Lecture 7. Masonry and mortars (tiilirakentaminen / muuraus)

Prepared by:
Fahim Al-Neshawy, D.Sc. (Tech.)
Aalto University School of Engineering
Department of Civil Engineering
A: P.O.Box 12100, FIN-00076 Aalto, Finland
7.1 Masonry units

A masonry structure (wall) is formed by combining masonry units, such as stone, blocks, or brick, with mortar. Masonry is one of the oldest construction materials. Examples of ancient masonry structures include the pyramids of Egypt, the Great Wall of China, and Greek and Roman ruins. Bricks of nearly uniform size became commonly used in Europe during the beginning of the 13th century. The first extensive use of bricks in the United States was around 1600. In the last two centuries, bricks have

---

been used in constructing sewers, bridge piers, tunnel linings, and multistory buildings. There is two
types of masonry:

- Structured/load-bearing $\uparrow$ this is used for exterior walls.
- Non structured/non load-bearing $\uparrow$ this is used for interior walls.

Masonry units, shown in Figure 1, are a popular construction material throughout the world and
competes favorably with other materials, such as wood, steel, and concrete for certain applications.
Several different types of masonry units are commonly used. Common masonry unit types include
clay and concrete units, which may be solid or hollow, and glazed or unglazed. Other masonry unit
types include cast stone and calcium silicate units.

![Figure 1. Examples of masonry units: (a) concrete masonry units, (b) clay bricks, and (c) structural clay tiles.](image)

### 7.1.1 Concrete masonry units

A concrete masonry unit (CMU) – also called concrete block, cement block, and foundation block – is
a large rectangular brick used in construction. Concrete blocks are made from cast concrete, example:
Portland cement and aggregate, usually sand and fine gravel for high-density blocks. Lower density
blocks may use industrial wastes as an aggregate.

- Solid concrete units are commonly called concrete bricks, while hollow units are known as
corcrete blocks, hollow blocks, or cinder blocks.
- Hollow units have a net cross-sectional area in every plane parallel to the bearing surface less
than 75% of the gross cross-sectional area in the same plane.
- If this ratio is 75% or more, the unit is categorized as solid
- Concrete masonry units are specified by their nominal dimensions. The nominal dimension is
greater than its specified (or modular) dimension by the thickness of the mortar joint, usually
10 mm. For example
  - A 200 x 200 x 400 block has an actual width of 190 mm, height of 190 mm, and length
    of 390 mm.
Load-bearing concrete masonry units are available in nominal widths of 100 mm, 150 mm, 200 mm, 250 mm, and 300 mm, heights of 100 mm and 200 mm, and lengths of 300 mm, 400 mm, and 600 mm.

Figure 2. Concrete masonry units: (a) stretcher, (b) single-corner, and (c) double-corner.

Advantages:
- High durability
- Different surfaces with different color shades
- Very good variability of use

Disadvantages:
- High weight
- Lower thermal resistance
- Demanding – labour consumption

Manufacturing of concrete masonry units

Manufacturing process of concrete blocks consists of four basic processes: (a) mixing, (b) molding, (c) curing, and (d) cubing as shown in Figure 3.

a) Mixing:
- Raw materials are weighed out in proportions and transported to the mixer.
- All raw materials are mixed for 6 to 8 minutes
- Very dry, no-slump concrete

b) Molding
- From the mixer the materials enter the block molding machine
- The molds consist of an outer mold box containing several mold liners.
- The molds are vibrated for 7 seconds.
- After the mold is removed the block are able to stand by themselves

3Concrete Block - http://www.madehow.com/Volume-3/Concrete-Block.html
c) Curing

- The concrete blocks are placed in a curing rack. Each rack holds several hundred blocks. When a rack is full, it is rolled onto a set of rails and moved into a curing kiln.
- Blocks remain in the curing kilns for 24 hours. They are baked in a moist steam heat at 60 °C.

d) Cubing.

- The rake of cured blocks is rolled out of the kiln.
- The blocks pass through a cuber which aligns each block and then stacks them into a cube three blocks across by six blocks deep by three or four blocks high.
- These cubes are carried outside with a forklift and placed in storage.

Figure 3. Four basic processes of the manufacturing process of concrete blocks: (a) mixing, (b) molding, (c) curing, and (d) cubing.

Properties of concrete masonry units

Concrete masonry units are manufactured in three classes, based on their density: lightweight units, medium-weight units, and normal-weight units, with dry unit weights as shown in Table 1. Well-graded sand, gravel, and crushed stone are used to manufacture normal-weight units. Lightweight aggregates such as pumice, scoria, cinders, expanded clay, and expanded shale are used to manufacture lightweight units.

