Mortar

ASTM C91 Specification for Masonry Cement
ASTM C144 Specification for Aggregate for Masonry Mortar
ASTM C270 Specification for Mortar for Unit Masonry
ASTM C780 Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
ASTM C1329 Specification for Mortar Cement
ASTM C1586 Standard Guide for Quality Assurance of Mortars

M a S o N w O r K

strongest weakest

Typical uses:
Type __: Exterior below grade
Type __: Exterior above grade and interior
Type __: Tuckpointing

Kinds of Mortars

_____________: a combination of cement and lime

• Proprietary product
• Contains Portland cement and fines, such as ground limestone
• Additives such as air entraining and water repellency agents.
• Simple batching and “fluffiness” due to entrained air leads to good productivity.
• Codes restrict use in high seismic areas.

_____________

• Proprietary product similar to masonry cement
• More stringent limitations on the amount of air
• Specified bond strength to a standard unit.
• Recognized by codes to be equivalent to PCL mortar.

Specifying Mortar

• __________ Specification
  • ________ for making mortar
  • Proportion specification governs if neither is given
• __________ Specification
  • Property specification is for ________ made mortar, not ____ mortar
  • Recipe developed based on lab mortar
  • Recipe used for field mortar

Recommendation: Specify mix by proportions, even though it is default.

Proportion Specifications

<table>
<thead>
<tr>
<th>Mortar</th>
<th>Type</th>
<th>Proportion by Volume (Cementious Materials)</th>
<th>Aggregate Ratio (measured in damp, loose conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Portland Cement Masonry or Mortar Cement</td>
<td>Hydrated Lime or Lime Putty</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M   S   N</td>
<td></td>
</tr>
<tr>
<td>Portland-Cement Lime</td>
<td>M</td>
<td>1</td>
<td>1/4 - 1/2</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>1</td>
<td>1/4 - 1/2</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1</td>
<td>1/4 - 1/2</td>
</tr>
<tr>
<td>Masonry or Mortar Cement</td>
<td>M</td>
<td>1/2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
### Property Specifications

<table>
<thead>
<tr>
<th>Mortar Type</th>
<th>Average compressive strength at 28 days (psi)</th>
<th>Aggregate Ratio (measured in damp, loose conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>2500</td>
<td>2 (\frac{1}{4}) to 3 times the sum of the separate volumes of cementious materials</td>
</tr>
<tr>
<td>S</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>350</td>
<td></td>
</tr>
</tbody>
</table>

Proportions are determined in the laboratory to meet these criteria, and then those proportions are used in the field. Field mortars do not have to meet these requirements. Compressive testing of field mortar is simply for verifying consistency.

### Properties of Plastic Mortar

1. Spread easily with trowel into separations and crevices
2. Support weight of masonry units when placed
3. Adhere to vertical surfaces
4. Readily extrude from mortar joints when mason applies pressure to bring unit into alignment
5. Essential for good ______ with masonry units
6. Measuring workability
   A. ________ is best judge by observing response of mortar to trowel
   B. ________: percent increase in diameter of base of truncated cone when placed on flow table and mechanically raised 1/2 in. and dropped 25 times in 15 seconds. Typical flow for construction mortars is in the range of 130 to 150%.

### Properties of Plastic Mortar, continued

Water __________: (most important property)
1. Measure of ability of mortar under suction to retain its mixing water.
2. Gives mason time to place and adjust unit without mortar stiffening.
3. Increased through higher lime content, or addition of sand fines within allowable gradation limits.
4. Determined by performing flow test after some water has been removed by a specific amount of vacuum.
   A. Water retentivity is ratio of initial flow to flow after suction, expressed as a percent.
   B. Typically, a water retentivity of 75% is required.

### Properties of Hardened Mortar

1. Strength: __________
   A. Increases with ______ content
   B. Because of workability, Type _ mortar generally gives maximum bond that can be achieved
   C. Bond can only be measured with units; thus not a property of mortar alone
2. ______: amount of surface bonded
   A. Lack of extent leads to __________ problems including moisture penetration, increased air flow, and increased sound transmission.
   B. Increased ______ content increases bond ______ but reduces bond ______ due to loss of workability and increased shrinkage.
   3. More serviceability problems with Type __ and Type __ mortars.
Properties of Hardened Mortar, continued

1. Increase in air content increases durability.
2. Oversanding, overtempering, or use of highly absorbent masonry units reduces durability

Maximum tensile strain at rupture:
1. Low strength, low moduli mortars exhibit greater plastic tensile strains than high strength, high moduli mortars.
2. Mortars with more plastic than necessary should not be used.

