TECHNICAL BULLETIN

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Color in Architectural Precast, Cast Stone & Glass Fiber Reinforced Concrete (GFRC)

1. OVERVIEW

1.1. Architectural Precast / Cast Stone / Glass Fiber Reinforced Concrete (GFRC)

Architectural Precast, Cast Stone and GFRC are versatile, sustainable, affordable and resilient products that can create efficiencies by using building components manufactured off-site and delivered to the job site when needed. Whether using larger precast panels for cladding, cast stone trim to mimic natural stone or the limitless possibilities of glass fiber reinforced concrete (GFRC), all these materials allow for a wide variety of colors & textures. Just as natural stone from the same quarry or vein can vary slightly in color and shading, so does architectural concrete. There are many reasons why slight variations in appearance / color occur from piece to piece or panel to panel – strong quality control programs help ensure consistency in the color, appearance and strength of the final product.

THIS BULLETIN WILL:

1) Address expectations regarding color and color choice;
2) Review the factors that can affect the color of concrete, both during and after production;
3) Identify design considerations that affect color which specifiers should evaluate when designing a project; and
4) Identify considerations to take into account when reviewing samples and product.

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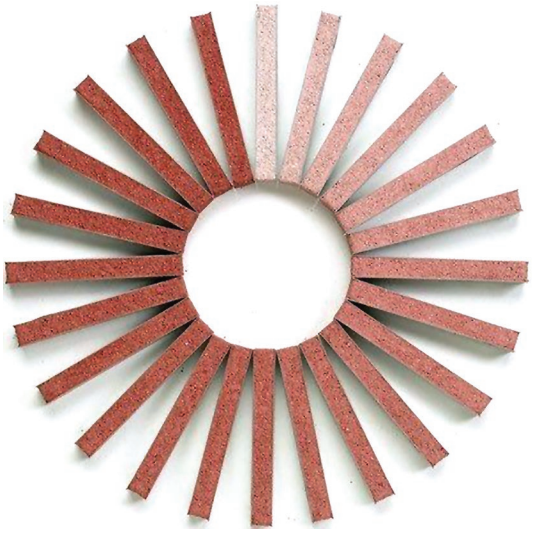
2. COLOR CHOICE

2.1. What is the right color?

There are a variety of questions that lead to the best color choice for a project:

- Are you trying to match an existing project or adjacent buildings?
- Are you trying to match or contrast adjacent materials?
- Are you trying to simulate natural stone or some other masonry product (brick, CMU, CIP)?
- Is this a project with an open or flexible palette?



In regard to color variation, designers should understand that different color ranges come with varying levels of risk. For example, dark colors with a high percentage of pigment, colors that are extreme / bold (blues and greens) and aggregates that contrast with the base mix's color can lead to a higher level of color variation (see Design Considerations below). Concrete is made from naturally occurring materials that will vary, so designers should expect some variation. Seek consultation from an APA Certified Plant to discuss color options and varieties in depth.

2.2 How do we communicate the color we are looking for?

- Specify an APA Certified Plant and advise that the design team will select a color from its standard range (grays, buffs, white, cream, etc.).
- Describe a custom color and a desired finish within the contract documents, educating bidders on what to expect. It is important for owners and owners' representatives to expect some variation in the finished product dependent on which color and finish are selected.
- Clearly state the design intent: matching a specific structure, mimicking a type of stone, etc.
- Include images, links, samples, etc.

2.3 How can we ensure that the manufacturer is aware of what will be acceptable when it comes to color variation?

- Require that a mock-up or sample panel be built to demonstrate finishes and treatment of actual sections, anchoring, color, finish, variation and overall application to compare with adjacent building materials. Require written approval before work begins.
- Request multiple rounds of samples, made on different days, to compare different batches and production runs of the required finish.
- Hold early conversations with the contractor and producer to establish clear and fair expectations.

3. FACTORS AFFECTING COLOR

First and foremost, the importance of a quality control program to ensure consistency in the color and appearance (as well as the overall quality and strength) of a concrete project cannot be overstated. Quality batching equipment will precisely control the addition of raw materials and minimize variation between batches. Adequately trained and certified production personnel and control systems ensure concrete is produced consistently throughout a project's production. This is why the APA Plant Certification Program requires that quality control personnel and batch plant operators be certified and tested. The program also conducts semi-annual, unannounced inspections, which assess more than 100 aspects of the manufacturing process.

