suppliers of planetary mixers today include: Arcen, Damman-Croes, Fejmert, Haarup, Kniele, OMG Sicoma, ORU, Pemat, Schlosser-Pfeiffer, Simem, Sipe, Skako, Taurus, Teka and Wiggert.

Counter current intensive mixer

In 1924 Eirich developed the first mixers with driven mixing vessels (Figure 10). This mixing principle is unique. The mixers were introduced into many industries as "Eirich counter current intensive mixers" or simply "Eirich mixers".

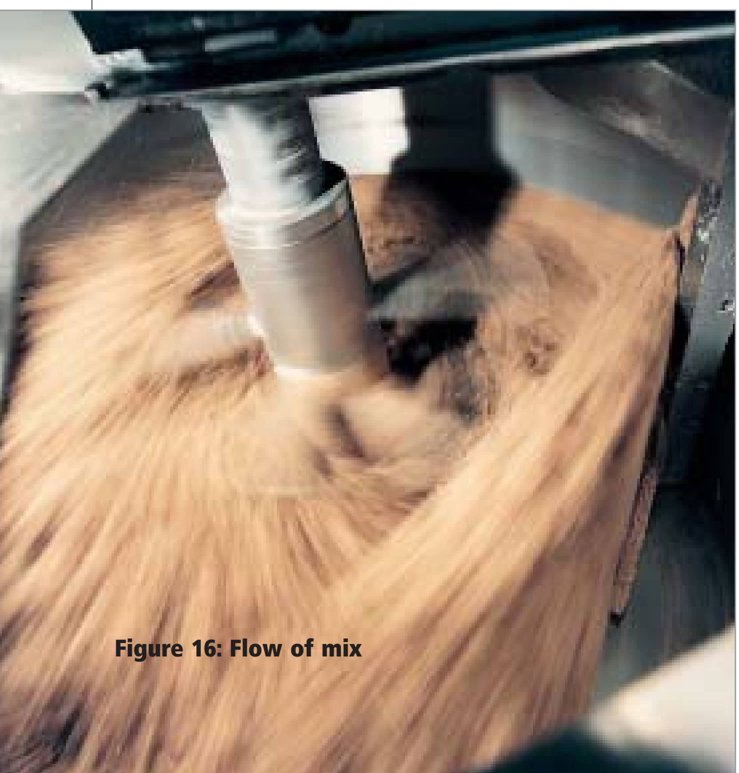

Figure 16: Flow of mix

This innovation again brought a new level of performance to the market: Fill, mix and empty in 40 seconds (Figure 11).

The production of planetary mixers ceased in 1924. Around 1970 the characteristics of the annular trough mixers , planetary mixers and Eirich mixers were described as follows [24]:

Figure 15: Mixing principle of the inclined Eirich mixer

Annular trough and planetary mixer:

- The circular tool guide only achieves a limited mixing effect
- Heavy wear on the wall and floor of the mixing container and the tools.
- With large mixers a large number of tools is needed.
- A high percentage of the energy used is converted to friction (wear).
- The filling height is limited by the peripheral speed of the mixing blade.

Eirich mixer:

- The eccentric positioning of the mixing stars and their movement against the material stream produced by the rotating mixing vessel creates a large number of changes in the spatial position of each individual particle of the mix in both a vertical and horizontal direction, conditions for a rapid and thorough mixing.
- At one turn in every five to 10 seconds, the floor surface of the mixing container is cleared several times by the mixing tools.
- The mixing blade circulated the incoming mixing batch in the style of a ploughshare
- Only a few tools are necessary to keep the mix in constant motion.
- The movements of the mixing container and the mixing tools reinforce one another. Also a relatively low number of revolutions minute produces a mixing effect.
- Stationary wall and corner scrapers force all the mix into the mixing process.
- Mixing tools arranged on a number of levels give the most favourable filling height and thus a high mix output.

Mixers experienced a strong upswing around 1930. At that time a large number of concrete roads were built [25]. In the magazine DIE BETONSTRASSE [CONCRETE ROAD] there were reports on projects from Europe and the USA.

In TEER UND BITUMEN [TAR AND BITUMEN] in 1931 the Eirich mixer was described as the only "universal machine", "which allowed for use with the most diverse range of building materials, like tar, bitumen and concrete" [26].

Accepting something newer and better has always been difficult - even in those days. In 1928 de Weerdt wrote in "Experimental mixing in one of Germany's largest concrete works" that "unfortunately even today, in the technological age, one can still find specialists who cannot come to terms with the fact that mixing systems that were once usable and profitable could now have been overtaken" [27]. The trials included tube mixers, annular trough mixers, planetary mixers and Eirich mixers. De Weerdt also described how "with the Eirich mixer only 5/7 of the mixing time is required, compared to other systems, to produce a 40% greater increase in strength".