Properties of Hardened Mortar, continued

Compressive strength:
1. Importance of compressive strength is
2. Strength and extent, <latex>1</latex>, and water <latex>2</latex> are generally more important.
3. Increases with increase in <latex>3</latex> content
4. Decreases with increase in lime, sand, <latex>4</latex>, or air content
5. Measured using 2 inch cubes
6. Mortar in practice is confined by units and in <latex>5</latex> state of stress
7. Strength of mortar has only a small effect on prism, or wall strength
   A. Tests on clay tile prisms showed an order of magnitude increase in mortar compressive strength only doubled prism strength
   B. Empirical relationship suggest prism strength is proportional to fourth root of mortar compressive strength.

Ingredients of Mortar

1. Contributes to strength and durability of mortar
2. Provides early strength of mortar which is essential for speed of construction
3. Straight PC mortars are not used since they lack plasticity, have low water retentivity, and are harsh.
4. PC mortars would give a strong wall, but the wall would be vulnerable to cracking and rain penetration.

Ingredients of Mortar, cont

1. Natural or manufactured sand can be used
2. Void ratio of sand is about <latex>1</latex> in <latex>2</latex>. Cementious materials will fill voids in sand; mortar mix is approximately volume of sand.
3. Measured in damp loose condition. Dry sand is <latex>3</latex> times as dense as damp, loose sand.
4. Well-graded sands reduce separation of materials in plastic mortar, which improves workability.
   A. Sands deficient in fines produce harsh mortars.
   B. Sands with excess fines produce weak mortars; in extreme cases the mortar may not set up.
   C. Sands that do not meet gradation requirements of C144 can be used provided resulting mortar can meet property specification.
Sand

Grain size distribution of natural river sands in Knoxville

Ingredients of Mortar, cont

1. _______________: generally not needed. Masonry cement typically has air entraining agents. Type A Portland cement is usually used, which has some air entraining additions.
2. _______________: require careful measuring and mixing
3. _______________: Polymeric admixtures (Example is DRY BLOCK from W.R. Grace). One part is mixed throughout concrete during manufacture of masonry unit. Other part is added to mortar during mixing. Polymers cross link during curing to form resistance to water penetration.

Mortar Mixing

Mix _____ minutes in mechanical batch mixer.

Workability is maintained by _____________.
Slightly reduces compressive strength
Increases bond strength

Best results usually obtained if mortar is maintained at ______ workable consistency.

Discard mortar if it begins to stiffen or after 2.5 hours.

Placing Mortar and Units (3.3.B)

1. Thickness: \( \frac{3}{8} \pm \frac{1}{8} \) in.
2. Starting course: at least \( \frac{1}{4} \) in. and not more than:
   A. \( \frac{3}{4} \) in. when masonry is ungrouted or partially grouted
   B. \( 1 \frac{1}{4} \) in. when first course is solid grouted
3. Thicker bed joints decrease compressive strength
4. Solid units: ____________ bed joints
5. Hollow units: ____________ bedding except in starting course, in columns and pilasters, and adjacent to grouted cells.

   ________:
1. Solid units: ______ head joints
2. Hollow units: Width of ____________ thickness
### Placing Mortar and Units (3.3.B)

**Additional Requirements:**
1. Tool joints with round jointer to create a weather resistant surface.
2. Do not disturb units after initially positioned; leads to reduced bond.
3. Remove protrusions greater than \( \frac{1}{2} \) in. that will interfere with grouting.

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### Guide to ASTM Specs on Mortar

**ASTM C 1586 Standard Guide for Quality Assurance of Mortars**

**Prior to Construction:** ASTM C 270
- Choose ____________ or __________ specifications
- If property, make _____________ mortar specimens
- Test mortar at a flow between 105% and 115%
- Representative of moisture content after mortar placed in wall
  - Units will absorb some water
  - Drying of mortar from environment
- Use recipe determined from laboratory property tests

**During Construction:** ASTM C 780
- Tests for ____________ of field produced mortar
- Strengths will be approximately ___% of lab tests
- Field mortar has a flow between 130% and 150%
- More water required for placement of units
- Better test is mortar aggregate ratio
  - Alcohol is used to retard hydration
  - Sieve analysis is performed

