Efficient Manufacture of Colored Concrete Products

Producers of paving blocks and related building materials know all about concrete, about cement and aggregates, about formulation, strength and stability, but they like it grey - coloring pigments are "foreign matter" in a concrete plant, better not to use them! But ..., yes, but the customer likes to have colored concrete ware! Therefore the pigment user under compulsion can expect the advice of the pigment manufacturer for questions of the right choice of pigments and the correct method of dosage. The following overview intends to discuss the relevant parameters to make this choice a rational one.

Choice Of Pigments For Coloring Concrete

A great lot of publications in the past have dealt with the general basic requirements for pigments for coloring of building materials. The practice results of decades have proved that oxide pigments of iron, titanium, chromium, mixed metal oxides exhibit excellent properties in concrete. Meanwhile also a lot of national and international standards exist from which advice can be taken for choice of the right sort of pigment. Representatively e.g. EN 12878 "Pigments for the colouring of building materials based on cement and/or lime - Specifications and methods of test" (which is the working basis for an European standard, too) prescribes the necessary properties of pigments for coloring concrete. Pigments for which the manufacturers certify the general suitability in accordance with such norms are, for sure, a good selection; such materials will be insoluble in water and the alkali of the cement, will not influence the concrete strength and setting, will be stable in weather and have uniform color and tinting strength - in one sentence: they fulfill the basic general requirements for coloration of concrete.

But this is only one aspect; the next choice to be made now concerns the form of delivery. Meanwhile, besides the traditional form of pigment powder also fluid preparations (water-borne slurries) and pigment granules are established in the market. A decision for a certain form of supply normally is a decision for a certain method of pigment dosage into the concrete mix - an essential point to be discussed in detail.

Up to now a defined color did not occur in our considerations! This will be the main issue some chapters later. Before coming to this point, we at first should deal with some facettes of the state of the art in pigment dosage, in order to make the best out of this "foreign matter pigment" in the concrete plant.

Considerations About Dosing

Often, if metering of pigment in the concrete industry is under discussion, automatically the idea of mechanical, computerized dosing comes up. But a lot of producers of concrete articles who have only smaller demand of colored items conduct their pigment dosage manually with good results, since years. They are manually weighing their pigments into dosing vessels and add them directly into the concrete mixer by hand. If we assume an annual demand of 20 tonnes of pigment, worked up with a paving block machine with a 0.5-m³ mixer, holding a good 1000 kg of fresh concrete, then we can estimate as an average 20 dosing cycles per day. Naturally, the investment of an automatic metering equipment is not reasonable in such a case. But even in this minor example, the change of powder-pigment to granule-pigment will increase the ease of handling during the manual weighing and improve the hygienic working conditions by reduction of dusting during all phases of production.

Tab. 1: Catalogue of Bayferrox® liquid grades

Grade	Farbe	Solid content DIN ISO 787 Part 2 [%]		Density [g/ml]		pH value DIN ISO 787 Part 9		Viscosity Brookfield 20 °C, No. 4, 100 U/min [mPa·s]	
		min.	max.	min.	max.	min.	max.	min.	max.
Bayferrox® 110 liquid	Red	65	70	2,0	2,3	7	10	700	1500
Bayferrox® 120 liquid		65	70	2,0	2,3	7	10	700	1500
Bayferrox® 130 liquid		65	70	2,0	2,3	7	10	700	1500
Bayferrox® 350 liquid	Black	50	55	1,5	1,7	7	10	800	1300
Bayferrox® 686 liquid	Brown	54	61	1,7	2,0	7	10	800	1300
Bayferrox® 920 liquid	Yellow	37	42	1,2	1,5	7	10	400	800

Table 2: Formulations for on-site-preparation of Bayferrox-Slurries

2.1 Slurries for direct use (storage stability max. 1 day)

	Bayferrox® 110	130	330	920
Water	1220 kg	1000 kg	1497 kg	4550 kg
NaOH (50 % in water)	4.4 kg	4 kg	5 kg	8 kg
Pigment	1000 kg	1000 kg	1000 kg	1000 kg
Solid content	45 %	50 %	40 %	18 %

