Architectural concrete and colour – an ideal combination

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Coloured concrete materials, such as concrete roofing tiles, paving blocks and paving slabs nowadays make an important contribution to making our environment more attractive, and they are widely accepted by the general public.

With these materials, builders are able to combine technical functionality with an aesthetically pleasing appearance.

Nevertheless, concrete frequently has a rather negative image even though the outstanding technical properties of this all-purpose material are acknowledged by even the layman. Terms like "concrete jungle" and "as grey as concrete" are often used to describe an environment in which man does not feel particularly contented. The architectural design and, in particular, the colour of a building tend to be the decisive factors in whether a project is viewed as successful or whether it is seen more as a dismal and monotonous structure.

This publication describes how pigments can be used to make concrete attractive.

How do we make coloured concrete?

There are many ways of giving concrete a coloured appearance.

The most simple method, of course, is to paint the concrete surface, but the problem is that a coat of paint only has limited durability, and renewing it would in many cases be a particularly arduous task. Setting up the scaffolding and applying a new coat of paint not only involves considerable cost, it is also in many cases technically impossible.

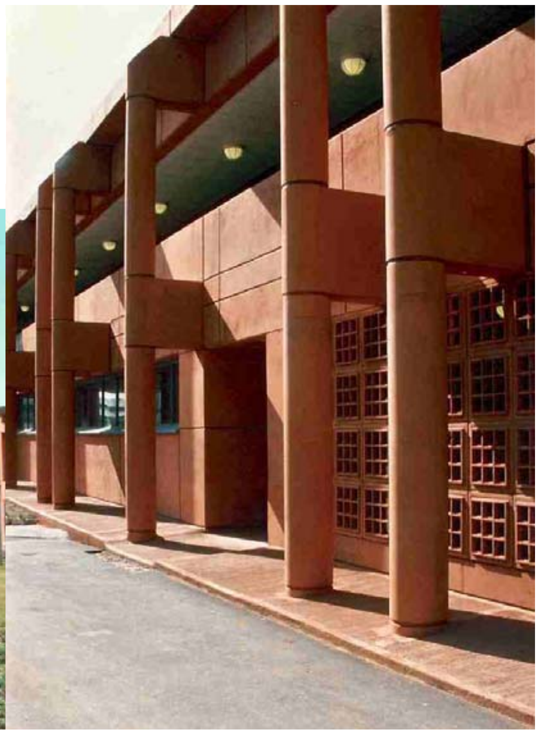
Another method is to give the concrete a more lively appearance by using different aggregate materials. The possibilities for producing a colourful design with this method are nevertheless very limited.

In most cases, the method of choice is to integrally colour the concrete, and a wide range of suitable pigments is nowadays available for this purpose. They enable almost any shade to be achieved, and have virtually unlimited durability.

The production of coloured concrete mixes does not basically differ from that of a grey concrete. We shall now look at what points need to be considered to produce attractive concrete surfaces through the addition of pigments.

South Africa: Administration building of an aluminium works (Alusafi Hillside Smelter), site-mixed concrete, pigmented with Bayferrox® 960

Pigment concentration: 4 %
Built: 1993 – 1995
Architect: (Engineering, Procurement and Management) Alprom
Building company: Murray and Roberts



Norway: Olympic arena, Lillehammer (Lysgaard skijump); Site-mixed concrete, pigmented with Bayferrox® 318

Pigment concentration: 1.5 %
Built: 1992
Architect: ÖKAW Arkitekter AS, Oslo
Building company: Martin M. Bakken Entrepreneurforretning A/S, Elverum

The raw materials

a) The pigment

Due to the formation of calcium hydroxide, cement that is freshly made up with water is highly alkaline. One of the main demands made on the pigment is therefore that it is absolutely resistant to alkalis, in other words, the colouring effect of the pigment must not be impaired by the lime content of the cement.

Furthermore, the pigment must be neither destroyed nor washed out through the effects of the weather - especially sunlight and the constant changeovers between heavy rain, heat and frost.

Many years of observation of coloured concrete products exposed to different climates in various parts of the world have shown that inorganic oxide pigments can satisfy the requirements expected of pigments for colouring concrete.