The Eirich mixer brought a considerable increase in strength. With "iron concrete", a rise of 178 to 377 kg/cm² was reported after one minute mixing time, while with road concrete the increase was from 354 to 666 kg/cm² [28]. Today in Italy, Croci produces a counter current intensive mixer based on the Eirich of 1924.

Tab. 1 – Typical tool speeds (peripheral speed)	
Annular trough mixer, planetary mixer	up to 4 m/s
Single shaft mixer, double shaft mixer	up to 6 m/s
Eirich mixer, D-Type, horizontal	up to 25 m/s
Eirich mixer, R-Type, inclined	2 to 40 m/s

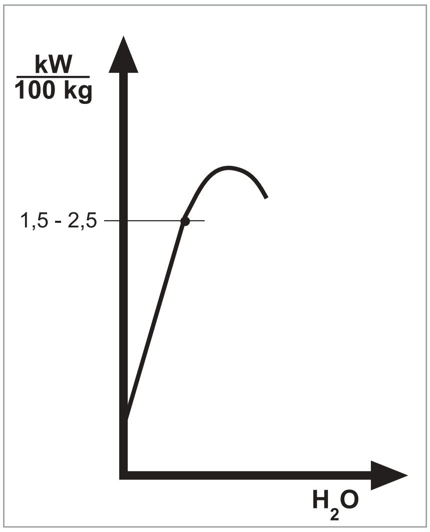

Figure 17: Relationship of power input and consistency

Counter current high-efficiency mixer with agitators

In 1960 Eirich invented a fourth generation of mixers, the counter intensive mixer with additional agitators, which brings an ideal fine disintegration (Figure 12 and Figure 13).

The agitator can run at a peripheral speed of 25 metres per second. Its effect was described as follows [24]: "the insertion of additional high-energy agitators increases the intensity of movement of the particles, forcing the complete homogenisation of components that are hard to associate and the mixing of dies or binding agents without any streaking, all with the goal of improving quality and achieving large savings (e.g. cement, lime, coal dust, Bentonite, oxides and the like)."

The combination of
- A horizontally rotating mixing pan
- One or more eccentrically positioned slow turning mixing tools
- One or more eccentrically positioned fast running agitators

makes it possible to achieve an exceptionally intensive mixing process; that is why these mixers can be found in many different industries.

This fourth generation Eirich mixer produced concretes of a quality of that until then had been unknown. Between 1960 and 1975 "model 1924" was replaced by "model 1960", including in the concrete industry. There are many testimonies from this period. And mixers made at that time are still in use today, as are the previous models. Eirich still supplies spare components and wearing parts, even for mixers that have already been running for over 60 years. Again and again customers confirm that even these old Eirich mixers make outstanding concrete make, better than new conventional mixers.

Intensive mixers with inclined mixing containers

The fifth generation of the Eirich mixer started in 1972. The mixers have a rotary mixing plate that stands at an angle, a fixed floor and walls scraper and a fast turning agitator. In mixers of up to three cubic metres there is only one moving tool; in larger mixers two or three agitators are running.

The mixing principle is unique in the world. In the mixing vessel the mix is transported upwards by friction with the wall. From there it falls down under the force of gravity. Supported by the wall scraper, the mix is directed towards the fast turning agitator (Figure 15 and 16). Within one turn of the container, that is to say within a few seconds, 100% of the batch has been circulated. Here the agitator runs with a peripheral speed of between two and 40 metres per second.

In the meantime seventh generation mixers are now being built, bringing a hitherto unknown quality of mixing to many different industries. Depending upon the mixing task, the mixer can work against the current or in the same direction. With premium concretes, the mixing vessels and agitators usually run in the same direction, because this means that the maximum shear stress can be applied to the mixture.

The characteristic difference between "simple mixers" and Eirich mixers is that in the Eirich mixer the transport of the mix is decoupled from the actual mixing process. The separation between transport of the mix and mixing process makes it possible to vary the speed of mixer tools (and thus the energy introduced into the mixture) within a wide range (Table 1). The introduction of mixing energy into the mixture can then be systematically controlled.

Tab. 2	Volume [kg]	Loose aggregates [l]	Hardened concrete [m³]	Drive power [kW]	Specific power [kW/100 kg]
Annular trough mixer	2,400	1,500	1.0	37	1.54
Annular trough mixer with agitators	2,400	1,500	1.0	37 + 22	2.46
Planetary mixer	2,400	1,500	1.0	44	1.83
Eirich mixer	2,400	1,500	1.0	90 *	3.75

* up to 110 kW possible

In every other mixing system the mixing tools have the primary task of moving the mix. A significant speed increase is not possible.

Mixing –what actually is it?

Mixing means moving position. One must differentiate between two fundamental processes:

1. Distributive mixing – a simple change in the position of the particles; no high shear speeds are required and
2. Dispersive mixing - macerating agglomerates; requires high shear speeds.

