THE COLOURING OF CONCRETE

PROCESSING INSTRUCTIONS

Planners, architects and builders nowadays have a variety of modern building materials at their disposal which not only satisfy the primary technical requirements, but also have aesthetic appeal. The use of coloured building materials like concrete roofing blocks, pavers etc. is an important element in designing the world we live in. Coloured concrete products have, in fact, been on the market for several decades, and their method of production differs only slightly from that of uncoloured products.

This brochure summarises the results of laboratory trials we carried out on the colouring of concrete, and also takes into account the experiences of the building industry. The aim is to provide the user of colour pigments with a guide for the manufacture of high-quality products.

The raw materials in the manufacture of coloured concrete products

1 The Pigment

The choice of pigment is of major importance for the quality of the end-product. Years of tests on coloured concrete products exposed to different climate conditions all over the world have shown that inorganic oxide pigments have particularly good fastness properties.

Bayer's Bayferrox® and Chrome Oxide Green pigments satisfy these conditions and thus offer

"Quality for life".

Modern production facilities and a proven quality system have been setting standards for the processing of inorganic pigments in concrete.

Which shades can be produced?

The oxide pigments commonly used in building materials cover all the most popular colours. The shades are oriented to the opaque colours as they occur in nature, and thus fit harmoniously in with the environment:

Red :	yellowish bluish red
Yellow:	greenish to reddish yellow
Brown:	light to dark brown / red brown
Black:	dark grey to charcoal

In addition, white, green and blue can be produced. Pure colours like yellow can be made by using white cement.

Brilliant, glossy shades, like those obtained in plastics and surface coatings, are very difficult to produce in building materials because of the composition and structure of the concrete.

Demands made on pigments for colouring concrete

Pigments must withstand the aggressive influence of the strongly alkaline cement paste. They must also be lightfast and weather-stable, as well as insoluble in the mixing water during processing they must become firmly integrated in the concrete matrix. Inorganic pigments, and especially oxide pigments, are particularly suitable for this.

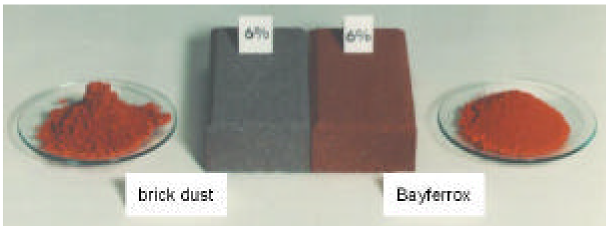
The most important oxide pigments

Colour	Name	Bayer pigment
Black	Iron oxide black	Bayferrox Black
Red	Iron oxide red	Bayferrox Red
Yellow	Iron oxide yellow	Bayferrox Yellow
Brown	Iron oxide brown	Bayferrox Brown
Green	Chrome oxide green	Chrome Oxide Green

The tinting strength of pigments

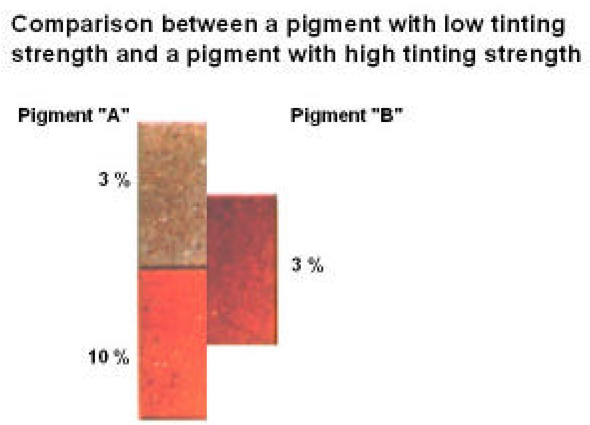
The tinting strength of pigments is an important quality characteristic which is essential in evaluating their cost-effectiveness. The tinting strength is defined as the ability of a pigment to impart its natural colour to the medium being coloured. Let me give an example to explain this.

