Suggestions for improving coloured concrete products

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Introduction

Very often people ask if there are really any new ways to make the colour and surface structure of concrete products look as good as, or better than natural stone or clay products.

The purpose of today's lecture is to explain how you can best achieve this.

There are many reasons why people prefer concrete, such as its superior strength and the variety of applications where it can be used.. On the other hand, one of the main arguments for natural stone is that it looks better and the surface is more compact.

There are no revolutionary new breakthroughs that are going to make concrete the twin of natural stones. Nevertheless, there are a number of things that we can do to control and regulate the production of concrete products so that the above mentioned requirements can be fulfilled. With today's knowledge of technology and performance possibilities, it is possible to create a near twin to natural stone out of concrete, if the quality assurance system of each concrete plant controls and optimises every step of the concrete block production and handling until the blocks are laid.

This presentation deals only with the 11 most important points. I have grouped them under the following headings:

A. Raw materials

1. sand and aggregates
2. cement and fly ash
3. pigment
4. additives

B. Production

5. water/cement ratio
6. mixing schedule
7. compaction
8. curing

C. Laying

9. bedding
10. joint filling sand
11. vibrator.

If we deal with each group in turn we arrive at the following picture.

A. Raw materials

Sand and aggregates

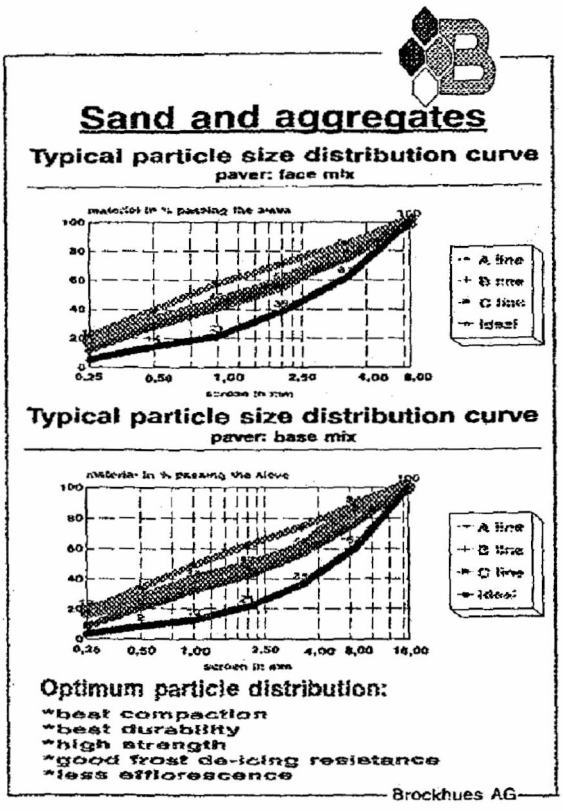
The distribution curves for sand and aggregates in concrete recipes for different concrete products are well known. Basic recommendations for face and base mixes of block paving stones have been available for decades.

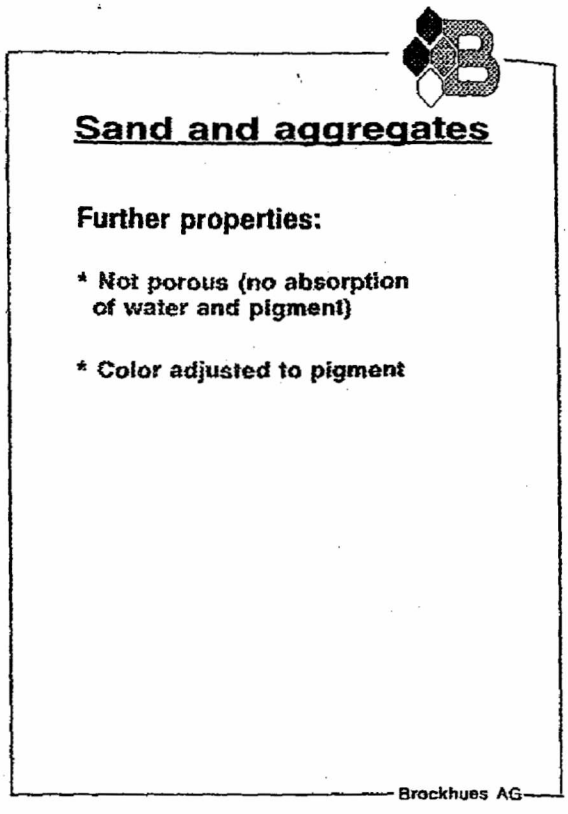
Is the distribution curve optimised and adapted to the available sand and aggregates in each individual plant?

It also depends on how much money you want to spend on sand and aggregates.

Of course there are some regions of the country where certain parts of the distribution curve requirements can not be fulfilled. Does it not make sense in those cases to buy such specific materials from far away in order to improve the quality significantly and thereby improving the sale of the product?

It is worth taking another look at the technical advantage to be gained by a certain investment. You'll be surprised how often it leads to an improvement in the quality of your concrete products.





The optimised distribution curve is the basis for a good concrete product resulting in the highest possible compaction. It therefore shows less efflorescence, maximum durability, highest strength and a good frost resistance.