There are many parameters, which have an effect on the mixing process, for example particle size, particle size distributions, particle shape, surface roughness, density differences, adhesive forces or flowability.

The mixing process can thus be divided into two mechanisms:

- rough mixing (exchange of larger particles between material flows) and
- fine mixing (change in position of neighbouring particles).

To mix concrete, work must be done. As high a relative velocity as possible must be forced upon the components by introducing kinetic energy. The individual particles must constantly change their position relative to each other.

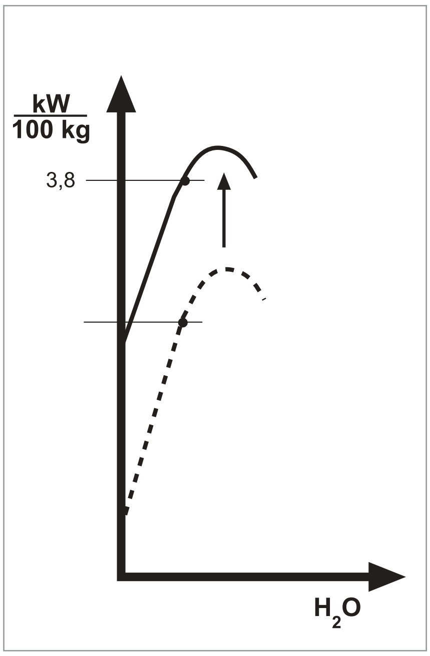

Figure 18: Increase of the power input via higher tool speed

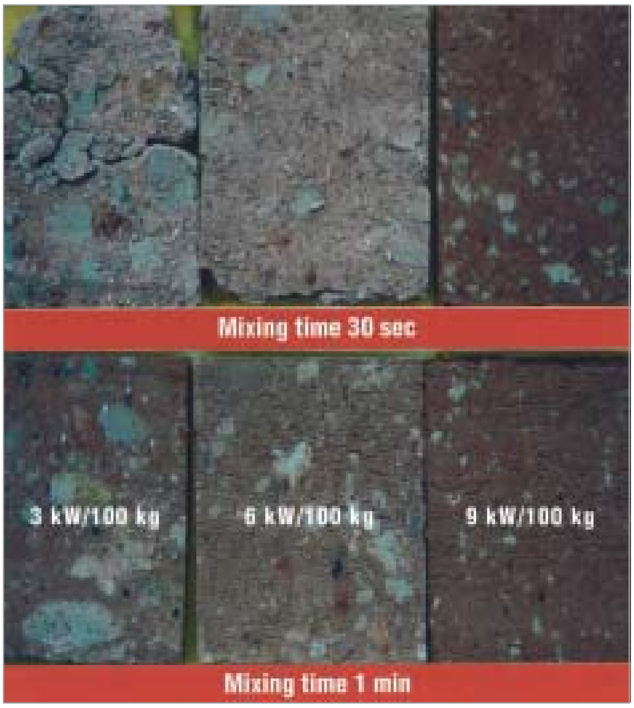

Figure 19: Clay / feldspar mixture, sample test specimen after 2, 4 and 6 minutes mixing time, manufactured on mixers with an energy input of 3, 6 and 9 kW/100 kg

Why is a high mixing speed sometimes important?

In order to be able to cause those processes that result in a change of position in the mixer, energy must be introduced to the system. In a given mixer, a power input / current take-up arises, which depends solely on the consistency of the mix. Experimentally this is calculated from the effective load on the motor for a particular mixing process and weight of mixture, the so-called specific power consumption in kilowatts per 100 kilograms.

The maximum specific power can be calculated from the drive power of the mixers. An example (taken from a brochure) is shown in table 2.

A dry mixture takes up less energy, a flowable mixture a lot. In our example with simple mixers and when related to a certain concrete consistency, the power input is 1.5 to 2.5 kilowatts per 100 kilogram (Figure 17).

The mixing work required to manufacture "good" concrete depends on its composition. Everyone knows that a mortar or fine grain concrete is far more difficult to mix than a concrete with 0/16 or 0/32 granulation; splintered grains macerate pigments faster than round grains etc.

In a conventional mixer and there is no possibility to increase the input of energy. However, with an Eirich mixer, the energy input can be regulated over a wide range by the mixing tool speed (Figure 18). In the above example the mixer is set up for an energy input of 3.75 kilowatts per 100 kilograms.

Why does a higher tool speed and result in a higher energy input? The input of energy into a mixer is very complex, and up until now has not been modelled mathematically. However, to a first approximation, the Eirich mixer can be compared to a stirrer. Here, according to the theory of an ideal stirrer, the power input is proportional to the cube of the peripheral speed.

Only an Eirich mixer can mix stably at speeds of 2 to 40 metres per second. It can be adapted to give the best results with any particular application. If a material is mixed first with two, and then with eight metres per second, according to the theory this means the energy input is 20 times higher. This leads to the best mix quality, in particular with fine grain concretes.

