

QUALITY COLORS.



Coloring of Concrete Processing Instructions

X BAYFERROX®
Color for Life.

X COLORTHERM®
Color for Life.

QUALITY WORKS.

LANXESS
Energizing Chemistry

COLORING CONCRETE

PROCESSING INSTRUCTIONS

Concrete is a modern material that offers urban planners, architects and builders a variety of creative options for the design of urban environments and infrastructure. Using inorganic pigments to color materials such as concrete pavers and roofing tiles also produces solutions with esthetic appeal that integrate harmoniously into the surroundings. The method of production differs only slightly from that of corresponding uncolored products. In order to obtain the best possible result, however, there are a number of important details that need to be considered when using pigments.

This brochure summarizes the results of laboratory trials with colored concrete carried out by LANXESS. It also takes account of building industry experience. The aim is to help users of inorganic pigments in concrete to manufacture high-quality end-products.



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COMPONENTS REQUIRED FOR MANUFACTURE

The pigment

The choice of pigment is of major importance for the quality of the end product. Years of observing colored concrete products exposed to different location- and climate-specific conditions have shown that inorganic oxide pigments exhibit particularly high durability due to their color stability and resistance properties. LANXESS markets these oxide pigments worldwide under the names **Bayferrox®** and **Colortherm®**.

Bayferrox® pigments – sustainability and the environment

The introduction of quality hallmarks for sustainable products in many sectors clearly demonstrates the broad consensus in our society as regards the need to handle the resources available to us responsibly. Sustainability is a key issue and customers not only appreciate sustainable behavior, but have come to expect it.

Sustainable and responsible environmental and social behavior is an integral part of LANXESS's corporate strategy. Products and production processes are designed to conserve resources and preserve the environment – and to be safe and sustainable. They are also subject to continuous improvement.

Our **Bayferrox®** iron oxide and **Colortherm®** chromium oxide green pigments are neither toxic nor do they irritate the skin or mucous membranes. From an environmental and health protection perspective, they are ideal for coloring building materials, although the generation of dust should be avoided for occupational health reasons.

Although the insolubility of **Bayferrox®** and **Colortherm®** pigments means they are not harmful to aquatic organisms, they do result in significant discoloration of water. Any pigments that are spilled should therefore always be cleaned up, either by wet or dry method.

Prerequisites of pigments used for the coloring of concrete

Oxide pigments are perfect for coloring building materials. Due to their chemical composition and structure, they are insoluble in water and dilute acids, resistant to lime and alkalis, and completely weather- and light-stable.

Which shades can be produced?

The oxide pigments suitable for coloring building materials cover all the most popular colors. These shades are similar to colors occurring in nature, which means they blend into their surroundings:

- Red:** Yellowish to bluish red
- Yellow:** Greenish to reddish yellow
- Brown:** Light to dark brown/red brown
- Black:** Dark gray to anthracite

Shades of white, green and blue can also be produced, while pure colors such as yellow can be made using white cement. However, the options for producing brilliant shades, like those achieved in plastics and surface coatings, are very limited due to the composition and surface texture of concrete.

Fig. 1: Overview of the most important oxide pigments

Color	Name	LANXESS brand name
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	Chromium oxide	Colortherm® Green
Blue	Cobalt blue	–
White	Titanium dioxide	–

The tinting strength of pigments

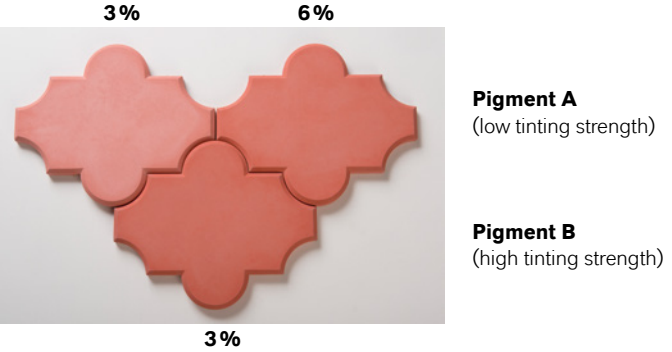
The tinting strength of pigments is an important quality characteristic that is essential in evaluating their cost-effectiveness. A pigment's tinting strength is its ability to transfer its inherent color to the medium being colored. The graphic below shows an example: two seemingly equally red powders – brick dust on the left and a Bayferrox® Red pigment on the right. The difference in the two samples' tinting strength only becomes apparent when they are used to color concrete or tested in the laboratory. The above-mentioned laboratory test is performed in accordance with EN 12 878 and is the basis for the tinting strength tolerances given in the product specification for Bayferrox® pigments.

Fig. 2: Comparison of pigments' tinting strength

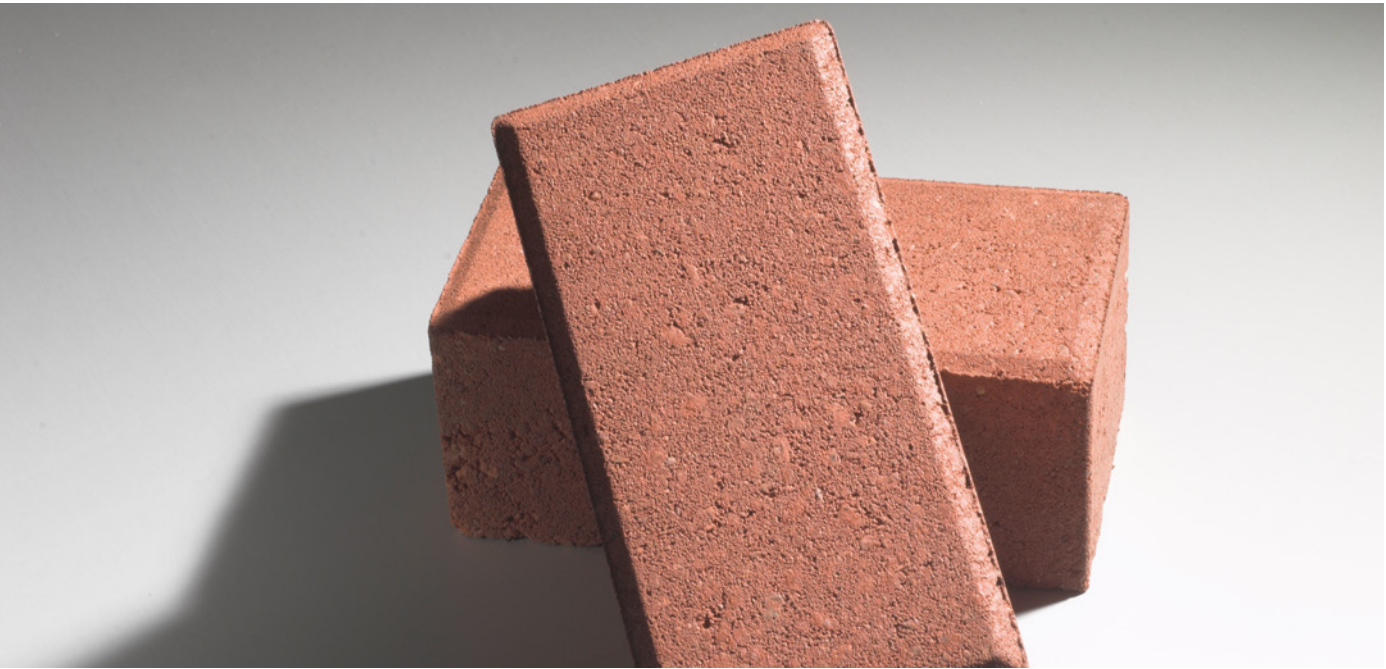


Comparing pigments with low and high tinting strengths
Taking the practical example of a concrete factory: An iron oxide red pigment "A" has been offered. A 6% concentration of this pigment is required to obtain a given shade. As the samples shown here demonstrate, however, it is also possible to obtain the desired shade by adding 3% of red pigment "B".