Two further points should be considered:

The aggregates should not be porous because it is not possible to control the amount of water and pigment they absorb. This can cause significant changes in colour from batch to batch.

The colour of sand and aggregates should be chosen to match the desired colour and the colour of the pigment. When the cement lime surface of a black paver containing a light quartz aggregate weathers away, the quartz aggregate may reflect so much light that it cancels out the effect of the black pigment. This phenomenon may be so pronounced that the paver may no longer seem black. The most suitable aggregate for a black paver is of course basalt.

Cement and fly ash

The quantity of cement in concrete recipes such as block paving recipes for Portland cement PZ 45 F should never drop below 16% of the total weight of the aggregates in the recipe, even when today's' cost cutting policies may tempt you to use less.

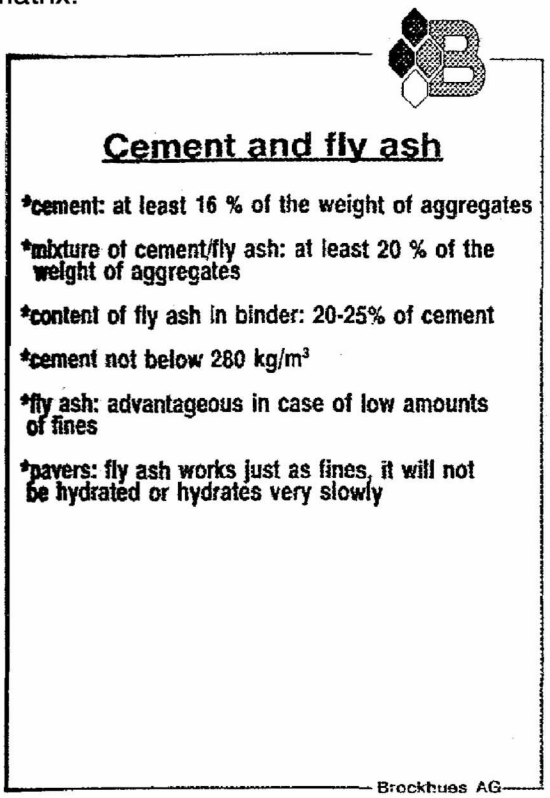
If a mixture of cement and fly ash is used the total binder content of such a mixture should be at least 20% of the total weight of the aggregates in the concrete mix. The content of fly ash in the binder should be between 20% and 25%.

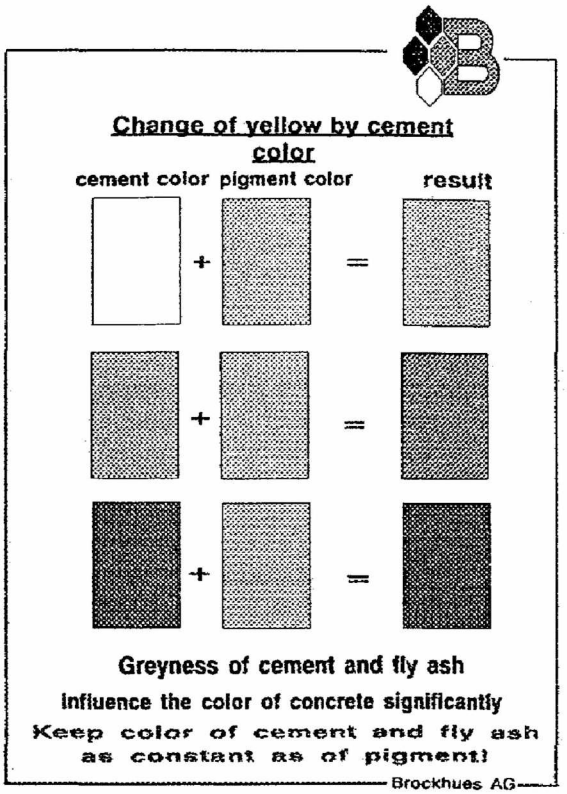
In other words the minimum cement requirement is 280 kg/m^3.

Fly ash has the great advantage of being a fine particle which improves the high density and strength if the fines content is too low. Therefore fly ash can improve quality and be cost-effective at the same time.

When using a semi-dry concrete mix for concrete blocks it is important to remember that fly ash will not hydrate or will hydrate very slowly in comparison to its reaction in a wet concrete mix. It therefore does not

contribute in any way to the cement lime matrix.





For the long-term image and the successful marketing of the concrete block it is definitely worth optimising in a cost-effective way - it may pay to spend money on an investment which is going to save money in the long run.

Regarding coloured concrete it is important to note that the blackness in grey cement naturally acts as a black pigment, which in turn has an important influence on the colour of the final product.

When yellow and orange pigments are used with grey cement the final product is often a nasty shade of green. This effect can only be compensated by using a lighter cement or by increasing the dosage of the pigment.

Red colours may often seem brown, which is not at all the desired effect.

In addition to controlling the colour at this stage of production, once the required shade has been reached, you have to make sure that the colour of the cement or the binder mix is kept as constant as the colour of the pigment itself.

Pigments

For colouring concrete, raw materials suitable for the rough reality of concrete are necessary. By rough reality we mean that these pigments have to be weather resistant, light-, especially UV-light resistant, alkali (cement) resistant and heat resistant for temperatures up to 120 °C.