2.2 Stabilised slurries (storage stability 8 – 10 weeks)

	Bayferrox® 110	130	330	920
Water	526 kg	526 kg	1211 kg	1490 kg
Wetting agent (40 % in water)	15.4 kg	15.4 kg	11.1 kg	6 kg
NaOH (50 % in water)	3.1 kg	3.1 kg	4.4 kg	4 kg
Pigment	1000 kg	1000 kg	1000 kg	1000 kg
Anti-setting agent/ thickener	3.1 kg	3.1 kg	4.4 kg	4 kg
Preservative	3.1 kg	3.1 kg	4.4 kg	4 kg
Solid content	65 %	65 %	45 %	40 %

There is another situation within a concrete factory with a yearly through-put of 200 tonnes of pigment. Normally here at least a 1-m³ mixer will be installed, working up 2,3 tonnes of fresh concrete per cycle. Under such conditions one can expect approximately 100 dosing strokes of 10 kg a day - enough to consider the installation of a sophisticated metering equipment and to look for the most comfortable form of pigment supply.

The Special Case - Dosing And Manufacturing Of Slurries

Although the iron oxide pigments have been "invented as powders" and therefore the dosing of powders has the oldest history, we should start our survey with a short excursus to slurry metering, since in most cases this technique will be combined also with the own manufacturing of these water based dispersions. If we look to the catalogue of Bayferrox® fluid pigment preparations in Table 1, we find that such liquid colors contain around 50 % of water. A direct supply from the industrial producer therefore only is suggestive in a certain limited area around the factory, in order to have reasonably low freight cost. In all other instances the water-pigment preparations have better to be prepared on site. If a high daily pigment through-put in the concrete factory is planned, then one can have in view simple two-component mixtures from water and pigment for red and black slurries. With a high speed mixer the pigment can be stirred into the water to get 40 to 50 % solid containing dispersions (Table 1), only the pH-value should be adjusted to the suitable alkaline range. In the case of yellow iron oxide pigments the high water demand of these needle-shaped particles calls for relatively high amounts of water, only leading to low solid contents of maximum 20 %; in these cases to much water may be incorporated into the concrete together with the pigment. Additionally with such unstabilised pigment slurries some precautions have to be taken: By proper continuous stirring the dispersion has to be kept homogeneous and all vessels, pipes and nozzles should be cleaned already for short periods of stand-still. But, if the limited range of colors and the a.m. restrictions can be accepted, then this method offers a low-cost possibility of making pumpable, dust free preparations.

The more flexible method naturally is, to manufacture stabilized pigment slurries using wetting agents, pH-adjusting chemicals and anti-settling additives. In Table 2 workable formulations are given for the range of Bayferrox® pigments, showing that under these circumstances also highly concentrated yellow slurries can be produced, with water contents low enough to make concrete with the desired range of water/cement ratio. Periodically stirred in the storing vessel, such dispersions are stable at least for some weeks.

Unconcerned how and by whom the slurries are manufactured, once in the factory they are offering a variety of possibilities under the point of view of metering pigments. Dosing now is a clean and easy thing. If a new dosing equipment shall be installed in an existing concrete plant, space problems often occur; mostly there is not enough room above the concrete mixer for e.g. a powder station. Since the slurries can be pumped over longer distances, they may be the solution. With these homogeneous preparations with a fixed specific gravity, both possibilities of metering can be applied: Volumetric and gravimetric dosage, the respective equipment offered by a lot of reliable engineering companies.

Having in mind these positive properties, some limitations must not be ignored. Also with highly concentrated, stabilized dispersions every dosing stroke adds some amount of water. Especially, if the agglomerates contain also some water (wet sand, e.g.), some regions of water/cement-ratios cannot be achieved: Let us imagine a concrete with 100 kg of cement with a agglomerate/cement-proportion of 6 : 1. If the agglomerates contain 5 % of water (a value often found in practice), then only by this percentage 30 kg of water are incorporated into the concrete, giving a water/cement-ratio of 0.3. If we now want to add 3 % of pigment (related to cement) by use of a slurry with a solid content of

Fig. 1: View on pigment-silo, originally used for powder, now holding the respective pigment-granules – notice the step cones

40 %, we add another 4,5 kg of water, leading to a total water/cement-ratio of 0.35. This is the lowest ratio possible, whereas with a dry pigment a ratio of 0.3 could be achieved.

What has been said for the non-stabilized pigment dispersions is also valid for the stabilized ones, but to a less detrimental level: In cases of longer stand-still the supplying pipes should be cleaned by rinsing with water in order to avoid settling in the pipes and choking of nozzles. If these measures are taken and the a.m. limitations kept in mind, the user of "liquid colors" will belong to the big number of satisfied customers.