Fig. 3: Comparison of pigments' tinting strength

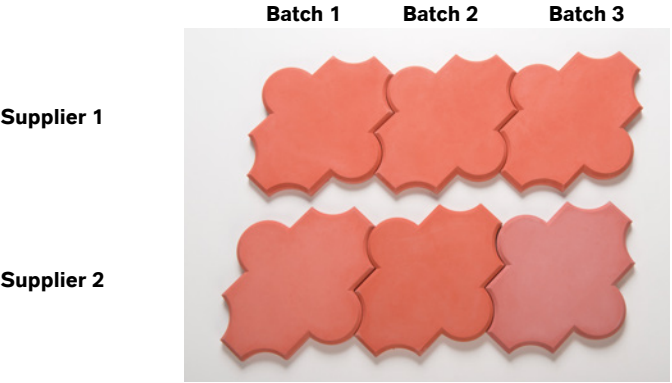


Conclusion:
Price alone says little about cost-effectiveness. Even if pigment "A" is cheaper, the additional quantity needed to obtain the desired shade may mean it is the much less cost-effective option.



Color consistency
Another extremely important quality criterion for pigments alongside tinting strength is color consistency – i.e. whether there are differences in color between different deliveries (Fig. 4). Thanks to state-of-the-art production facilities and painstaking quality control, LANXESS has been offering its customers absolute color consistency in its end products for decades.

Fig. 4: Color consistency

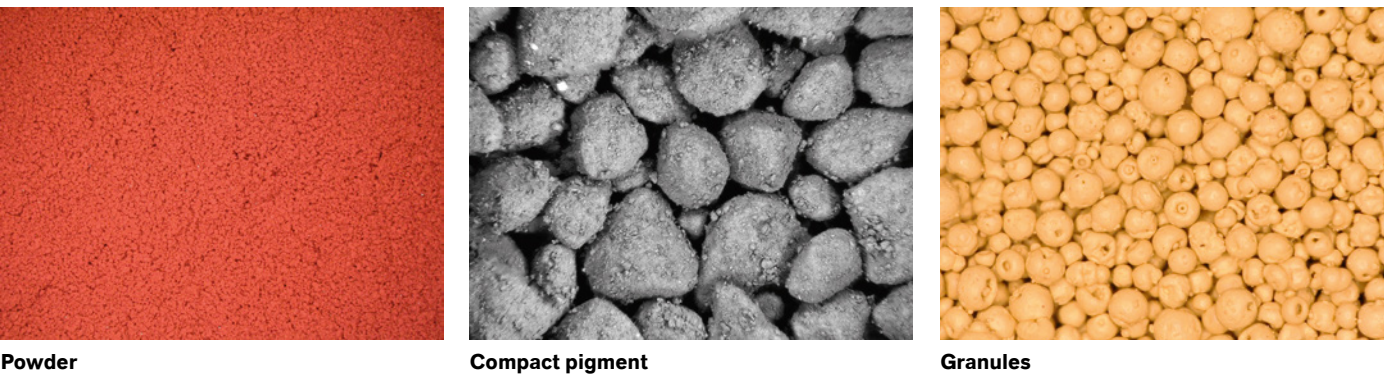


Supply forms
Pigment processability requirements have changed over the years. Initially, most of the pigments used in the construction industry were powder pigments, then waterborne pigment slurries subsequently became established in the market.

Besides the complete absence of dust, these slurries offer processors the benefit of easy handling and metering. However, they have a relatively high water content, which means that they cost more to transport than powder pigments. In addition, the pigment may settle if suspensions are not periodically stirred if they are stored for a prolonged period of time. For the above-mentioned reasons, it only makes sense to purchase ready-made pigment suspensions if located within a certain distance from the supply plant.

Free-flowing dry pigment preparations are the most recent supply form to be developed. They facilitate the easy emptying of silos, sacks and bulk bags, and only a minimal amount of dust is generated during transfer and metering. Further details about supply forms and packaging are available on request.

Fig. 5: Light micrographs (100x magnification) of Bayferrox® pigments



INFLUENCE OF THE FORMULATION ON THE COLOR OF CONCRETE

The cement

Gray cement is still used for most construction projects, which has implications for the possible coloring options. Unlike white cement, gray cement takes the brilliance out of all colors. As a result, bright, radiant colors cannot be obtained in pigmented concrete manufactured using ordinary Portland cement.

However the gain in color purity yielded by using white cement depends on the pigment used. In the case of black pigments, there is virtually no difference between products made using white or gray cement. The difference is slight when working with dark brown and red pigments, but very pronounced with yellow and green ones. The brighter and cleaner the desired shade, the greater the dependency on white cement.

Even a layperson can easily understand this difference in coloring white and gray cement. However, specialists also need to know that gray cement can vary in color from light to dark gray. When changing cement type or supplier, these differences in the inherent color of cement may often influence the shade of the concrete as well.

