**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

---

**Kinds of Mortars**

<table>
<thead>
<tr>
<th>Mortar Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry cement</td>
<td>A combination of cement and lime</td>
</tr>
<tr>
<td>PCL mortar</td>
<td>Contains Portland cement and fines, such as ground limestone</td>
</tr>
<tr>
<td>Sulfur mortar</td>
<td>More stringent limitations on the amount of air</td>
</tr>
<tr>
<td>Corn cements</td>
<td>Specified bond strength to a standard unit</td>
</tr>
</tbody>
</table>

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

---

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

<table>
<thead>
<tr>
<th>Mortar</th>
<th>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>Portland-Cement Lime</td>
<td>M</td>
<td>2500</td>
<td>2 1/4 to 3 times the sum of the separate volumes of cementious materials</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>Masonry or Mortar Cement</td>
<td>M</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td></td>
<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 ________________:
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
2. ______: amount of surface bonded
   A. Lack of extent leads to ______ problems including moisture penetration, increased air flow, and increased sound transmission.
3. Increased ______ content increases bond ______ but reduces bond ______ due to loss of workability and increased shrinkage.
4. 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 unnecessary than necessary should not be used.

Mortars and Grouts 10

Properties of Hardened Mortar, continued

strength:
1. Importance of compressive strength is absolute.
2. _____ strength and extent, _____, and water _____ are generally more important.
3. Increases with increase in _____ content
4. Decreases with increase in lime, sand, _____, or air content
5. Measured using 2 inch cubes
6. Mortar in practice is confined by units and in _____ 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

1. Provides workability, water retentivity, and elasticity
2. Straight lime mortar would have low compressive strength and higher water retentivity
3. Lime mortars would have a lower strength, but have a greater resistance to cracking and rain penetration.

Bonus Slide, Not in Video

Ingredients of Mortar, cont

1. Natural or manufactured sand can be used.
2. Void ratio of sand is about ___ in ___. Cementious materials will fill voids in sand; mortar mix is approximately volume of sand.
3. Measured in damp loose condition. Dry sand is _____ 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

Compressive strength from 15 sets (3-4 cubes each) for Type N masonry cement mortar

- Average: 1930 psi
- Minimum: 1240 psi
- COV: 25%

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. $\frac{3}{8}$ 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.

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.

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

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:

Sed-runner jointers
S-splashed jointers
Slicker
“V”
Concave
Steel blade
Hardwood
”D"
**Grout**

**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>Fine</td>
<td>1</td>
<td>0 - 1/10</td>
<td>2 1/4 to 3 times the sum of the volumes of cementious materials</td>
</tr>
<tr>
<td>Coarse</td>
<td>1</td>
<td>0 - 1/10</td>
<td>2 1/4 to 3 times the sum of the volumes of cementious materials</td>
</tr>
</tbody>
</table>

Coarse aggregate: 85% pass 3/8 sieve; 100% pass ½ sieve

**Compressive Strength**

Compressive Strength: ______ psi, or ______ compressive strength.

Average strength is about 4000 psi.

**Preferred Method**

Grout boxes: Requires calibration with grout prisms

**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

**Visual Stability Index**

<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>
**Grout Pour and Lift Heights**

**_Height:_** Total height of masonry to be grouted prior to erection of additional masonry. A pour can consist of several lifts.

**_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.

**Table 3.2.1 Grout Space Requirements**

<table>
<thead>
<tr>
<th>Grout type</th>
<th>Maximum pour height (ft)</th>
<th>Minimum clear grout space dimensions (in. x in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>1</td>
<td>1 ½ x 2</td>
</tr>
<tr>
<td></td>
<td>5.33</td>
<td>2 x 3</td>
</tr>
<tr>
<td></td>
<td>12.67</td>
<td>2 ½ x 3</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>3 x 3</td>
</tr>
<tr>
<td>Coarse</td>
<td>1</td>
<td>1 ½ x 3</td>
</tr>
<tr>
<td></td>
<td>5.33</td>
<td>2 x 3</td>
</tr>
<tr>
<td></td>
<td>12.67</td>
<td>3 x 3</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>3 x 4</td>
</tr>
</tbody>
</table>

**Grout Space Requirements**

Area of vertical reinforcement: ≤ 6% of grout space (6.1.2.4). 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.

Note the difference: grout space vs. cell area

Required grout thickness between bars and masonry (6.1.3.5):
- 1/4 in. for fine grout
- ½ in. for coarse grout.
- Cross webs of hollow units can support horizontal reinforcement.

8 in. CMU cell area
- Thickness: assume 1.25 in. face shell and 0.25 in. taper
  - 7.625 - 2(1.25) - 2(0.25) = 4.625 in.
- Length: assume 1 in. webs
  - Stack bond: [15.625 - 2(0.75) - 3(1) - 3(0.25)]/2 = 5.1875 in.
  - Running bond: (0.5+0.25/2+5.1875) - (0.375/2+0.75+1) = 3.875 in.
- Stack bond: Area = 4.625(5.1875) = 23.99 in.²
  - 4% cell area = 0.04(23.99) = 0.96 in.² (#8 bar)
- Running bond: Area = 4.625(3.875) = 17.92 in.²
  - 4% cell area = 0.04(17.92) = 0.72 in.² (#7 bar)
### Grout Space Requirements

8 in. CMU \( (a = 5.8175 \text{ in.}) \)

<table>
<thead>
<tr>
<th>Bond beam bars</th>
<th>'b' (in.)</th>
<th>Area (in.²)</th>
<th>6% Area (in.²)</th>
<th>Max pour height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - #4</td>
<td>3 ⅛</td>
<td>18.18</td>
<td>1.09 (#9)</td>
<td>24</td>
</tr>
<tr>
<td>2 - #4</td>
<td>2 ⅛</td>
<td>15.27</td>
<td>0.92 (#8)</td>
<td>5.33</td>
</tr>
<tr>
<td>1 - #5</td>
<td>3</td>
<td>17.45</td>
<td>1.05 (#9)</td>
<td>24</td>
</tr>
<tr>
<td>2 - #5</td>
<td>2 ⅜</td>
<td>13.82</td>
<td>0.83 (#8)</td>
<td>1</td>
</tr>
</tbody>
</table>

**Example:** calculation of b

Block width \( 7.625 \)

Face Shell \( 2(1.25) = 2.5 \)

Taper \( 2(0.25) = 0.5 \)

Protrusions \( 2(0.5) = 1.0 \)

Bar diameter (1 - #4) \( 0.5 \)

TOTAL \( 7.625-2.5-0.5-1.0-0.5 = 3.125 \)

### Cleanouts

**Cleanouts (3.2.F)**

- Required when grout pour height exceeds 5 ft. – 4 in.
- 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.

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

### 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.