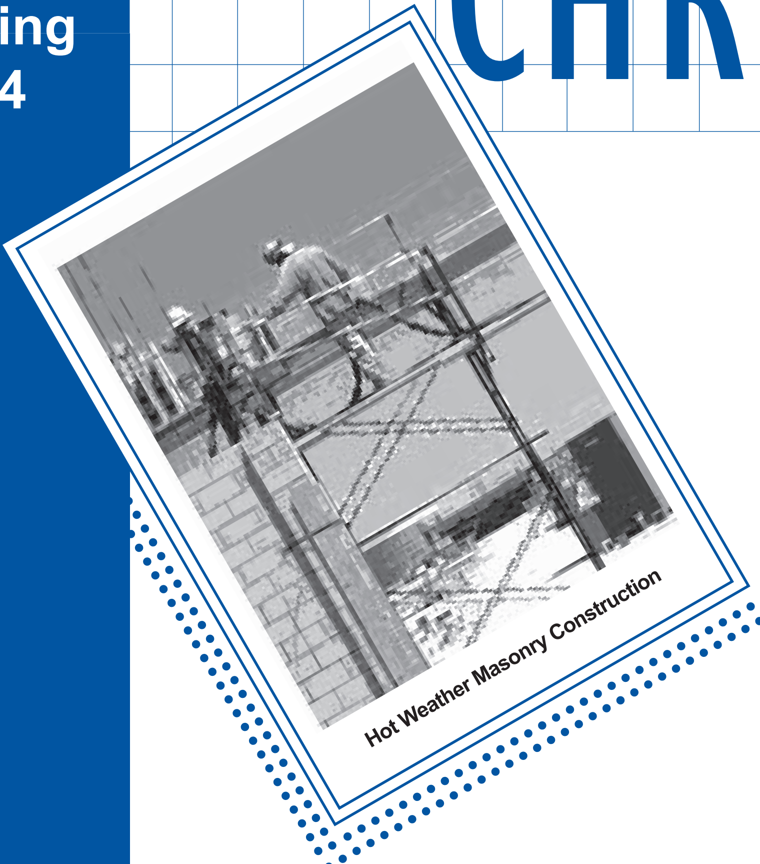
Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

Spring 2004



Hot Weather Masonry Construction Limiting your Exposure

Introduction

Those who design with masonry appreciate its appearance, durability, flexibility, and rapid rate of construction. We also know it as a construction material whose final product is dependent upon the quality of its individual components and the care and craftsmanship taken to assemble them. Under normal working conditions this care is often challenged by the unique shapes and congested reinforcing cells that must be accommodated. When environmental conditions become extreme, maintaining good quality becomes increasingly difficult.

This article addresses one particular environmental factor that rarely gets much attention - hot weather. It will explore the effects that hot weather construction can have on the overall quality of masonry construction and to recommend some provisions to help mitigate poor results. Included are some suggestions taken directly from ACI 530.1-02/ASCE 6-02/TMS 602-02 "Specification for Masonry Structures". These same provisions are also included as part of the 2001 IBC. Also included, are a number of suggestions for items such as pre-construction meetings and required submittals that specifically address the safeguards to be taken when hot weather conditions exist. The intent is to get everybody thinking about the possibility of encountering these conditions and having plans ready to execute in case they do occur.

Signs of Hot Weather

Most of the challenges associated with hot weather masonry construction are similar to those of concrete and relate to an increased rate of hydration and an increased rate of evaporation of the grout and/or mortar. Where proper provisions are not implemented, the following undesirable affects could be encountered during construction:

- Decreased 28-day strength.
- Decreased workability and increased rate of stiffening
- Excessive shrinkage and poor bonding of grout to concrete masonry units
- Moisture kiss

Poor quality of masonry construction during hot weather can also be exacerbated by several other common practices that should be considered in conjunction with any special procedures that may be developed. These items include:

- High lift versus low lift grouting techniques and consolidation
- High slump grout mix and pumping
- Use of admixtures

Each of these items is discussed below in more detail within the following sections.

Curing and 28-Day Strength

During periods of hot weather, the ultimate design strength of both mortar and grout can be compromised. This reduction in strength is generally due to both the increased ambient temperature and/or low humidity, and to the additional water that must often be added to achieve the same workability. High curing temperatures, for example, tend to promote higher initial strengths (1-Day), but ultimately lead to a reduced 28-Day Strength. This relationship is illustrated in figure 1 below. Note that an increase in ambient air temperature of roughly 65°F will cause a strength decrease of approximately 30%. Low or even decreasing relative humidity, a factor often associated with high temperatures, will likely promote further strength reductions. Since grout and mortar are both cement-based materials of similar composition to concrete, the same conclusion could be drawn for these materials.