Automatic Mechanical Dosage Of Pigments In Powder And Granular Form

The longest experience in handling and dosing exists with powder pigments. These materials are designed chemically and physically to form fine particles in the sub-micron range, this means up to hundred-fold smaller than the anyhow small grains of cement. These small sizes are absolutely necessary to achieve the desired colors and the opportune high tinting strength. Such fine powders have a high specific surface where attractive forces cause the particles to form lumps, to build-up layers on the walls of vessels and tubing and to form bridges of sticky powder in silos. This behavior of powders also leads to bulk densities greatly dependant on the "history" of the material: The apparent density is low just after production and milling, but increases with the vibrations during transport, conveying and storing. The only conclusion can be that volumetric metering by no means can be applied and that only gravimetric dosing will result in sufficient accuracy.

In practice of pave making the overwhelming majority of mechanical pigment dosage works with powder. A great number of engineering companies in many countries have developed suitable machinery to overcome the problems with metering and feeding fine pigment: So it is difficult to convey powders upward. Therefore it is highly recommendable to install the silo at a high point in the plant, and to transport the powder by downstream movement. The adhesiveness of powders also prohibits to construct silos with flat bottom angles; the angle of gradient should not be smaller than 60 degrees from the horizontal line. In order to support a steady flow of powder pigment, the walls of the cone of a silo should be vibrated during the feeding cycle, but - this is important - not continuously. Continues vibration would otherwise lead to compactation in the outlet of the silo. The real metering