Years of experience have shown that only certain metal oxides as iron oxide, chrome oxide, titanium dioxide or cobalt aluminium oxide as well as Carbofins for black colour shades are suitable for long term colouring of the cement lime. These compounds do not change under the above mentioned conditions.

Traditional carbon blacks or organic dyes often have been and are still being used in an attempt to cut costs. However, experience has taught us that these compounds are definitely not suitable. They fade so don't be surprised if your customers complain.

Pigments

Have to be:

*weather resistant
*light, UV-light resistant
*alkali, cement resistant
*heat resistant < 120 °c

Suitable are:

*metal oxides
-iron oxides
yellow, orange, red, black, brown
-chromium oxide
green
-cobaltaluminium oxide
blue

*Carbofins
black

Not suitable are:

*normal carbon blacks
*organic dyes

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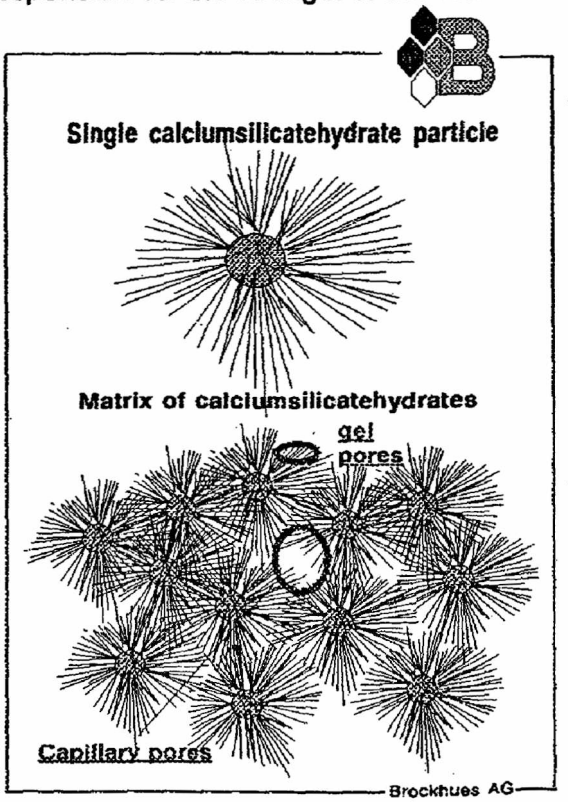
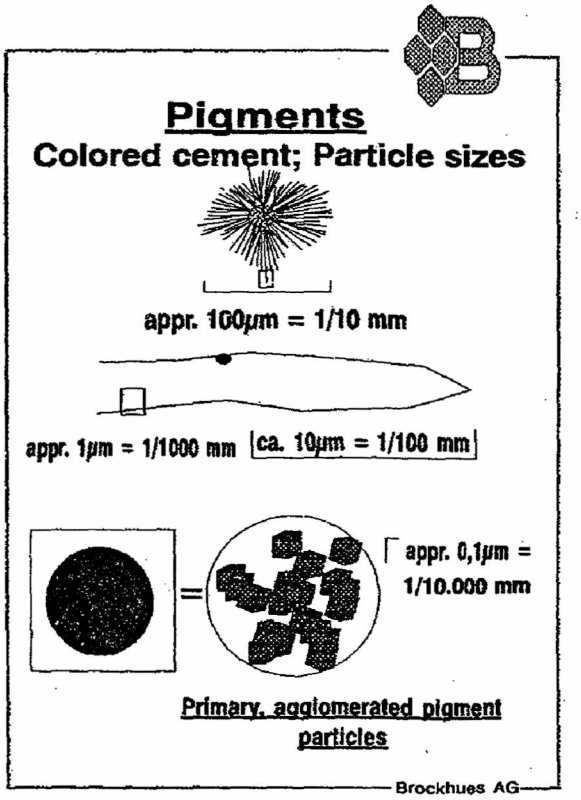
At this point some explanations concerning the quality of pigments and the way they work are necessary.

As you already know the amorphous cement clinker hydrates with water to form calcium silicate hydrate particles which in the end are responsible for the strength of the concrete.