Table 1. Weight classifications and allowable maximum water absorption of concrete masonry units

<table>
<thead>
<tr>
<th>Weight Classification</th>
<th>Unit Weight (kg/m³)</th>
<th>Maximum Water Absorption (Average of 3 units) (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight</td>
<td>Less than 1680</td>
<td>288</td>
</tr>
<tr>
<td>Medium Weight</td>
<td>1680 – 2000</td>
<td>240</td>
</tr>
<tr>
<td>Normal Weight</td>
<td>2000 or more</td>
<td>208</td>
</tr>
</tbody>
</table>

The amount of water absorption of concrete masonry units is controlled to reduce the effect of weathering and to limit the amount of shrinkage due to moisture loss after construction. The absorption of concrete masonry units is determined by immersing the unit in water for 24 hours. The absorption and moisture content are calculated as follows.
Absorption \( \left[ \frac{kg}{m^3} \right] = \frac{W_s - W_d}{W_s - W_i} \times 1000 \)  \( (1) \)

Absorption \( [\%] = \frac{W_s - W_d}{W_d} \times 100 \)  \( (2) \)

Moisture content as a percent of total absorption = \( \frac{W_r - W_d}{W_s - W_d} \times 100 \)  \( (3) \)

Where:  
\( W_s \) = saturated weight of specimen, (kg)  
\( W_d \) = oven-dry weight of unit, (kg),  
\( W_i \) = immersed weight of specimen, (kg), and  
\( W_r \) = weight of specimen as received

Table 1 shows the allowable maximum water absorption for load-bearing concrete masonry units.

Concrete masonry units can be classified as load bearing and non–load bearing. Load-bearing units must satisfy a higher minimum compressive strength requirement than non–load-bearing units, as shown in Table 2.

**Table 2. Strength requirements of load bearing and non–load-bearing concrete masonry units** \(^{(2)}\)

<table>
<thead>
<tr>
<th>Type</th>
<th>Minimum Compressive Strength Based on Net Area [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average of Three Units</td>
</tr>
<tr>
<td>Load bearing</td>
<td>13.1</td>
</tr>
<tr>
<td>Non-load bearing</td>
<td>4.1</td>
</tr>
</tbody>
</table>

**Applications of concrete masonry units**

The typical uses for concrete block include:

- Foundation walls - typically rockfaced.
- Basement walls.
- Partition walls - usually plainfaced.
- Exterior walls - usually plainfaced and then often covered with stucco.
- Most concrete block was used as a back-up material or for cavity wall construction.
- Coatings are often are applied to concrete block in order to prevent water penetration.
- Lightweight units have higher thermal and fire resistance properties and lower sound resistance than normal weight units.
Figure 4. Applying surface-bonding cement to a dry-stacked, concrete block wall (4).

7.1.2 Clay bricks

Clay bricks are defined as "burnt clay masonry units". Burnet "Fired" bricks are burned in a kiln which makes them durable.

![Common brick sizes in Finland](http://www.todayshomeowner.com/build-a-concrete-block-wall-the-easy-way-with-quikrete-quikwall/)

Figure 5. Common brick sizes in Finland. PT = Burned bricks, PRT = Basic hollow clay block, NRT = Normal hollow clay block, MRT = Module sized hollow clay block, MTL = Module sized Brick Slab (5).

Normally, brick contains the following ingredients:

- Silica (sand) – 50% to 60% by weight
- Alumina (clay) – 20% to 30% by weight
- Lime – 2 to 5% by weight
- Iron oxide – ≤ 7% by weight
- Magnesia – less than 1% by weight

**Advantages:**

- Tradition and classic material and classic modular format

---

• Good strength at relatively low weight
• Excellent ability to accumulate heat
• Environmental Compliance (natural material)
• Good sound insulation properties
• High durability and high fire resistance

Disadvantages:
• Demanding – labor consumption
• Accuracy of production
• Lower thermal resistance – insufficient thermal insulation properties

Manufacturing of clay bricks

Manufacturing of clay bricks consists of the following 5 operations or steps, as shown in Figure 6.

a) Preparation of brick clay or brick earth
b) Molding of bricks
c) Air drying of bricks
d) Burning and cooling of bricks
e) Packing and delivery

a) Preparation of brick clay or brick earth

• In this step the soil is excavated in steps and then laid on leveled ground.
• Then the soil is cleaned of impurities such as vegetation matter, stones or pebbles etc.