Fig. 6: Influence of the cement color on the shade of the concrete



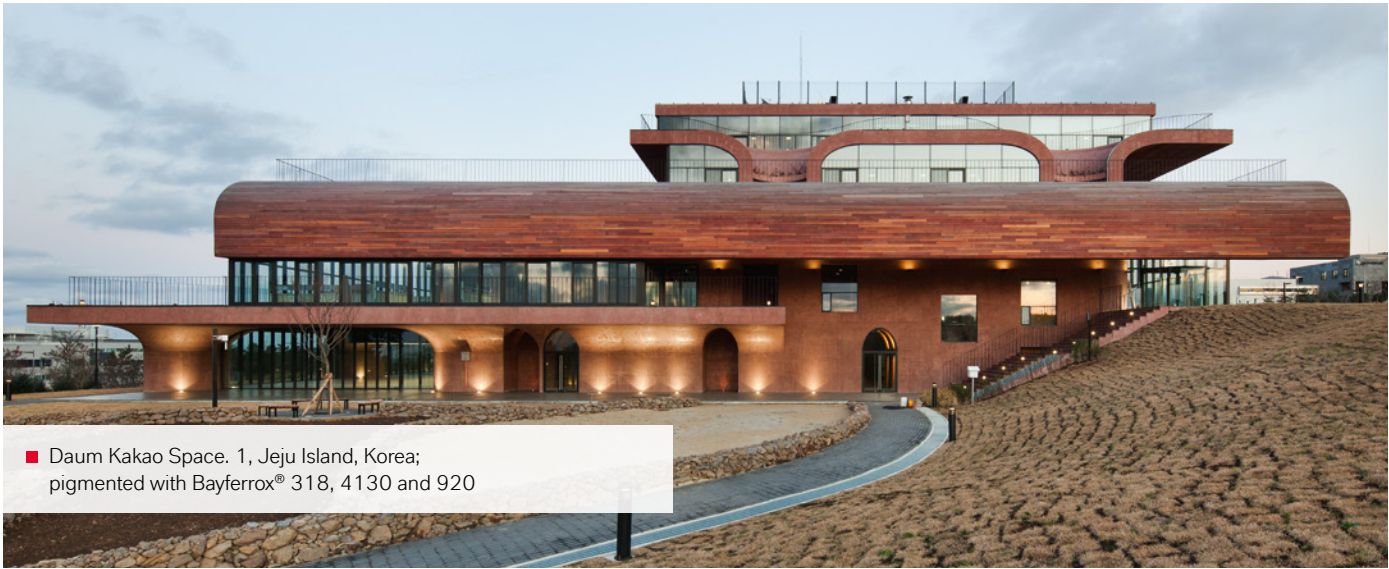
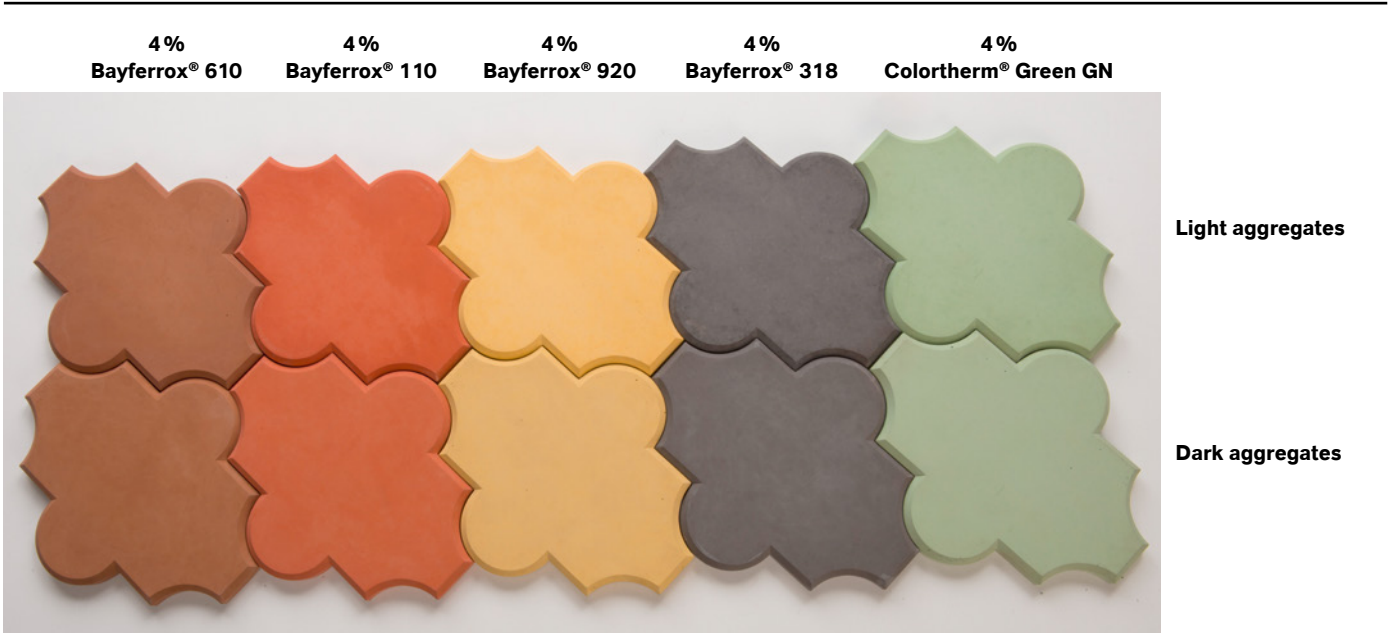
The aggregates

When manufacturing colored concrete, the aggregate particles are covered by the pigmented cement paste. The particles of a highly pigmented aggregate may not be completely covered, with the result that the inherent color of the aggregate affects the color of the end product. This effect is already apparent when producing colored concrete. However, the influence of the aggregate's inherent color becomes even more evident when weathering and surface erosion expose

the aggregate particles. The human eye then sees a composite shade made up of the color of the hardened cement matrix and that of the exposed aggregate.

Like cement, the inherent color of the sand also has a more noticeable effect on light-colored concrete (e.g. yellow, green) than on dark concrete (e.g. brown, black).

Fig. 7: Influence of the aggregate color on the shade of the concrete



Influence of the pigment addition rate on the shade of the concrete

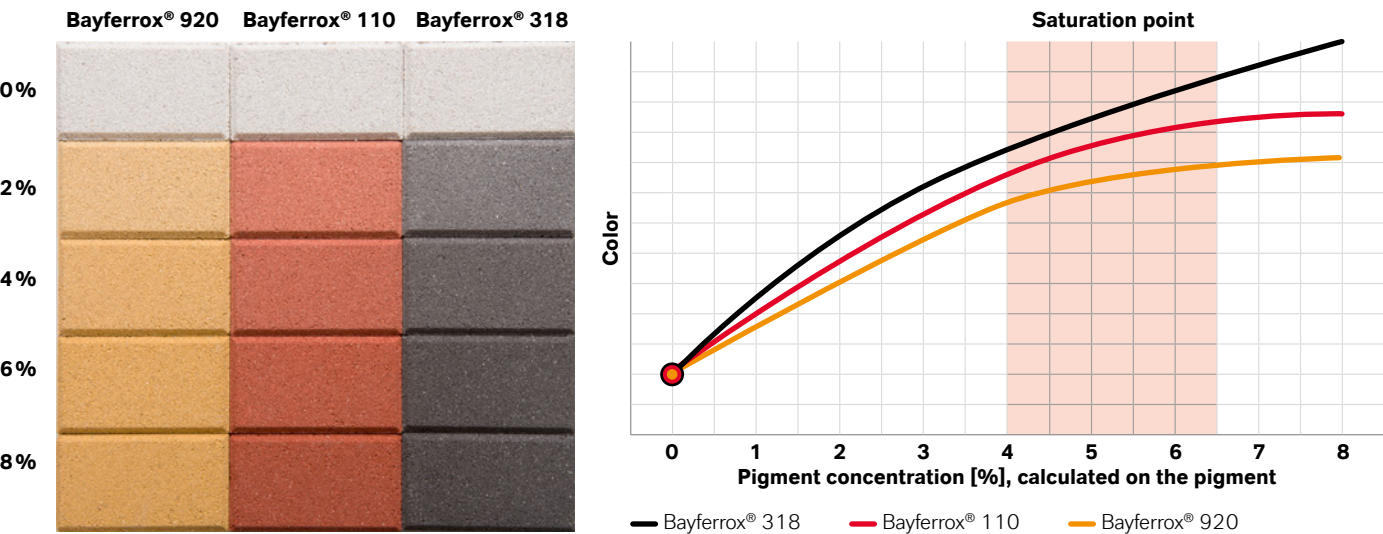
Knowing the optimal pigment addition rate is a key economic and technical factor. It helps achieve transparency regarding the costs of coloring concrete and is also essential to producing the desired shade and intensity.