The picture on the right shows two red powders: brick dust on the left and a Bayferrox red pigment on the right. Only when they are used to colour concrete or are tested in the lab does the difference in tinting strength of the two samples become evident.



The laboratory test is carried out by mixing a defined amount of pigment with a defined amount of barium sulphate according to EN 12 878. This is the basis for the tinting strength tolerances given in the product specification for Bayferrox pigments.

Let us come back to a practical situation in the concrete factory. An iron oxide red pigment "A" is currently being used. To attain a given colour shade, a pigment concentration of 10 % of this pigment is required.



However, as the concrete pavers show, it is equally possible to obtain the desired shade by adding 3 % of red pigment "B".

The conclusion is that even if pigment "A" is cheaper, it is certainly not always the most economical.

How are pigments supplied?

The demands made on the processability of pigments have changed over the years. Whereas it was nearly always powder pigments that were used in the building industry in the initial years, aqueous pigment slurries have now also been making their mark.

Apart from the fact that the processor does not have any dust problems, there is also the advantage of simple handling and metering. On the other hand, they contain a relatively high proportion of water, which means higher transport costs than for powder pigments. In addition, the pigment may settle at the bottom if the pigment suspensions have not been stirred for a long time. For these reasons, it is really only worthwhile purchasing ready-to-use pigment suspensions if the supplier is in the local vicinity.

The latest development as regards the supply form of pigments is as free-flowing dry pigment preparations. These have been developed specifically for use in the building industry and allow easy emptying of silos, sacks and bulk bags, and make both silo storage and metering a perfectly clean affair because of their low-dust formation.

More information on supply forms and packaging is available on request.

Pigments and the environment

The production of Bayferrox and Chrome Oxide Green pigments at Bayer AG involves the use of modern processes which ensure that the impact on the environment and resources is kept to a minimum.

These pigments have neither a toxic nor an irritant effect on the skin or mucous membranes. Nevertheless, the development of dust should be avoided for basic occupational health reasons.

Although Bayferrox and Chrome Oxide Green pigments do not harm aquatic organisms because of their insolubility, they do lead to heavy discoloration of the water. Spilled pigments should therefore be mopped up wet or dry.

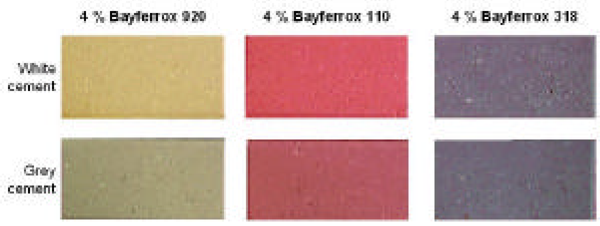
2 The influence of the cement colour on the colour of the concrete

Grey not only makes the washing look grubby, it takes the brilliance out of absolutely any colour, wherever it is used. This is why concrete manufactured with normal Portland œment is never going to produce such bright colours as one made with white cement.

However, the gain in colour clarity obtained by using white cement depends on which pigment is used. If the pigment is black, there is virtually no difference between concrete made of white and grey cement. With dark brown and red, the difference is slight, and with yellow and blue, it is very pronounced. The brighter and cleaner the desired shade, the greater the dependency on white cement.

This difference in the colouring of white and grey cement is easily understandable even for the layman. People in the trade will, however, also be aware of the fact that grey cement can vary appreciably in colour from light to dark grey. When changing over the grade of œment or cement supplier, it often happens that there are differences in the natural colour of the cement which can have an appreciable influence on the final colour.

