Issues Affecting Color Durability in Concrete Masonry, Segmental Retaining Wall Units and Unit Concrete Pavers

prepared by

National Concrete Masonry Association
Concrete Color Durability Task Group

NATIONAL CONCRETE MASONRY ASSOCIATION

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NATIONAL CONCRETE MASONRY ASSOCIATION

The National Concrete Masonry Association (NCMA) is a non-profit organization whose mission is to support and advance the common interests of its members in the manufacture, marketing, research, and application of concrete masonry products. The Association is an industry leader in providing technical assistance and education, marketing, research and development, and product and system innovation to its members and to the industry.

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The NCMA Research and Development Laboratory is exclusively devoted to the scientific research and testing of concrete masonry products and systems. The Laboratory is staffed by professional engineers and technicians with many years of experience in the concrete masonry industry. The Laboratory is equipped to perform nearly any physical research or testing of concrete masonry units and assemblages. The Laboratory performs research and development work for both the Association and individual companies.

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NCMA CONCRETE COLOR DURABILITY TASK GROUP

The Concrete Color Durability Task Group evaluates and recommends methods for maintaining color stability in concrete units. The task group considers, but is not limited to, concrete admixtures including colorants and aggregate make-up.

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Introduction

Designers, owners, builders, and product manufacturers alike may benefit from an increased understanding of color pigments and their use in the concrete product manufacturing process. Color pigments are classified as admixtures; they are added into the concrete mix during production to create long-lasting integrally colored concrete products including "architectural" concrete masonry units (CMUs), segmental retaining wall (SRW) units and paving products. These products continue to grow in popularity in design-conscious communities due to the aesthetic value of the many shapes, colors, and textures available. While these attributes increase the applications available to concrete masonry products, they carry the responsibility of meeting higher expectations for appearance, color consistency, and color durability. These expectations are often the only criteria used when a simple visual inspection is made to determine the acceptance of a shipment of the various concrete products.

Consistent color is the result of managing a complex set of manufacturing variables. Raw materials, mix design, machine settings, curing conditions, curing time, and in the case of colored units, color pigment additives, all have an effect on the final product appearance. This paper is a discussion of what masonry color is, how color pigments are used to make colored concrete products, and how to achieve better color durability in concrete masonry.

Color Pigments Additives

Pigments used in concrete products must be insoluble. This insolubility is a mandatory trait in order to achieve color durability in the final concrete products. In any concrete product, the pigment particles are incorporated or bound into the cement paste; simply illustrated, sticking to the cement particles like color "reflectors." Color pigment additives are available in two forms: dry, which includes powder and granules, and liquid, which is commonly called pigment slurry. Liquid colors, or slurries, are made by blending finished or semi-dried iron oxide pigments with water, dispersants, pH-controlling agents, stabilizers, and biocides to form a "suspension". Granules are made by incorporating an appropriate binder with either liquid color or dry powder and processing the mixture through spray drying or compaction.

The four most common pigment types used for the coloration of concrete products are:

1. Iron Oxide pigments come in three primary colors: red, yellow, and black. These primary colors are then blended together to make shades of tan, buff, orange and brown;
2. Chrome Oxides are a green shade of pigment usually found with either a bluish or yellowish undertone;
3. Titanium Dioxide is a primary white pigment, used mainly as a means to lighten gray cement; and
4. Cobalt Blue Pigments are used in the manufacturing of bluish shade concrete products.

Each of these pigment types used in the manufacture of concrete masonry products is required to comply with ASTM C979, *Pigments for Integrally Colored Concrete* (Ref. 4), a standard specification for certifying that pigments are water soluble, water-wettable, light resistant, alkali resistant, stable under curing, and will not have a detrimental effect on concrete strength or consistency when mixed at recommended dosage rates.

Iron oxide pigments that comply with ASTM C979 can be produced in a synthetic process or refined from naturally occurring ore deposits. Today, synthetic pigments are the most widely used to color concrete. Iron oxides are popular for their wide range of colors, relatively low cost, stability against chemicals and weather exposure, and because they are non-toxic.

Carbon black pigments are very high in tinting strength and listed under ASTM C979. However, they should be used with caution by the manufacturers of concrete masonry products. Masonry products colored with carbon black or brown blends containing carbon black tend to fade or discolor significantly when exposed to weathering, even at low dosage rates.