Figure 6. The manufacturing process of clay bricks.

http://civilblog.org/2014/02/25/4-primary-steps-involves-in-brick-manufacturing/
• After removing impurities it is exposed to weather for few months.
• This is called the process of weathering. After completion of weathering process the soil is blended with other material to prepare good brick earth.
• Then the mixed soil is tempered by being thoroughly broken up, watered and kneaded. The tempering is usually done in pug mill.

b) Molding of bricks

• Bricks are molded in many ways depending on the quality of the product to be made. Generally the molding is done in the following two ways:
  v **Hand molding:** For hand molding the tempered clay is forced in the mound in such a way that it fills all the corners of the mold. Extra clay is removed either by wooden strike or frame with wire. Mold is then lifted up and raw brick is left on ground.
  v **Machine molding:** Machine molding is used where large numbers of bricks are to be made. Machines used for molding is generally of two types.
    ß **Plastic clay machines:** In plastic clay machine the clay in plastic state is forced to rectangular openings of a size equal to the length and breadth of the bricks and are then cut into strips of thickness of the brick with wires in frames.
    ß **Dry clay machines:** In dry clay machines, dry clay is reduced to powder, filled dry into mold by the machine and then are subjected to high pressure to form hard and well-shaped bricks.

c) Drying of bricks

• Drying is usually done by placing the bricks in sheds with open sides so as to ensure free circulation of air and protection from bad weather and rains.
• The bricks are allowed to dry till they are left with 5 to 7 percent moisture content.
• The drying period usually varies from 7 to 14 days.
• The molded bricks are dried because of the following reasons.
  v If damp bricks or green bricks are directly taken to burning then, they are likely to be cracked and distorted
  v To remove maximum moisture from the brick so as to save time and fuel during burning
  v To increase the strength of raw bricks so that they can be handled and stacked in greater heights in the kiln for burning without damage.

d) Burning and cooling of the bricks

• After drying, the bricks are fired in high temperatures in furnaces called kilns.
• Firing, one of the most specialized steps in the manufacture of brick, requires from 2 to 7 days depending upon kiln type and other variables.
• The two general types of kilns are tunnel and periodic kilns:
A periodic kiln is one that is loaded, fired, allowed to cool and unloaded, after which the same processes are repeated.

In a tunnel kiln, units are similarly loaded on special cars which pass through various temperature zones as they travel through the tunnel. The heat conditions in each zone are carefully controlled and the kiln operates continuously.

- Firing consists of:
  - Water smoking ~200°C → evaporation of free water
  - Dehydration ~450°C-750°C → evaporation of chemically bound water
  - Oxidation ~450°C-950°C → oxides are formed
  - Vitrification ~950°C-1300°C → low melting components liquify and fill the pores

- After the temperature has reached the maximum and is maintained for a prescribed time, the cooling process begins. 48 to 72 hours are required for proper cooling in periodic kilns; but in tunnel kilns, the cooling period seldom exceeds 48 hr.
- Because the rate of cooling has a direct effect on color and because excessively rapid cooling will cause cracking, cooling is an important stage in the firing process.

### e) Setting and packaging

- After the bricks are fired and cooled, it is unloaded from the kiln car.
- Automated setting machines have been developed that can set brick at rates of over 18,000 per hour and can rotate the brick 180 degrees.
- Usually set in rows eleven bricks wide, a stack is wrapped with steel bands and fitted with plastic strips that serve as corner protectors.
- The packaged brick is then shipped to the job site, where it is typically unloaded using boom trucks.

#### Properties of brick units

All properties of brick are affected by (i) composition of the raw materials and (ii) the manufacturing processes. Bricks are manufactured in different colors, such as dark red, purple, brown, gray, pink, or dull brown, depending on the firing temperature of the clay during manufacturing.

- Clay bricks have an average density of 2000 kg/m³
- Absorption is one of the important properties that determine the durability of bricks.
- Highly absorptive bricks can cause efflorescence and other problems in the masonry.
- Absorption by 24-hour submersion, absorption by 5-hour boiling, and saturation coefficient are calculated as:

\[
\text{Absorption by 24 h submersion} \ [\%] = \frac{W_{524} - W_d}{W_d} \times 100
\]
\[ Absorption \ by \ 5h \ boiling \ [%] = \frac{W_{b5} - W_d}{W_d} \times 100 \] (5)

\[ Saturation \ coefficient = \frac{W_{s24} - W_d}{W_{b5} - W_d} \] (6)

Where: \( W_{s24} \) = saturated weight of specimen after 24h submersion in cold water, (kg)
\( W_{b5} \) = saturated weight of specimen after 5h submersion in boiling water, (kg)
\( W_d \) = dry weight of unit, (kg).

- Clay bricks are very durable and fire resistant, and require very little maintenance.
- They have moderate insulating properties, which make brick houses cooler in summer and warmer in winter, compared with houses built with other construction materials.
- Clay bricks are also noncombustible and poor conductors.
- Other mechanical properties of bricks include modulus of rupture, tensile strength, and modulus of elasticity.
- Most clay bricks have modulus of rupture between 3.5 MPa and 26.2 MPa.
- The tensile strength is typically between 30\% to 49\% of the modulus of rupture.
- The modulus of elasticity ranges between 10.3 GPa and 34.5 GPa.