3.1. Production Related Factors

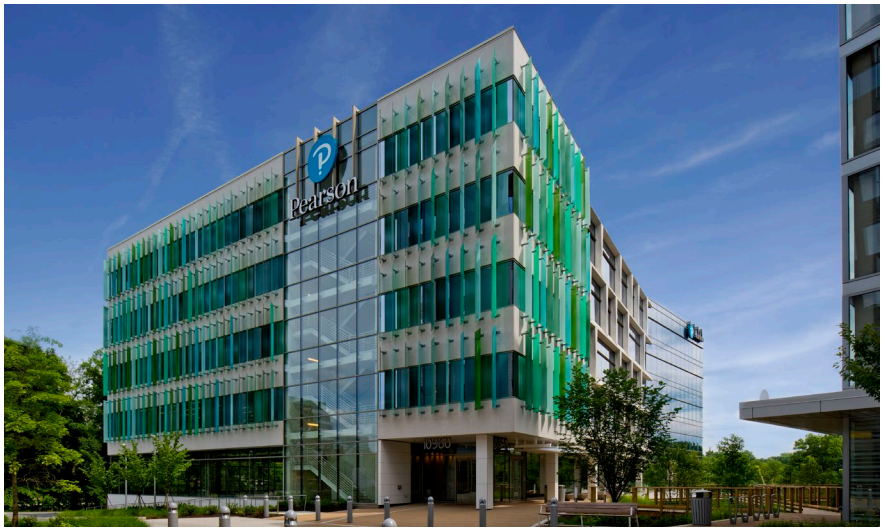
3.1.1. Batching

Extreme inconsistencies in water-cement ratios will create variations in color. Proper and consistent manufacturing controls, such as water flow meters and measurement of the moisture content in aggregates, remedy this.

3.1.2. Sequence of Events

A consistent mixing sequence when batching concrete helps color consistency. A good model for precasters to follow includes starting by adding the aggregate, sand and any water needed to pre-wet the aggregates and dry pigment (if applicable). Next, allow the mixer to churn before adding the cement. This helps disperse the pigment and uniformly blend the fine and coarse aggregate. Then add the cementitious materials, liquid pigment (if applicable) and the final batch water. Chemical admixtures should be introduced per the admixture manufacturer's and color manufacturer's recommendations.

When using lightweight aggregate, some producers add dry pigments near the end of the batching sequence. Porous lightweight aggregate can absorb pigment if incorporated before the cement. This can contribute to color inconsistency between batches. By adding the pigment after the cement and mix water, it will not be as readily absorbed by the aggregate.



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3.1.3. Mixing Time

Sufficient mixing time is needed to fully disperse the constituent materials and develop a homogeneous mixture. If the mixing time is not consistent from batch to batch, a slight variation in the achieved color, strength, durability and overall appearance can occur. Mixing times depend on mixer style, size of batch and the materials used. Liquid pigments are generally incorporated into the mix faster than dry pigments.

3.1.4. Curing

Consistency of curing times among pieces and panels before finishing helps minimize color variation. Architectural precast elements that receive a finish treatment within a day or two of being placed may look slightly different than elements finished after curing for a few weeks or longer. However, architectural precast pieces almost always mature into a more consistent color as time and temperature ages the concrete. Variations in color due to curing time typically arise when the time between production and delivery is short due to scheduling constraints.

3.1.5. Form Release

As with other materials, the same form release agent should be used throughout the production process. Using a different release agent manufacturer or using a different release agent from the same manufacturer may result in slight color changes. Overapplying release agent may also create a localized difference in color or lead to a greater concentration of bug holes (very small holes in the surface caused by the movement of air (and moisture)). These may be difficult to rub out or patch, again leading to a slight color variation.

3.1.6. Form Temperatures / Ambient Temperature Swings

Concrete and mold temperatures also can affect color, but in the long term any variances should even out over time. For example, a steel mold that is extremely cold the day before a warm front comes through may produce a slightly darker color.