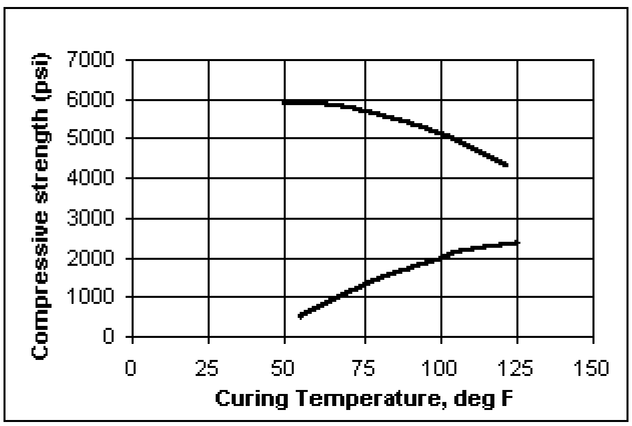


Figure 1 Effects of Curing Temperature on Concrete Strength

Workability & Stiffening

Aside from curing temperature, the amount of water in a mix is the other factor that will significantly influence ultimate design strength. During hot weather conditions, water is often added to grout and mortar at the jobsite to maintain effective pumping and workability. This need for increased water is caused by higher rates of water evaporation and higher initial mix temperatures. Unless more cementitious materials are added, or a portion of the mix water was initially left out at the batch plant, the resulting grout and mortar will most likely exhibit decreased strength and durability. Aggregate or cement that is left out in the sun, for example, will retain considerable heat and lead to higher mix temperatures. This higher initial mixing temperature will subsequently require more water to maintain the same slump. Figure 2 indicates that a 1-inch difference of slump can be expected for each 20° F change in concrete temperature. This figure also illustrates that at 60°F, it takes approximately 2.25% more water to increase the slump 1". Where concrete temperature has reached 125° F, the same 1" increase in slump would require approximately 4½% more water. This is obviously a non-linear relationship with progressively far more water required at higher mix temperatures.

Once mixed, the usable life for both mortar and grout are obviously limited. This shelf life is largely dependent upon mix consistency, temperature during set, and the rate of water loss caused by evaporation or absorption to the adjacent block.

Although the reaction between cement and water are very complex, one can generally assume that the reaction rate or stiffening will double for each increase of 20°F in mix temperature. Most codes allow for a one-time re-tempering of mortar with water to maintain workability, but state that mortar must be discarded 2 ½ hours after initial mixing. Grout, by contrast, generally has enough water so set time is not generally as critical. Even so, care must be taken to limit grout placement such that re-consolidation between successive lifts can be conducted within one hour of placement.

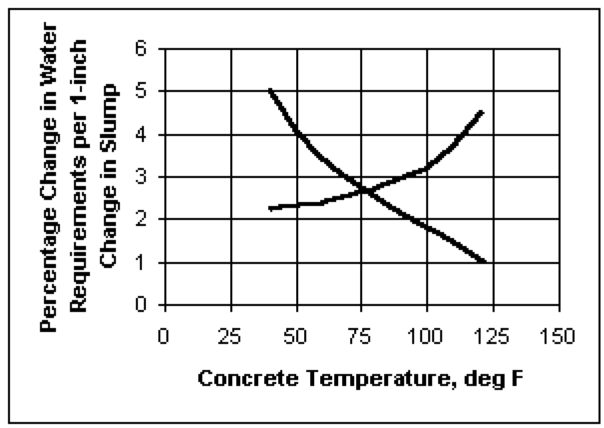


Figure 2 Effects of Temperature on Water Requirements

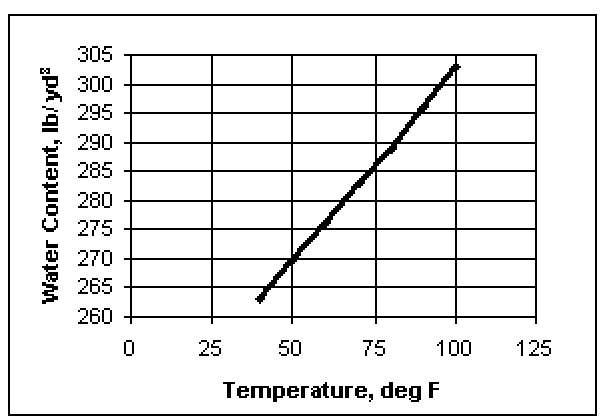


Figure 3 Effects of Concrete Temperature on Slump & Water

Excessive Shrinkage and Poor Bonding

Construction of concrete masonry generally requires high slump grout mixes and small aggregates that can be easily pumped into congested spaces. Under normal environmental conditions, mixes with such a significant amount of water and high fine-aggregate contents will experience considerable plastic and drying shrinkage that must be considered. This problem is often exacerbated during hot weather as water requirements increase without design mix modifications.