Influence of the aggregate colour on the final colour shade

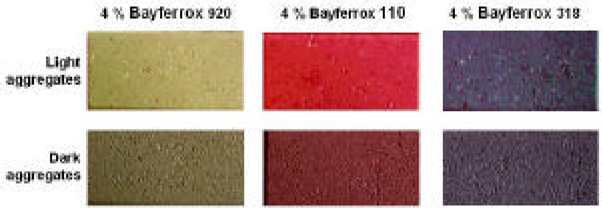


3 The aggregates

In the production of coloured concrete, the aggregate particles are covered by the pigmented cement paste. It is possible that the grains of an intensively coloured aggregate do not become completely covered, resulting in the colour of the final concrete being affected by the natural colour of the aggregate. While this effect can be apparent even during the production of the coloured concrete, it becomes particularly evident when the end-product is exposed to the weather, as the aggregate particles become visible through weathering of the surface. What we then see is a mixed shade made up of the colour of the cement paste and the exposed aggregate.

Like cement, the natural colour of the sand also has a more marked effect on light-coloured concrete (e.g. yellow, green) than on dark concrete (e.g. brown, black).

Influence of the cement colour on the final colour shade



Influence of the formulation on the colour of the concrete

1 Influence of the pigment concentration on colour

Knowing the optimum pigment concentration helps to save money because we then know we are not adding more pigment than is absolutely needed.

If increasing amounts of pigment are added to a concrete mix, the colour intensity initially rises linearly with the pigment concentration.

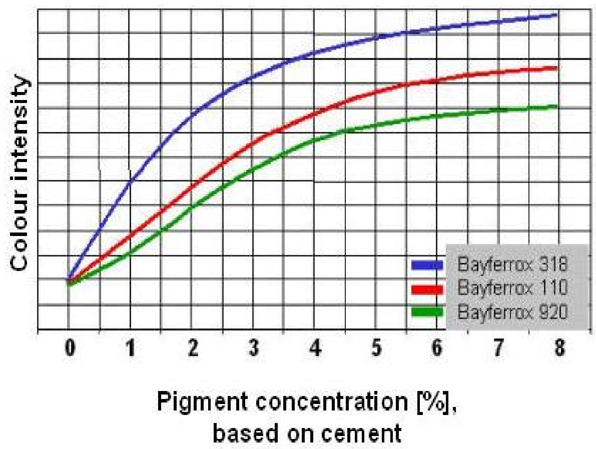
However, as more and more pigment is added, we move into a range in which the addition of further pigment does not significantly deepen the shade and is therefore uneconomical. Establishing the saturation range is dependent among other things on the system parameters of the concrete but, in general, additions above 5 % (calculated on the binder) are not necessary for the high-strength Bayferrox pigments.

With the weaker pigments, the saturation range is not reached until much larger amounts of pigment are added. The amount of pigment required to produce a given shade can sometimes be so large that this increase in the quantity of fines has a negative effect on the technical properties of the concrete.

2 Water-cement ratio and the colour of concrete

Have you ever wondered when looking at a glass of beer why the froth is white even though the beer itself is yellow?

The foam consists of many tiny air bubbles, which scatter the light in the same way that white pigments do. This digression is important because it explains the relationship between the colour of the concrete and its water-cement ratio. The excess mixing water evaporates from the concrete and leaves behind cavities in the form of fine pores. These act like the bubbles in the beer froth. They scatter the incident light and thus make the concrete lighter. Thus the higher the water-cement ratio, the lighter the concrete appears. As the photo on the right shows, grey concrete without any pigment is just as much subject to this law as pigmented concrete.

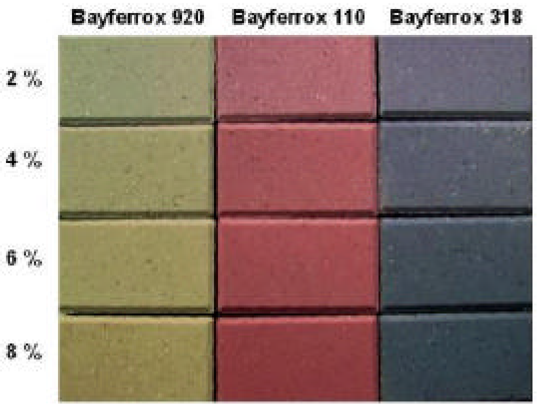


What does this mean in practical application?