Adding increasing amounts of pigment to a concrete mixture initially results in a linear increase in color intensity in line with the pigment concentration. As more pigment is added, however, a point comes at which the addition of further pigment does not significantly deepen the shade and is therefore uneconomical. The saturation range is determined in part by

the system parameters of the concrete. However, generally speaking, pigment additions above 5% (relative to the amount of binder) are not necessary for **Bayferrox®** pigments due to their high tinting strength.

In the case of pigments with a lower tinting strength, on the other hand, the saturation range is reached only after adding much larger amounts of pigment. The amount of pigment required to produce a given shade can thus sometimes be so large that the increase in the quantity of fines has a negative effect on the concrete's technical properties.

Fig. 8: Influence of pigmentation level on final shade



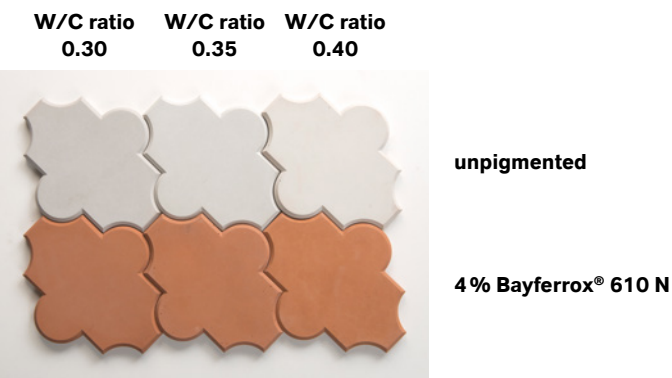
Water-cement ratio and the color of concrete

When drinking a glass of beer, you may have wondered why the foam is white although the beer itself is amber in color?

The foam is made up of countless tiny air bubbles, which scatter the light in the same way as white pigments. This digression is important as it explains the relationship between the color of the concrete and its water-cement ratio.

The excess mixing water evaporates from the concrete, leaving behind cavities in the form of fine pores. These act like the bubbles in the beer foam. They scatter the incident light and thus lighten the color of the concrete. The higher the water-cement ratio, the lighter the concrete appears. As the following photo shows, unpigmented gray concrete is affected just as much by this phenomenon as pigmented concrete.

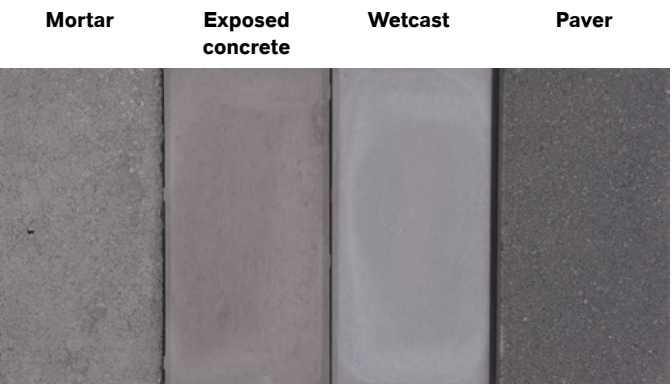
Fig. 9: Influence of water-cement ratio on color of concrete



What does this mean in practice?

When comparing the color of concrete with very different water contents (e.g. concrete pavers and in-situ concrete), the color of the samples differs although the pigment addition rate is the same.

Fig. 10: Color impression in different applications



Pigment addition rate in all samples: 3% Bayferrox® 330

A different picture emerges for comparisons within a particular product line. Consistency usually has to be kept within narrow limits to ensure trouble-free processing of the concrete in a concrete manufacturing unit, which means that the manufacturer normally needs to meter the mixing water very carefully

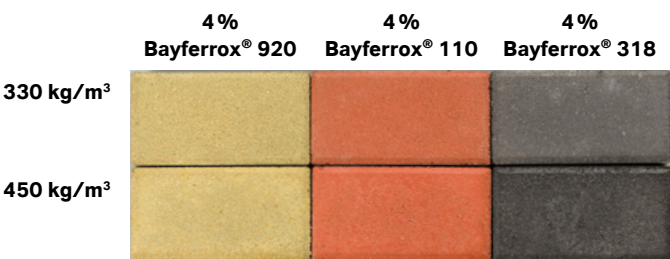
For this reason, color fluctuations that occur on a production line due to the water-cement ratio tend to be the exception rather than the rule. On the other hand, the differences in shade can be substantial if the excessive moisture in the concrete results in the formation of a thick layer of sludge on the surface of the concrete. This sludge – 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. As a result, the concrete has a different appearance than if there was a thin layer of sludge on the surface.

The color of concrete in relation to cement content

When coloring concrete, it is not the aggregate that is pigmented but the cement paste, which then forms a layer around the individual aggregate particles.

In considering whether the cement content of the colored concrete influences its color, we assume for the sake of simplicity that it is a two-substance mixture comprising colored cement paste and aggregate. The more the colored cement paste is “diluted” with aggregate, the less intense the color of the concrete is. This theory is confirmed in practice. Concrete with a high cement content will have a much stronger color than concrete with the same pigment concentration – which is normally calculated as a percentage by weight of the cement – but a lower cement content.

Fig. 11: The color of concrete in relation to cement content



The metering and dispersion of pigments in concrete

Quality is increasingly important nowadays. For this reason, the metering and dispersion of pigments are key criteria in the building industry, because high-quality colored concrete products cannot be produced without precise metering and the thorough and homogeneous dispersion of pigments.

Once pigment consumption at a concrete factory has reached a certain level, the next logical question is whether the addition process can be automated. As is often the case with technical solutions, there are both advantages and disadvantages. There is no one single answer to the question of whether wet or dry metering is better. All that can be done is to provide suggestions which, together with precise knowledge of local conditions and consideration of various commercial aspects, can help in the decision-making process. Besides the obvious advantages of automatic pigment metering, concrete manufacturers can add further colors to their product line. Bayferrox® pigments are available in the primary colors red, black and yellow. Various shades of each color are also available.

Combining two or three Bayferrox® pigments enables the creation of a virtually unlimited number of additional shades. Present-day concrete mixing technology allows several individual pigments to be added directly and simultaneously to the mixer. There is no need to premix the pigments.

