Quality and Production Control for Color Consistency in Concrete

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In our initial paper titled "Coloring Concrete using Integral Pigments", a lot of information was presented about the properties and characteristics of pigment itself. Although that document provides ample information about the basics of pigments, there are numerous additional factors that are critical to producing consistent colored concrete.

The objective of this paper is to examine those other factors. This paper will review the other raw materials and production factors that influence the finished color of architectural precast concrete.

Raw Materials

There are many recommendations that should be used under 'ideal' circumstances. Due to a variety of reasons, this is not always possible. However, this paper outlines the recommended materials and procedures when no other constraints are present.

Sand

Outside of pigment, sand has the strongest effect on the concrete color. Whenever possible, washed sand is preferred to remove dust and other potential contaminants. It is best to have the sand color be similar to the intended tone of the concrete. Contrasting sand color will show more variation in color. Be aware when working with manufactured sand that it can retain significantly more water than natural sand. This is important because if proper moisture control practices are not in place in aggregate storage areas the additional amount of water that can come with manufactured sand may lead to extreme swings in water cement ratios and the accompanying problems this will create.

Rock/Stone

Whenever possible all rock should be washed. As with sand, similar color of rock to the base color of the mix will yield more consistent results. Changing aggregates, or sand, during a project will negatively impact the consistency of color of the project. Tracking aggregate color can be helpful during the course of a project. Keep track of aggregate color comparisons, wash comparisons, and sieve analysis to ensure that aggregate variations are being noticed.

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Cement

Whenever possible white cement should be used to produce architectural precast concrete. White cement is more consistent in color than grey cement and therefore will produce more consistent colored concrete. A single type and brand of cement should be used throughout a project. If other pozzolanic materials, such as fly ash, are being used for a project, it is critical to monitor the color consistency of those ingredients. In general, pozzolans, such as fly ash, are not controlled for color and can lead to inconsistencies.

When creating a mix design with grey cement, make every effort to have the freshly poured concrete look as similar to the cured concrete as possible. This problem is highlighted when trying to make buff or orange colors using synthetic yellow iron oxide and red. This leads to the freshly poured concrete looking darker and having a red/greenish cast from the grey cement. The yellow does not become visible until the grey cement is fully cured and becomes lighter in hue. This is not typically a problem when producing small 12" x 12" samples, but as the production size increases, the time for the pieces to fully cure also increases. There have been jobs where the yellow is not visible in a larger piece for at least a month. Ultimately, the pieces will cure to the correct buff or orange color, but the time to wait is very long. In these cases, it is advisable to add a buff pigment to the original blend so that the freshly poured concrete looks more similar in color to the fully cured concrete.

Admixtures

Admixtures can impact the color of concrete. Therefore, as with other materials, close control of amounts of admixtures used and processes for adding them are key to consistency. Changing the amount, type, or brand of admixture, or sequencing of admixtures may lead to some color change.

PCI MNL 116

4.3.1 Batching Equipment Tolerances

Pigments in powder form are used in extremely small dosages and shall be batched by hand from premeasured containers packaged in amounts sufficient for proper dosages per unit volume of concrete. Powdered pigments shall be weighed to the nearest +/- 1% of the required weight.

Liquid pigments: +/- 3% of the required cumulative weight of material being weighed

4.1.11.1 Water-Cementitious Material Ratio

The water-cementitious material ratio (w/cm) shall not exceed 0.45 by weight with an allowable variation during production of +/- 0.02.

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Pigment

Beyond the information about the pigment itself presented in 'Coloring Concrete with Integral Pigments', there are several quality control and production practices that should be followed when using pigments.

The color itself, obviously, must remain constant and the amount added per batch must not vary. Be sure to add all pigment by weight regardless of form – powder, granular or liquid. Batch sized bags are recommended. Use of batch sized bags eliminates the need to weigh material in the plant and puts it into the hands of the pigment manufacturer. It is also strongly recommended that if the producer is using dry pigment, then the producer only buys pre-blended colors. This would mean that if the producer does have to weigh the color, it would only be a single color and would remove the need for multiple components to be subsequently blended in the mixer. Pre-blended, batch size bags are available in any color and for any batch size. If, for some reason, the producer does not wish to buy batch sized bags, always add the color by weight and not by volume. Pigments have varying densities and therefore cannot be accurately added volumetrically.