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### Grout

**ASTM C476 Specification for Grout for Masonry**

**ASTM C1019 Sampling and Testing Grout**

Grout is high-slump concrete (8-11 in.) made with small size aggregate. It serves three functions:
1. ________ wythes together in composite masonry
2. Bonds ______________ to masonry
3. Increases masonry _________ for bearing and fire resistance

Grout can be specified by either:

__________

__________

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**Proportion Specifications**

<table>
<thead>
<tr>
<th>Type</th>
<th>Portland Cement</th>
<th>Hydrated Lime or Lime Putty</th>
<th>Aggregate Ratio (measured in damp, loose conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Coarse</td>
</tr>
<tr>
<td>Fine</td>
<td>1</td>
<td>0 - ( \frac{1}{10} )</td>
<td>( 2 \frac{1}{2} ) to 3 times the sum of the volumes of cementious materials</td>
</tr>
<tr>
<td>Coarse</td>
<td>1</td>
<td>0 - ( \frac{1}{10} )</td>
<td>( 2 \frac{1}{2} ) to 3 times the sum of the volumes of cementious materials</td>
</tr>
</tbody>
</table>

Coarse aggregate: 85% pass 3/8 sieve; 100% pass \( \frac{1}{2} \) sieve
Grout Properties

Compressive Strength: _______ psi, or _______ compressive strength. Average strength is about 4000 psi.

Fluid Pressure: Grout exerts an equivalent fluid pressure of about _____ pcf. Thus, the pressure at the base of a 5 foot pour is _____ psf.

Bond Strength: Moisture content of units (30-90%) does not affect grout compressive strength or bond strength between grout and unit. Average bond strength is 250-300 psi.

Self-Consolidating Grout (2.2 A)

- Slump flow spread of between 24 and 30 in. (cone can be filled either upright or inverted)
- Visual Stability Index ≤ 1

<table>
<thead>
<tr>
<th>VSI Value</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = Highly Stable</td>
<td>No evidence of segregation or bleeding.</td>
</tr>
<tr>
<td>1 = Stable</td>
<td>No evidence of segregation and slight bleeding observed as sheen on the concrete mass.</td>
</tr>
<tr>
<td>2 = Unstable</td>
<td>A slight mortar halo ≤ 0.5 in. and/or aggregate pile in the center of the concrete mass.</td>
</tr>
<tr>
<td>3 = Highly unstable</td>
<td>Clearly segregating by the evidence of a large mortar halo &gt; 0.5 in. and/or a large aggregate pile in the center of the concrete mass.</td>
</tr>
</tbody>
</table>

Visual Stability Index

VSI = 0 – Concrete Mass is Homogeneous and No Evidence of Bleeding.
VSI = 1 – Concrete Shows Slight Bleeding Observed as a Sheen on the Surface.
VSI = 2 – Evidence of a Mortar Halo and Water Sheen.
VSI = 3 – Concentration of Coarse Aggregate at Center of Concrete Mass and Presence of a Mortar Halo.

Grout Pour and Lift Heights

Pour Height: Total height of masonry to be grouted prior to erection of additional masonry. A pour can consist of several lifts.

Lift Height: Height of grout placed in a single operation. Limited to 5.33 ft. (12.67 ft if masonry has cured 4 hrs, slump is between 10 and 11 in., and no intermediate bond beams between top and bottom of pour height)

Consolidation:
- Pour height < 12 in: Puddling
- Pour height > 12 in: Mechanical vibration Reconsolidate after initial water loss

Placement of reinforcing: Place and secure rebar prior to grout placement. Typically secure rebar at every 200 bar diameters (about 8 ft for a #4 bar).

Cleanouts: Required with high lift grouting.
Grout Space Requirements

See Table 3.2.1 for grout space requirements. Pour heights up to 24 ft are allowed. For fine grout, only a 3 in x 3 in space is required for a 24 ft pour. A 3 in x 4 in space is required for coarse grout for a 24 ft pour.

Area of vertical reinforcement shall not exceed 6% of grout space (Table 3.2.1). UBC allowed 12% of area at splices. Strength design limits area to 4% of cell area (9.3.3.1). IBC allows 8% at splices.

Required grout thickness between bars and masonry is 1/4 in. for fine grout and 1/2 in. for coarse grout (6.1.3.5). Cross webs of hollow units can serve as support for horizontal reinforcement.

Cleanouts

- Cleanouts (3.2.F)
  - Required when grout pour height exceeds 5 ft.
  - Construct so space to be grouted can be cleaned and inspected.
  - In solid grouted masonry, space cleanouts horizontally at a maximum of 32 inch on center.
  - Minimum opening dimension is 3 inch
  - After cleaning, close cleanouts with closures braced to resist grout pressure.