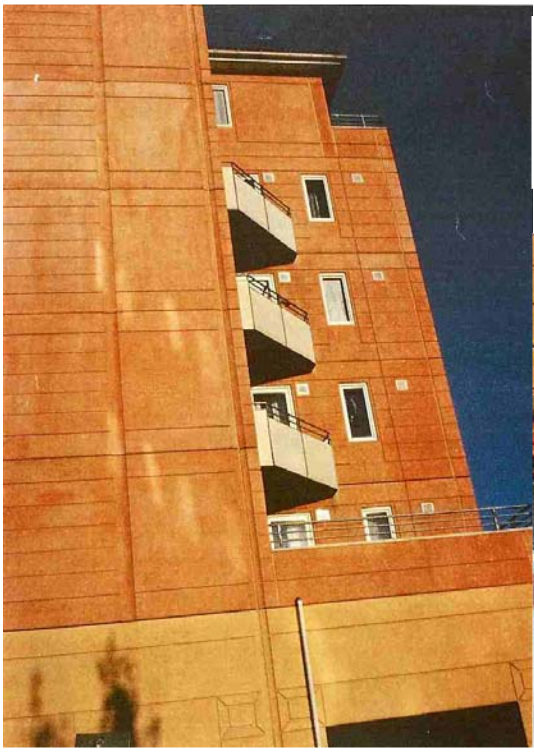
The builder has a choice of various colours. Iron oxide pigments (e.g. the Bayferrox® grades) are available in red, yellow, black and brown. Greens can be obtained by using chrome oxide green pigment. White colours can be created with titanium dioxide pigments, and blues with lightfast pigments if the concrete is made with a light-coloured cement.

b) The cement

It is well-known that the various types of cement can also differ in their inherent colour. Whereas, generally speaking, fluctuations in the colour seldom occur within the production from one cement factory, there can be considerable differences in the shade of the cement from different manufacturers.

In practice, it is therefore normal - particularly with larger building projects - to purchase all the cement from the same supplier. This is strongly recommended when producing a coloured concrete, because it should largely eliminate any fluctuations in colour due to differences in the colour of the cement.

As mentioned before, white cement is naturally also particularly recommended for coloured concrete, because it is also possible to produce pastel shades.



Norway: Residential and office building Grønland Tork, Oslo Site-mixed concrete, pigmented with Bayferrox® 110 and Bayferrox® 960

Pigment concentration: 4 %
Built: 1991
Architect: Anker & Hoklaas, Architektkontoret A/S, Oslo
Building company: Selmer A.S., Oslo

Sweden: Bridge: Kvick Bron, Helsingborg
Site-mixed concrete, pigmented with Bayferrox® 130

Pigment concentration: 6 %
Built: 1995 – 1996
Architect: Nilsson & Rahmquist, Helsingborg
Building company: Ballast Syd, Helsingborg

c) The aggregates

The colour of the sand and pebbles also affects the colour of the final concrete.

If the exposed concrete surfaces are to be subsequently treated by sandblasting, bush hammering etc., the colour of the pebbles should not differ too much from the coloured concrete. The question regarding the choice of aggregate materials can be resolved by carrying out a few preliminary tests, which do not take up much time and are not particularly costly. On the basis of these trials, the manufacturer can see exactly which combination of sand, pebbles, cement and pigment produces the best colour.

d) The water

Accurate control of the water supply in a concrete mixing unit is, of course, an integral part of efficient concrete production. For this reason, particular importance is attached anyway to ensuring that the volume of water added to the individual batches of concrete is precisely regulated.

However, apart from the technological properties, the colour of the concrete is also dependent on the selected water-to-cement ratio. Excess water evaporates from the concrete and leaves behind cavities in the form of fine pores. These scatter the incident light and thus make the concrete lighter. In other words, the higher the water-to-cement ratio, the lighter the concrete looks, regardless of whether it is a grey concrete or one which has been coloured by the addition of pigments.

Production of the concrete mix

In practice, it has proved best to add the pigment dry to the aggregates in the mixer, and to premix it for around 30 seconds. Only then should the cement be added. After further premixing for about 30 seconds, the water can be added and the mixing process completed.