3.1.7. Materials

3.1.7.1. Cement

White and gray cements are both used to produce architectural precast. White portland cement is considered more consistent in color than gray portland cement and will produce more consistent colored concrete. Typically, gray cement is not color controlled and may vary between shipments. However, these factors vary by region throughout the U.S. Light colored concrete or concrete with subtle or pastel colors is typically not achievable with gray portland cement. Discuss with your APA Certified Plant the type of cement that best suits your project's aesthetic and other needs.

3.1.7.2. Other Cementitious Materials

Some project specifications require the use of supplemental cementitious materials (SCMs) such as fly-ash, which can reduce the required cement content and benefit the concrete's mechanical performance. Like portland cement, these materials become part of the paste portion of the mix and will strongly affect the concrete's color. Many SCMs are produced as a waste or byproduct of other industries and are not controlled for color.

Light colored or white supplementary cementitious materials such as metakaolin, ground glass or pumice can be used effectively to produce colored concrete. Their color consistency will vary from source to source. As with all raw materials incorporated into architectural concrete, it is important for concrete producers to closely monitor their consistency and overall effect on the concrete's appearance and performance.

Fly-ash, a byproduct of coal-fired electrical power production, is widely used to good effect in the ready-mix concrete industry. However, it can vary widely in color from lot to lot depending on the source. Fly-ash is not recommended for use in concrete where color consistency is required. Not all SCMs are available in every region. Consult with an APA Certified Plant to determine what, if any, supplementary cementitious material is right for a given project.

3.1.7.3. Pigments

Architectural precast concrete widely uses pigments combined into concrete during the mixing process to obtain the desired matrix color. Most often these powerful coloring agents take the form of fine powders, granulated powders or liquid solutions formulated specifically for use in concrete mixtures.

Most pigments used to color concrete are iron oxide pigments – both natural and synthetic – and hence tend to be earth tones. Natural iron oxides are widely available in earth tone red, yellow ochres and umbers. Synthetic iron oxides are manufactured in shades of red, yellow and black. Other pigments are available to achieve green and blue shades.

All pigments should pass ASTM C979, Pigments for Integrally Colored Concrete. Pigments must be of high quality and be carefully controlled to produce a concrete project with minimal color variation. It is critical they be combined into the mixture according to the manufacturer's recommendations.

3.1.7.4 Fine and Coarse Aggregate Impact

Next to cementitious materials and pigments, fine aggregate (sand) has the strongest effect on concrete color. Sand is a naturally occurring material so its color must be carefully monitored and controlled. Light-colored sand should be selected for light-colored concrete, while darker sand may be appropriate to use for darker concrete elements. Dust from the aggregate's surface, very fine sand or any clay contaminants (if present) are incorporated into the paste portion of the concrete and can significantly alter the concrete's color. For this reason, washed or clean sand is preferred for producing architectural concrete mixes.

Coarse aggregates that contrast in color, when compared to the base color of the mixture, will more likely yield an inconsistent appearance than aggregates of a complementary color. Slight variation in the exposure level of an aggregate with a high degree of contrast can create a significant difference in appearance affecting the overall project's color and tone. That said, a perceived color variation may be due to the inherent variation within the aggregate(s), their exposure level and their influential role in the concrete's appearance, not the consistency of the mix.

Producers should source aggregates, both sand and stone, that are consistent in source, gradation and color. As a pit expands, these natural products will vary. A producer can do very little to eliminate these natural variations, besides monitoring incoming materials to ensure nothing is out of the norm.

Depending on the project size, schedule and budget the same aggregates should be used for the project's duration. Whereas this may not always be possible, it should be a goal toward achieving greater consistency. A wide variety of fine and coarse aggregate colors and appearances can be combined with multiple surface and finish treatments to produce diverse architectural options in precast concrete. Consult with an APA Certified Plant to determine what aggregate, finish and color combinations are available for a given project and budget.

3.2. Post-Production Related Factors

3.2.1. Finish Processes and Finish Depth

Architectural precast concrete, cast stone and GFRC offer an array of different finish and texture options. These include as-cast (form finish), acid etch, sand blast (at varying levels), and honed and polished.

As-cast finishes show the paste portion of the hardened concrete matrix and tend to be uniformly smooth with a flat, untextured appearance. As-cast concrete mirrors the surface of its form, showing even the slightest imperfections. Also variations between the pieces and within the pieces are more pronounced. If color consistency is a goal, an as-cast finish is not recommended. The smooth surface can accentuate even the smallest surface flaws such as bug holes, slight discolorations due to variations in the mold material or dust from within the forms.