**Applications of clay bricks**

Depending on weather resisting capability bricks are three types -

- **Severe Weather grade (SW):** SW type of bricks can withstand against repeated freeze-thaw actions. These are useful for the countries where severe freeze-thaw actions happened.
- **Moderate Weather grade (MW):** MW type of bricks can be useful for hot-weathering affected countries where freeze-thaw action doesn’t happen much.
- **No Weather grade (NW):** NW type of bricks are general and it doesn’t have any weather resisting capability. It’s mostly used in interior wall.

**Table 3. Physical requirements for clay building bricks.**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Min. Compressive Strength, Gross Area, Mpa</th>
<th>Max. Water Absorption by 5-hour Boiling, %</th>
<th>Max. Saturation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average of Five Bricks</td>
<td>Individual</td>
<td>Average of Five Bricks</td>
</tr>
<tr>
<td>SW</td>
<td>20.7</td>
<td>17.2</td>
<td>17.0</td>
</tr>
<tr>
<td>MW</td>
<td>17.2</td>
<td>15.2</td>
<td>22.0</td>
</tr>
<tr>
<td>NW</td>
<td>10.3</td>
<td>8.6</td>
<td>No limit</td>
</tr>
</tbody>
</table>

- Clay bricks are used for different purposes, including building, facing and aesthetics, floor making, and paving.
- **Building bricks** (common bricks) are used as a structural material, and are typically strong and durable.
- **Facing bricks** are used for facing and aesthetic purposes, and are available in different sizes, colors, and textures.
- **Floor bricks** are used on finished floor surfaces, and are generally smooth and dense, with high resistance to abrasion.
- **Paving bricks** are used as a paving material for roads, sidewalks, patios, driveways, and interior floors. Paving bricks are available in different colors, such as red, gray, or brown. Paving bricks are typically abrasion resistant, and could usually be vitrified (glazed to render it impervious to water and highly resistant to corrosion).

Figure 7. Examples of the clay brick applications - Load Bearing Masonry Wall (7), facing, floor and paving bricks.

### 7.1.3 Calcium silicate units (8)

Calcium silicate masonry units (AKA. Cast sand stone), shown in Figure 8, are produced from sand and silica, which is mixed with hydrated lime and other elements. The no-slump mixture is then pressed into modular-sized molds and cured in an autoclave. Calcium silicate contains no Portland cement.

Figure 8. Calcium silicate unit.

---

8 [http://www.arriscraft.com/pdfs/w-calciumsilicate-masonry-units.pdf](http://www.arriscraft.com/pdfs/w-calciumsilicate-masonry-units.pdf)
Advantages:

- High strength
- High density - slim bearing walls
- Optimal protection against heat loss

Disadvantages:

- Demanding – labor consumption
- Lower thermal resistance
- Price

Manufacturing of calcium silicate units

Calcium silicate masonry units are a manufactured masonry product.

- Lime and silica-based sand are mixed and then pressed into modular-sized units under high pressure.
- The “green” units are then subjected to high pressure steam (curing) in an autoclave to produce a masonry unit with uniformly fine-grained texture. During this process, dried bricks are loaded into an autoclave where they are exposed to synergistic effect of elevated temperature (the temperature range is 170°C to about 195°C) and adequate pressure saturated steam (pressure approximately 16 bars).
- A calcium silicate hydrate binder is formed when the elements in the raw materials chemically react in the autoclave. This results in a durable, strong and integrally bonded unit.

A wide variety of distinctive colors can be produced, many of which cannot be matched by other types of masonry units. These range from natural white to pastel shades to earthen tones. Proprietary color blending techniques make it possible to produce striations and ranges similar to those in natural stone.

Properties of calcium silicate units

- The strength of dry calcium silicate bricks is approximately 30%-50% higher than when saturated.
- Prolonged exposure to acidic atmospheric gases in moist air may degrade the calcium silicate bricks.
- Sulfur dioxide decomposes the hydrated calcium silicate cementing agent, forming a skin of calcium sulfate (gypsum) and hydrated silica.
- Carbon dioxide ingress marginally increases strength but causes slight shrinkage.
- Absorption of liquids (about 7-16% by weight) is similar to some clay bricks (except engineering bricks).
- The thermal conductivity (k) of calcium silicate masonry is moisture content and density dependent; for masonry of density 2000 kg/m³, k = 0.92 W/mK at 1% moisture content by
volume (sheltered conditions) and \( k = 1.24 \text{ W/mK} \) at 5\% moisture content by volume (exposed conditions).

- Ordinarily there are no water soluble salts present in calcium silicate bricks; however, repeated crystallization of sea salt may cause surface deterioration; they are not recommended in these locations.
- The resistance of calcium silicate bricks to frost damage is mainly related to their mechanical strength and they are not recommended for use in highly exposed conditions (e.g., pavings).