What effect does a higher mixing speed have on the mixing time?

A higher speed means a greater energy input, which in turn means shorter mixing times. An example: a mixing task with a work requirement of 2 kilowatt hours per tonne. A conventional mixer with a specific power input of 10 kW per tonne requires a mixing time of 12 minutes, whereas an Eirich mixer with a specific power input of 50 kW per tonne requires a mixing time of 2.4 minutes.

With the type R Eirich mixer, the energy input can be considerably increased via the mixing tool speed, if the mixing task requires it. Investigations are currently being carried out at a university, which show that with tool speeds of around two metres per second on an inclined Eirich mixer, the mixing performance of a planetary mixer can be simulated. Such low speeds are mostly only used in the Eirich mixer in order to incorporate lightweight aggregates into a mortar suspension that has been prepared at higher speeds. This is to produce aerated concretes without any destruction of the grains, or to mix in coarse aggregates.

Why can't conventional mixing systems mix faster?

Each mixing process is overlaid by a separation process. Separating while mixing has been described in numerous publications. For example, in 1996, Koch and others reported on trials carried out with a horizontal single shaft mixer [29]. Heavy particles tend to accumulate towards the outside, whilst lighter particles accumulate near the shaft. This is explained in that "a higher energy is transmitted to the heavier particles by the movement of the blades than for lighter particles. They are therefore thrown out further, right into the outer zone of the mixing drum".

This applies in principle to every mixing system. The difference with the inclined Eirich mixer is that within one revolution of the mixing container, the mix is circulated one hundred percent and back mixing takes place. This is why it can work at high tool speeds without separation.

How does one determine the mixing work, which is to be input during a certain mixing task?

The only way is by carrying out trials, until the desired mix quality is reached. With concrete, at present nobody knows any values for the mixing work required in order to mix a particular

Figure 20: Paving stone with washed out pigment, laid 1997

concrete adequately. The authors are aware of several universities that are working on the determination of the mixing work for "modern concrete".

The meaning of mixing quality can be visualised by an example from the ceramic industry. If one mixes or kneads a light and dark clay together, then the homogeneity is easily recognisable to the eye. This is shown by the example of a clay / feldspar mixture. During mixing, samples were taken from the mixer and formed into sample test specimens. These were cut in half (Figure 19). For the visible size of the clay particles that have not yet been dispersed a score of 1 (homogeneous mixture) to 5 (clay particles of up to 15 millimetres visible) is given.

The results of the experiment are shown in table 3.

Raising the energy input from 3 to 9 kW/100 kg resulted in
- the mixing time falling from 15 minutes to 4 minutes.
- the mixing work (and thus the energy consumption) falling from 7.5 to 6 kilowatt-hours per tonne.

Figure 21: Paving stone with pigment smears, laid 1997

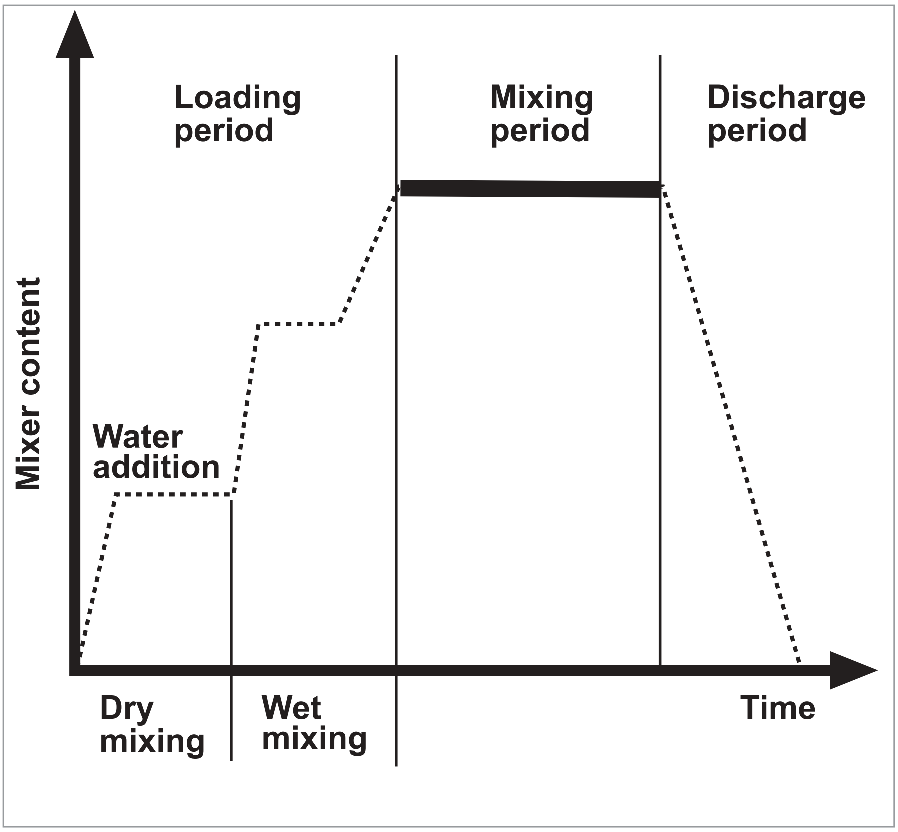

Figure 22: Mixing process after RILEM

This is linked to the fact that not all of the energy that is input becomes effective as mixing energy, but is converted into useless friction and wear. The use of powerful mixers saves not only time but also energy - and thus money.

