## CEMEX USA - Technical Bulletin 8.0

# Manufacturing Quality Concrete Products

*Establishing or Upgrading a Quality Program*

**Overview**

The following guidelines were developed for MCP (manufactured concrete products) producers to assist in the manufacture of quality products on a regular basis. These are best practices that may be incorporated into the producer's quality assurance program. These guidelines are broken up into 6 steps.

**Step 1 – Quality Program**

The first step in manufacturing any product consistently is having a documented Quality Assurance Program. Everyone in the company should buy into the program and recognize how their job has a positive impact on the bottom line. Besides the responsibility of meeting high industry standards, your customers (and their customers) expect top-notch quality consistently.

**Step 2 – Raw Materials**

The quality and consistency of materials used in manufacturing concrete products is extremely important. Materials should meet relevant standards (i.e. ASTM); however the most important issue is how to they perform in your manufacturing process & environment.

The material supplier should be reliable and aware of the characteristics that you expect. The quality of materials should be monitored on a regular basis. It is much better to catch potential problems or make design adjustments before manufacturing questionable or poor quality units.

*Cement* is obviously very important since it is the glue that holds the matrix together. As specified in Section 4 of ASTM C 90, C 936, and C 1372, the cementitious materials should meet the minimum requirements of ASTM C 150, C 595, or C 1157. For quality purposes it should be consistent in color and performance over time. The cementitious content of concrete product mixture designs varies by region, materials, equipment, and product type. Below are some typical products & cement contents (in percent by batch weight).

- Standard Gray CMU (Concrete Masonry Unit) 8-10%
- Architectural CMU (often split face) 10-12%
- SRW (Segmental Retaining Wall Units) 11-14% (13-14, freeze/thaw applications)
- Interlocking Concrete Paving Units 14-18%
- Other Concrete Landscaping Products Vary with performance requirements

*Aggregates* should meet the requirements of ASTM C 33 (normal weight) or ASTM C 331 (lightweight) or be proven to provide minimum performance and desired characteristics in the final product. There are several types of aggregate available regionally with varying degrees of strength, hardness, density, absorption, gradation, particle shape, color, etc.

Since MCP mixtures use a much finer aggregate blend (than ready-mix type), it leans out the cement paste further (due to more aggregate surface area) and therefore, plays a very important role in the concrete performance. Many producers have the capability to blend 3 to 5 different aggregates (the more aggregates blended, the less significant individual aggregate changes will influence performance). The individual and composite gradations should be monitored on a regular basis to maintain consistency in production and performance.

Aggregate moisture should be monitored as well, especially with lightweight aggregate. This is discussed further in the production section.

*Water* should be potable (drinkable) and accurately dispensed into the mixing vessel. Even though these concrete mixtures appear very dry, the water/cement ratios are similar to typical ready-mix designs (0.35-0.50).

*Pigments* have become an important part of concrete products over the years, and in some areas, production of colored units has become greater than standard gray units. Pigments can be purchased in three forms (raw powders, granulated, or liquid). One of the most common for the MCP market is the granulated pigment. Many large producers now use automated systems. The minimum requirements for pigments can be found in the ASTM C 979 standard. While the quality of pigment (i.e. tinting strength and particle size distribution) is extremely important, there are several other factors that will also have an effect on the final color of the product, such as loading rate (% by cementitious weight), water/cementitious ratio, aggregates, curing, and the degree of potential efflorescence on the concrete surface. The main issue with maintaining homogeneous color is the overall consistency of all the above.

*Admixtures* should be supplied by a reliable provider that can guarantee consistency over time and preferably supply and maintain dispensing equipment. While quality concrete products can be manufactured without admixtures, they generally provide benefits to both the producer and end user.

Admixtures formulated for MCP mixtures are *not* required to meet ASTM C 494 (which is a specification for wet-cast or slump concrete mixtures). Plasticizing admixtures designed for “dry-cast” concrete mixtures may enhance production output, cement contents, strength, density, durability, and/or machine/mold wear. Water-repellent/efflorescence-controlling admixtures are used to reduce absorption rates, improve color vibrancy, and lower efflorescence potential. Both can help achieve desired surface texture as well.