**Applications of calcium silicate units (9)**

A calcium silicate masonry unit used for masonry veneer construction. Veneer applications include:

- Thin-clad installations.
- For interior and exterior use in residential, commercial and institutional applications (chimneys, fireplaces, behind wood stoves, outside entranceways, front of house, exterior walls etc.).
- For the base of the buildings, stairways, terraces
- Paving

![Figure 9. Examples of the calcium silicate masonry applications (9).](http://www.masonrymagazine.com/architectural-cast-stone/)
7.2 Types of masonry walls

Masonry walls are the most durable part of any building or structure. They provide strength, durability to the structure and also helps to control indoor temperature. Based on the wall construction, the types of masonry walls are:

- Load Bearing Masonry Walls
- Reinforced Masonry Walls
- Hollow Masonry Walls
- Composite Masonry Walls
- Post-tensioned Masonry Walls

7.2.1 Load bearing masonry walls

Load bearing masonry walls are constructed with bricks, stones or concrete blocks. These walls directly transfer loads from the roof to the foundation. These walls can be exterior as well as interior walls. The construction system with load bearing walls are economical than the system with framed structures.

![Example of a clay bricks - Load bearing masonry wall.](http://theconstructor.org/building/types-of-masonry-walls/10800/)

The thickness of load bearing walls is based on the quantity of load from roof it has to bear. For example, a load bearing wall with just a ground floor can have its outer walls of 230mm, while with one or more floors above it, based on occupancy type, its thickness may be increased. The load bearing walls can be reinforced or unreinforced masonry walls.

7.2.2 Reinforced masonry walls

Reinforced masonry walls can be load bearing walls or non-load bearing walls. The use of reinforcement in walls helps it to withstand tension forces and heavy compressive loads. The unreinforced masonry walls are prone to cracks and failure under heavy compressive loads and during earthquakes. They have little ability to withstand lateral forces during heavy rain and wind. Cracks
also develop in un-reinforced masonry walls due to earth pressure or differential settlement of foundations.

![Figure 11. Example of a vertically reinforced masonry wall.](image)

To overcome such problems, reinforced masonry walls are used. Reinforcement in walls are at required intervals both horizontally and vertically is used. The size of reinforcement, their quantity and spacing are determined based on the loads on the walls and structural conditions.

### 7.2.3 Hollow masonry walls

Hollow or Cavity masonry walls are used to prevent moisture reaching the interior of the building by providing hollow space between outside and inside face of the wall. These walls also help in temperature control inside the building from outside wall as the hollow space restricts heat to pass through the wall.

![Figure 12. Hollow masonry walls.](image)

When the wall is exposed to moisture for a sustained period and penetrates through the outer face, the water reaches the cavity or the hollow space and flows down. Then they are drained through the weep holes to the exterior of the building. These hollow spaces may be coated with water repellent coating or damp-proofing to further reduce the ingress of moisture.
7.2.4 Composite masonry walls

These walls are constructed with two or more units such as stones or bricks and hollow bricks. This type of masonry wall construction is done for better appearance with economy.

In composite masonry walls, two wythes of masonry units are constructed bonding with each other. While one wythe can be brick or stone masonry while the other can be hollow bricks. A wythe is a continuous vertical section of masonry one unit in thickness. These wythes are interconnected either by horizontal joint reinforcement or by using steel ties.

![Composite masonry walls](image1)

Figure 13. Composite masonry walls.

7.2.5 Post-tensioned masonry walls

Post-tensioned masonry walls are constructed to strengthen the masonry walls against the forces that may induce tension in the wall such as earthquake forces or wind forces. These walls are constructed from the foundation level and post-tensioning rods are anchored into the foundation. These rods are run vertically between the wythes or in the core of concrete masonry units. After the masonry wall construction is completed and cured, these rods are tensioned and anchored on the steel plate at the top of the wall.

![Post-tensioning of masonry walls](image2)

Figure 14. Post-tensioning of masonry walls.
Mortar is a mixture of cementitious material, aggregate generally with a grain size of less than 4 mm, water and possibly additives and/or admixtures. Mortar can be classified as cement-lime mortar, cement mortar, lime mortar or masonry cement mortar. Mortar is used for the following functions:

- To bind materials together (e.g. masonry mortar and tile adhesive mortar, either non-reinforced or reinforced)
- To serve as a seating and levelling material for the masonry units
- To provide aesthetic quality of the structure and a level or smooth finish (e.g. floor screed mortar, internal plastering)
- To protect against weathering (e.g. external rendering)
- To improve thermal insulation of walls (e.g. external thermal insulation composite systems, thermal insulation rendering mortar, lightweight masonry mortar)
- To repair and renovate constructions (e.g. concrete repair mortar, damproofing mortar, or renovation mortar)

Figure 15. Examples of mortars use.