Manufacture

Masonry products come in a spectrum of color hues and shades that are created by adding different color pigments, or by increasing or decreasing the amount of pigment in the batch. The amount of pigment used is controlled by the manufacturer and expressed as a percentage (by weight) of the cementitious content in the batch.

Pigmentation of a concrete product reaches what is known as a saturation point when increasing the dosage rate fails to make an appreciable difference in the color intensity of the final product. Most color shades are achieved at dosage rates well below 7%. Pigments with high tinting strength reach saturation at a lower dosage rate than those with low tinting strengths. Black iron oxide generally achieves saturation at a 6% to 7% dosage. Brown and red iron oxides have slightly higher saturation point leveling off at approximately 7% to 8% dosage, followed by yellow at around 9%. ASTM C979 permits dosage rates up to 10% by weight at which point compressive strength can be affected. For example, iron oxide pigment particles are 10 to 20 times finer than cement particles. These additional fine particles absorb water that is needed to maintain workability and alter the water-to-cement ratio of the mix. This change in water-to-cement ratio could have a detrimental effect on the concrete strength when dosage rates exceed 10%.

Color Quality Practices

Quality control practices within the pigment industry measure tinting strength and color using computerized color measuring instruments, such as spectrophotometers or colorimeters. These devices cast a light source on the surface of the color sample being evaluated. Depending on the color of the test sample, certain wavelengths are absorbed while others are reflected back into the device where the computer converts those wavelengths into numerical values. The numerical values are then compared mathematically to a reference standard stored in the equipment. Most pigment suppliers evaluate these measurements (in addition to visual assessment) before approving a pigment batch for distribution.

Pigment manufacturers can certify their manufacturing processes via ISO certification. This is not a guarantee of pigment quality. Rather, this annual certification assures that all steps in the manufacturing process have been outlined and results documented.

Factors Affecting Color Consistency

The color of the pigment particles and the aggregates does not change over time. Therefore, these two basic raw materials do affect color durability. Their greatest effect is on color consistency of newly produced concrete products. Other raw materials and manufacturing processes, however, have a limited effect on color durability.

Portland Cement

Portland cement itself may yellow, although this effect is masked somewhat in colored units. High-quality concrete pigments exhibit excellent durability when exposed to sunlight and weather. However, the ability of concrete masonry to withstand the test of time is a result of the integrity of the entire masonry unit, not just the color component. If the paste is strong and the aggregates are hard, then the concrete is strong. If the paste and aggregates are durable, the concrete is durable. Since only the cement paste can be colored, it is obvious that an increase in the amount of cement (with the amount of pigment increased proportionally) will result in a less-perceived change over time. This option, however, has economic limitations.

Raw Materials Influence Color

Cement color and its fineness (Blaine) is an important variable impacting the color of concrete products. It is particularly important for non-pigmented units, and units produced with low pigment dosage rates such as light buff shades. That is because an increase in cement fineness can have an effect on final color, appearing as a loss in color when compared to a concrete product with cement of lower cement fineness (Blaine). This apparent loss of color saturation is because the pigment has to cover an increased surface area of cement particles. Although a change in cement fineness (Blaine) can have an effect on color consistency, it does not have an effect on the color durability of the concrete.

The base color of cement also influences the palette of colors, which can be achieved by the addition of pigment additives. Cement that is lighter in color will in general produce lighter, more vivid colored units. White cement is used to produce pastel shades and is recommended for use with blue or green pigments. Dark colored cements are fine for producing darker colors or earth tones; however, they are not good for lighter buff tones. Dark colored cements may be lightened with the addition of titanium dioxide, thus producing lighter colored units. In order to control cement's effect on color consistency, masonry producers may monitor incoming cement shipments by retaining samples and mill reports.

Since aggregates make up the largest percentage of materials of a concrete mix, their inherent color and gradation contribute significantly to the final appearance of any colored concrete. Well-graded aggregates that achieve a tighter, less permeable concrete matrix will typically increase color durability when adequate cement is used to cover the increased surface area. Even minor changes in aggregate color will be readily apparent in split-face or ground-face units. Aggregates also affect color durability, as their color does not change over time. Complimentary or contrasting aggregate colors can achieve unique color effects.