This method of adding the pigment during the mixing process is more the ideal than the norm, because it is sometimes simply not possible in practice where on-site concrete is concerned. However, one practical possibility for colouring on-site concrete is to add the pigment directly to the readymix trucks. This procedure is, of course, only advisable if the mixing action of the truck mixer is adequate and homogenous distribution of the pigment can be guaranteed. The question should be clarified by carrying out suitable practical trials before beginning the concreting work.

Germany: Administration Building of Zueblin AG, Stuttgart, Precast Elements, pigmented with Bayferrox® 110

Built: 1984
Architect: Prof. G. Boehm, Cologne
Building company: Zueblin AG, Stuttgart

Application of the concrete

For working with coloured, ready-mixed concrete, the same principles basically apply as for producing exposed grey concrete surfaces. Care should nevertheless be taken with the choice of release agent. If too much release agent is applied, it will get on to the fresh concrete and stain the surface.

The above points, which need to be observed to obtain perfect results, should also be taken to heart for the production of non-coloured exposed concrete surfaces. Experience has shown that only a short time is needed for workers to become so familiar with the technique of colouring concrete that they can produce perfect results every time. The manufacturer will in any case be rewarded for the extra care by the success he achieves in complying with the wishes of the architects and building clients as regards the colour of the concrete.

From what has been said so far, the impression may be gained that the process described for colouring concrete is something new. This is certainly not the case. The possibility of using colour pigments for colouring architectural concrete has existed for some time now. Examples of buildings in Germany which demonstrate the perfect symbiosis of architecture and colour are the Züblin House in Stuttgart and the Landratsamt in Waldshut, which have lost none of their charm more than twenty years after their completion.

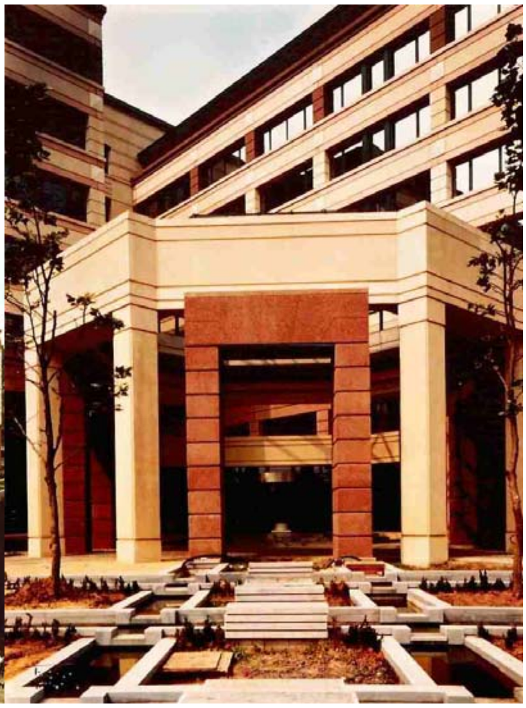
Chile: Hotel and Information Centre for the European Southern Observatory at Cerro Paranal
Site-mixed concrete, pigmented with Bayferrox® 600 N

Pigment concentration: 2,3 %
Built: 2001
Architect: Auer + Weber, Munich

In most cases, it is this combination of design and colour which gives a building its unique flair. Nevertheless, it has to be admitted that colour on its own will seldom be able to make up for a lack of attractive architecture. However, if the element of colour can be used as a supporting element to an attractively designed building, the result will most certainly be well worth looking at, as is illustrated by the following examples:

Belgium: Bureaux Tractebel, Woluwe St. Lambert
Combination of natural stone and prefabricated concrete, pigmented with Bayferrox® 660

Pigment concentration: 1 %
Built: 1989
Architect: Jaspers, Hasselt
Building company: Decomo, Belgium



An anniversary - 25 years of outdoor weathering of pigmented building materials

Nowadays, it is common practice to pigment building materials such as rendering, mortar, concrete pavers, concrete roof tiles and prefabricated concrete products. There was a rapid increase in the manufacture of pigmented building materials in the 1960s, a trend which has continued world-wide until today. Seminal work on the safe manufacture of pigmented building materials has been conducted at the Uerdingen production site. Various pigments are available, primarily inorganic color pigments such as iron oxides and chrome oxides. One of the key criterions in selecting suitable pigments for building materials is weather stability. The significance of this parameter and the need for outdoor weathering tests were recognized at a very early stage.

Which building materials are tested?

