Masonry 101 – Mortar

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

This course provides a comprehensive introduction to mortar for new masonry construction, especially for those who have little to no experience with masonry but find themselves needing to design or review projects.

It describes the purpose of mortar joining masonry units and the desirable properties of fresh and hardened mortar.

It describes the materials that comprise mortar and explains how mortars are specified, batched, and mixed. Mixing considerations necessarily include good practices for hot and cold weather construction and the additional care required for colored mortar, both for materials and mixing requirements. Some brief comments about specialty mortars are also included.

This course briefly describes quality assurance and quality control for mortar, the difference between QA and QC, and typical reporting requirements related to that.

Learning Objectives

- Describe fresh and hardened mortar properties for masonry construction and describe the materials used to produce plain or colored masonry mortar
- Explain the two methods for specifying mortar for masonry construction and reporting requirements (submittals)
- Overview the proper construction practices for mixing and placing, and review quality assessment procedures
- Review specialty mortars and ingredients and discuss differences with more traditional mortars

Mortar & Mortar Mixing

Mortar Introductory Remarks

- ASTM C270 mortar specification
- ASTM C780 test methods for mortar
- TMS 402/602 Code and Specification
- We will briefly describe other (specialty) mortars:
  - Proprietary mortars
  - Repair mortars
  - Thin-set mortar for AAC masonry
  - Adhered veneer mortars, latex-modified, and epoxy mortars
  - Refractory mortar
- More information on some of these specialty mortars can be found in IBC Section 2103.2

Mortar

Mortar is a basic component of reinforced and unreinforced masonry.

- Bonds units together
- Accommodates dimensional variations
  - 3/8 in. typical mortar joint
- Serves as a weather barrier

Mortar Properties: Plastic (Unhardened)

- Workability
- Water retention
- Board life
- Consistency
- Adhesion

Mortar Properties: Hardened Mortar

- Strength
- Bond
- Moisture-proof
- Durability
- Appearance

Mortar Composition

Mortar consists of a mixture of cementitious material and aggregate to which sufficient water and approved additives, if any, have been added to achieve a workable, plastic consistency.

Mortar Materials

- Cementitious Materials
- Water
- Aggregates (Sand)
- Sometimes, Admixtures, and Color Pigments
- Materials are defined by an ASTM specification, named by the letter “C” and a number, for example, C150 for portland cement
- There are two key ASTM standards for mortar:
  - C270 for mortar
  - C780 for mortar tests

Cementitious Materials

Cementitious materials for mortar are required to be one or more of the following:

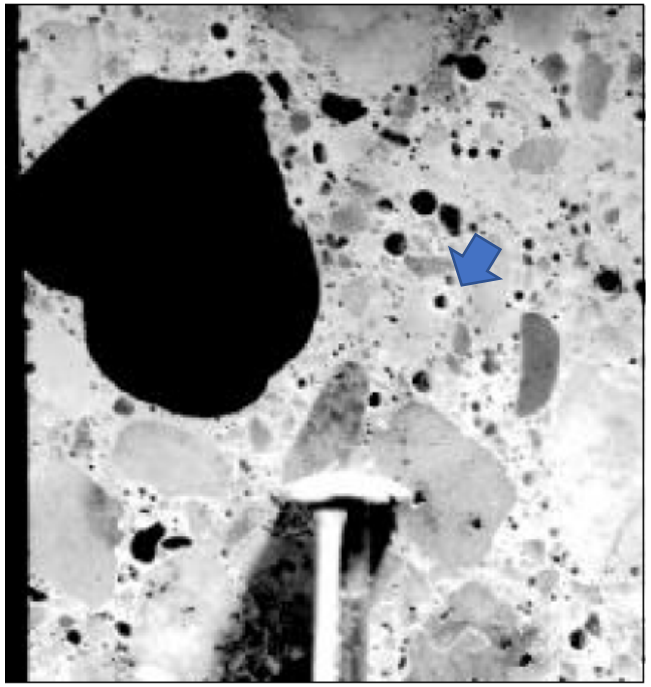
- Portland cement
- Blended cement
- Hydraulic cement
- Lime
- Masonry cement
- Mortar cement