If we compare the colour of different concrete with varying water content (e.g. concrete pavers and in-situ concrete), we find that, even if the pigment concentration is the same, the colour differs.

If we make comparisons within a single product line, we get a different picture. To ensure unproblematical processing of the concrete mixture through a concrete manufacturing unit, its consistency normally has to be kept within narrow limits, which means that the manufacturer must meter the mixing water very carefully. For this reason, colour fluctua-

Influence of the pigmentation level on the final colour shade



Influence of the water-cement (w/c) ratio on the colour of the concrete

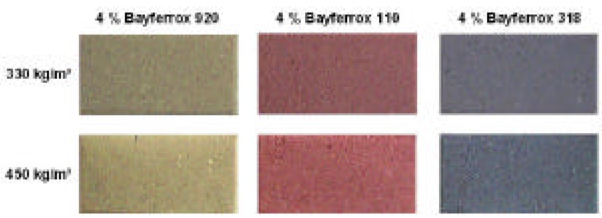
tions within a production line due to the water-cement ratio tend to be the exception rather than the rule. On the other hand, the differences in shade can be appreciable if the excessive moisture in the concrete results in the formation of a surface sludge on the concrete. This sludge – also called 'orange-peel' in paving block manufacture – contains the very fine components of the concrete such as cement, fines and an above-average accumulation of pigment, so that the concrete takes on a different appearance than if there were little or no sludge on the surface.

3 The colour of the concrete in relation to the cement content

In the colouring of concrete, it is not the aggregate that is pigmented, but the cement paste, which then forms a layer on the individual aggregate particles.

For our considerations as to whether the cement content exerts an influence on the colour of the pigmented concrete, we will, for the sake of simplicity, assume that we are talking about a mixture of two substances: coloured cement paste and aggregate. The more we "dilute" the coloured cement paste with the aggregate, the less intensive the colour of the concrete. This theoretical consideration is confirmed by practical experience. A concrete with a high cement content will, at equal pigment concentration (which is usually a percentage based on the weight of cement) have a much stronger colour than a concrete with a lower cement content.

Influence of the cement content on the colour of the concrete



Influence of the cement content on the colour of the concrete

1 Metering and dispersion of the pigments in the concrete

Today, quality plays an increasingly important role.

Because accurate metering and homogeneous dispersion of the pigments are essential factors in the manufacture of high-quality coloured concrete products, the building industry has devoted considerable effort to establishing the optimum parameters.

Dispersion of the pigments

Recommended sequence for adding to the concrete mixer:
Aggregates + premixed pigment + cement + water

Mixing time with forced circulation mixer: 1.5 - 2 min

Mixing time:

Sand + pigment	approx. 15 - 20 s
Sand + pigment + cement	approx. 15 - 20 s
Sand + pigment + cement + water	approx. 1 - 1.5 min

Every type of mixer has a minimum mixing time. With shorter mixing times, homogeneity is not longer possible, even if the mixing times of the individual ingredients or the order in which these are added are changed.

The required mixing times are highly dependent on the performance of the concrete mixer. The data given here on mixing time are only a rough guide.

As regards the dispersion of the pigments, it has been found that it is very critical to know when the pigment should be added to the mixer. Experience has shown that the ideal sequence is to mix the pigment with the aggregate for about 15 seconds before the cement is added.

From then on, the mixing process is the same as with unpigmented concrete. Something which must be avoided at all costs is the adding of all the components simultaneously, or that cement is mixed in immediately after the sand. The mixing time naturally also plays an important role in whether or not a homogeneous dispersion of the pigment is achieved.

Every mixer needs a minimum mixing time. With forced circulation mixers, this is 1.5 – 2 min. If the time is reduced, it will not be possible to produce a homogenous mix even by altering the individual mixing time or the adding sequence for the individual components.