Dispersion of pigments in concrete

As already explained, pigments are very fine products. Like other fine powders, they tend to form loose clumps during transportation and storage. Although these clumps of pigment are relatively soft and easy to break down, they may survive the mixing process intact if mixing conditions are unfavorable. This has a particularly unattractive effect if the clumps of pigment are visible on the surface of the concrete, as can be clearly seen in Fig. 12.

Fig. 12: Paver with lumps of pigment on the surface

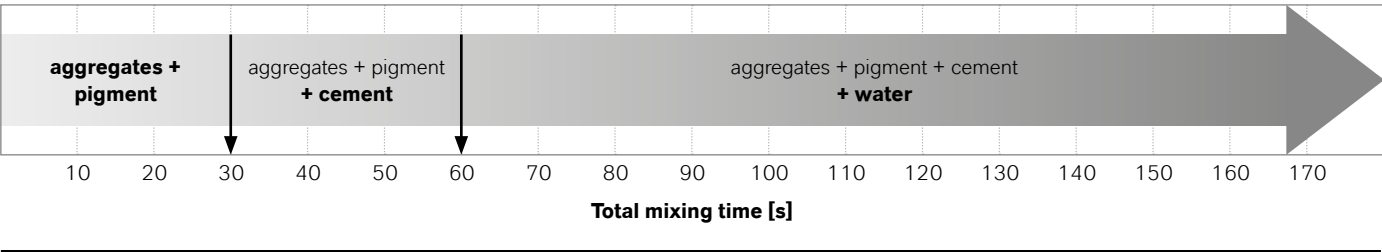


As a result, the mixing process is a vital aspect of manufacturing concrete. In addition to the usual requirements, i.e. optimal dispersion of all other components to maximize strength, good dispersion is the only way of ensuring evenly colored concrete.

Given that mixing times can nowadays be extremely short, it is of the utmost importance to add components during the mixing process in an order that ensures clumps of pigment are broken down and pigment particles are dispersed effectively in the mixture.

Lab tests and practical experience have shown that good results are always achieved if the pigment is premixed with the aggregate for around 15 – 30 seconds before the cement is added and this is followed by dry mixing for a further 15 – 30 seconds. The mixing process is otherwise the same as for unpigmented concrete. Adding all of the components simultaneously or mixing in the cement immediately after the sand should be avoided at all costs.

Fig. 13: Recommended mixing sequence when manufacturing colored concrete



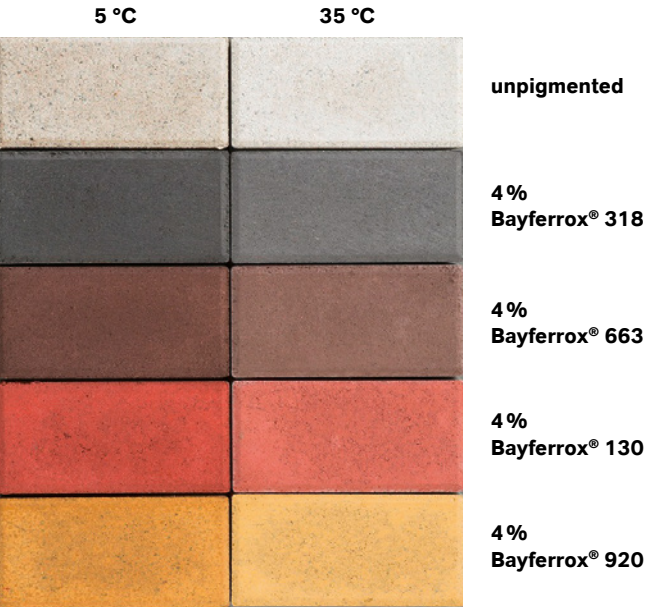
Of course, the mixing time also plays a role in determining whether or not homogeneous dispersion of the pigment is achieved. Each type of mixer has a minimum mixing time requirement. In the case of forced circulation mixers, this is around 1.5 – 2 minutes. Any shorter and it is impossible to achieve a homogeneous mixture, even if the mixing times of the individual components or the order in which these are added is changed.

The influence of curing conditions on the shade of concrete

The cured cement matrix, which is formed from the reaction between the mixing water and the cement, forms crystals of varying size, depending on the temperature at which the concrete is cured. The size of these crystals is, in turn, responsible for scattering the light that falls onto the concrete. The following principle applies: Higher curing temperatures result in finer crystal needles. The stronger light scattering resulting from the fine crystal needles makes the color of the concrete lighter than that of the same concrete cured at a lower temperature. However, this phenomenon generally only becomes apparent when the difference in temperature reaches a certain magnitude, for example when steam-cured concrete is compared with concrete cured at normal room temperature and humidity.

Fig. 14 illustrates these behavior patterns. It compares the coloring of concrete cured at 5 °C and 35 °C.