*Other cementitious/pozzolanic materials*, such as slag, fly ash, or silica fume, may be used as a partial cement replacement (typically 10-20% range). Fly ash is one of the most popular materials and the two concerns with its use are typically early strength and color consistency over time. The ASTM standards for fly ash, slag cement, and silica fume are C 618, C 989, and C 1240, respectively.

### Step 3 – Mix Design Optimization

Unless the plant is a start-up operation, most concrete mixture designs have been set up (but may be evaluated for further optimization). Most MCP producers batch materials by weight formulas instead of by volume.

First, look at the cementitious content to see if it is near the ranges given in the previous section. Next, consider that many producers have had success using supplemental cementitious materials such as fly ash, slag, or silica fume to enhance mixture designs (again consistency is key, especially with color products). The use of plasticizing admixtures may provide additional strength, density, or potential cement reduction (test samples are typically provided by the supplier).

As mentioned in the aggregate section, it takes more cement paste to cover the higher surface area. The overall aggregate gradation is very important and the better the fit of aggregates, the less cement paste is needed to fill the gaps. Typical “best-fit” curves can be used to analyze and optimize your aggregate gradation such as the one shown in Figure 1. These curves were designed for best granular flowability, compaction, density, and performance. Different curves have been developed for various products.

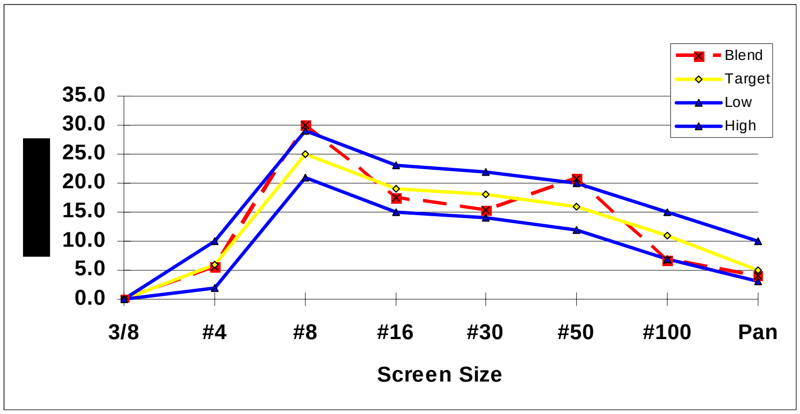

Figure 1 (Best Fit Curve, Architectural CMU)

For complete mixture optimization, trials are recommended to demonstrate the best production, appearance, performance, and profitability. When comparing mixture designs, wet densities should be considered along with surface appearance and cycle times. Many vendors offer technical consulting services as well.

### Step 4 - Production

All batching equipment should be checked on a regular basis to assure accuracy. One area that seems to be difficult to monitor is the moisture in the aggregates. If not adjusted, significant water contributed by wet aggregates will increase designed water/cement ratio, lighten color, increase chipping & efflorescence potential, and lower strengths, durability & density of final product. On the other hand, aggregates that are too dry can also negatively impact manufactured concrete products by absorbing moisture needed for cement hydration and/or workability.

Consideration should be given to the “free-moisture” that may be contributed by wet aggregates. Free moisture is that moisture above and beyond what the aggregate can absorb. For example, if an aggregate is found to have 8% total moisture and has a 3% absorption rate, it is contributing 5% free moisture (if 5000 lbs. of this aggregate were weighed, 250 lbs. should be considered mix water). In order to actually batch the correct amount of aggregate with this moisture, 5263 lbs. should be weighed (then the 263 lbs. of free-moisture would be included as mix water).

Since production equipment types/brands vary considerably, most manufacturers offer training programs for machine operators regarding efficient usage of the equipment. Plasticizing admixtures have been developed for MCP mixtures that can enhance the production (i.e. shorter cycle times, less mold & machine wear), product appearance and performance characteristics. When evaluating various plasticizers, it is important to analyze cycle time, density, strength, and appearance of the units.

Mixing concrete thoroughly is very critical along with the sequencing of raw materials. In general, the following guidelines typically produce homogenous concrete mixtures for MCP production.