Other finishing treatments etch or abrade away the paste to expose different aspects of the concrete matrix. To even out the color and texture of the finished product, some level of exposure is needed. Each finish can create a vastly different appearance, color and tone within the same color/mix design. Slight differences in the finish treatment's level, or depth, can create the appearance of color variation, even with pieces from the same batch.

A light finish or no finish will result in a greater color variation from piece to piece. Deeper finishes penetrate the concrete and expose more sand and stone causing the aggregate to have an increased effect on the overall color. Experienced producers have the expertise required to yield a consistent finish that reveals the beauty of the architectural concrete matrix and exposes the project's selected aggregates. Discuss with an APA Certified Plant the many finishing options available (acid etching, retarders, sandblasting, etc.) to achieve your design objectives.

3.2.2. Acid Burn

Acid burn occurs during the acid-etching process when the aggregate reacts with the acid and discolors, often turning a yellow or orange tint. Limestone-based aggregate is more susceptible to discoloration when exposed to acid solutions vs. silica-based aggregate. Acid burn can be eliminated or controlled by carefully applying the acid solution followed by a clean water wash to neutralize the acid.

3.2.3. Transport

Dunnage stripes (often caused by trapped moisture during shipping) take time and heat to dissipate but will eventually fade away. In addition, compressible shipping materials retain moisture. Sometimes these materials are needed and are appropriate. Any issues they create will typically resolve themselves over time.

3.2.4. Sealers

There are many different types of sealers and each has different qualities and properties. For example, sealers can be penetrating or film-forming, water-based or solvent-based, etc. It is very important to review product

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data in order to determine the potential effect on color variation. The production of samples with the preferred sealer should be utilized to detect how the sealer may impact the appearance of the concrete. If using a sealer, discuss the options and their product data with an APA Certified Plant.

3.2.5. Efflorescence

Efflorescence is a whitish 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.

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. Accelerators help because they reduce the time that water can move through capillaries. Retarders, on the other hand, extend the time. Likewise, SCMs that react with calcium hydroxide and pull it out of the solution reduce the occurrence of efflorescence. However, it is almost always present at some level.

Specially formulated cleaners can be used to wash away efflorescence if it occurs. Timing of the application of these treatments is important, so the efflorescence does not reoccur. Once the concrete is sufficiently cured and clean, sealers can prevent the wetting/drying cycle, greatly reducing the movement of soluble salts through the concrete matrix. Properly cured and finished, high-performing concrete mixes that produce dense concrete with low permeability can minimize the presence of efflorescence.

3.2.6. Installation / Job Site Storage

Once delivered to a job site, precast must be properly protected. It must be stored correctly if it is not installed immediately. In order to avoid staining, moisture damage and other problems with the finished product, discuss proper site storage with an APA Certified Plant.

4. DESIGN CONSIDERATIONS

As noted above, many factors can affect the color and appearance of architectural precast concrete. However, there are several design choices that can be made to help ensure more consistent color.

4.1. Color Choice

The components used in making concrete are based on naturally occurring materials. Therefore, it is easier to replicate natural/neutral colors on a consistent basis. Blue and green pigments are not only more expensive but they also require more care during finishing. They are more difficult to consistently reproduce. Designers should have a conversation with an APA Certified Plant about color choice for their project. If bold colors are desired, ask about their experience working with bold and/or pigment-heavy colors.

4.2. Mix Designs

The right mix design can minimize the degree of color variation. As discussed earlier, cement color, pigments, and fine and coarse aggregates will all affect the final product. Aggregates that complement the hue of the paste portion of the mix (as opposed to contrasting aggregate) will generally show less color variation in an architectural element or between elements when the finish depth varies. Dark aggregates in a light-colored matrix can yield dramatic effects but they are more susceptible to color variation. If the designer's goal is to highlight this type of contrast, it will be important to follow an APA Certified Plant's recommendations when specifying the mix to ensure the best possible outcome for the project.

4.3. Sealer Selection

As mentioned in section 3.2.4, sealers can affect the appearance of concrete. If you anticipate specifying the application of a sealer, be sure to have a conversation with an APA Certified Plant about the benefits and drawbacks of specific sealers.