Fig. 14: The influence of curing conditions on the shade of colored concrete

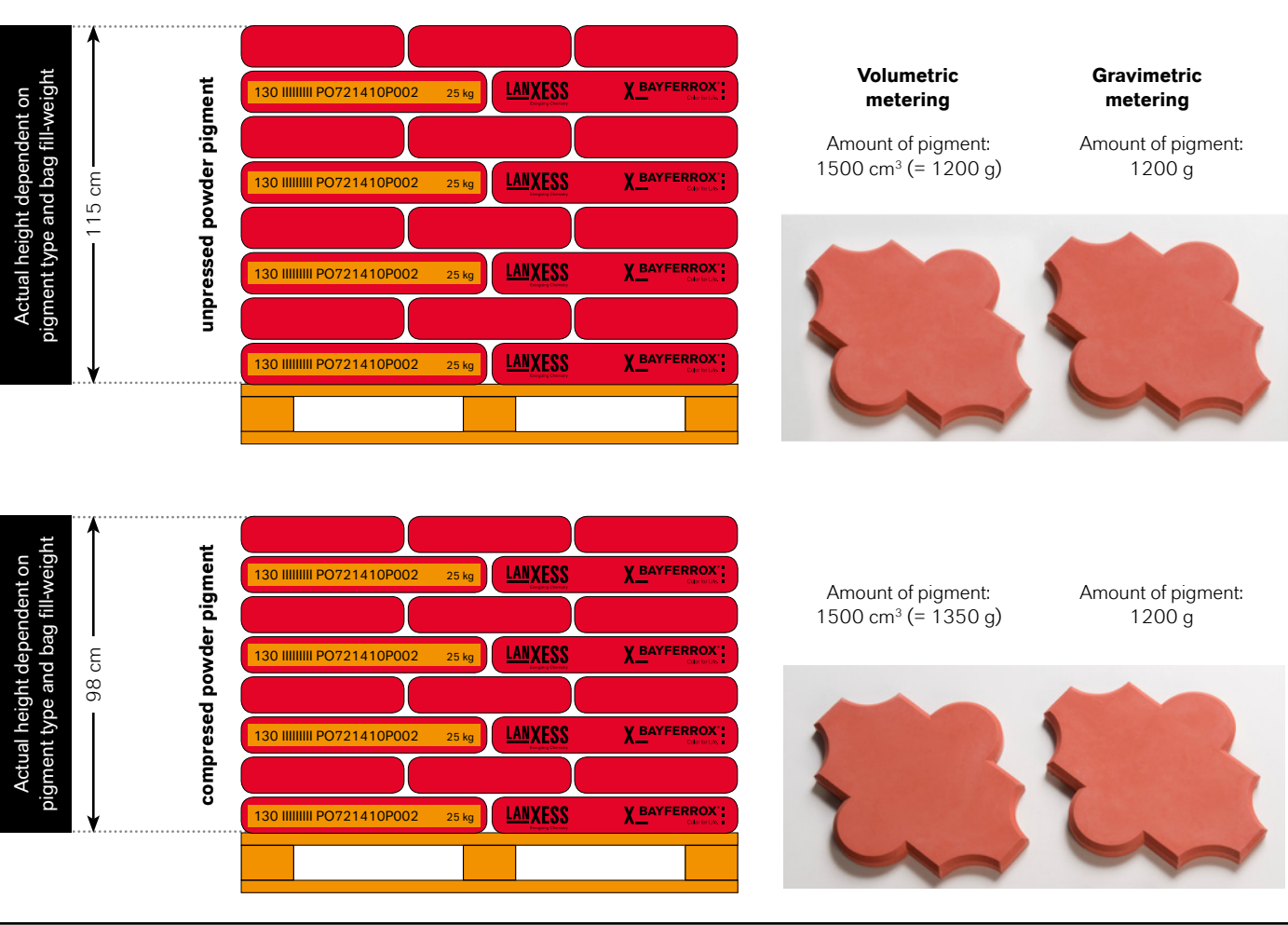


WEATHERING BEHAVIOR OF COLORED CONCRETE

One final important point regarding how pigments should be measured and metered: color pigments are very fine powders (around ten times finer than cement) and very sensitive in terms of compressibility. This means that the bulk density of fine powders can vary due to all kinds of external influences (such as storage and transportation conditions).

In the case of volumetric measurement of powder pigments, it is therefore entirely possible for the volumes measured to be the same but for the quantity of pigment to differ in terms of weight. The differences in color this causes can easily be avoided by using weight-based measurement.

Fig. 15: Comparison between volumetric and gravimetric measurement



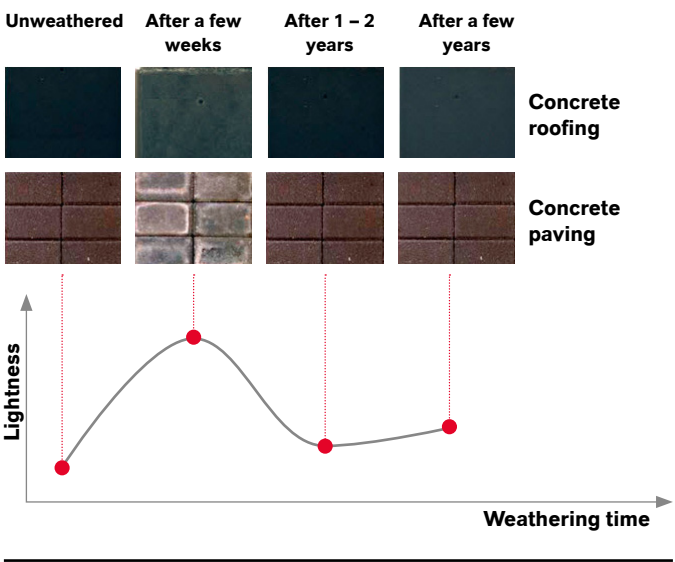
The Roman aqueduct that supplied the German city of Cologne with water from the Eifel hills two thousand years ago was built using trass cement. Had this ancient “concrete” been pigmented with natural iron oxides – which were already known at the time – the structure, parts of which can still be visited, would still be colored today. The difference from the original shade would be quite small. There are various reasons for these color changes, which occur in both colored and uncolored concrete. They may be temporary (e.g. efflorescence) or permanent (e.g. exposure of aggregate).

Efflorescence on concrete

Efflorescence is the curse of all concrete manufacturers, especially if color is involved and particularly high standards are specified for the appearance of the concrete.

It is important to note that neither Bayferrox® nor Colortherm® pigments have any influence on the occurrence of efflorescence. By their very nature, however, white lime deposits are more noticeable on colored concrete than on natural gray or white concrete. Efflorescence results from the formation of free lime when the cement sets. Dissolved in the mixing water (primary efflorescence) or in external water such as rain or dew (secondary efflorescence), the lime migrates to the surface of the concrete, where it reacts with carbon dioxide in the air to form insoluble calcium carbonate. The porosity of the concrete also plays an important role. The denser it is, the less likely efflorescence will occur.

Fig. 16: Efflorescence



In a slow reaction, the calcium carbonate on the surface of the concrete reacts with carbon dioxide dissolved in water to form calcium bicarbonate, which is in turn soluble in water. The efflorescence is thus weathered away. Acidic components in the atmosphere also cause lime deposits on the concrete surface to dissolve.

LANXESS Deutschland GmbH has published a brochure about efflorescence on concrete, which is available to customers on request.

Weathering of the cured cement matrix

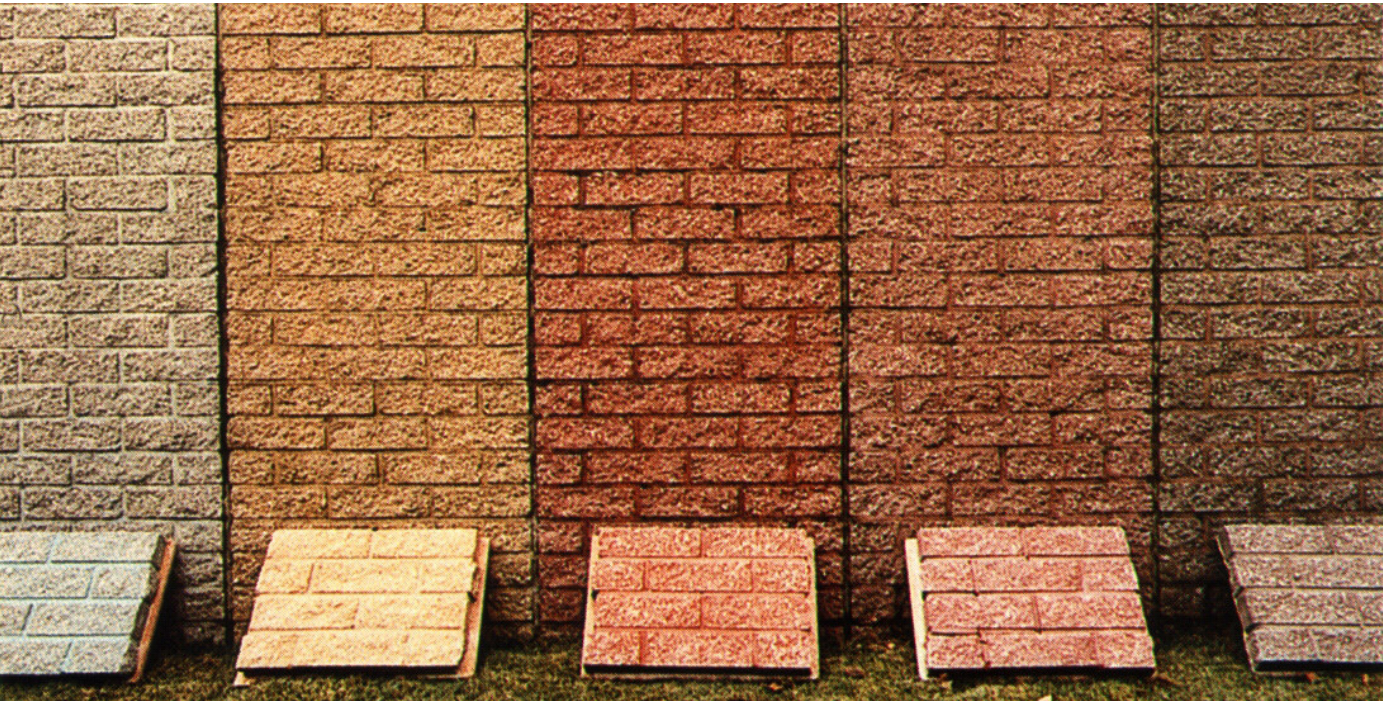
There is a sludge layer consisting of aggregate fines and cement on the surface of the concrete. Its thickness depends on the formulation, method of compaction, etc. This layer (cured cement matrix) is gradually weathered away and, after a few years, the aggregate particles on the surface become more exposed and thus contribute more to the overall color of the product. The photo below shows that the color changes in pigmented building materials are relatively small. These changes are due to the color of the aggregate and the different way light is reflected.