- blend aggregates & partial mix water (mix 30-45 seconds, lightweight 75-90 seconds pre-wet mixing)
- add cement (mix minimum 45-60 seconds)
- final water & admixtures (mix minimum 60-75 seconds after all ingredients added)
- total mix time 5-6 minutes optimum, depending on equipment mixing efficiencies

As mixing equipment (paddles, blades, etc.) become worn, the mixing action will be less efficient and may require longer mixing cycles to acquire a homogeneous mixture.

On-line inspection, including visual appearance, ease of feed/finish times, and wet density evaluation, should be conducted on a daily basis and whenever a change in product or process had been made. The most accurate check on density (unit weight) is to weigh the units on the pallet and subtract the actual pallet weight (and divide by number of specimens to get a weight per unit). An alternative method is to scrape off one unit into a container and record the net weight (a thin sheet of plexiglass or other rigid material may be used to place in between units, allowing for a clean swipe off the pallet).

**Step 5 – Curing**

Lack of curing in concrete can lead to a loss of up to 50% of the strength of the same mixture properly cured. The main concept of proper curing is to prevent moisture loss in concrete so that the cement can hydrate. Increased temperature will accelerate set time & strength gain.

Steam curing is commonly used since it provides moisture & high temperatures. Products should set for 2 to 3 hours prior to steaming (premature steaming may lead to case-hardening). A maximum rate of $60^0$ F per hour temperature rise (or drop) in the concrete is a good rule of thumb. Steam should be shut off at equilibrium (when concrete will gain no further weight or when the inside concrete temperature is equal to the ambient air temperature of the kiln). While equilibrium typically occurs at $130\text{-}180^0$ F, the time will vary with kiln size, type of product, rate of temperature gain, insulation and starting temperature. After the steam is shut off, the concrete should go through a soaking period (4-6 hours is typical) prior to ramping down the temperature. Pulling product from the kiln can be accomplished as early as handling can be performed without damaging the product. Temperature and humidity probes can be used to evaluate kiln efficiencies as shown in Figures 2 and 3.

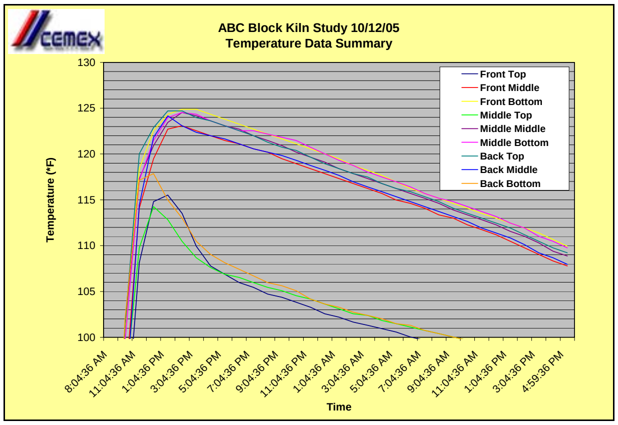


Figure 2 (Temperature Analysis of Kiln)

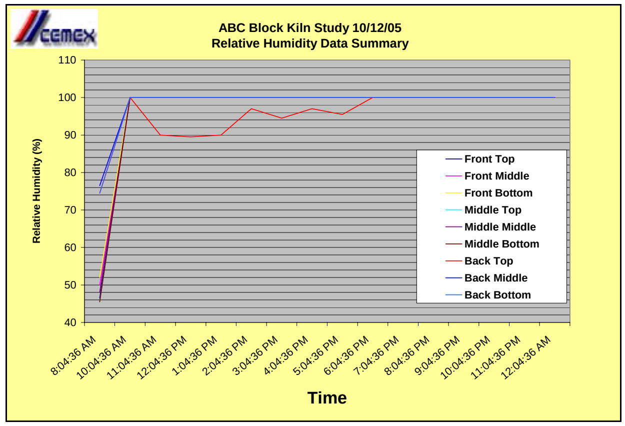


Figure 3 (Relative Humidity Analysis of Kiln)

**Step 6 – Quality Control & Continuous Improvement**

As part of a successful Quality Program, everyone needs to "buy-in" to the process. All levels of employees need to understand that their job is important and that their results all combine to create quality products. Quality Control is making the quality as designed, while Quality Assurance is the program that assures quality through out the entire process. The producer may choose to have their own internal QC requirements set above and beyond those of the ASTM product specifications. This way if a product is border-line to the internal QC specification, it will still exceed the ASTM standard.