In the late 1950s, the department for application technique was manually producing samples - usually rendering and mortar - for weathering on racks at its Uerdingen production site. As the technical department expanded in the 1960s, the weathering station in Krefeld was developed. Here too, work initially involved only rendering, mortar and in-situ concrete. This work laid the foundations for systematic weathering tests with manufacturing facilities for products such as concrete roof tiles, paving slabs, concrete masonry blocks, calcium silicate brick and concrete pavers.

A compacting machine from Rino has been available since around 1968 for the manufacture of paving slabs. Machinery from Schade for manufacturing concrete roof tiles was added in 1970 (Photo 1). This can be used to produce small, non-corrugated products.

The first weathering tests at the weathering station near the Uerdingen production site (Photo 2) were carried out using paving slabs, rendering and mortar.

Once the capacity to produce roof tiles was available, testing was improved significantly as these small components are easier to handle. Other building materials such as concrete masonry blocks and calcium silicate brick were also produced for various trials. A press from Henke was acquired for this purpose in 1971.

Photo 2: Krefeld weathering station

Concrete pavers are an important product group in which iron oxide pigments are used. A concrete paver machine, also from Henke, was purchased in the early 1980s (Photo 3) so that realistic testing of weather stability could be carried out. Up until then, concrete pavers were produced on the compacting machine, i.e. in a way not usual in the industry.

Photo 1: Concrete roof tile machine (extrusion press), Schade (1970)

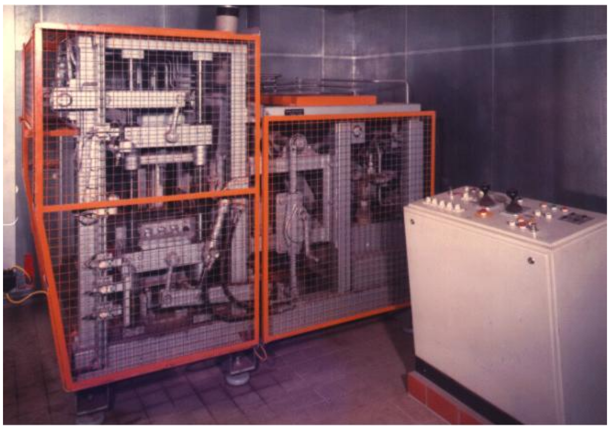


Photo 3: Concrete paver machine (Board machine), Henke (1982)

The acquisition of this machinery meant that the test facility was fully equipped within a short space of time to produce all types of modern building materials under standard industry conditions.

What began with just a few test samples has grown into a large test series with more than 9,000 different samples of building materials at the weathering station in Krefeld alone. Smaller weathering stations have also been developed in Germany and abroad so that the differences between various climatic zones can be recorded.

New samples are constantly being sent to the weathering stations since new angles of investigation are always being developed, new products are being launched on the market, research products require testing and customer samples are tested within the framework of our customer service.

There are a number of preconditions for successfully testing the weather stability of pigmented building materials. The first of these is that the test samples are produced under standard industry conditions. The test site must be well equipped, i.e. it should have a weather station, suitable racks, a store of reference samples, etc. Nowadays, suitable colorimetric instruments should also be part of the basic equipment.

Photo 4: Mineral rendering, Weathering commenced: 1970, Photo taken: 1995

Pigment content:
1 = 3 % Bayferrox® 110; 2 = 3 % Chrome Oxide Green GN; 3 = 3 % Bayferrox 660; 4 = 3 % Bayferrox 960; 5 = 3 % Le 70; 6 = 3 % LG 200; 7 = 3 % Bayferrox 180; 8 = 3 % Lightfast Blue 100; 9 = 3 % Bayferrox 140; 10 = 3 % Bayferrox 920; 11 = 3 % Ue 5015 (trial product); 12 = 3 % Tronox® A

It should also be ensured that the sample data, measured values, weather data, etc. are carefully documented. Today, this is of course made much easier by the use of computer systems.