The mixing quality

For every mixing task there is an optimal mixing quality. In order to achieve it, the necessary amount of energy must be put into the system. According to theory, the mixing quality is a measurement of the variations of a material property in the mixture in question. It describes the degree of inhomogeneity in the mixture during the mixing process. A comparable parameter in a production process is the quality consistency. Mixing quality and quality constancy are thus quality criteria, which do not themselves described properties, but rather their inhomogeneity. Unfortunately at present there is no suitable method to measure the mixing quality during the mixing of concrete. Only later does it becomes apparent whether or not it has been mixed for long enough.

Mixing time [minutes]	Energy input 3 kW/100 kg [degree of homogeneity]	Energy input 9 kW/100 kg [degree of homogeneity]
0.5	5	3
1	4	2
2	4	2
3	3	2–1
.............4.............	3	.............1.............
6	3	
8	2	
10	2	
12	2–1	
.............15.............	.............1.............	

Table 3

With precast concrete elements and concrete products a bad mixing quality is thus identifiable on the finished product, such as paving stones with sand flecks or accumulations of pigment.

In both cases as can be proved that no Eirich mixer was used.

In other industries one often can see nothing on the outside of the finished product; the problems only come when in use, when for example a pigment line is visible in the finished tile joint.

Independent investigation

Independent institutes also confirm that Eirich mixing technology achieves a quality of mixing better than of other mixing systems. The Institut für Fertigteiltechnik und Fertigbau Weimar e.V., (IFF) [Institute for Prefabricated Element Technology and Prefabricated Construction] in Weimar, Germany carried out an investigation into planetary mixers and Eirich mixers using samples from a manufacturer of concrete products. In the report "Untersuchungen zur Mischgüte von Vorsatzbetonmischern" [Investigations into the Mixing Quality of Mixers for Face Concrete]' on 11 February 2003, one can read "The Eirich mixer ... is characterised by very short mixing times... economic advantages...". Moreover, the high uniformity of the concrete prepared with the Eirich mixer is apparent. With fresh concrete, the gross density coefficient of variation of the Eirich mixer amounted to 0.19 per cent, whereas with the planetary mixer it was 0.46 per cent. Something similar shows up with the water content, solid content and resistance to frost and de-icing salt. The Eirich mixer was rated as having "a better uniformity of concrete quality" - reached "in a substantially shorter mixing time than in the X-mixer" [30].

Determining the quality of the pigment dispersion (Bayer AG measured the colour intensity at 2 points on each of 3 paving-stones, and compared them with a reference block to which the value of 100 was allocated), the paving-stone made of face concrete from an Eirich mixer resulted in a fluctuation of around 8 units (136-144); blocks originating in two simple

Figure 23: Bridge section made of Ultra High Performance Concrete, produced by Max Bögl, Neumarkt, Germany

mixers showed fluctuations of 33 and 34 units (100- 132, 126-160).

In other industries where very good mixtures are needed, Eirich mixing is well spoken of. For example in the preparation of glass batches: “The fast Eirich mixers provide a higher level of batch homogeneity”. That is why Philips only operates Eirich mixers worldwide. [31].

On 12 May 2004, a lecture was given concerning extensive investigations into the comparative mixing quality provided by different intensive mixers used in the preparation of glass batches [32]. Not surprisingly, the annular trough mixer had the worst performance, and the inclined Eirich mixer became out best. The mixing quality has a substantial effect on the operation of the melting operation.

A view of the advantages and benefits

The individual suppliers of double shaft mixers, annular trough mixers and planetary mixers offer very similar products. Their job is to convince customers that their particular mixer is better than that from another manufacturer who works on the same system.

A good mixer is something that should last for decades. So anyone who needs a new mixer should carefully analyse the actual performance hiding behind the advertising claims, which may include:

- We are one the largest manufacturers,
- We invented the planetary mixer around 1950,
- We save cement,
- We give 5 years warranty,
- We have a more innovative mixing system than the others
- We mix at differential speeds

Arguments like “my mixer requires less power” should be treated sceptically. Work is the product of power and time. The laws of physics apply to the mixing of concrete too.

One should always scrutinise the data regarding mixing time. Following RILEM [33] some manufacturers understand it to mean the short mixing time of the finished product, after addition of all the components (Figure 22, thick line). The actual mixing time is substantially longer.