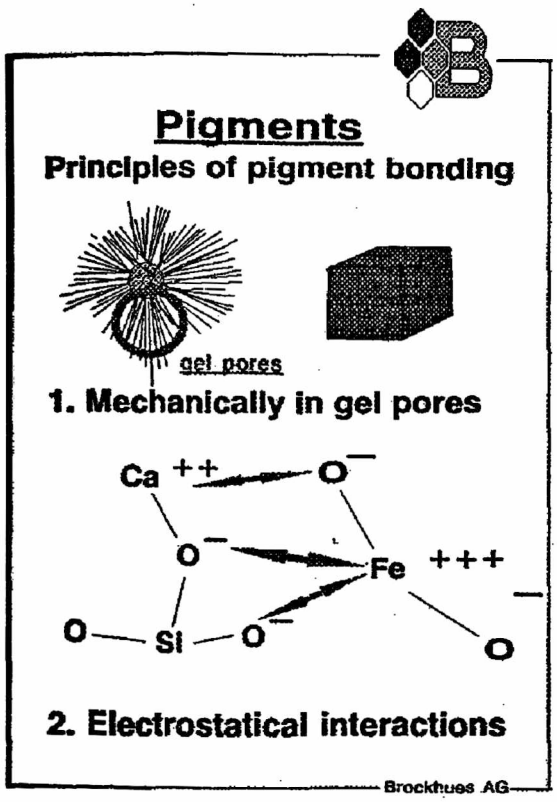


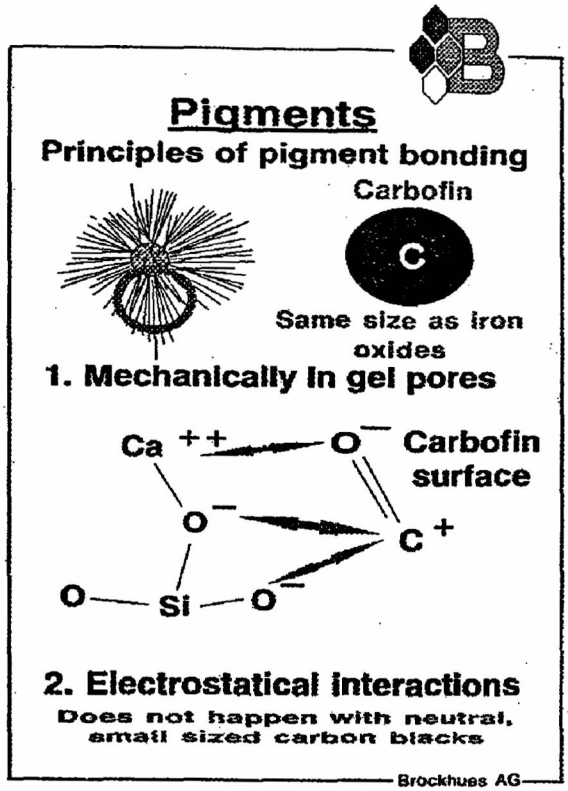
The single hydrates interlock to form a matrix. Two different types of pores appear in the structure of concrete: the gel pores as a space between the single hydrates and the obviously bigger capillary pores between the hydrate particles.

Pigments are active in the range of the gel pores. A single hydrate particle is about 1/10 mm. If we look at an area of approx. 1/100 mm (a single hydrate crystal needle) the crystal needles are covered by agglomerated pigment particles which are around 1/1000 mm = 1 µm. If you take a closer look at such an agglomerate you can find out that this consists of primary pigment particles which are approx. 1/10000 mm (or 0.1 µm or 100 nm) each.



The stable pigment agglomerates are fixed by means of the primary particles by mechanical bonding into the gel pores of the same size. In addition there is an electrostatic interaction between comparable ionic structures. Opposites attract.





We used the same principles when developing Carbofin, the special large particle carbon pigment manufactured by Brockhues. Normally the structure of carbon (chemical symbol C) is not polar. By partial oxidation the Carbofin surface is polarised like metal oxides. By controlling our production process we reach particle sizes comparable to metal oxide pigments. A stable pigment for the cost-effective black tinting was thus created. We can look back on 10 years of positive experience.

Sometimes people think that Carbofin is the same as traditional carbon black. Please do not make that mistake. Carbon blacks are not polar and are much smaller than Carbofin so that they leach out of the concrete surface very easily. Many producers have unpleasant memories of fading carbon blacks.