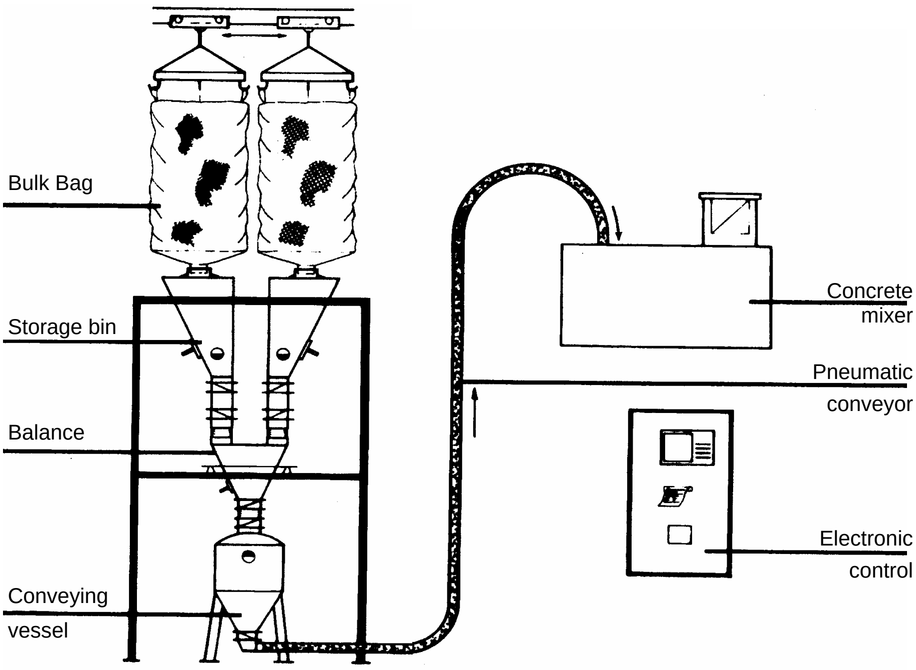

Fig. 2: Schematic sketch of a pneumatic dosing system for pigment granules

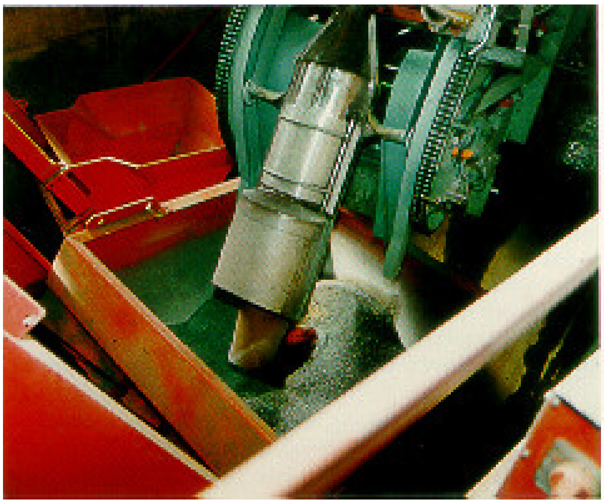

Fig. 3: Movable weighing vessel, emptying into the half-filled elevator bucket

in an automatic balance is normally done with a conveyer screw where the product flow is supported by an additional spiral for breaking up lumps. For calculating the pigment dosing strokes in accordance with the concrete mixing cycles one should keep in mind the principles of such automatic weighing: With high speed the major part of pigment is transported into the weighing vessel ("rough dosage") and then with low speed, but high accuracy, the small rest is added to the former amount. If. e.g., three colors have to be weighed into one formulation, this total weighing/dosing time, defined by the manufacturer of the weighing device, has to be considered in planning the whole process.

Furthermore must be decided where to supply the metered pigment amount to the concrete mix; several possibilities meanwhile are the state of the art. In some plants the storing and dosing device is situated quite close over the concrete mixer and the pigment dosed directly falls into the mixing chamber. Space problems often makes it necessary to construct the metering facility a little bit aside. A proved place is at the upper part of the conveyer belt with which the main stream of finer agglomerates is transported to the elevator bucket or directly to the mixer. The pigment powder freely falls on the moving agglomerates and a device, constructed like a plough-share, narrows the product stream and covers the pigment with agglomerates to prevent dusting.

If we now change to metering of pigment granules, all becomes more easy. Pigment granules namely combine some advantages of the powder with the benefits of pigment slurries: We have dry material with 100 % coloring power and in addition free flowing behavior, like a fluid, easy to dose, non-sticky, with the possibility of being transported pneumatically.

Because iron oxide granules are a development of the recent past, there are more practical cases to change from powder dosing to granule metering than instances, where an absolutely new factory is planned with the intention to tailor-make it for granule dosage. Therefore it is good to know that a change from an existing powder dosing device to a granule facility is relatively easy. Passing over from adhesive powders to free flowing granules allows to use the same silos and one can shut off the