Following the expiry of the relevant Eirich patents, the manufacturers of some annular trough and planetary mixers have integrated agitating tools into their mixers too. However the effects are very modest, since firstly the filling height of the mix is low and secondly the mix is not directed towards the agitator. The additional energy input is thus limited, as demonstrated by the example of an annular trough mixer fitted with agitators in table 2.

In the meantime, some mixer manufacturers claim to “increase the number of revolutions during the mixing process and so to raise the intensity of mixing” [34]. Anyone who needs a mixer with a higher number of revolutions per minute, should enquire of the suppliers what the power input is and have a look at some operating plants as references.

The term “counter current intensive mixer” has also been taken from Eirich. But a new name does not make a planetary mixer into an Eirich mixer. As already discussed, today the inclined Eirich mixer usually runs with the current in the same direction for concrete applications.

Continuous mixing

In the precast concrete element, concrete pipe and concrete products industries, the mixing is usually carried out in batches. So we have not covered continuous mixers, which are sold as trough mixers, pan mixers and Eirich mixers.

Multi-stage mixing processes

For some applications, it is appropriate to mix at different speeds. For example when manufacturing lightweight concrete or glass fibre reinforced concrete, a flowable mortar is produced with high tool speeds; during the flowable phase the energy input is at a maximum, and an ideal dispersion of the components and binding agent is achieved. Here the tool speeds can often be higher than 10 metres per second, so that a 30 second mixing time is sufficient. At the end of the rapid mix phase, the remainder of the water required by the recipe is added. Then the light aggregates or glass fibres are mixed in, at low speeds without destroying them. The manufacture of porous concrete is similar.

The authors are aware that work is being carried out in universities on multistage “hybrid” mixing processes for self-compacting concrete. The mixing time for self-compacting concrete

(SCC) in Eirich mixers (starting from when one begins to add water) is around 70 seconds at present.

Mixing in a vacuum mixer

With Ultra High Performance Concrete (UHPC) it can be an advantage to introduce air into the mixing process and then remove it again. The thick, honey-like consistency of the concrete prevents it from venting when it is vibrated.

Firstly the inclined Eirich mixer is ideal for the preparation of such fine grain concrete; secondly it can always be used under a vacuum. At the end of the mixing process, the pressure is lowered in the mixing container for 30 seconds by up to 50 hPa. A co-operative research project between the Technical University of Munich, Germany and its partners Degussa, Eirich, Ph. Holzmann, Schwenk, Woermann and Hochtief has developed a high-performance fine grain concrete using this mixing technology [35].

At the 3rd Kassel Building Material and Solid Construction Conference on 10 September 2003, Max Bögl of Neumarkt, Germany showed a prototype bridge section as part of the theme " Ultra High Performance Concrete - design and construction of the first bridge with UHPC in Europe" [36] (Figure 23). The concrete was prepared in an Eirich vacuum mixer (Figure 24).

Some universities that are working on concretes of the future, use the Eirich vacuum mixer, which is available in size is from three to 7000 litres.

Hot mixing, cold mixing

A multiplicity of mixer manufacturers have overcome the problems of introducing hot air, hot water or hot steam in order to produce a warm concrete.

Figure 24: Eirich vacuum mixer, type RV 23 Vac

Today cold mixing can be achieved not only by adding ice water but also by cooling with liquid nitrogen. This new method of cooling, which has already been tried out in ready mix concrete, has also been used with an Eirisch mixer for the production of a special fire resistant concrete where, irrespective of the weather, the temperature of the mixer is kept at 16°C. This technique can be used for normal concretes too.

Wear

It is well known that with annular trough mixers the mixing result also depends on the degree of wear of the mixing blades. This may be the basis of the general statement, that in the case of forced action mixers " the mixing quality is substantially affected by the position of the blades" [11].

How much wear is acceptable in order to achieve a perfect mixed depends on the assessment and experience of the operator.

A variety of materials are available that offer wear protection for the floor, walls and mixing tools, including ceramics and carbides. No empirical values are available from the various manufacturers, or at least are not published. The general rule is that in the main, wear in a mixer takes place between fixed and turning machine elements. This means:

Mixers with fixed mixing vessels: Both the mixer tools and the mixing vessel, from which the tools take the material, wear heavily.

Eirich mixers with turning mixing vessels: mainly the mixer tools that are subject to wear (with the inclined mixer, it is the agitator blade)

One may find this statement surprising, since the Eirich mixer has substantially higher tool speeds. But nevertheless wear is lower. Anyone who visited mixer manufacturers at Bauma 2004 in Munich will have seen mixers that in many cases were lined with ceramics. But not at Eirich. Ceramics are used with these mixers, but only in very special cases, such as when they are working continuously with throughputs of 750 tonnes per hour for nine months without interruption, or in cases such as iron ore mixtures where up to 5 million tonnes of throughput can be achieved without any repairs being required as a result of wear (Figure 25).