Once the amount of pigment used in a concrete factory reaches a certain level, the question automatically poses itself as to whether the addition of the pigment can be automated. As is often the case with technical solutions, there are advantages and disadvantages. There is no all-embracing answer to the question of whether wet or dry metering is the most favourable. All we can do is provide suggestions to help plant engineers decide one way or the other, while taking commercial aspects into account. The table on the right endeavours to show, in simplified form, the advantages (+), disadvantages (–) and comparability (=) of the various metering methods.

Alongside the obvious advantages of automatic pigment metering, the concrete producer also has the possibility of producing additional shades himself. Bayferrox pigments are manufactured in the basic colours red, black and yellow. Various shades are also available within each of these colour ranges.

By combining two or three Bayferrox pigments, it is possible to produce an almost un-

Pros and cons for the various metering methods

1 = powder; 2 = micro granules;
3 = on site slurry: 4 = pre-manufactured slurry

	Dry metering		Liquid metering	
	1	2	3	4
Accuracy	=	++	=	=
Space requirements	-	++	+	+
Cleanliness	+	++	+	++
Aggregates (wet sand)	++	++	--	(+)
Cost				
Investment	--	+	--	(+)
Operating cost	(+)	(+)	+	--
Colour change	=	=	=	=

Combination of Bayferrox pigments

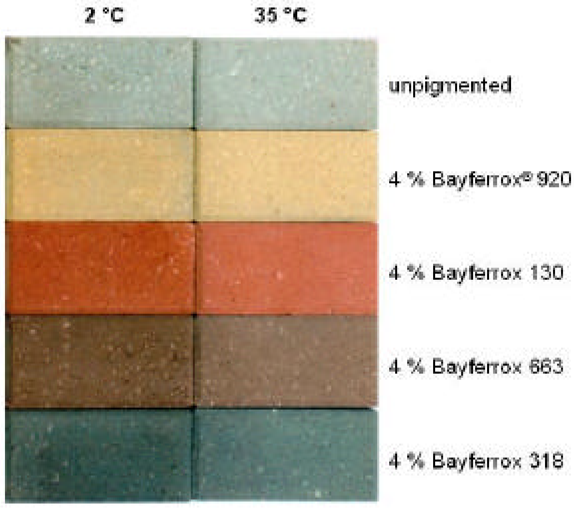
limited number of shades. Here, for example, a Bayferrox red pigment has been combined with a Bayferrox black to produce a brown shade.

Present-day concrete mixing technology allows several individual pigments to be added simultaneously to the concrete mixer. There is no need to premix the pigments.

2 Influence of the hardening conditions on the shade of the concrete

The hardened cement paste, which is formed from the reaction between the mixing water and the cement, produces crystals of varying size, depending on the temperature at which the concrete is hardened. The size of these crystals is, in turn, responsible for how the light which falls onto the concrete is scattered. The following principle basically applies: higher hardening temperatures result in finer crystal needles, and the more pronounced light scattering of fine crystal needles makes the colour of the concrete lighter than that of the same concrete hardened at lower temperatures. However, this phenomenon generally only becomes recognisable when the difference in temperature reaches a certain order of magnitude, for example, when steam-hardened concrete is compared with concrete hardened at normal room temperature.

Influence of the hardening temperature



The weathering behaviour of pigmented concrete

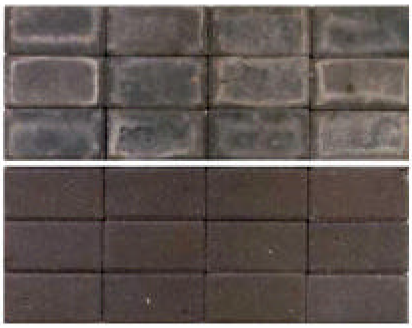
The Roman aqueduct, which supplied Cologne with water from the Eifel hills two thousand years ago, was built with trass or poszolanic cement. Had this antique "concrete" been pigmented with natural iron oxides – which at that time were already known – the structure (parts of which can still be viewed) would still have been coloured today. The difference from the original shade would have been quite small. These colour changes, which manifest themselves just as much on uncoloured as on coloured concrete, have various causes and may be both of a temporary (e.g. efflorescence) or a permanent (e.g. surface exposure of the aggregate) nature.