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4.4. Viewable Surface Area

Consider the size of the viewable surface areas of the precast on the project. Then consider the options that can help provide better color consistency. Large viewable surface areas can be broken up into smaller sections to achieve an overall better appearance. A 10-by-30-foot panel with no reveals is not going to have as consistent an appearance as a similarly sized surface comprising smaller panels, or a similarly sized panel with vertical, horizontal or diagonal reveals. Using these simple architectural features can help achieve the desired architectural effect. They can also help create a more consistent appearance and should be discussed with an APA Certified Plant.

4.5. Vertical Casting

Architectural precast is almost always cast face down (horizontally) to simplify forming. This method also ensures the face of the product is as free as possible from tiny bug holes and other minor imperfections that may appear on the upper exposed surface. This upper surface will be the back of the product, which is not seen. Situations that call for monolithic returns or vertical casting increase the opportunity for imperfections in concrete. This is sometimes referred to as sagging or drapes in GFRC. Discuss ways to avoid situations that result in vertical casting with an APA Certified Plant.

5. SCHEDULING FACTORS

Ensuring the design and production teams are on the same page regarding timetables and other expectations on the front-end of a project will ensure the best possible product arrives on-site, when needed. Architectural precast is a custom, hand-made product. Unrealistic expectations, poor planning, expedited schedules, incomplete drawings and a variety of other factors can result in the sacrifice of overall quality, including color consistency, of architectural precast.

6. REVIEW

Considerations to Take into Account When Reviewing Samples and Product

6.1. Lighting conditions, weather conditions (humidity/moisture) and distance...

are key factors when reviewing samples and finished product. The commonly accepted standard for review and acceptance of finished product are:

6.1.1. Concrete should be evaluated...

under lighting conditions that will be typical for the architectural element when it is in service.

6.1.2. Concrete should not be evaluated...

when light is illuminating the surface from an extreme angle or across the concrete surface. The shadows caused will accentuate minor surface irregularities.

6.1.3. Concrete should not be evaluated...

in high-moisture atmospheric situations such as rain, fog and snow, as moisture can affect its appearance.

6.1.4. There should be no obvious imperfections...

other than minimal color and texture variations when viewed from a 20-foot distance with the naked eye.

All these factors underscore the importance of the essential need to determine permissible variations when mock-ups are approved.

Pinchin & Burke Residence Halls - Colgate University
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CHECKLIST TO ASSIST WITH OVERALL COLOR CONSISTENCY

Specify an APA Certified Plant and:

- ❑ Discuss color choice early in the design process.
  - ❑ If using bold colors, ask producers about their experience working with bold/ pigment-heavy colors.
  - ❑ Determine the aggregate, finish and color combinations available for your project and budget.
- ❑ If aggregate is going to be used to achieve contrast, discuss mix design to ensure the best possible outcome for your project.
- ❑ Address the type of cement that best suits the aesthetic and other needs of your project.
- ❑ Identify the finishing option(s) (acid etching, sandblasting, etc.) that best meet the design objective.
- ❑ If the use of sealers is anticipated, have a conversation about the benefits and drawbacks of water-based, solvent-based, penetrating, film forming, anti-graffiti and other types of coatings.
- ❑ Discuss ways to avoid situations that result in vertical casting.
- ❑ Consider the use of reveals to help achieve desired architectural effects and create a more consistent appearance.
- ❑ Address anticipated delivery timelines and proper on-site storage of the finished product.

RESOURCES

Architectural Precast

Master Spec 03450 - Architectural Precast Concrete
ACI PRC 533.1R-02 Design Responsibility for Architectural Precast Concrete Projects
ACI PRC 533R Guide for Precast Concrete Wall Panels

Cast Stone

Master Spec 04720 – Cast Stone
Standard Specification for Architectural Cast Stone
ADD ASTM C1194-18 Standard Test Method for Compressive Strength of Architectural Cast Stone
ASTM C1195-18 Standard Test Method for Absorption of Architectural Cast Stone
ASTM C426-16 Standard Test Method for Linear Drying Shrinkage of Concrete Masonry Units
ASTM C 979 - Standard Specification for Pigments for Integrally Colored Concrete.
TMS 404 / 504 / 604 - Masonry Society "Standards for Architectural Cast Stone Design, Fabrication and Installation"

GFRC

Master Spec 034900 – Glass Fiber Reinforced Concrete

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