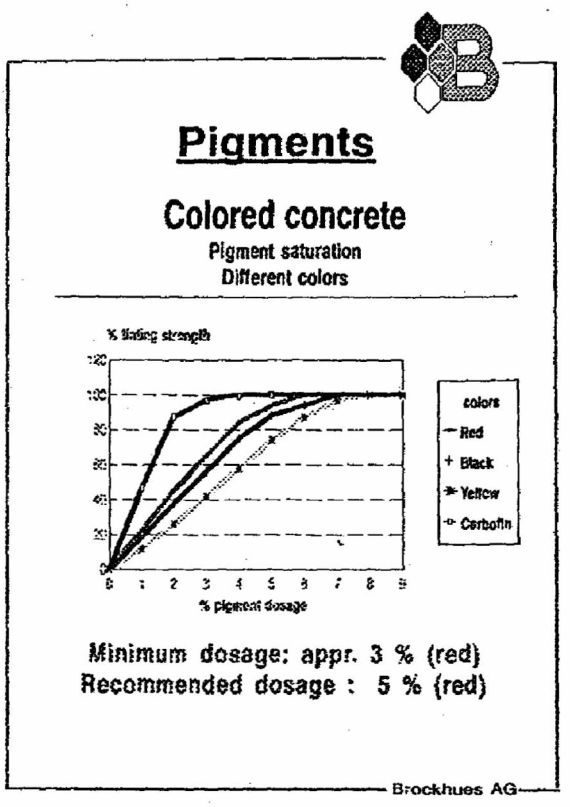
Pigment saturation

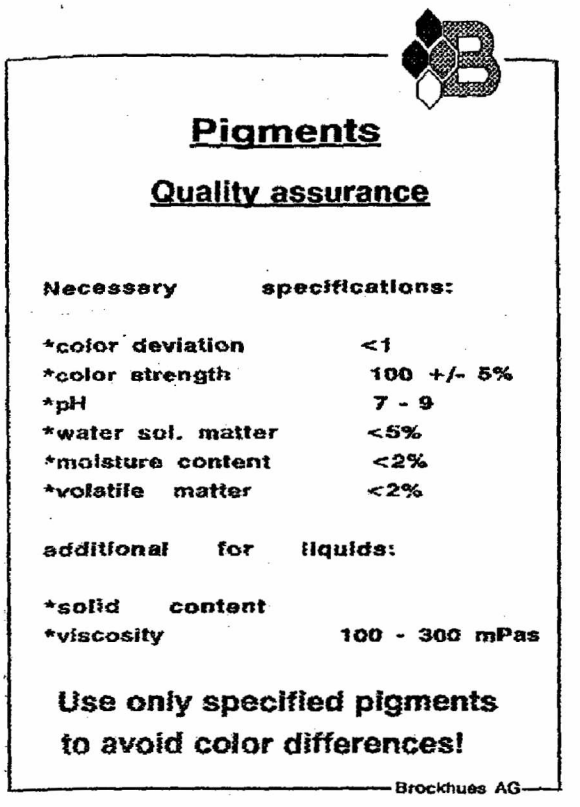
Another question is how to explain the saturation effect of the pigment addition .

As previously seen, the pigment particles cover the hydrate crystal surface. Due to the comparable sizes of both particles (red pigment and PZ 45 F) an almost complete layer is achieved when the pigmentation $\geq$ 5 % of the cement content. Further pigmentation does not result in a stronger colour. All that happens is that the thickness of the layer is increased. The cement particles do not affect the colour any more.

Now it is easy to understand why you have to use more pigments in grey cement than in white cement to obtain the same colour shade. The black component in grey cement influences the colour of the final product, whereas in white cement the colour of the final product is more or less the same as the pigment colour . If approx. 1% pigment is dosed in white cement , this results in a pastel shade .

These factors must be taken into account when working with saturation curves.





These curves vary depending on the cement and the pigment. The same cement used with different pigments results in different saturation curves and the same pigment used with different cements results in different saturation curves. Due to it's fineness PZ 55 for example not only needs more water but also more pigment.

Let us go back to ways of improving the quality of coloured concrete.

Since pigments are crucial to the appearance of coloured concrete, they have to have an assured quality. The colour deviation $\triangle E$ should be < 1. For different batches the tinting strength should be 100 ± 5 %. The pH should be above 7, between 7 and 9 to be cement resistant. Water soluble matter, moisture content and volatile matter for powder and granules should be less than the data shown in order to make sure that there are no fluctuations due to the pigment.

For liquid pigments the following parameters are also required: the solids content, so that we know how much water they contain, and the viscosity, to ensure the liquid's workability.

Even if these data are mentioned on the technical data sheet you should not take them at face value. Ask your supplier about his quality assurance system. Make sure that the supplier measures each parameter for each batch. This is very important when the colour deviation and the tinting strength are measured with a colour spectrophotometer. The standard specifications describe well defined measuring methods. Each batch is tested against the standard for that particular product using these methods. Every separate delivery must be accompanied by a test certificate containing the specification for that product along with the measurements made on that batch.

Pigments

Quality assurance

Test methods

*color deviation	- color spectrophotometer
*color strength	- color spectrophotometer
*pH	- pH - electrodes, indicator
*water sol. matter	- water solution:residue deter.
*moisture content	- drying chamber, infra-red
*volatile matter	- drying chamber,
*solid content	- drying chamber
*viscosity	- viscosity measurement (i.e.Brookfield)

Methods acc. DIN, ISO, BS, NF or ASTM have to be used!

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Only this procedure assures a continuously high quality standard.

Commercially available pigments are supplied in three different forms: as powder, as a liquid suspension and as granules. However, I am not going to talk about that today.

BASIC APPLICATION FORMS OF PIGMENTS

POWDERS



LIQUID SUSPENSIONS



GRANULES



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Let us return to the importance of quality. It makes sense to ask the producer how he assures the above mentioned consistence in quality. In the case of granules it is often easier to achieve the quality consistency in comparison to the other forms of pigment.This is due to the specific production process as the homogenisation in each production lot has been improved significantly.

In the end, even in the case of pigment,the concrete manufacturer must choose between cheap and cost-effective products. The calculation of costs at the end of the business year is perhaps more important than the momentary thrill of purchasing some cheap loads of pigment with a low kilo price.

Additives

The fourth important raw material in concrete is additives.

We can summarise the influence additives have,especially on coloured concrete, as follows:

*Plasticisers support a better pigment dispersion which leads to a faster homogenisation.

*Flowing agents show no effect in the semi-dry concrete used for concrete blocks.

*Air entraining agents might be useful in making the pavers more resistant to salt in winter, however they do not influence the actual appearance of coloured concrete.

*Concrete wetting agents improve the compaction of concrete including the surface structure and the colour impression. However, they might also create conditions favourable to efflorescence and therefore have the opposite effect.