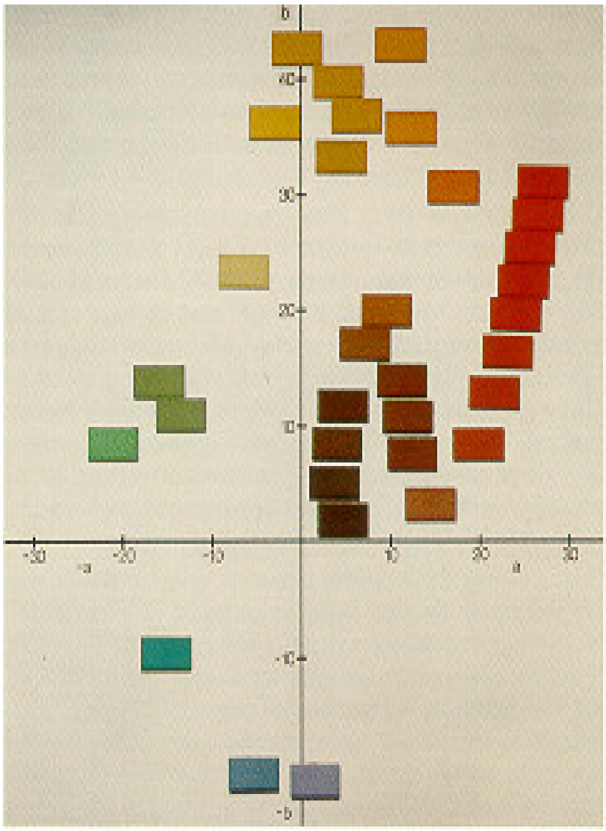

Fig. 4: Total color space, achievable in concrete with oxidic pigments

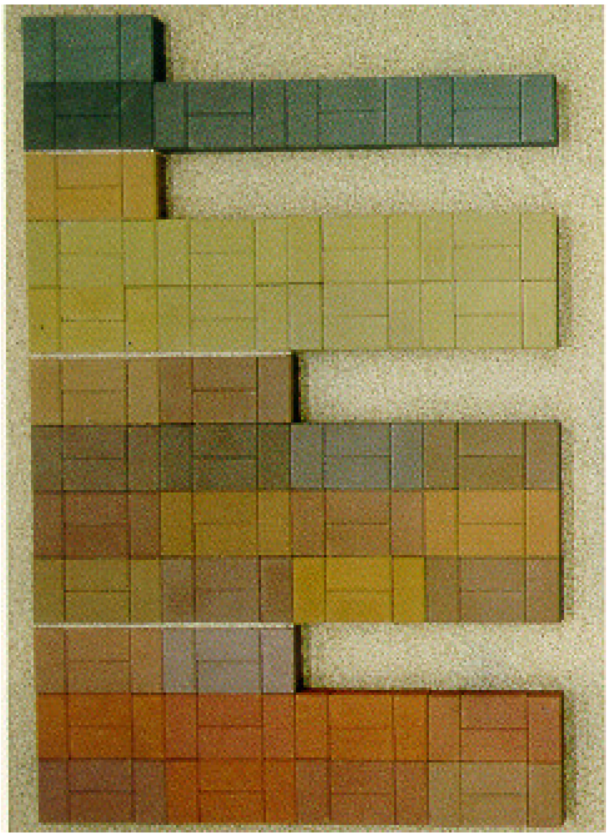

Fig. 5: Colorspace, achievable in concrete with iron oxide Bayferrox

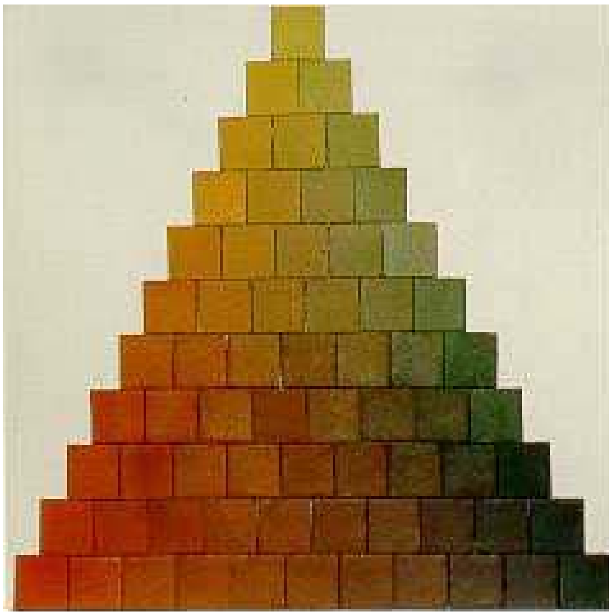

Fig. 6: "Color triangle", demonstrating a mixing scheme with three Bayferrox granule grades (top: Bayferrox 920 G, left: Bayferrox 110 G, right: Bayferrox 330 G

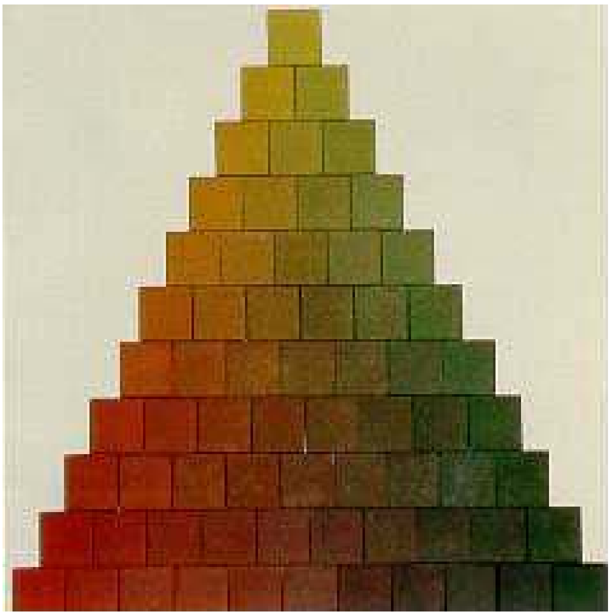

Fig. 7: "Color triangle", demonstrating a mixing scheme with three Bayferrox granule grades (top 920 G, left: Bayferrox 130 G, right: Bayferrox 330 G

vibrators. The existing conveying systems in the automatic balance can be used, the only modification normally being, to close the transport screw after every dosing cycle (e.g. by a pneumatic valve) in order to stop the easily moving granules from flowing out uncontrolled. An example is demonstrated in Figure 1: The typical steeply walled silos have been constructed and used for powders; for the change to granules only the unnecessary vibrator engines have been removed and the plant runs granules now since two years without difficulties.