Plastic shrinkage, or the loss of volume during initial setting, occurs when the rate of evaporation exceeds the rate of bleed water migrating to the surface or when mixing water is rapidly drawn out of the mix by contact with the block. For both mortar and grout, this rapid water loss can lead to unsightly cracks, poor bonding, and on occasion, a cement paste that is under-hydrated. Proper consolidation and especially reconsolidation after excess moisture has been absorbed, but before plasticity is lost, is the first line of defense against this problem. Improved mix designs that incorporate water reducing, retarding, and expansive agents1 are another item that may be considered.

Drying shrinkage, in contrast, occurs after grout or mortar has set and is caused by the continued loss of water over years. This shrinkage is largely dependent upon the original content of water within the mix, the proportion and properties of coarse and fine aggregate, and the curing conditions. An increase in mixing water of 1%, for instance, will generally produce a 2% increase in shrinkage. Soft aggregate or those that absorb considerable moisture are also more prone to drying shrinkage.

CMU and Moisture Kiss:

The use of concrete masonry units is advantageous as it permits intricate work in tight conditions and eliminates the use of additional wood or steel forms. During periods of hot weather, however, special attention should be given to these blocks as they can significantly influence the characteristics of the grout mix as placed. Blocks that are excessively hot or dry, for instance, can cause rapid moisture loss in the grout and significant plastic shrinkage as described above. This rapid loss of mix water, which is labeled "moisture kiss," can even rob mortar of the water required to fully hydrate and exacerbate the ability of the grout to properly bond to the inside face of block. Similar to grout, mortar can also experience a rapid moisture loss where blocks are excessively hot and dry leaving mortar partially un-hydrated and with decreasing strength. Exposed surfaces of these joints are particularly susceptible since they are also subject to a higher rate of evaporation. This may leave the finished mortar joint sandy or chalky to the touch with reduced strength and durability.

Suggested Guidelines for Hot Weather

Poor results due to hot weather conditions can be linked to high ambient air temperature, low relative humidity, wind speed or any combination of these factors. To be effective any triggers linked to these factors must be practical, easily distinguished and applied to each sequence in the construction process. To this end, the Masonry Standards Joint Committee (MSJC) has established special provisions that must be followed whenever hot weather conditions exist. These guidelines are shown in matrix form in table's 1a, 1b, and 1c below and are divided up into requirements during preparation of the masonry work (prior to construction), during construction (work in progress), and for protection (after masonry elements are constructed). These guidelines are followed by some additional suggestions that can be either incorporated into design specifications, or discussed at pre-constructions meetings as appropriate.

Table 1a: Preparation (Prior to conducting masonry work)

Condition	Requirement
Ambient Temperature exceeds 100°F or exceeds 90° F, with a with a wind velocity greater than 8 mph.	1. Maintain sand piles in a cool loose condition. 2. Provide necessary conditions and equipment to produce mortar having a temperature below 120°F[2]
Ambient Temperature exceeds 115°F or exceeds 105°F, with a with a wind velocity greater than 8 mph.	In addition to the requirements above, provide the following: Maintain sand piles in a damp loose condition

[1]Admixtures, especially those containing water reducers, should be tested with a particular mix well in advance of use to ensure good performance and compatibility with the remaining mix components.

[2] Most building codes limit concrete temperature at time of placement to 90°F.

Table 1b: Construction (While masonry work is in progress)

Condition	Requirement
Ambient Temperature exceeds 100°F or exceeds 90°F, with a with a wind velocity greater than 8 mph.	1. Maintain temperature of mortar and grout below 120°F 2. Flush mixer, mortar transport container, and mortar boards with cool water before they come into contact with mortar ingredients or mortar. 3. Maintain mortar consistency by re-tempering with cool water. 4. Use mortar within 2 hours of initial mixing.
Ambient Temperature exceeds 115°F or exceeds 105°F, with a with a wind velocity greater than 8 mph.	In addition to the requirements above, provide the following: 1. Use cool mixing water for mortar and grout. Ice is permitted in mixing water prior to use. Do not permit ice in mixing water when added to other mortar and grout.

Table 1c: Protection (While masonry work is curing)

Condition	Requirement
Ambient Temperature exceeds 100°F or exceeds 90°F, with a with a wind velocity greater than 8 mph.	1. Fog spray all new completed masonry work until damp at least three (3) times a day until masonry work is three (3) days old.