For **CMUs** (concrete masonry units), the product should meet the current minimum requirements of ASTM C 90, the Standard Specification for Loadbearing Concrete Masonry Units. It is suitable for loadbearing or non-loadbearing units.

At time of delivery to the purchaser, the units should have at least 1900 psi net compressive strength (average of 3 units, with no individual result less than 1700 psi) and absorption rates less than 13 lb/ft$^3$ for normal weight block (125 lb/ft$^3$ or higher), 15 lb/ft$^3$ for medium weight block (105-125 lb/ft$^3$), or 18 lb/ft$^3$ for lightweight block (less than 105 lb/ft$^3$). ASTM C 140 covers the sampling and testing methods for dimensions, compressive strength, absorption, unit weight (density), and moisture content of the units. There are also dimensional tolerances and a maximum linear shrinkage requirement of 0.065% (ASTM C 426).

For **SRWs** (segmental retaining wall units), the product should meet the current minimum requirements of ASTM C 1372, the Standard Specification for Segmental Retaining Wall Units.

While the water absorption requirements are the same as for CMUs, the minimum strength requirement is higher (3000 psi, average of 3 units with no individual result less than 2500 psi). For areas where repeated freezing and thawing under saturated conditions occur, durability must be demonstrated by proven field performance or test. If test is specified, ASTM C 1262 is required. The weight loss of 5 specimens (also cut coupons) should be no more than 1% over 100 cycles (or 1.5% over 150 cycles in 4 of the 5 specimens). Some states may require testing in saline solution versus water, which is a much more severe test. This method is being evaluated for its high degree of variability. It has been proven that cement content, aggregate durability, absorption rate, and density will have the greatest impact on freeze/thaw performance. Aggregates can be analyzed for soundness under ASTM C 88, although this is still no assurance that the SRW will pass the stringent freeze/thaw test. The best practice for making durable units includes using sound aggregates, increasing cement contents (13-15%

minimum), mixing a little wetter & longer than normal, increasing compaction (increased density and lower absorption). Some admixtures have also demonstrated the ability to improve freeze/thaw resistance in these products.

For **concrete paving units**, the product should meet the current minimum requirements of ASTM C 936, the Standard Specification for Solid Concrete Interlocking Paving Units.

At time of delivery to the work site, the units should have at least 8000 psi (pounds per square inch) net compressive strength (average of 3 units, with no individual break less than 7200 psi) and absorption rate no greater than 5% (average of 3 units, with no individual unit greater than 7%). ASTM C 140 covers the sampling and testing methods for dimensions, compressive strength, absorption, unit weight (density), and moisture content of the units. There are also dimensional requirements listed in ASTM C 936.

Within the specification there is also a freeze/thaw requirement that states products should be tested for resistance (according to ASTM C 67, which is scheduled to be updated to C 1645) at least every 12 months (or satisfy purchaser by demonstrating proven field performance). Finally, there is an abrasion test (ASTM C 418) that is required (with no maximum time frame or statement about satisfying the purchaser with proven performance). This is a specialized test and is not commonly requested.

For all of the MCP types referenced, there may be occasions where specifications call for more stringent requirements than the corresponding ASTM standards.

Quality Assurance should be a continuous improvement process. A documented QA/QC Program is highly recommended and all records should be maintained. Regular meetings with all levels of operations are helpful to show progress (or regression) and plans for improvement. Continue to optimize the process over time.

*References:*

*ASTM C 33, C 67, C 88, C 90, C 140, C150,C 133, C 426, C 494,C 595, C 618, C 936, C 979, C 989, C 1157, C 1240, C 1262, C 1372, C 1645 (standard specifications & test methods), American Society for Testing and Materials, West Conshohocken, PA*

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