One widely offered possibility for granule dosage is to meter the foreseen quantity as prescribed above, and then to convey the weighed amount pneumatically into the mixing chamber. Under these circumstances the offered solution (see Figure 2) for the separation of solids and transporting air on the concrete mixer is to install a cyclone and/or a filter bag. Since this design is not quite simple - dry compressed air is necessary, bigger quantities of conveying air have to be separated from the solid material - other solutions have been developed. Figure 3 shows how a closed, movable weighing vessel with the total quantity of pigment granules for one mixing cycle empties into the elevator bucket. Because this is done during the filling of the bucket, the dosed granules are dug in the centre of the aggregates and therefore later on in the mixer take part in dispersion from the very beginning.

Rationalization Of Pigment Stock Keeping By Additive Mixing Of Concrete Colors

Until now, when dealing with metering of iron oxide pigments, color still did not play any role. But, naturally, we must not forget the real purpose of pigmentation: To add color to the grey concrete.

With inorganic oxidic pigments which correspond with the standards, the color spectrum of Figure 4 is achievable, including also very light yellow shades and green and blue.

Economic reasons in most cases, however, will be the cause to concentrate on the iron oxide pigments which offer an optimum performance for reasonable price. In Figure 5 demonstrating overview is given over the color range of the iron oxides Bayferrox® in realistic concrete paving blocks. Counting the specimens, the user now has the burden to chose from 10 reds with light to dark shades, from 8 yellows and 5 blacks with different undertone, from 13 browns more or less yellowish or more or less blackish, partly in two varieties on different tinting strength levels. Is it necessary to keep all these possible shades on stock, in order to comply with the demands of the market?

Having in mind the possibilities of pigment dosage in the concrete plant, let it be manual or automatic, then with three or four suitably chosen pigments a broad range of desirable shades can be blended on site.

The typical colors of clay, e.g., can be achieved by blends of yellowish reds and high amounts of yellow. A variety of light and yellowish browns are accessible by mixing "middle reds" and yellow, whereas maroon shades contain all three basic iron oxide colors red, yellow and black. The very dark browns are blends of red and black only. If a producer of concrete ware is able to dose pigments correctly, he can realize these shades for his own. Figures 6 and 7 are our "color triangles"; we are showing what can be achieved with three basic colors red, yellow and black. In a concrete mixes formulated for a front layer of paving blocks, we incorporated Bayferrox® granule pigments. In the first case we took Bayferrox® yellow 920 G, Bayferrox® black 330 G and as a red we have chosen

Tab. 3: Color variation of a Bayferrox® blend of 64 Bayferrox® 420 and 36 % Bayferrox® 110 by tinting strength variation

Blend made of tinting strength[%]	Bayferrox 420	Bayferrox 110	Pigmentation 3.6 % ΔE*	Pigmentation 3.6 % tinting strength [%]	Pigmentation 2.0 % ΔE*	Pigmentation 2.0 % tinting strength [%]
100	X	X	0.0	100	0.0	100
95	X	X	0.2	101	0.5	101
105	X	X	0.6	103	0.7	106
95 100 105	 X	X	0.3	100	0.5	99
95 100 105	X	 X	0.5	102	0.6	105

Tab. 4: Color variation of a Bayferrox blend of 55 % Bayferrox® 320 and 45 % Bayferrox® 110 by tinting strength variation

Blend made of tinting strength [%]	Bayferrox 320	Bayferrox 110	Pigmentation 3.6 % ΔE*	Pigmentation 3.6 % tinting strength [%]	Pigmentation 2.0 % ΔE*	Pigmentation 2.0 % tinting strength [%]
100	X	X	0.0	100	0.0	100
95	X	X	0.3	98	0.1	101
105	X	X	0.2	101	0.4	103
95 100 105	 X	X	0.3	98	0.4	98
95 100 105	X	 X	0.5	102	0.4	100

Bayferrox® 110 G, because we wanted to use the lightest red with the most yellowish undertone in our range. The blending formula for the three colors changes in steps of 10 %, either in two-fold mixtures or - in the interior of the triangle - three-fold mixtures. In Figure 6 we took the same yellow Bayferrox® 920 G, the same black Bayferrox® 330 G, but changed the red to Bayferrox® 130 G which is approximately in the centre of the red range. With this red as one corner in the color triangle the browns gain more reddishness, opening the field for a new series of browns. In total in the two figures 132 colors are realized and one has to keep in mind that more are possible by using other blending ratios. Now it becomes obvious: To answer quickly to the demands of the market and to chose colors easily means to blend pigments on site.