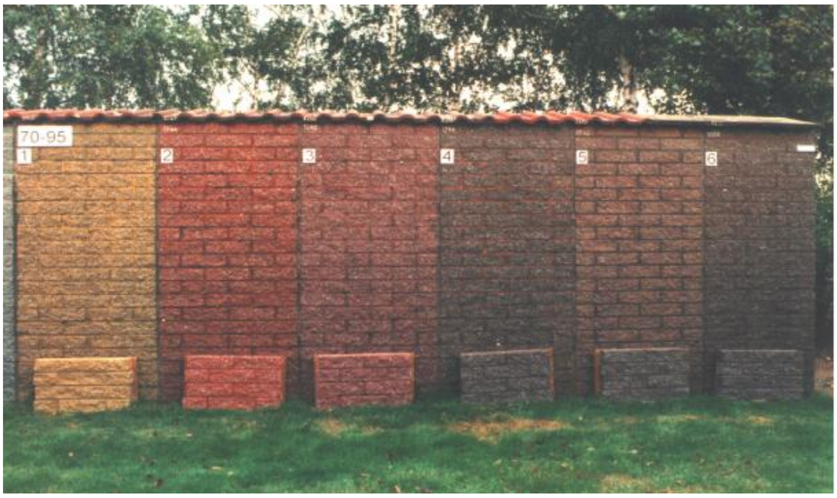


Photo 5: Concrete masonry blocks (unweathered reference samples in foreground), Weathering commenced: 1970, Photo taken: 1995

Pigment content:
1 = 5 % Bayferrox 920; 2 = 5 % Bayferrox 120; 3 = 5 % Bayferrox 160; 4 = 5 % Bayferrox 686; 5 = 2,7% Bayferrox 110 I Carbon Black 2 (70 : 30); 6 = 5 % Bayferrox 663

Photo 6: Calcium silicate bricks (unweathered reference samples in foreground) Weathering commenced: 1970, Photo taken: 1995

Pigment content:
1 = Chrome Oxide Green GN; 2 = 1 % Bayferrox 920; 3 = 1 % Bayferrox 960; 4 = 1 % Bayferrox 110; 5 = 2 % Bayferrox 660/6

What results have been yielded by these long and detailed tests?

The first thing to note is that pigmented building materials in many variations have been weathered at the Krefeld station for more than a quarter of a century. Results are available for a number of specific investigations, for example, the influence of the raw materials, the water/cement ratio or the manufacturing conditions. The long-term weather stability of inorganic color pigments such as iron oxides, titanium dioxides and chrome oxides has been demonstrated in building materials manufactured under standard industry conditions. This can be shown very impressively by the oldest test sample. Photo 4 shows a wall covered with mineral rendering containing various inorganic color pigments which has been weathered for 30 years. The following photos show the relationship between weather stability and the pigments used in other building materials. Photo 5 shows concrete masonry blocks and Photo 6 calcium silicate brick, both containing inorganic color pigments and both weathered for around 25 years.

These test samples and many others allow conclusions to be drawn about the stability of the entire system and not just of the pigments used. It has been found in many cases that various pigments, for example, carbon blacks or certain organic pigments do not have adequate weather stability. Photos 7 and 8 show concrete masonry blocks and calcium silicate brick colored with various black pigments after outdoor weathering for around 25 years. Photo 9 shows concrete pavers after outdoor weathering for two years in Den Helder, The Netherlands. The carbon black pigment used has already faded in this relatively short period of time. The most important conclusion to be drawn from this, apart from the familiar fact that certain pigments are not stable enough, is that this fading process is irreversible and not merely a temporary phenomenon.

Photos 10 and 11 show various blue and green pigments used in concrete masonry blocks and calcium silicate brick and tested for their long-term stability. Here too, it can be seen that there are considerable differences in the weather stability of the various pigments. Chrome oxide green or cobalt oxide spinel blue provide durable color in the pigmented building materials. It should be pointed out again that the fading of organic pigments is an irreversible process, i.e. not merely a temporary phenomenon. Numerous authors [1, 2] have discussed this subject in great detail.