Fig. 17: New and weathered paver, on which the color of the sand is evident



THE TECHNICAL PROPERTIES OF COLORED CONCRETE

Fig. 18: Concrete walling blocks after 25 years of outdoor weathering



Weather stability of pigments

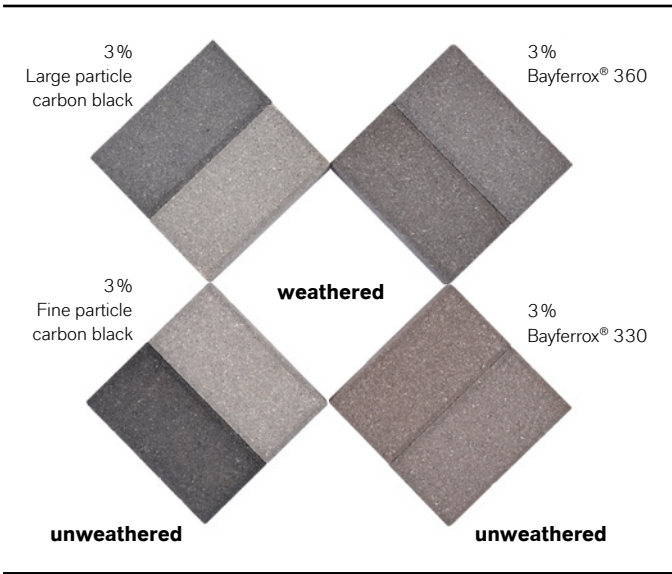
Provided that weather-stable pigments such as Bayferrox® and chromium oxide green (i.e. oxidic) pigments are used for coloring building materials, their color can be expected to last. This is based on experience from over a quarter of a century of systematic trials of the stability of pigmented building materials. In these studies, which looked at a variety of issues, it was also found that only outdoor natural weathering tests can truly provide reliable information on the weather stability of pigments used in building materials.

The photo above shows that the color changes in pigmented building materials are relatively small. Compared with the unweathered specimen in the foreground, concrete bricks weathered for 25 years show very little change apart from slight soiling of the surface. The long-term weather stability can be completely different, though, depending on the pigment selected.

In a maritime climate, for example, the color of concrete paving stones pigmented with carbon black faded after a relatively short weathering period and only stones pigmented

with iron oxide black exhibited the required color stability. This proved that a number of pigments (e.g. carbon blacks and various organic pigments) do not provide adequate weather stability (Fig. 19).

Fig. 19: Weather stability of black pigments



Standards

The requirements relating to pigments for coloring building materials are specified in various standards. The relevant standard in Europe is EN 12 878 “Pigments for the colouring of building materials based on cement and/or lime”, while ASTM C 979 “Pigments for integrally colored concrete” applies in the United States.

EN 12 878

Conformity is confirmed by means of factory production controls and the resulting certification by a notified body (CE mark). The notified body issues certificates that replace the certificates of conformity used previously.

The CE mark, which is also placed on the delivery paperwork, documents the product’s conformity.

EN 12 878 specifies additional testing requirements for reinforced concrete (Cat. B), in particular relating to test frequency, a lower tolerance for chloride content and a low proportion of water-soluble components. To satisfy the requirements of the standard, including as regarding documentation, LANXESS lists these products separately as special formulations. The test certificate lists the required data for each batch and includes a declaration of the intended use.

ASTM C 979

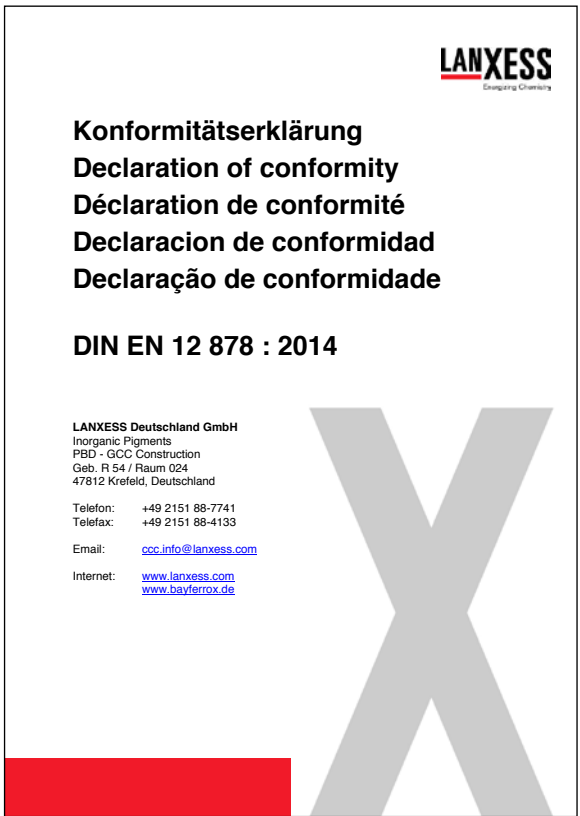
This standard establishes the requirements for pigments used in colored concrete all of which are fulfilled by Bayferrox® & Colortherm®.

Conclusion:

LANXESS pigments satisfy the requirements of EN 2878 and ASTM C 979.

Concrete strength and curing behavior of cement

Besides dealing with questions regarding the testing of pigments, EN 12 878 also specifies thresholds for the extent to which pigments may influence the curing behavior of cement and the strength of concrete.