The fact that Eirich mixers work with less wear than other mixers was reported back in 1928. One user, who operated several mixing systems, referred at the time to the fact that the walls of the mixer showed hardly any wear. He attributed this to the “ friction work in the mixed batch occurring mainly inside the batch itself” [37].

Concrete as a subject for research and development

As already mentioned in the introduction, universities and colleges across the world are working on producing concrete with even higher performance - concrete of the future, which to some extent will replace steel. For concrete technologists - and those who want to have such a title - there are mixers available today that have more than just an on-off switch and a single speed.

In addition to the laboratory mixers with three to five litres (R 02) and 8 to 10 litres (RV 02) Eirich specially recommends the pilot plant mixers with 40 litres (R 05) or 75 litres (R 08) capacity. For these sizes (and likewise for R 09, 150 litre, which is running in several institutes) an intelligent control has been designed and that is unique in the world: The speeds of the mixing container drive and the agitator drive can be adjusted within a wide range, and the parameters are recorded.

During the mixing process, the power input of the mixing container drive and agitator drive is measured, logged and also displayed graphically.

The total energy input can be preselected; after this quantity of energy has been introduced, the mixing process is automatically stopped and the mixer switched off.

Using this equipment one cannot only measure the mixing work, but also investigate how changed experimental conditions (e.g. the tool speed, tool geometry, counter current mixing, direct current mixing) has affected the concrete.

Figure 25: Continuously working mixer for iron ore, 6000 litres of useable volume

Prospects

Different mixer types are available the manufacturers of precast concrete elements and concrete products. As a rule conventional mixing systems are adequate for standard concrete. Selection should take account of whether or not the mixer supplier can give good references.

However, in the case of fine grain and high-performance concretes, conventional mixers are often overloaded. At the end of the day, the concrete producer must decide whether or not he can afford to supply the market with products that are possibly inadequate (see the paving stones in Figures 20 and 21). Alternatively he can segregate his scrap. But scrap costs money. Investing in a better mixing technology can pay for itself within a short time.

In the Editorial of the BFT 11/2003, Holger Karutz quoted the English social reformer John Ruskin, (1819 - 1900) [38]: “There is hardly anything in the world that some man can’t make a little worse and sell a little cheaper, and the people who consider price only are this man’s lawful prey. It’s unwise to pay too much, but it’s unwise to pay too little. When you pay too much you lose a little money that is all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing you bought it to do. The common law of business balance prohibits paying a little and getting a lot. It can’t be done. If you deal with the lowest bidder, it’s well to add something for the risk you run. And if you do that, you will have enough to pay for something better”.

Today, one hundred years later, this still applies. Today, Ruskin’s saying is called “good management” or “a maxim of business”.

“Whoever works with his grandfather’s pickaxe will only achieve what his grandfather achieved - and only earn what his grandfather earned” wrote the publisher of CPI, Gerhard Kloeckner in his editorial in BWI No. 5, October 2002. “And the answer to the crisis can only be this: be better than the competition, ... produce at lower cost. That means make less mistakes, and have less production scrap” [39]

For a particular application, to have a concrete that is sufficiently well mixed is the first step towards being better than the others. ■

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Literature:

[1] Hillemeier, B.: Neue Baustoffe – Innovationen aus der Mikrowelt, Akademie-Journal 1/2001, S. 24-28

[2] DIN EN 206-1 – Produktionskontrolle, Beton Kalender 2002, Ergänzungsband, Verlag Ernst & Sohn, Weinheim, S. 233 f

[3] Bereiten und Verarbeiten von Beton, Zement-Merkblatt Betontechnik, B7 8.2002, Bauberatung Zement, Bundesverband der Deutschen Zementindustrie, August 2002

[4] Ferraris, Ch. F., J. Res. Natl. Inst. Stand. Technol. 106, 391–399 (2001)

[5] Ries, H.: Die Intensiv-Aufbereitung von Beton – Grundlagen und Ergebnisse aus der Praxis, Betonstein-Zeitung Heft 4, 1967, Sonderdruck Maschinenfabrik Gustav Eirich, 1969

[6] Wischers, G: Einfluss langen Mischens oder Lagerns auf die Betoneigenschaften, Beton 13 (1963), Heft 1, S. 23-30 und Heft 2. S. 86 –90

[7] Umek, A: Die Intensivaufbereitung des Betons, Untersuchungen Universität Ljubljana, Sonderdruck Maschinenfabrik Gustav Eirich, 1973

[8] Beton + Fertigteil-Jahrbuch, 52. Ausgabe, Bauverlag, Gütersloh 2003, S. 342

[9] Zement Taschenbuch, Verein Deutscher Zementwerke, Verlag Bau + Technik, 50. Ausgabe 2002, S. 179