Cement serves as main binder in modern mortars and provides durability, early strength, and bond

All cements are available in white

Portland, Blended, Hydraulic Cements

- Portland Cement: ASTM C150
  - Types I, II, III, V and their **air-entrained counterparts**
- Blended Cement: ASTM C595
  - Types IL, IS, IP, IT and their **air-entrained counterparts**
- Hydraulic Cement: ASTM C1157
  - Performance spec, can be a portland or blended cement
  - Types GU, HE, MS, and HS
- All general use cements for any type of construction
- For mortar, **must be used with lime** to provide workability and water retention



Air entrainment: cut and polished section of concrete to show air bubbles in hardened matrix

Masonry Cement

- Masonry cement: ASTM C91
  - Formulated for use in mortar. Provides good workability and easy mixing. ***Not*** for use in concrete construction.
  - Types N, S, M
  - Contains portland cement, plasticizing materials, and additives
    - Air content: 8% to 21%
  - *Partial restrictions* in SDC D, E, F (TMS 402, Section 7.4.4.2.2)
    - **Allowed** for fully grouted participating members
    - **Allowed** for non-participating members
    - **Not allowed** for partially grouted participating members
  - Annually, 70% to 80% of mortar is made with masonry cement

Mortar Cement

- Mortar cement: ASTM C1329
  - Like masonry cement, formulated for use in mortar, but for more demanding structural applications such as buildings in areas of greater seismic activity. *Not* for concrete construction.
  - Types N, S, M
  - Contains portland cement, plasticizing materials, and additives
  - **Minimum flexural bond strengths are required** (this differentiates C1329 from C91 masonry cement)
    - Minimum bond strength requirement: 70, 100, 115 psi (Type N, S, M)
    - Air content: 8% to 21%

Lime

- Hydrated lime, ASTM C207, is used for most modern mortars:
  - Type S, SA (special)
  - Type N, NA (normal)
- Lime putty, ASTM C1489, is allowed but less common now
- Lime provides
  - Late-age strength
  - Workability and board life
  - Water retention
  - Autogenous (self) healing
- Lime is **not** used with:
  - Masonry cement or mortar cement, as they contain other plasticizing materials