The currently most common types of mortar are (13):

- Masonry mortar which is divided into general purpose mortar, lightweight mortar, and thin layer mortar
- Rendering mortar which is used to protect buildings against weathering and to give them a decorative look. Thermal insulating renders are part of this group.
- Plastering mortar to finish inside walls
- Floor screed mortar; mainly self-levelling
- High-technology dry mortars (tile adhesive, concrete repair etc.)
- External Thermal Insulating Composite Systems (ETICS)

(13) http://www.euromortar.com/product-range/mortar/
7.3.1 Mortar types

The mortars are generally classified according to their composition, application, requirements, their production method, and their supply method.

Mortars classified according to their composition

a) Cement mortars
b) Hydraulic lime mortars
c) Air lime mortars: they are mortars produced with hydrated air lime and sand which are used for internal and external coatings
d) Composite mortars made from cement and hydraulic lime
e) Composite mortars made from cement and air lime: these limes can be mixed with different amounts of cement (common or white)

Mortars defined by their application

a) Mortars for masonry construction
b) Mortars for coatings
c) Mortars for paving
d) Adhesive mortars
e) Mortars for repair work
f) Waterproofing mortars

Mortars defined by their requirements

a) Mortars made with recipes or prescriptions: They are normally known based on their declared components. For example: Cement:Lime:Sand mortars, Lime:Sand mortars or Cement:Sand mortars.
b) Designed mortars: A mortar which is required to have a certain characteristic, which can be a particular strength, adherence or water resistance. For example: an M-5 masonry mortar should achieve a compression strength after 28 days of 5 N/mm² in accordance with the EN 998-2(14) regulation.

Mortars defined by their production method

a) Masonry mortar produced on site: a mortar composed of the individual components measured and mixed on site.
b) Semi-finished factory produced masonry mortar:
   i. Pre-dosed masonry mortar: a mortar whose components are completely factory dosed and are supplied to the place where they will be used and where they are mixed in accordance with the manufacturer's specifications and conditions.

ii. A premixed lime and sand masonry mortar: a mortar whose components have been completely factory dosed and mixed and are supplied to its place of use where other factory specified or supplied components are added (i.e.: cement).

c) Factory made masonry mortar (industrial mortar): mortar dosed and mixed in a factory. It can be "dry mortar", a prepared mix which only requires the addition of water or "wet mortar" which is supplied ready for use.

Mortars defined by their supply method

a) Dry mortar in silos: the procedure is simple, clean and economical in its consumption. The manufacturer provides one or more silos and the exact type of mortar (transported in tank trucks) defined by the designer. It is only necessary to add the indicated water to create the mix at the construction site.

b) Dry mortar in bags: dry mortars can also be supplied in bags. Their use on site is very simple because there is no dosing or selection of components required on site. The supplier's instructions should be followed for manual or mechanical mixing with mixers.

c) Wet mortar: principally produced with lime putty, it is supplied ready for use in bags or containers.

7.3.2 Mortar materials

Conventional masonry mortars are composed of water, sand, and cementitious materials.

Water:

- Water is required for hydration of the cementitious materials. Strength gain of mortar is not related to evaporation of water but to the chemical combination of water with cement compounds in the mortar.
- Since some mixing water is lost to absorptive units and evaporation, the maximum amount of water consistent with optimum workability should be added to mortar.
- Significant levels of contaminants such as alkalis, sulfates, sugars, or detergents may adversely affect the performance of mortar. Therefore drinkable water, free of such contaminants, should be used for mixing mortar.

Sand:

- The specifications with which aggregates for the production of mortars must comply are contained in the EN 13139 harmonized standard (15).
- The sands can be: calcic, dolomitic or siliceous.
- Sands is not recommended to exceed a maximum size of 4 mm.

---

15 EN 13139:2002 - Aggregates for mortar
• Sand used for masonry construction should be clean and well graded. The cleaning of the sand is essential, sands should be used which do not contain clay materials, organic matter, compounds which reduce the durability of the mortars, for example: oxidisable iron sulphides (pyrites, marcasites); mica particles, shales with laminar or scaly structures in sufficient quantities that can affect the finish of the mortar, and its mechanical strength and hardness.

Cement:
• Masonry Cement: Masonry cement consists of a controlled homogeneous mixture of Portland or blended cement and inorganic plasticizing materials such as hydrated lime or pulverized limestone, together with other materials introduced to enhance mortar properties.
• Mortar Cement: Mortar cements are similar to masonry cements, but they have lower air contents than masonry cements, and the mortar cement specification includes a minimum bond strength requirement.
• Portland Cement
• Blended Cements: Blended hydraulic cements are produced from Portland cement or Portland cement clinker and pozzolans or slags.