[10] Zement Taschenbuch, Verein Deutscher Zementwerke, Verlag Bau + Technik, 50. Ausgabe 2002, S. 446

[11] www.baumarkt.de/lexikon

[12] Zement Taschenbuch, Verein Deutscher Zementwerke, Verlag Bau + Technik, 50. Ausgabe 2002, S. 184

[13] Bild entnommen der BETONSTEIN-ZEITUNG, Heft 10/1964, S. 529

[14] Zement Taschenbuch 2000, Verein Deutscher Zementwerke, Verlag Bau + Technik, 49. Ausgabe, S. 187

[15] Patentschrift Nr. 71321 Kaiserliches Patentamt, Deutschland

[16] II. Beton-, Zement- u. Kalkindustrieausstellung Berlin, 2. Juni bis 18. Juli 1910, Firmenschrift K. Bayr. Hüttenamt Sonthofen

[17] BHS, Prospekt Doppelwellenmischer, 07/2003

[18] Bayer. Berg-, Hütten- und Salzwerke AG, Zweigniederlassung Hüttenwerk Sonthofen, Prospekt Baumaschinen, 1930

[19] Maschinenfabrik Rhein und Lahn, Gauhe, Gockel & Cie., Oberlahnstein, Katalog 1908

[20] Maschinenfabriken Karl Peschke, Zweibrücken, Katalog 1910

[21] Mitteilung von Paul Eirich, Maschinenfabrik Gustav Eirich, Hardheim

[22] Prospekt 'Universal-Mischmaschinen Patent Eirich', Klöckner-Werke AG, Abteilung Georgs-Marienhütte, Osnabrück, um 1920

[23] Kaiserliches Patentamt, Patentschrift Nr. 267965, Deutschland

[24] Aus 'Typenübersicht der Eirich Gegenstrom-Mischer', Hardheim, um 1970

[25] DIE BETONSTRASSE, Nummer 4, 1.4.1928, 3. Jahrgang

[26] Seiler, E.:, Die Maschinen des neuzeitlichen Straßenbaues, TEER UND BITUMEN, 1. März 1931, Heft 7, 29. Jahrgang

[27] De Weerdt, H.E. Fehlerfreie Betonmischungen, Westfälische Bauzeitung Köln, Nr. 32 vom 8.9.1928

[28] Garbots, G.: Leistungsversuche an Beton-Mischmaschinen und O. Graf, Die wichtigsten Ergebnisse der Versuche mit Beton-Mischmaschinen, VDI Zeitschrift, Zeitschrift des Vereins Deutscher Ingenieure Heft 23, Sonderdruck Maschinenfabrik Gustav Eirich

[29] Koch, T., Hauser, G., Zettl, T und Sommer, K.: Mischzeitenbestimmung an einem horizontalen Einwellenmischer, Schüttgut, 2. Jahrgang, Nummer 1, Januar/März 1996; Sonderdruck der Fa. Zettl, München

[30] Untersuchungen des IFF Weimar: Gleichmäßigerer Beton mit Eirich-Mischtechnik, Beton Fertigteiltechnik (BFT), 4/2003, S. 93

[31] Philips values performance, reliabilty of intensive batch mixers, Case history, PBE International, September/October 2003, S. 22-24

[32] Rikken, F., Industrial Service & Support, Philips Lighting Components, Powder Technology & Project Management, Eindhoven, The Netherlands, auf Symposium Mischtechnik, Hardheim / Deutschland, 12. Mai 2004

[33] Charonnat, Y. und Beitzel, H.: RILEM TC 150 ECM, Mater. Struct. (Suppl. 196) 30, 28-32 (1997)

[34] Doppelwellen-Chargenmischer im Mittelpunkt des Messeauftritts, BHS-Sonthofen GmbH, BetonWerk International (BWI) Nr. 1 Februar 2004, S. 47

[35] Schachinger, I. A.: Hochleistungs-Feinkornbeton, TU München, Schriftenreihe Baustoffe Heft 3/2003, Jahresmitteilungen 2002/2003, S. 55

[36] Schmidt, M. und Fehling, E.: Tagungsbeiträge zu den 3. Kasseler Baustoff- und Massivbautagen, Ultra-Hochfester Beton - Planung und Bau der ersten Brücke mit UHPC in Europa, Schriftenreihe Baustoffe und Massivbau 2, kassel university press, 2003

[37] Schmidt, Der Gegenstrom-Schnellmischer, Beton und Eisen, XXVII Jahrgang 1928, Heft 4, Sonderdruck Maschinenfabrik Gustav Eirich

[38] Karutz, H.: Herbstgedanken, Editorial zu Beton Fertigteiltechnik (BFT), 11/2003, S. 1

[39] Klöckner, G.: Beton – Baustoff des 3. Jahrtausends, Editorial zu BWI BetonWerk International Nr. 5 Oktober 2002, S. 3