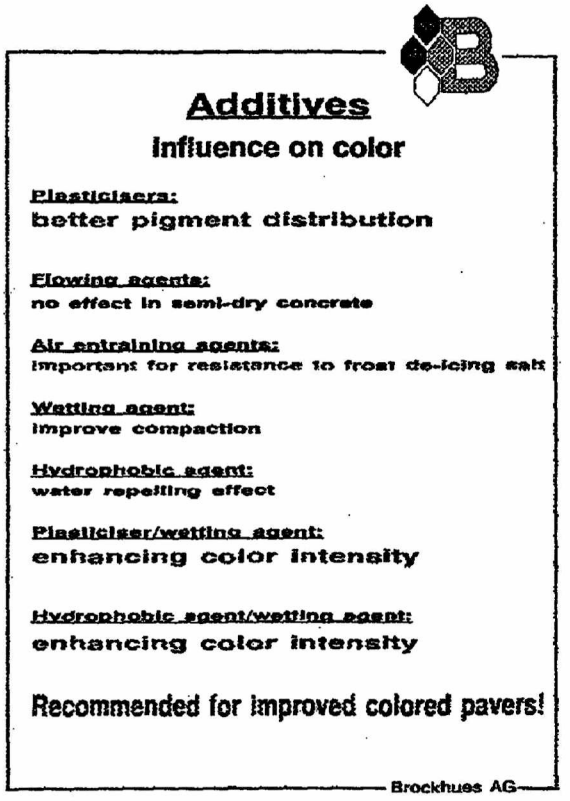
*Hydrophobic agents have a water repelling effect and are able to decrease efflorescence. This is naturally appreciated by the customers of the concrete block paving industry.

If you want to use additives to enhance the colour of the concrete (by improving the compaction and as a result suppressing

efflorescence), mixtures of plasticiser and wetting agent as well as recently developed mixtures of hydrophobic and wetting agents are the state of the art solution .

The plasticiser in a mixture of plasticiser and hydrophobic agent causes a higher compaction during the concrete production. The hydrophobic agent acts by covering the capillary pores with a water repelling layer which suppresses efflorescence.

The only way to find out how effective the different products are for you is to try them out in your production.



B. Production

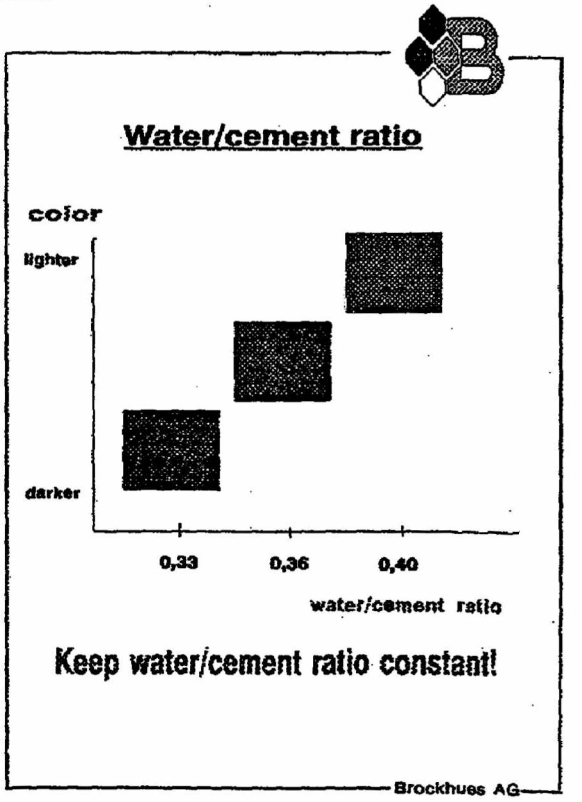
Like raw materials different production parameters have a decisive influence on the quality of coloured concrete:

Water/cement ratio

The water/cement ratio does not only have an important influence on the compaction and strength of a concrete block, it also affects the colour.

The lower the water/cement ratio, the darker the resulting colour shade, despite the fact the pigment is identical.

It is worth your while to take the time to try out different ratios until you have found the water/cement ratio that gives you the best strength in your fresh concrete and best colour brilliance. Once you have decided on the right ratio for your sand, aggregates and binder, we recommend that you invest in a state of the art water dosing system that guarantees according to today's technical know-how the best reproducibility of the w/c ratio.



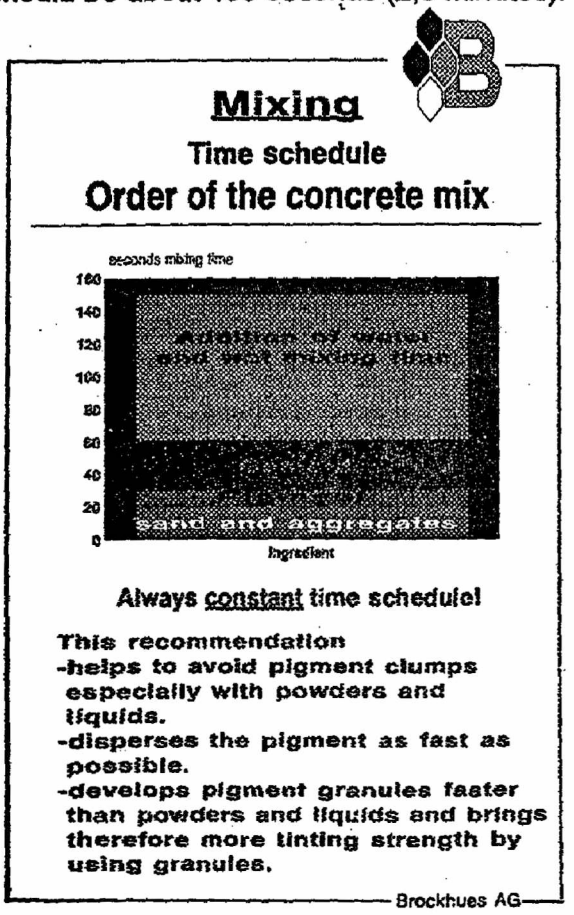
It is certainly to your advantage to involve the manufacturers of these systems in your plans and to test the equipment to see whether it does everything they say it does.