Lime:
• Air limes:
  o Calcium limes: Calcinated pure limestones >95% richness of calcium
  o Dolomitic limes: Calcinated dolomitic stones which contain magnesium
• Hydrated Lime: Limestone contains clays rich in silica, aluminium and iron, which harden with water:
  o Natural Hydraulic Limes (NHL), which are produced by the calcination of a stone with a mix of clays which are lean and rich in silica
  o Artificial Hydraulic limes (HL), which are composed of calcium hydroxide, calcium silicates and calcium aluminates produced by the appropriate mix of ingredients
  o Formulated Limes (FL), which are limes with hydraulic properties composed of air lime (CL) and/or natural hydraulic lime (NHL) with additional hydraulic and/or pozzolanic material

Admixtures:
• Aerating agents: Air content modifiers
• Plasticizers: Rheology modifiers while in fresh condition
• Retardants: Modifiers of setting and/or hardening times (Setting retardants)
• Water repellents: Those which minimize the absorption of water
• Water retainers: Those which increase the capacity to retain water
• Resins: Provide chemical adherence
Mortar strength classifications according to ASTM C270 - 14a (Standard Specification for Mortar for Unit Masonry):

- Type N – All purpose
- Type S – High flexural bond strength
- Type M – High compressive strength but low workability
- Type O – Low strength, usually limited to interior applications

Table 4. Minimum required compressive strength and material quantities in mortar.

<table>
<thead>
<tr>
<th>ASTM Mortar Type</th>
<th>M</th>
<th>S</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength (MPa)</td>
<td>17.2</td>
<td>12.4</td>
<td>5.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Volume Ratio</td>
<td>1:1 / 4:3</td>
<td>1:1 / 2:4</td>
<td>1:01:06</td>
<td>1:02:09</td>
</tr>
</tbody>
</table>

Proportions by Volume

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>S</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>0.33</td>
<td>0.22</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>Lime</td>
<td>0.08</td>
<td>0.11</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td>Sand</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Proportions by Weight

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>S</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>31.3</td>
<td>20.9</td>
<td>15.7</td>
<td>10.4</td>
</tr>
<tr>
<td>Lime</td>
<td>3.3</td>
<td>4.4</td>
<td>6.7</td>
<td>8.9</td>
</tr>
<tr>
<td>Sand</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>

Mortar classification in Finland:

- K Lime (Air Limes) Kalkki (ilmakalkki)
- HK Hydrated Lime Märkäsammutettu kalkki
- KS Lime + cement Kalkki+sementti
- M Masonry mortar Muurauslaasti

For example:

- KS 65/35/600 is lime-cement mortar, where 65%-weight is lime, 35% is Portland cement 600 unit weight of dry aggregates.
- M 100/600 is a masonry mortar, where 100 part of lime and cement / 600 part of sand.

7.3.3 Desirable mortar properties

Workability:

- Workability may be defined as the behaviour of a mix in respect of all the properties required, during application, subsequent working and finishing.
- Ease of use, i.e. the way it adheres or slides on the trowel.
- Ease of spread on the masonry unit.
- Ease of extrusion between courses without excessive dropping or smearing.
- Ease of positioning of the masonry unit without movement due to its own weight and the weight of additional courses

**Water Retentivity & Air content:**
- This is the property of mortar that resists water loss by absorption into the masonry units (suction) and to the air, in conditions of varying temperature, wind and humidity. Water retentivity is related to workability.
- The air content of the mortar in its plastic state is also important. In order to achieve good durability it is necessary that there is sufficient air content (entrained air) to enable freeze-thaw cycles to be resisted without disrupting the matrix of the material.

**Stiffening and hardening:**
- The progression of stiffening, defined in the European Standard as workable life, refers to the gradual change from fresh or plastic mortar to setting or set mortar.
- Hardening refers to the subsequent process whereby the set mortar progressively develops strength.

**Properties of hardened mortar:**
- Durability of mortar may be defined as its ability to endure aggressive conditions during its design life.
- A number of potentially destructive influences may interact with the mortar: these include water, frost, soluble salts and temperature change.
- In general, as the cement content increases so will durability.
- Air entrainment of mortars improves resistance to freeze-thaw damage.

**Compressive strength:**
- The use of too much cement will produce a more rigid mortar, which may result in vertical cracking passing through units and mortar joints as stresses are imposed.
- Use of the appropriate mortar should not result in cracking, but any that does occur, (e.g. due to movement), will tend to follow the joints, which will be much easier to repair.

### 7.4 Grout

Masonry grout is a cementitious mixture used to fill cores or cavities in masonry construction. While usually added for structural reasons, grout can also increase: fire ratings, security, acoustical

---

performance, termite resistance, blast resistance, thermal storage capacity and anchorage capabilities.