Long-term testing has also yielded valuable information about efflorescence on various building materials. Photo 12, for example, shows the process of efflorescence on concrete roof tiles. Testing has shown that this phenomenon is virtually impossible to prevent. However, if concrete roof tiles are sprayed with an unpigmented plastic disper-

Photo 7: Concrete masonry blocks (unweathered reference samples in foreground) Weathering commenced: 1970, Photo taken: 1995

Pigment content:
1 = 5 % Bayferrox 318; 2 = 3.5 % Bayferrox 320; 3 = 2.8 % Carbon Black 1; 4 = 1.2 % Carbon Black 2; 5 = 1.7 % Carbon Black 3

Photo 8: Calcium silicate bricks (unweathered reference samples in foreground) Weathering commenced: 1970, Photo taken: 1995

Pigment content:
1 = 3 % Bayferrox 303 T; 2 = 1.1 % Carbon Black 1; 3 = 0.5 % Carbon Black 2; 4 = 0.9 % Carbon Black 3; 5 = 0.5 % Carbon Black 4

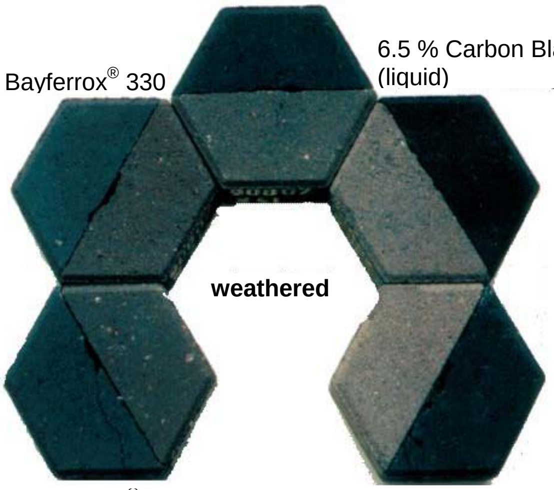


Photo 9: Weather stability of black pigments, Concrete pavers, Weathering commenced: 1990, Photo taken: 1993

Pigment content:
bottom left: 6.5 % Bayferrox® 350 liquid
top left: 4 % Bayferrox® 330
middle: 6.5 % Bayferrox® 350 liquid/Carbon Black 5 (1 : 1)
top right: 6.5 % Carbon Black 5
bottom right: 3.6 % Carbon Black 5

sion, efflorescence does not occur, as shown by the samples in Photo 13. On the basis of this fact and the recognition that virtually no efflorescence occurs at a later stage, these tests have provided useful pointers on how to reduce the tendency for efflorescence to occur on building materials. This information has been detailed in various publications [3].

With the introduction of colorimetric assessment in the mid-1970s, it became possible to record a wide range of data in addition to purely visual assessment and photographic documentation. This allowed conclusions to be drawn about the exact process of weathering in various building materials over the course of a number of decades. Photo 14 shows the individual phases of weathering in concrete roof tiles of varying composition.

As already mentioned, we have only had the capability to produce concrete pavers on a board machine under standard industry conditions for the last 15 years. Nevertheless, we have already made valuable discoveries about the stability of the