1 Efflorescence

Efflorescence is the curse of all concrete manufacturers, especially when colour is involved and when particularly high demands are made on the appearance of the concrete. To begin with, it is important to note that neither Bayferrox nor Chrome Oxide Green pigments exert any influence on the occurrence of efflorescence. Nevertheless, it is obvious that deposits of white lime are more noticeable on a coloured concrete than on natural grey or even white concrete.

Efflorescence is the result of free lime, which is dissolved in the mixing water (primary efflorescence) or in rain or dew (secondary efflorescence), depositing on the surface of the concrete, where it reacts with carbon dioxide

Weathering of efflorescence

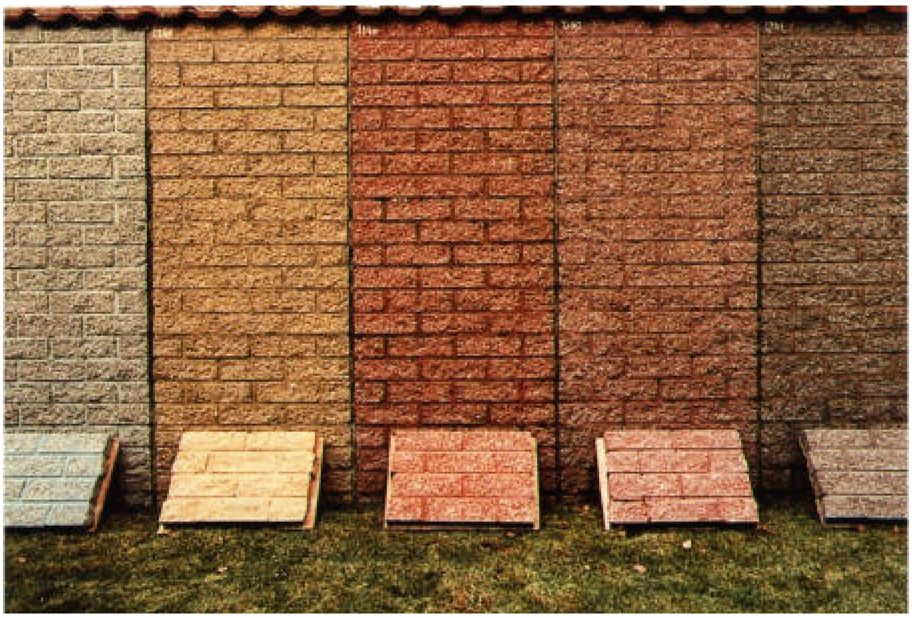


in the air to form insoluble calcium carbonate. The porosity of the concrete plays an important role here. The more compact it is, the lower the tendency to efflorescence. In a slow reaction, the calcium carbonate on the surface of the concrete is able to react with carbon dioxide dissolved in water to form calcium bicarbonate, which, in turn, is soluble in water. In this way, the efflorescence is washed off again by the weather. Acid constituents in the atmosphere naturally also have a dissolving effect on lime deposits on the concrete surface.

A special report on the subject of "Efflorescence on concrete" has been published by Bayer AG and is available to customers on request.

2 Weathering of the hardened cement paste

On the surface of the concrete there is a sludge layer consisting of the aggregate fines and the cement. Its thickness depends on the formulation, method of compaction etc. This layer is gradually weathered away and, after a few years, the aggregate particles in the surface become exposed resulting in their contributing more to the overall colour of the system.



The next photo shows that the colour changes in pigmented building materials are relatively small. Compared with the unweathered specimen in the foreground, concrete bricks exposed for 25 years to the weather on the weathering stand show very little change apart from a slight soiling of the surface.