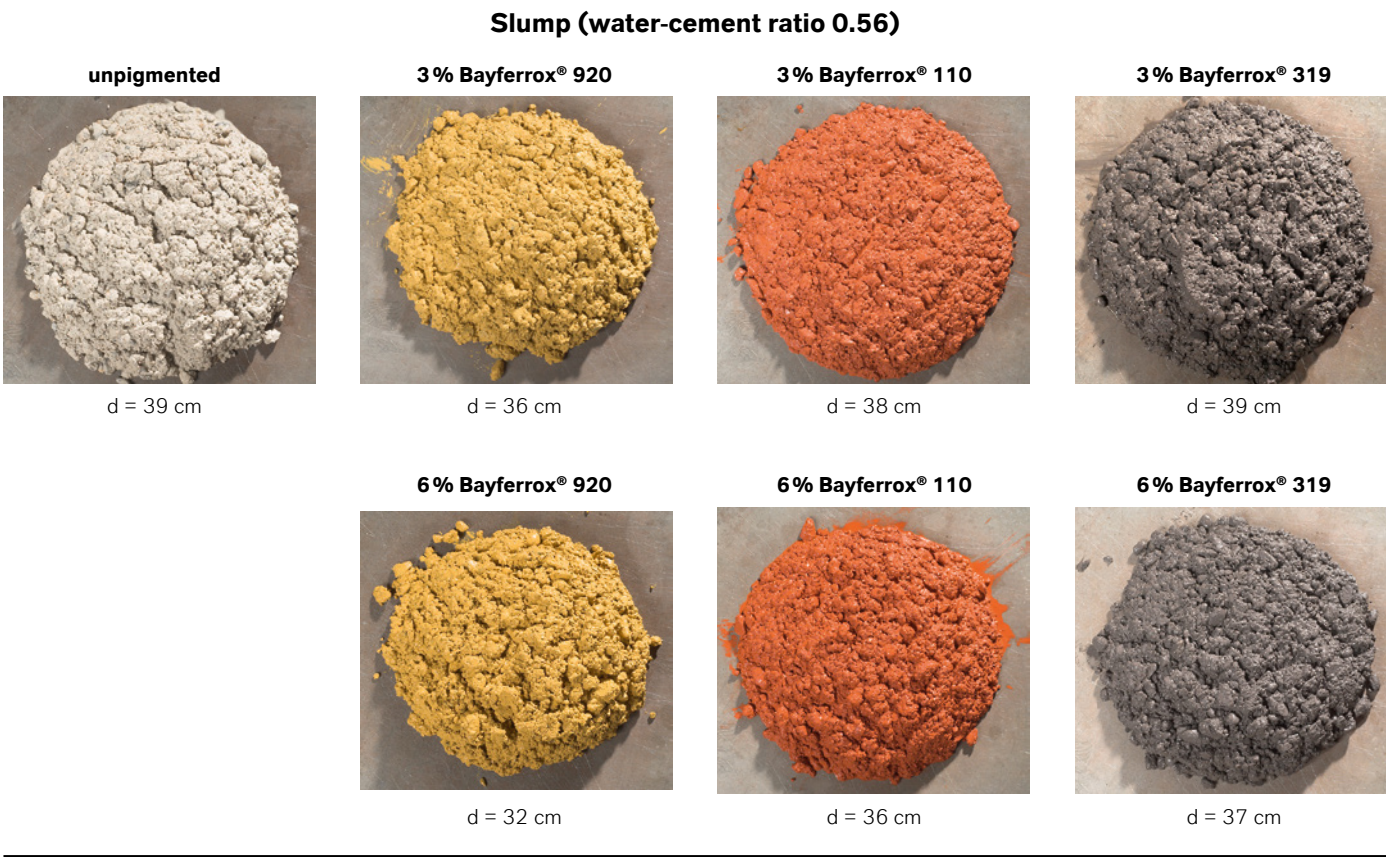
Concrete consistency

Pigments are made up of very fine particles. The shadecard shows precise details about the mean particle size, which can vary considerably depending on the grade. As a rough guide, pigments are approximately 10 – 20 times finer than cement. Consequently, pigment processors must ask themselves whether adding such a fine product has some influence on the water required by the concrete.

The amounts of Bayferrox® Black and Bayferrox® Red pigments added in practice have virtually no effect in this respect. Iron oxide yellow pigments differ from the above-mentioned black and red iron oxides in that they have a needle-shaped structure and can therefore adsorb more water on their surface. However, this effect only becomes noticeable at pigment concentrations above approx. 4–5%. This value is generally not exceeded when using pigments with a high tinting strength, such as Bayferrox® Yellow grades. The higher water adsorption of the yellow pigments is therefore of only limited interest to concrete manufacturers.

If larger amounts of iron oxide yellow pigments are added to the concrete, however, the water bound to the pigment surface results in a tangible reduction in the effective water-cement ratio and associated changes in the consistency of the concrete. To achieve the same slump as uncolored concrete, the amount of water added must be increased, which may adversely affect the strength of the concrete.

Fig. 20: Slump test comparing unpigmented and pigmented in-situ concrete



On closer examination, it quickly becomes clear that concrete and pigment technology are fundamentally different technical disciplines. If concrete manufacturers have a lab, this is normally restricted to performing technical concrete tests and developing concrete formulations. Such labs are not, however, set up to deal with issues relating to coloring, such as the task of producing concrete in a highly specific color. Nor, generally speaking, are they equipped to deal with rationalization issues regarding the number of pigments required for the concrete manufacturer's color range, or with issues relating to the color consistency of building materials.

This is where the pigment manufacturer's specialists come in. The Global Competence Center Construction of LANXESS Inorganic Pigments offers customers a comprehensive global application engineering service that not only covers color matching under realistic conditions, but also all issues relating to the use of pigments as well as mixing and metering technology.

This enables LANXESS to help customers significantly improve the quality of their end product.





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Health and safety information

Appropriate documentation was compiled with information on the health and safety measures that have to be observed in handling the LANXESS products mentioned in this brochure. For materials mentioned here that are not LANXESS products, the operational hygiene and other safety measures recommended by the respective manufacturers must be observed. Before working with these products, you must read and familiarise yourself with the available information on their dangers, proper use and handling. This point is of decisive importance.

Information is available in various forms: such as safety data sheets, product information and product labels. Please contact your LANXESS representative in Germany or the Department of Regulatory Affairs and Product Safety of LANXESS Deutschland. For business in the USA, please contact the LANXESS Product Safety and Regulatory Affairs Department in Pittsburgh, Pennsylvania.

Information on Regulatory Compliance

For some end use purposes of the products found in this brochure, the applicable regulations must be observed, including those of the FDA, BfR, NSF, USDA and CPSC. If you have any questions regarding the approval status of these products, please contact your representative at LANXESS Deutschland GmbH or the Department of Regulatory Affairs and Product Safety of LANXESS Deutschland GmbH or, for business in the USA, your representative at LANXESS Corporation, the LANXESS Regulatory Affairs Manager in Pittsburgh, Pennsylvania.

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