Always record the color and lot numbers of the pigments being used. In the event of a color issue, this will enable the pigment manufacturer to recheck the pigment for inconsistencies.

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Production Considerations

Everything a producer does in their plant to make production processes repeatable and standardized will improve the consistency of the color of finished pieces. Examining each part of production to create consistent, reliable, repeatable processes throughout the plant will help make more consistent colored concrete.

Planning for the Job – Mix Design Considerations

It is recommended to create mix designs with pigment addition rates between 1% and 5% of the weight of the cement. There are, however, many producers who regularly use less than 1%. This practice is not recommended because it is very difficult to control the weighments of all ingredients with enough accuracy to maintain color consistency at this low addition rate.

Keeping pigment additions at or under 5% is recommended because at higher additions the large volume of fines being added to the mix may reduce the compressive strength or lengthen the initial set of the concrete. In laboratory conditions all pigments except synthetic yellow iron oxide and burnt umber pass ASTM C979 at a 10% addition for compressive strength.

These two pigment do, however, pass ASTM C979 for compressive strength at a 7% addition rate.

Pigments can only be evaluated when mixed into concrete. Comparing pigment samples in the powder, liquid, or granular form will not give you reliable information about their acceptability. The same color formulation can look different in the raw state from batch to batch due to blending differences. If the difference is due to blend, the difference will be eliminated when mixed into concrete.

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Samples, Mock-Ups & Range Panels

When making any kind of samples, include the color number and lot number in mix design, along with the pigment addition rate. It is recommended to replace 12″x12″ samples at least every three years due to possible cement color changes, yellowing of cement over time, pigment lot retention and depletion of aggregates.

Range panels give the producer an opportunity to set expectations with an architect regarding the range of color that will be acceptable on a project. In order to create a range, the producer has to decide what components to change and by how much. Generally, DCS' recommendation is to make small changes to the pigment addition rate. This allows the producer to fabricate the range they want to present. Typically on lower pigment additions of approximately 1% changes of +20% and -20% addition will give a good range. Thus if the mix design were to call for 10# of pigment per yard, the producer should vary the higher range sample to 12# and the lower range sample to 8#. For pigment additions at the higher rate of 5%, changes of +15% and -15% addition will give a good range. So similarly, if the mix design calls for 35# of pigment per yard, the producer should vary the higher range sample to 40# and the lower range sample to 30#. Other changes can be made to the mix design or the finishing depth which will accentuate the range presented.

Water/Cement Ratio

It is commonly believed that water is the number one factor in color inconsistency. In an effort to understand that better, testing was done to examine color changes based on changing water cement ratio (w/cm). Samples were made from .35 w/cm to .55 w/cm, increasing at .05 increments. The results showed that from .40 to .50 w/cm there was virtually no change in color. This was somewhat surprising, but, ultimately, an incomplete analysis.

In closer examination of the samples at .35, .40, and.45 what became apparent is that there was a fairly significant color change between .35 to .40 and virtually no color change from .40 to .45. Based on this, the conclusion being drawn is when a producer is working in the lower w/cm range, below .40, changes in w/cm ratio have a fairly significant impact on the finished color of the concrete. Creating mix designs that are at .40 and above will make the control of w/cm ratio less critical. Water is always important to control, but the consequences diminish with slightly higher w/cm ratios.

In attempting to control w/cm ratio, all aspects of production need to be examined. Functioning moisture probes in the rock bins, sand bins, and mixer are critical to w/cm ratio control. Verification of moistures in the rock and sand with burn offs is a key check. Furthermore, It is critical to remove the ability for the batch plant operator to add discretionary trim water, and this is only possible with working moisture probes and batch controls that compensate for the changes in moistures.