Relations Between The Accuracy Of Additive Mixing And Color Fluctuations Of Concrete Paving Blocks

A manufacturer of colored concrete who has up to now used pigments blended by the pigment producer, is accustomed to tolerances for the tinting strength of 100 ± 5 %. If he now changes to on-site-blending, the question will arise, how the shades of the blends will fluctuate, if the components' tinting strength varies between 95 and 105 % from one delivery to the next. The technical realization of dosing systems meanwhile is so sophisticated that a metering accuracy of better 2 %, often 1 %, is the state of the art.

In order to evaluate this uncertainty, we designed a series of experiments. We prepared concrete mixes, typically used for the front layer of a two-layer paving block and colored them with 2 % and 3.6 % of pigment blends. The idea was, to look into a very low pigmentation (2 %), far away from the color saturation point, where color differences should be visible very well, and into a normal pigmentation rate (3.6 %). We mixed three artificial blends: an "orange" consisting of 64 % yellow Bayferrox® 420 and 36 % red Bayferrox® 110, a dark brown consisting of 45 % red Bayferrox® 110 and 55 % of black Bayferrox® 320 and a lighter brown consisting of 50 % yellow Bayferrox® 920, 36 % of red Bayferrox® 130 and 14 % of black Bayferrox® 330. In these mixtures we varied the weight of all components on the level of 95, 100 and 105 %, simulating tinting strength fluctuations from 95 to 105 %. Preparation, curing and storing of the blocks occurred under controlled laboratory conditions in order to avoid color changes other than caused by our intended tinting strength variations. After proper drying of all test specimens we measured the color differences between the respective "standard" (all components with tinting strength 100 %) and the varied blocks. The detailed results are listed in the tables 3, 4 and 5. As a summary out of 92 single experiments we can underline: Although we varied up to three components in all possible permutations with the maximum tinting strength variations, the resulting tinting strength of the mixed color only fluctuates between 98 and 106 % with a mean at 102 % and the color differences ΔE* from 0.1 to 1.0 with an average of 0.5. This clearly demonstrates that on-site-blending of pigments leads to colored concrete end products within tight tolerances.

Tab. 5: Color variation of a Bayferrox® blend of 50 % Bayferrox® 920, 36 % Bayferrox® 130 and 14 % Bayferrox® 330 by tinting strength variation

Blend made of				**Pigmentation 3.6 %**		**Pigmentation 2.0 %**	
tinting strength [%]	**Bayferrox 920**	**130**	**330**	**ΔE***	**tinting strength [%]**	**ΔE***	**tinting-strength [%]**
100	X	X	X	0,0	100	0,0	100
95	X	X	X	0,3	98	0,2	99
105	X	X	X	0,5	104	0,3	100
95 100 105	X 	 X	 X	0,5	105	0,8	106
95 100 105	 X 	 X	 X	0,4	102	0,4	103
95 100 105	 X 	X 	X 	0,2	100	0,5	103
95 100 105	 X	X 	X 	0,3	98	0,3	101
95 100 105	X 	**X** 	 X	0,5	102	0,6	105
95 100 105	 X 	X 	 X	0,5	104	0,5	102
95 100 105	 X	X 	 X	0,4	102	0,6	106
95 100 105	X 	 X	X 	0,3	100	0,8	106
95 100 105	 X 	 X	X 	0,4	99	1,0	105
95 100 105	 X	 X	X 	0,5	101	0,2	101

Summary

For coloring concrete in many shades iron oxides are well established in the concrete industry. Nowadays the user not only has the choice of variation black to a spectrum of browns, but also of different forms of preparations: the traditional pigment powder, slurries ready for use or produced on site, or most modern, pigment granules.

The different parameters of the above mentioned products will be summarized which define the quality of coloration of cementitious or lime bound building materials.

By discussing the main topic "Dosing of powders and granules" future trends will be focused on; evaluation of the dosing accuracy will lead to recommendations for additive mixing of the whole iron oxide color spectrum and will give ideas for optimizing and rationalizing the necessary pigment pallet in a concrete plant.