Water-to-Cement Ratio

A consistent water-to-cement ratio is important for achieving uniform color and surface texture of produced concrete products. Changes in water-to-cement ratio impact color shade. Concrete masonry manufacturers take elaborate measures to ensure an accurate amount of water is added to each batch. In general, higher water content produces a smoother exterior that appears lighter in color. This is because water evaporates during the curing process, leaving tiny air voids in the surface, which cause light to scatter. As the water content changes, the color of the units will change. Lower water content produces darker, more coarse-textured units. When increasing amounts of pigment are added to a given concrete batch at a constant water-to-cement ratio, the pigment, especially yellow, will absorb a small amount of water. However, with most pigments and addition rates, this effect is negligible.

Efflorescence

Efflorescence has no effect on color durability. Rather, efflorescence produces a white substance on the product's surface that affects the appearance of concrete products. This is a result of water-soluble salts within the cement migrating to the surface and reacting with atmospheric carbon dioxide. In effect, efflorescence results in color masking. Efflorescence on colored surfaces makes them look faded or lighter in color. To reduce efflorescence from occurring, concrete product manufacturers attempt to produce as dense a concrete product as feasible. This can be achieved through proper mix design, production techniques, and the use of admixtures that are designed to assist in the reduction of efflorescence. However, no admixture will completely eliminate efflorescence. When efflorescence occurs, it can be removed with mild detergent, acid-based cleansers or as directed by the manufacturer. Cleaner instructions should be followed and a test of the cleaner should be made in an inconspicuous area before full application to make sure the cleaner will not etch or discolor the surface. Rubber gloves and eye protection should be worn when handling acid-based cleaners.

Factors Affecting Color Durability

Effects of Weathering

Weather-durable masonry products are manufactured to minimize water absorption. The entire masonry structure must be designed and constructed to minimize permeability. The surface of most products made from concrete, including masonry products, can be expected to change over time due to weathering effects that are beyond the control of the manufacturer. After years of exposure, some of the cement paste may erode from the surface, taking the fine pigment particles with it. This exposes more of the coarse and fine aggregate, resulting in the aggregate color contributing more to the overall color of the product. Although the pigment is not fading or changing, the block can appear to have "faded". The more the inherent color of the aggregate differs or contrasts from the color of the cement paste, the more pronounced the final shift in color due to erosion.

There are many differences between horizontal and vertical weathering effects. The first and most important difference is the physical characteristic between units exposed to vertical weathering (typically CMUs and SRWs) and units exposed to horizontal weathering (pavers). Products used in vertical applications, in general, have lower cement to aggregate ratios (in turn lower pigment contents), lower densities, and higher absorption. The typical products for horizontal applications have higher cement ratios, higher densities, and lower absorption, which allow it to be used in a much more aggressive weathering environment. The other difference between these two applications is the friction and mechanical action of vehicular and pedestrian traffic, surface water runoff, vertical water impact (i.e. areas below roof lines), or other traffic that accelerates the weathering of products used in horizontal applications. On the other hand, vertical applications are more likely exposed to weathering from high winds coupled with loose or hard material that could actually blast the surface, or continued, uncontrolled water runoff such as surface water runoff on roofs not directed to collection structures or surface water runoff directed overtop and concentrated in one area of an SRW. Both applications are susceptible to UV exposure as well as acid rain. All of these factors can have an effect on the apparent color durability of the products as the colored cement erodes exposing more aggregate. This loss of colored cement can result in a color shift and is not related to color durability, but product durability.

Summary

It may seem quite a challenge to manage all the variables that can impact the color durability and uniformity of concrete masonry products. In reality, remarkably consistent concrete masonry products are produced by many NCMA members, who pay particular attention to the accuracy of all manufacturing steps as demonstrated in the color consistency of their uncolored and colored products. The color durability of concrete products is important to their continued specification and use. The basic raw materials and the manufacturing process influence the initial color consistency of the product, and over time, they will affect the long-term color durability. The effect of weathering, however, has the greatest impact on color durability. Manufacturers have all the tools necessary to make products that can diminish the effects of weathering, but a shift in the color of any building material product over time, regardless of material type, is to be anticipated. To ensure color consistency throughout the project, most member producers will provide representative masonry product samples and submittals for approval prior to final color selection on architectural projects. In addition, specifications should include construction of a full-scale mock-up panel using specified construction methods and materials. This panel should remain in place throughout the project for reference and evaluation of the work in progress.

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