The water/cement ratio is the most important factor, after the particle size distribution curve, that you have to take into account if you want to improve coloured concrete. Even so people often work with water dosing systems that leave a lot to be desired. Some systems are not able to control even within a big margin the water content in the concrete mixer.

Mixing schedule

The second important production factor is the mixing itself. It is important that the mixing cycle be reproducible every time if you want to produce high-quality concrete.

Pigment must be added with, or after the sand and aggregates, in a time span of 30 seconds. Cement acts as a lubricant in the mix thereby reducing the abrasive action of the aggregates on the pigment. Therefore it has to be added afterwards. After a dry mixing time of approx. 60 seconds, water should be dosed. The overall mixing time should be about 150 seconds (2,5 minutes).



Also in the case of granules a higher tinting **strength** is achieved in comparison to the **same** pigment in powder or liquid form as **dispersion** is better.. This means that by **using** granulate you get better value for your **money**.

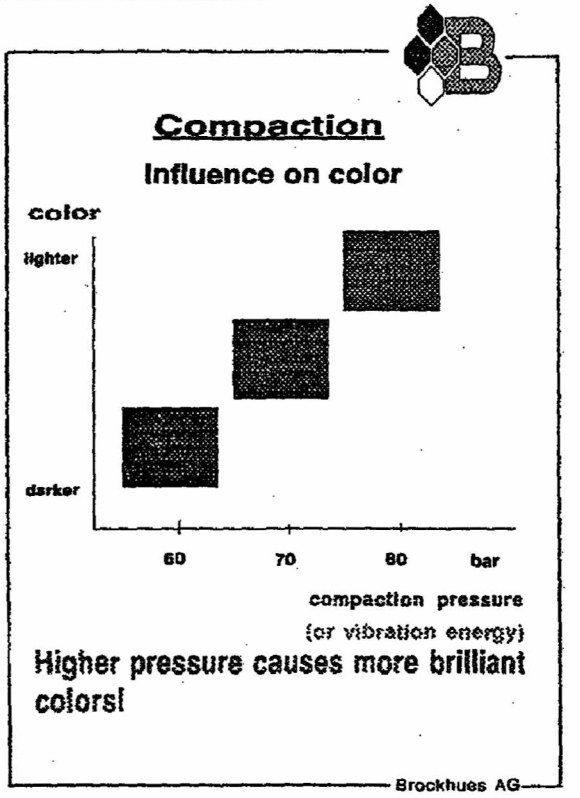
If you want to make good quality concrete **always** add the different components to the **mixer** in the same order and maintain a strict **time** schedule.

This is the only way to consistently achieve a good quality.

Compaction

The quality of the press has an important influence on the compaction and strength as well as on the colour, the colour shade and the tinting strength of the pigment.

The higher the compaction during production, the more brilliant the colour seems.
So the same pigment in a better compacted concrete looks much brighter.
As well as improving the quality of a concrete block by higher density and strength as well as a low water permeability, the brilliance of colour can be favourably influenced by the right choice of new production machines.



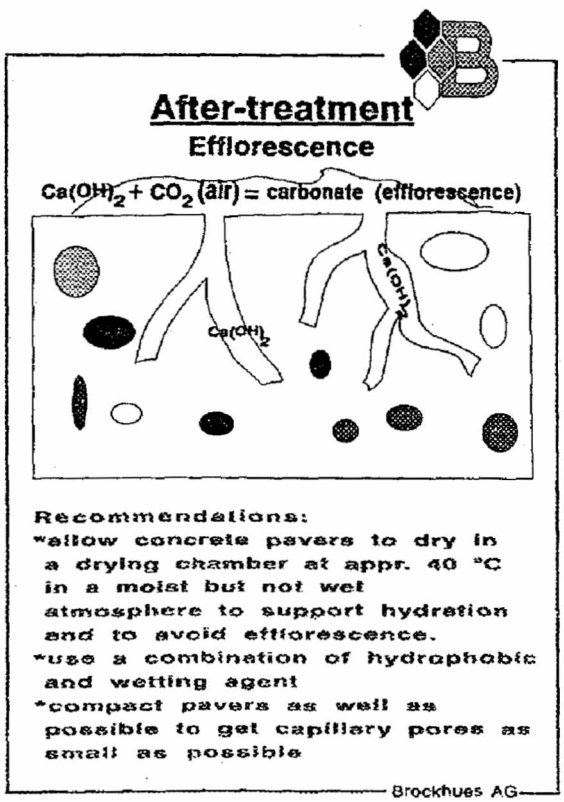
Even if you are not selecting new production machines, quality should be top priority with the machines you have. Consistent quality can only be achieved with your current machines when the machines' set-up is optimised and then kept constant by regular maintenance with a proper maintenance schedule.