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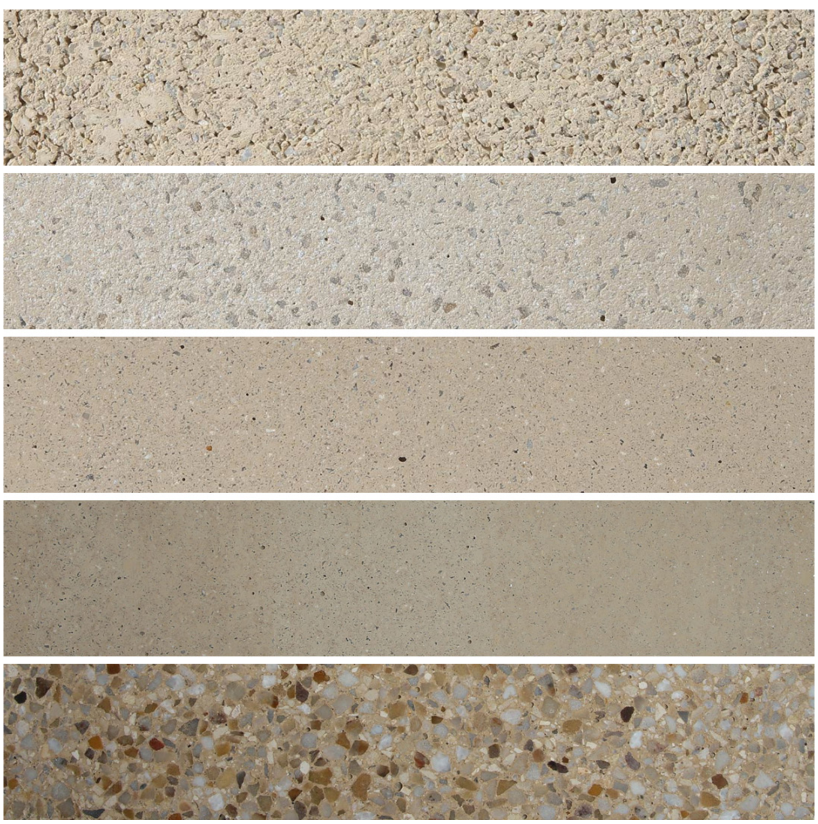
Producing the Job – Batching and Finishing Considerations

Batching

Always add the color at the same point in the mixing process. The recommended sequence is to dry-mix the aggregate, sand, cement, and color for a minimum of 30 seconds, then add the water and subsequent admixtures and continue to mix for an additional 2 minutes. It is imperative that the length of both dry and final mixing be consistent. The biggest potential problem with mixing is undermixing, which will result in streaks or blotches of color, especially when only a small quantity of color is added per batch. It takes a long time to evenly disperse a small amount of color in a huge mass of rock, sand, and cement.

Good overall control of your mix is one main key to making consistent colored concrete. This includes state of the art moisture control systems in all aggregate bins, and the mixer. Also, any admixture dispensers must be accurate and consistent. In general, the more factors that remain constant from batch-to-batch, the more consistent the finished color will be.



Finishing

The finish of the concrete has a profound impact on the finished color of the product. Form finish is not recommended unless variation in surface color is the desired look for the project. When consistent colored precast is desired, anything to remove the top paste from the piece will help consistency. The depth of exposure, through any means, sandblast, acid etch, retardation, must be consistent. Uneven depth of etch will cause color variation.

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Troubleshooting

Efflorescence

Efflorescence is a white, salty deposit of cement hydration products on a concrete surface. Capillary action transports soluble salts, most often calcium hydroxide, from within the concrete matrix to the concrete surface as it cures. Cold weather production tends to increase how often efflorescence occurs. In addition, darker or more intensely pigmented concrete has a greater tendency to show signs of efflorescence. It tends to be less visible on light-colored concrete. Efflorescence is more prevalent on a concrete surface that experiences repeated wetting and drying cycles. These cycles tend to draw soluble salts out of the matrix.

Efflorescence occurs when free salts are present in one or more of the raw materials and when these salts are dissolved and carried to the surface by water as drying occurs. If the cement contains free salts, changing to a low alkali cement, .6% or less, is recommended. Using washed sand and rock eliminates free salts in those materials. Pigment does not contain free salts, however it gives the existing free salts a contrasting background. Typically, this will make the presence of efflorescence much more visible.

There are admixtures that fill the capillaries within the concrete to block or reduce the movement of soluble salt through the concrete. These admixtures can reduce efflorescence but may not eliminate it altogether.

If efflorescence does occur and needs to be removed, there are specially formulated cleaners to wash away efflorescence. Specific recommendations are beyond the scope of this paper. Care must be taken when using any cleaners to be sure they do not affect the surface color of any piece being washed.

Conclusion

The biggest overall take away is that everything a producer does in their plant to standardize and make repeatable production processes will improve the consistency of the color of finished pieces. Examining each part of the process to create consistent, reliable, repeatable processes throughout the plant will help make more consistent colored concrete.

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