3 Weather stability of the pigments

Provided weather-stable pigments such as Bayferrox and Chrome Oxide Green pigments – in other words, oxide pigments – are used for colouring building materials, the colour is permanent. This statement is based on the experience gathered during a quarter of a century of systematic trials on the stability of pigmented building materials. In these studies, which deal with a variety of stability problems, it was also found that only our outdoor weathering tests are really able to provide reliable information on the weather stability of pigments in building materials.

Technical properties of the coloured concrete

1 Strength of the concrete and solidification behaviour of the cement

In EN 12 878, which also serves as the basis for a future European standard, the demands made on pigments for the colouring of cement and lime-based building materials are defined. Besides dealing with questions regarding the testing of pigments etc., the standard also lays down thresholds for the extent to which pigments may exert an influence on the solidification behaviour of the cement and the strength of the concrete. In corresponding tests at an independent testing institute which have been carried out at regular intervals for some time now, it was found that the Bayferrox pigments comply with the limits laid down in the standard.

2 Consistency of the concrete

Pigments have very fine particles. Exact details on the mean particle size, which can vary considerably depending on the type, can be found in the Bayferrox colour card. As a rough guide, it can be said that pigments are approximately 10 - 20 times finer than cement. With this in mind, a pigment processor may well ask whether the addition of such a fine product does not have an influence on the water requirement of the concrete.

As far as the Bayferrox pigments are concerned, the amounts of Bayferrox red and black that are normally added in practice have virtually no effect in this regard.

However, iron oxide yellow pigments differ from black and red iron oxides in that they have a needle-shaped structure and can therefore adsorb more water on the surface. Nevertheless, this effect only becomes noticeable at pigment concentrations above approx. 4- 5 %. Where pigments with high tinting strength are concerned, such as the Bayferrox yellows, this value is generally not exceeded, which means that the higher water adsorption of the yellow pigments is only of limited interest to concrete manufacturer.

Slump (water/cement ratio 0.56)

FORSCHUNGSINSTITUT DER ZEMENTINDUSTRIE, DÜSSELDORF

Grundprüfung für Pigmente
nach DIN EN 12878

Tagebuch-Nr.
474/11

Pigment:	Schwarzpigment		
Bezeichnung durch Hersteller - Einlieferer:	Bayferrox 318		
Eingeliefert von:	Bayer AG, Werk Uerdingen	Eingang am:	15.11.2001

Leim/Mörtel (CEM I 42,5 R)		**Ohne Pigment**	**mit Pigment*)**	**Differenz**
Erstarren	Beginn	170 min	175 min	+ 5 min
	Ende	200 min	200 min	- 0 min
	Wasseranspruch	28.0 M.-%	29.0 M.-%	-
Raumbeständigkeit	(Le Chatelier)	0.5 mm	1.0 mm	-
Druckfestigkeit 28 Tage (in MPa)	Einzelwerte	54.4 55.8 55.3 53.7 56.1 56.3	55.4 55.2 55.4 54.6 54.4 55.4	-
	Mittelwert	55.3	55.1	- 0.4 %

Mikroskopischer und chemischer Befund			**Hauptbestandteile**
Wasserlösliche Anteile	0.30	M.-%	Magnetit (Fe_3O_4)
Chloridgehalt	0.02	M.-%	
Nitratgehalt	<0.01	M.-%	
Sulfatgehalt als SO_4^{2-}	0.06	M.-%	Die Überprüfung erfolgte durch Röntgenbeugungsanalyse

Anmerkungen

Die Anforderungen an Einzelpigmente bei der Grundprüfung nach DIN EN 12878 wurden erfüllt.

Die Hauptbestandteile des Pigments entsprachen nach Art den Angaben des Pigmentherstellers.

*) Die Pigmentzugabe bei Erstarrungs- und Druckfestigkeitsprüfung betrug 5 % bezogen auf die Zementmenge.

Düsseldorf, den 01.02.2002

Sachbearbeiter Fischer

Forschungsinstitut der Zementindustrie Düsseldorf VDZ

Forschungsinstitut der Zementindustrie
Abteilung Qualitätssicherung