Curing - After treatment

The fourth important production factor is the famous curing process.

All of you know all about efflorescence, the reaction of calcium hydroxide originating from concrete itself with carbon dioxide in the air to form white calcium carbonate, which looks particularly ugly on coloured concrete surfaces. The curing process may play an important role in deciding how much efflorescence appears.

Let's suppose that all the known facts have been optimised and the best concrete block imaginable - including an optimised compaction - comes out of production. However, all your efforts may be in vain if you do not choose the right conditions for curing or storage of the blocks - if, for example, efflorescence is caused by storing in an atmosphere which is too cold and too moist so that you get water of condensation.



The ideal environment is a air-circulated drying chamber at around 40°C and an air humidity nearby the thawing τ point. This way there is enough humidity to support cement hydration, but the surface of the concrete is not wet enough to encourage efflorescence. Smaller capillary pores will be the result and therefore less efflorescence will occur later on.

In most cases the calculation of investment costs required for a drying chamber is going to be the decisive bottle-neck here as far as improving the concrete block quality.

Efflorescence is a result of the chemical and physical properties of concrete. As mentioned above a lot can be done against efflorescence by optimising the concrete production parameters. However, it is certainly not worth while waiting for a miracle agent.

C. Laying

Last but not least I would like to say something about the laying of concrete paving blocks or the processing of concrete products in general:

It is not just the choice of raw materials and production conditions that decides whether your concrete blocks have a good image. Everything that happens after the delivery of a perfectly manufactured product is just as important for the quality.

If the customer or the person laying the pavers does not handle the quality product properly, he destroys the concrete image and with it, the successful sale.

Therefore it might even be necessary for the concrete producer to advise the customer or even tell him what to do. Unfortunately you are all too familiar with paving on an inadequately prepared support that look terrible after a few years. There's nothing like it for frightening off potential customers .

Supports therefore have to prepared to suit the type of ground and the standards.

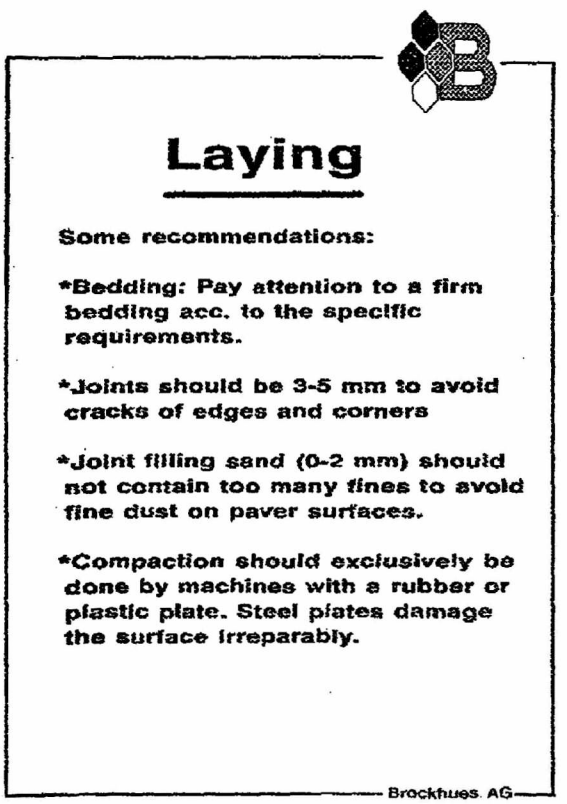
Surprisingly nowadays, there are still enough cases where the joints are too narrow and the wrong joint filling sand was used. The consequences are cracked edges and corners or concrete surfaces that were smeared with clay just after they had been laid.

The third problem that is connected with laying the pavers and which ruins the image

of concrete in the eyes of the general public is that the people laying the pavers sometimes tap the pavers with the sharp point of the hammer or vibrate the pavers with the steel plate directly instead of placing a rubber plate in between to protect the surface of the pavers.

There is no point in producing high-quality pavers with smooth, compact, uniformly coloured surfaces if they are going to end up all chipped and broken before the building site has even been completed.

This is why it is so important to include the people laying the blocks in your quality assurance programme.



Let us have another look at the summary of improvements.

sand and aggregates - optimise distribution curve

cement, fly ash - keep colour constant, use enough cement

pigment - use quality assured pigments according to din 53237

additives - use hydrophobic/wetting agent combinations

water/cement ratio - keep water/cement ratio constant

mixing sequence - mix in a certain order, always use the same mixing times

compaction - as high as possible, optimise the press

curing - drying chamber, moist but not wet atmosphere

bedding - careful preparation acc. to standard

filling sand - joints 3-5 mm, no fines

compaction - use rubber or plastic plate

Even if you only fractionally improve some or all of these parameters, you will see a marked improvement in the quality of your products, because many small mistakes may have a much more disastrous effect on your concrete than you think.

And any improvement in quality is a step in the right direction as far as ensuring a prosperous and happy future for all concrete manufacturers and their customers.

For further information, please contact:

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