Additional Considerations

Testing Mortar and Grout Temperature: As discussed above, the temperature of mortar and grout at placement has a significant effect on the final strength development and extent of shrinkage that will result. As noted in Table 1, the MSJC recommends keeping temperature of both of these constituents below 120°F to limit detrimental effects. In general, grout mixes rarely exceed 90°F as delivered to the job site due to the large quantity of water within a typical grout mix. In the author's opinion, 90°F may be more appropriate to provide consistency with concrete codes. These temperatures should be taken at the point of hose discharge or at the smaller mortar piles where block is being constructed.

Long black hoses exposed to the sun can significantly alter the grout temperature as placed. To help alleviate this problem, hoses should be shaded and flushed with cold water whenever possible. Wetting down the hoses with cold water at regular intervals is another option that can help reduce temperatures.

Proper Consolidation: Ensuring proper consolidation for grout is perhaps the most important safeguard that can be put in place under any weather conditions. Grout must be initially consolidated to ensure complete filling of voids, and then reconsolidated after excess moisture has been absorbed but before plasticity is lost. The timing for this second consolidation is critical for success and takes experienced workers and ample manpower. Under extreme conditions and where cells are congested, low-lift grouting may be more appropriate than high-lift grouting techniques. The reader is referred to the CMACN for procedures on high-lift versus low-lift grouting procedures.

Admixtures: Water-reducing or water-reducing and retarding admixtures can help improve workability by slowing down the initial rate of hydration and the stiffening process, as well as increasing the workability by decreasing the water demand. Some admixtures also contain components, which provide an expansive action that helps counteract shrinkage due to volume loss. All admixtures should be properly tested or have sufficient data to verify compatibility with the mix design prior to use.

Aggregate: Initial aggregate temperature will generally have the greatest affect on the initial temperature of the mix. This is due to the high relative mass and specific weight as compared to the other components. As mentioned above, aggregate supplies should be kept shaded or occasionally sprayed down to keep temperatures as low as practical. Where water is used to wet down the aggregate, care should also be taken to ensure consistent overall water cement ratios of the grout mix.

Use of Fly ash: Many suppliers recommend adding up to 15% fly ash to grout mixtures to help control the unsightly affects of efflorescence. Under the right conditions, fly ash can also help improve workability, slightly retard setting time, and increase 28-day design strength, as well as ultimate strength at later ages. Similar to admixtures, any mixes incorporating fly ash should be substantiated by previous testing data or be tested by trial batches to ensure proper results are achieved.

Water: Control of water quantities and temperatures are essential during hot weather. Reducing the temperature of water has been shown to be one of the most effective methods for controlling mix temperatures as placed. Water has a specific heat of approximately 4 to 5 times that of cement or aggregate and as such has the greatest effect per unit weight on initial mix temperature. Careful consideration should be given to initial water temperatures at the batch plant, as well as any water added on site to the grout. Maintaining cool mixing water at the site for both mortar and grout may be best accomplished with ice although any ice must be completely melted before mixing.

Alternate Grout Mix Designs: Alternate grout mix submittal may be advantageous during hot weather conditions. Such mix designs should be substantiated by previous test data or tested well in advance.

Preplanning: Last minute adjustments made to address hot weather conditions are rarely effective. Preplanning should start well before construction operations begin and be accompanied with specific procedures that are reasonable and understood by all parties. Decisions whether or not to implement these procedures should be made at least the day before construction begins and can be easily tied to local weather forecasts.

Employee Concerns: Working with masonry is physically demanding enough without soaring temperatures. Working in these conditions without additional precautions can lead to decreased productivity and care in quality, and increased injury and illness. Although there is little that a practicing engineer can do to dictate when, where, and for the most part how the work will be carried out, at least mentioning such items during the pre-construction couldn't hurt. Some suggestions that may be made include:

- Gradually adapting workers to the more strenuous tasks
- Preplanning work to and ensuring estimated daily goals are reasonable under the more difficult conditions.
- Postponing the most difficult tasks to cooler mornings or late evenings

Previous Test Reports: Grout is generally specified by proportion of volume or by minimum compressive strength. Where previous test reports are available, review of dates and listed temperatures may provide a rough guide to anticipate how the mix may perform during hot weather. Specifications could require any previous test data categorized this way. You may also want to verify that the original mix design and corresponding water-cement ratio was proportioned for hot-weather conditions.

References:

1. Building Code Requirement for Masonry Structures
   ACI 530-02/ASCE 5-02/TMS 402-02
2. 2001 California Building Code, Volume 2
3. 2003 International Building Code
4. ACI Manual of Standard Practice 2004, Part 2
   ACI 305R-99 Hot Weather Concreting
5. Specification for Masonry Structures
   ACI 530.1-02/ASCE 6-02/TMS 602-0

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