Masonry Cleanouts
**Grout Keys**

- Grout keys (3.5.F)
  - Form grout keys between pours.
  - Form grout keys between lifts if the first lift is permitted to set prior to placement of subsequent lifts.
  - Form a grout key by terminating grout a minimum of 1½ inch below a mortar joint.
  - Do not form grout keys within beams.

**Construction Practices**

Preparations in advance of laying masonry (Spec 3.1, 3.2)
1. Clean laying surfaces just prior to laying for good bond
2. Check alignment of dowels
3. Check foundation tolerances with respect to ACI 117

- Level alignment of footings: ±½ in.
- Relative alignment: slope not more than 1 inch in 10 feet
- Slope of 1:6 allowed for dowels (3.4.B.8.d)
Protection of Masonry During Construction

Cover top of unfinished masonry (1.8.B): Efflorescence is often caused by water in cells evaporating through the faces of the wall.

Avoid premature loading (1.8.A): An example is backfilling a basement wall before the top is supported by the ground floor.

Bracing of structure (3.3.E): Wind forces on walls are more severe during construction due to:
1. Lack of development of full strength
2. Lack of support (cantilever vs. simple support)
3. Increased wind pressure due to lack of enclosure

Internal bracing: Use of reinforced wall itself to provide stability


Cold Weather Construction

Objectives:
1. Allow sufficient strength gain from hydration of cement in mortar
2. Allow sufficient moisture reduction of mortar before it freezes

Problems:
1. Units with frozen moisture absorb less water, leading to reduced bond and lower quality mortar because of higher remaining moisture content
2. Cold units drain heat from mortar, possibly causing it to freeze before adequate moisture can be absorbed
3. Freezing water can expand and rupture mortar

Cold Weather Construction, Construction

Preparation: Do not lay masonry units having a temperature below 20°F or containing frozen moisture, visible ice, or snow on the surface. Remove visible ice and snow from top surface of masonry or foundation. Heat surface to above freezing.

<table>
<thead>
<tr>
<th>Ambient Temperature</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°F to 32°F</td>
<td>Do not heat water or aggregates above 140°F</td>
</tr>
<tr>
<td></td>
<td>Heat sand or mixing water so mortar is between 40°F and 120°F</td>
</tr>
<tr>
<td></td>
<td>Heat materials of grout to above 32°F</td>
</tr>
<tr>
<td>32°F to 25°F</td>
<td>Produce mortar between 40°F and 120°F; maintain mortar above freezing until used.</td>
</tr>
<tr>
<td></td>
<td>Produce grout between 70°F and 120°F; maintain grout above 70°F at time of placement.</td>
</tr>
<tr>
<td>25°F to 20°F</td>
<td>Heat masonry surfaces under construction to 40°F</td>
</tr>
<tr>
<td></td>
<td>Heat masonry to 40°F prior to grouting</td>
</tr>
<tr>
<td></td>
<td>Use wind breaks when wind speed exceeds 15 mph</td>
</tr>
<tr>
<td>20°F and less</td>
<td>Provide enclosure with temperature above 32°F in enclosure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Daily Temperature</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°F to 25°F</td>
<td>Cover with weather-resistant membrane for 24 hours</td>
</tr>
<tr>
<td>25°F to 20°F</td>
<td>Cover with weather-resistant insulating blankets for 24 hours Extend time period to 48 hours for grouted construction unless only type of cement in grout is Type III</td>
</tr>
<tr>
<td>20°F and less</td>
<td>Maintain masonry above 32°F for 24 hours using heated enclosures, heating blankets, or other methods Extend time period to 48 hours for grouted construction unless only type of cement in grout is Type III</td>
</tr>
</tbody>
</table>

1 Minimum daily temperature for grouted masonry
**Hot Weather Construction**

Objective: Prevent dryout of mortar and grout and allow for proper curing.

<table>
<thead>
<tr>
<th>Ambient temp &gt; 100°F or 90°F and wind speed greater than 8 mph.</th>
<th>Ambient temp &gt; 115°F or 105°F and wind speed greater than 8 mph.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain sand in damp, loose condition</td>
<td>Shade materials and equipment from direct sunlight</td>
</tr>
<tr>
<td>Produce mortar below 120°F</td>
<td></td>
</tr>
<tr>
<td>Maintain mortar and grout below 120°F</td>
<td>Use cool mixing water. Ice is permitted in mixing water prior to use. Ice is not permitted in water when added.</td>
</tr>
<tr>
<td>Flush mixer, transport containers, and mortar boards with cool water</td>
<td>Use mortar within 2 hours</td>
</tr>
</tbody>
</table>

Protection: Fog spray newly constructed walls three times a day for three days when mean daily temperature exceeds 100°F or 90°F and wind speed greater than 8 mph.