- Grout is composed of cement, aggregate, lime (optional) and sufficient water to allow ease of placement and ensure complete filling of the grout space.
- With approval, admixtures may be added to the grout mix.
- The high initial water content of typical grout mixes compensates for water absorption by the masonry during and after grout placement.
- The final water-to-cement ratio is significantly reduced, thus grout develops high compressive strength despite its apparent high initial water to cement ratio.
- Generally, grout is used to structurally bond wall elements into a wall system.
- The most common example is in reinforced construction, where grout bonds the steel reinforcing bars to the masonry, allowing them to act as one system in resisting loads.
- Grouted cores also increase the net cross-sectional area of concrete masonry and permit walls to carry higher compressive, shear loads and lateral loads.

Figure 16. Grouting of hollow unit block wall \(^{(17)}\).

### 7.4.1 Types of grout

Coarse Grout, the most commonly used type of grout, has a maximum aggregate size of 12 mm. The slump should be between 200 and 250 mm. This is much higher than typical ready mix concrete, but is very necessary to properly fill the cores of masonry units and flow around reinforcement or other elements within the wall.

Grout for use in concrete masonry construction should comply with ASTM C 476, Standard Specification for Grout for Masonry, or the governing building code which may permit grouting

options other than those in set forth in ASTM C 476. ASTM C 476 defines two types of grout: fine and coarse.

**Fine grout:**
- Contains sand smaller than 9.5 mm as its only aggregate
- Would only be used in small core units such as reinforced brick
- Fine grout is required to flow through small openings so a grout slump of over 250 mm is recommended.

**Coarse grout:**
- Allows pea gravel smaller than 13 mm, or other acceptable aggregate, in addition to the sand.
- Coarse grout may be used where the grout space for the grouted cavity of a double-wythe\(^{18}\) masonry construction is at least 4 cm in width horizontally, or where the minimum block cell dimension is 4 x 8 cm.

**Table 5. Grout proportions by volume**

<table>
<thead>
<tr>
<th>Type</th>
<th>Parts by volume of Portland cement or blended cement</th>
<th>Parts by volume of hydrated lime or lime putty</th>
<th>Aggregate, measured in a damp, loose condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine grout</td>
<td>1</td>
<td>0 to 1/10</td>
<td>2 1/4 to 3 times the sum of the volumes of the cementitious materials</td>
</tr>
</tbody>
</table>
| Course grout| 1                                                  | 0 to 1/10                                      | 2 1/2 to 3 times the sum of the volumes of the cementitious materials

\(^{18}\) Wythe = continuous vertical section of masonry one unit in thickness

**7.4.2 Grout materials**

The primary ingredients of grout are water, Portland cement, and aggregates. Sometimes hydrated lime is added in limited quantities (as may certain pumping aids or other admixtures) to improve flowability of the grout.

**Water:**
- Water functions as a lubricant in the grout and reacts with the Portland cement.
- Water should be potable (drinkable).
- Grout is mixed to a highly fluid consistency to facilitate filling voids.

**Aggregates:**
Grout may contain only fine aggregates (fine grout) or a mixture of fine and coarse aggregates (coarse grout). The quality of aggregates used is important both to the flowability and the strength development of the grout.

Cement:
- Portland cement. Portland cement reacts with water to provide required grout strength.
- Blended cements may be used in grout instead of Portland cement.

Admixtures:
- Grout admixtures may be used to modify grout properties.
- Examples are pumping aids or admixtures to reduce shrinkage.
- The manufacturer of such admixtures should provide data substantiating the performance of the products.
- Chloride-based admixtures are not recommended in grout because chlorides contribute to corrosion of steel reinforcement and accessories.

### 7.4.3 Desirable grout properties
- Masonry grout is most often used in conjunction with steel reinforcement in masonry walls.
- While mortar is placed between units as they are laid, grout is poured or pumped into the cores or cavities between wythes of masonry walls already in place.
- The grout must uniformly fill these grout spaces, harden to provide desired compressive strength, and bond to reinforcing steel and masonry units.
- To satisfactorily meet these performance requirements, the flowability, aggregate size, and proportions of a grout mix must be compatible with the application.

**Slump:**
- The flowability of grout at the time of placement is measured by its slump. The slump should be in the range of 200 to 250 mm.
- Although this is high compared to ranges common for concrete, it is needed to assure that grout spaces are completely filled.
- Some of the water used to achieve slump is absorbed by the masonry units, thus lowering the water-cement ratio of the grout in place.

**Compressive Strength:**
- In certain engineered masonry applications, the compressive strength of the grout may be specified at a value consistent with the desired compressive strength of the masonry $f_{cm}$, but not less than 13.5 MPa.