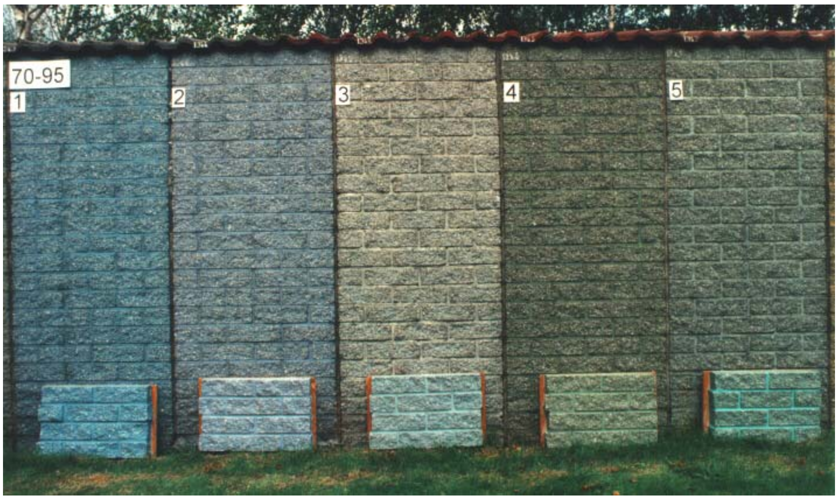


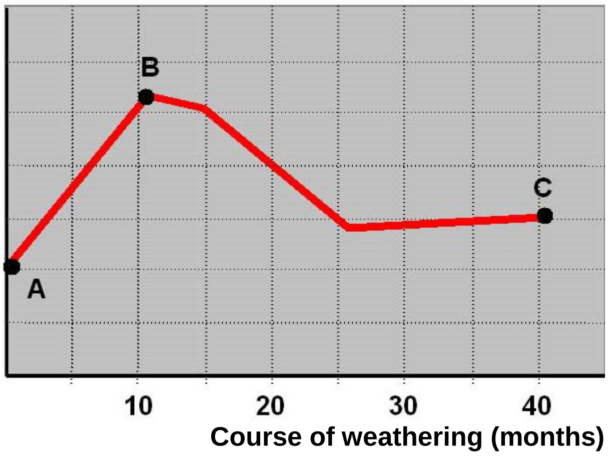
Photo 10: Concrete masonry blocks (unweathered reference samples in foreground) Weathering commenced: 1970, Photo taken: 1995

Pigment content:
1 = 3 % Lightfast Blue 100; 2 = 3 % Lightfast Blue 2 R; 3 = 0.2 % organic Blue pigment; 4 = 3 % Chrome Oxide Green GN; 5 = 0.5 % Organic Green pigment

Photo 11: Calcium silicate bricks (unweathered reference samples in foreground Weathering commenced: 1970, Photo taken: 1995)

Pigment content:
1 = 0,075 % Organic Blue pigment, 2 = 1 % Lightfast Blue 100, 3 = 0,15 % Organic Green pigment, 4 = 1 % Chrome Oxide green GN

Lightness



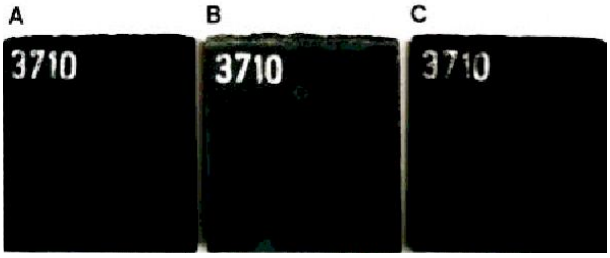


Photo 12: Efflorescence disappears during the course of weathering (Concrete roof tiles)

Pigment content:
5 % Bayferrox® 318

pigments used and the stability of colored concrete systems of varying composition. Photo 15 shows a selection of the oldest test samples.

A key property of a building material is its resistance to erosion. Colorimetric is of no help in assessing this. Although there are a number of highly complex tests, useful conclusions can only be provided by visual assessment, still an important feature of any testing.

The question arises here as to whether accelerated weathering tests could replace the time-consuming process of outdoor weathering tests. Work conducted to date in this respect shows that this method is of no use in the testing of building materials, despite its value in testing plastics and coatings [1].

It is as true now as it ever was that only outdoor weathering tests yield reliable conclusions as to the weather stability of pigments in building materials.

After more than a quarter of a century of systematic testing of the stability of pigmented building materials, many valuable conclusions have been drawn in response to a wide variety of questions. The main objective of these efforts has been to provide the manufacturers of building materials with accurate advice as to the suitability of color pigments for their products. Also revealed by the many years of testing is just how well through-colored building materials perform. This is not only of interest to the manufacturers of such products but also to users and specifiers such as builders and architects.

Summary

The weather stability of pigments used to color building materials can only be demonstrated by means of outdoor weathering tests.

Systematic testing of building materials has been carried out at the Krefeld weathering station for 25 years. Concrete roof tiles, masonry blocks and pavers, calcium silicate brick and rendering manufactured under standard and near-standard industry conditions have been weathered long enough to establish the weather stability of the Bayferrox®, Tronox®, Chrome Oxide Green and Lightfast pigments used.

The continuation of the tests will ensure that it is possible to answer further questions relating to the weather stability of pigmented building materials in future.