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**Quality Assurance Program**

**Code 3.1, Spec 1.6**

<table>
<thead>
<tr>
<th>Masonry</th>
<th>Facility</th>
<th>Quality Assurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical, Glass, Veneer</td>
<td>Non-essential</td>
<td>Level A</td>
</tr>
<tr>
<td>All other masonry</td>
<td>Essential</td>
<td>Level B</td>
</tr>
<tr>
<td>All other masonry</td>
<td>Non-essential</td>
<td>Level B</td>
</tr>
<tr>
<td>All other masonry</td>
<td>Essential</td>
<td>Level C</td>
</tr>
</tbody>
</table>

**Level B Quality Assurance**

Minimum Tests: Verify $f'_{im}$ prior to construction except where specifically exempted.

<table>
<thead>
<tr>
<th>Inspection Task</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Verify compliance with the approved submittals</td>
<td>Continuous</td>
</tr>
<tr>
<td>2. As masonry construction begins, verify that the following are in compliance:</td>
<td>Periodic</td>
</tr>
<tr>
<td>a. Proportions of site-prepared mortar</td>
<td>X</td>
</tr>
<tr>
<td>b. Construction of mortar joints</td>
<td>X</td>
</tr>
<tr>
<td>c. Location of reinforcement and connectors</td>
<td>X</td>
</tr>
<tr>
<td>3. Prior to grouting, verify that the following are in compliance:</td>
<td></td>
</tr>
<tr>
<td>a. Grout space</td>
<td></td>
</tr>
<tr>
<td>b. Grade, type, and size of reinforcement and anchor bolts</td>
<td></td>
</tr>
<tr>
<td>c. Placement of reinforcement and connectors</td>
<td></td>
</tr>
<tr>
<td>d. Proportions of site-prepared grout</td>
<td></td>
</tr>
<tr>
<td>e. Construction of mortar joints</td>
<td></td>
</tr>
<tr>
<td>4. Verify during construction:</td>
<td></td>
</tr>
<tr>
<td>a. Size and location of structural elements</td>
<td></td>
</tr>
<tr>
<td>b. Type, size, and location of anchors, including other details of anchorage of masonry to structural members, frames, or other construction</td>
<td></td>
</tr>
<tr>
<td>c. Welding of reinforcement</td>
<td></td>
</tr>
<tr>
<td>d. Preparation, construction, and protection of masonry during cold weather (temperature below 40°F) or hot weather (temperature above 90°F)</td>
<td></td>
</tr>
<tr>
<td>5. Observe preparation of grout specimens, mortar specimens, and/or prisms</td>
<td>X</td>
</tr>
</tbody>
</table>
## Level C Quality Assurance

Minimum Tests: Verification of $f_m'$ prior to construction and for every 5000 sq. ft during construction.

<table>
<thead>
<tr>
<th>Inspection Task</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Verify compliance with the approved submittals</td>
<td>X</td>
</tr>
<tr>
<td>2. Verify that the following are in compliance:</td>
<td></td>
</tr>
<tr>
<td>a. Proportions of site-prepared mortar</td>
<td>X</td>
</tr>
<tr>
<td>b. Grade, type, and size of reinforcement and anchor bolts</td>
<td>X</td>
</tr>
<tr>
<td>c. Placement of masonry units and construction of mortar joints</td>
<td>X</td>
</tr>
<tr>
<td>d. Placement of reinforcement and connectors</td>
<td>X</td>
</tr>
<tr>
<td>e. Grout space prior to grouting</td>
<td>X</td>
</tr>
<tr>
<td>g. Size and location of structural elements</td>
<td>X</td>
</tr>
<tr>
<td>h. Type, size, and location of anchors</td>
<td>X</td>
</tr>
<tr>
<td>i. Welding of reinforcement</td>
<td>X</td>
</tr>
<tr>
<td>j. Preparation, construction, and protection of masonry during cold weather (below 40°F) or hot weather (above 90°F)</td>
<td>X</td>
</tr>
<tr>
<td>3. Observe preparation of grout specimens, mortar specimens, and/or prisms</td>
<td>X</td>
</tr>
</tbody>
</table>