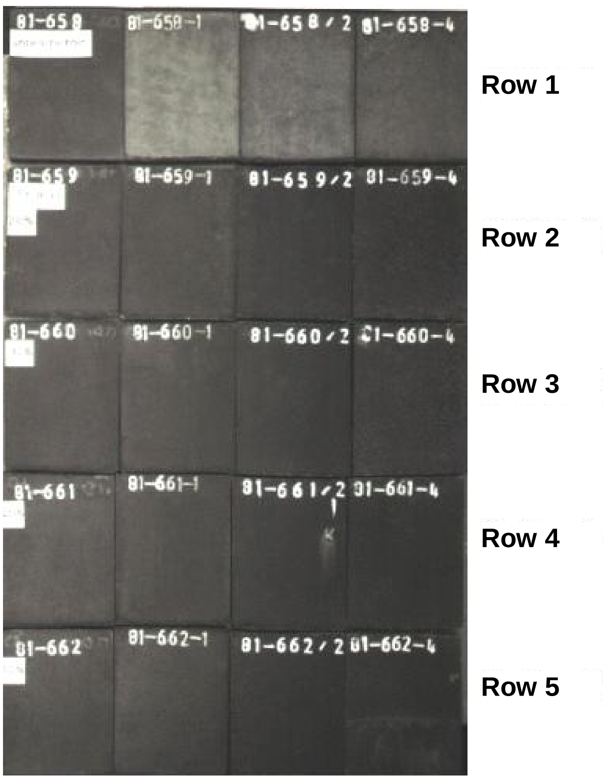
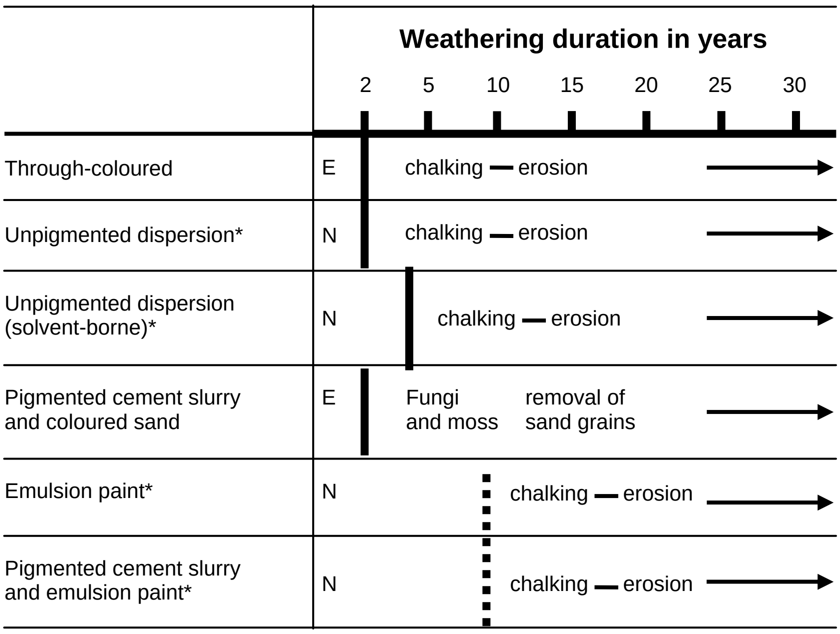


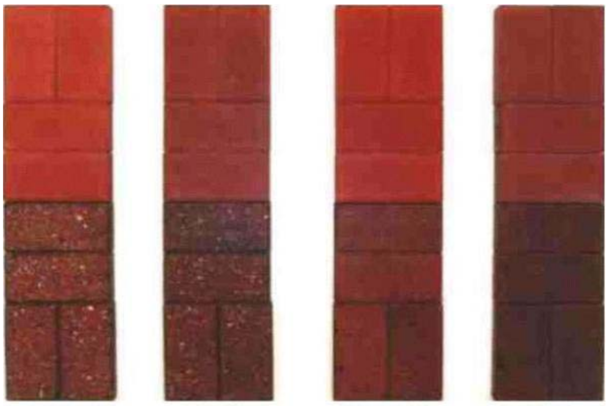
Photo 13: Tests of the prevention of efflorescence

Row 1	uncoated concrete roof tiles
Row 2 - 5	sprayed with a plastic dispersion (approx. 20 - 40 % solids content)



* The durability is dependent on the film thickness and the binder used.
E Efflorescence
NE No efflorescence

Photo 14: The individual phases of weathering in concrete roof tiles of varying composition



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Trough-colored concrete Pavers **Concrete pavers with facing layer**

Photo 15: Concrete pavers produced using different cements, colored with 5 % Bayferrox® 130

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