Masonry Sand

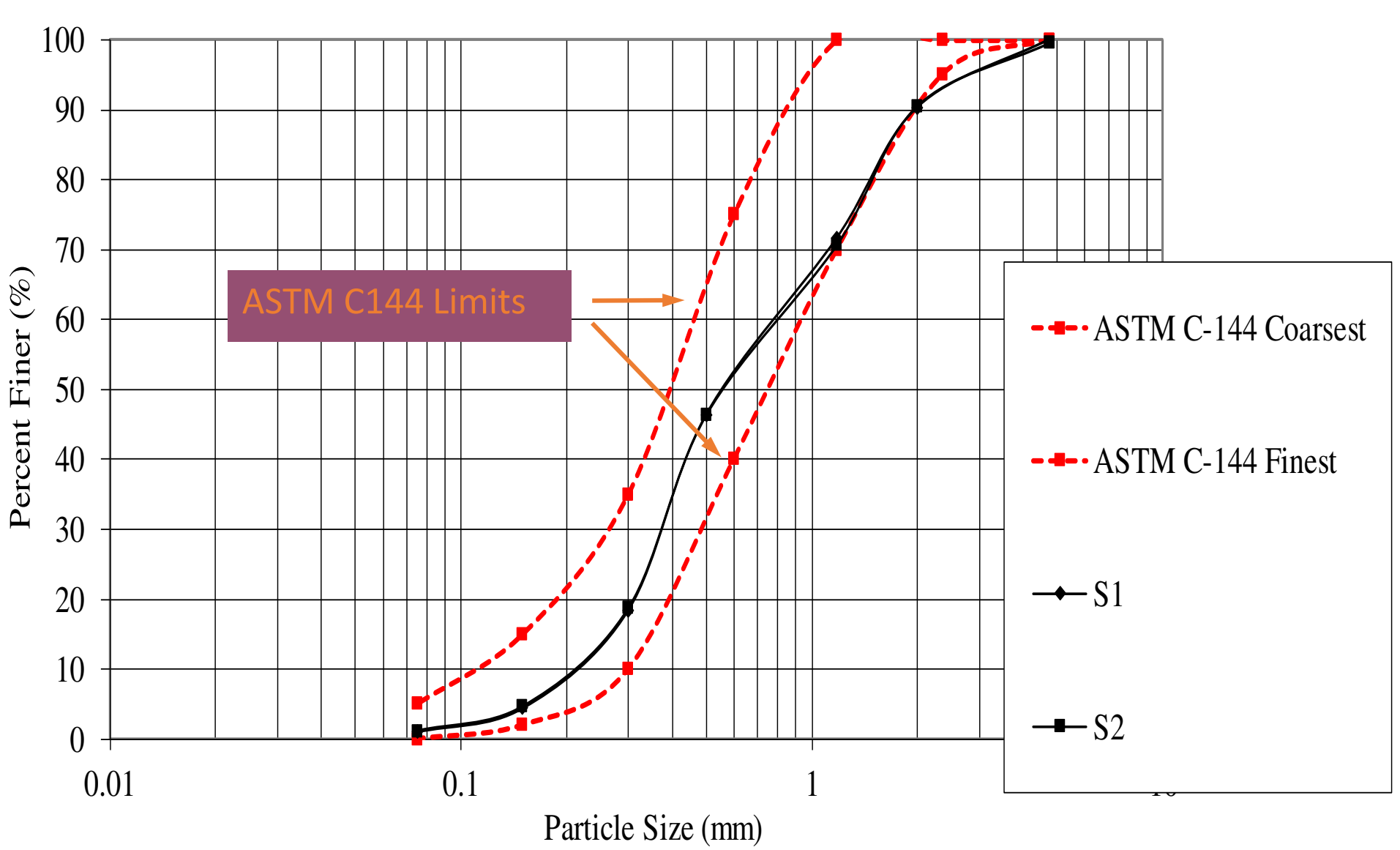
- Sand provides:
  - Bulk
  - Compressive strength
  - Shrinkage resistance
- Unless otherwise permitted, sand for mortar must comply with ASTM C144 and should be well graded

Sand should be stored in a clean, dry place and kept free from contamination. Sand should not contain "deleterious substances" such as clay, silt, or organic materials

Masonry Sand Gradation

ASTM C-144, Section 4		
Aggregate for use in masonry mortar shall be graded within the following limits, depending upon whether natural sand or manufactured sand is to be used:		
Sieve Size	Percent Passing	
	Natural Sand	Manufactured Sand
No. 4 (4.75 mm)	100	100
No. 8 (2.36 mm)	95 to 100	95 to 100
No. 16 (1.18 mm)	70 to 100	70 to 100
No. 30 (600-µm)	40 to 75	40 to 75
No. 50 (300-µm)	10 to 35	20 to 40
No. 100 (150-µm)	2 to 15	10 to 25
No. 200 (75-µm)	0 to 5	0 to 10

Aggregate Gradation, Sieve Analysis



Improperly Graded Masonry Sand

- If an aggregate fails the gradation limits, can it be used for mortar?
- Yes, but testing is required
- Results of mortar testing must comply with the **property specs** of Specification C270, with requirements for:
  - Compressive strength
  - Water retention
  - Air content

TABLE 1 Property Specification Requirements[A]

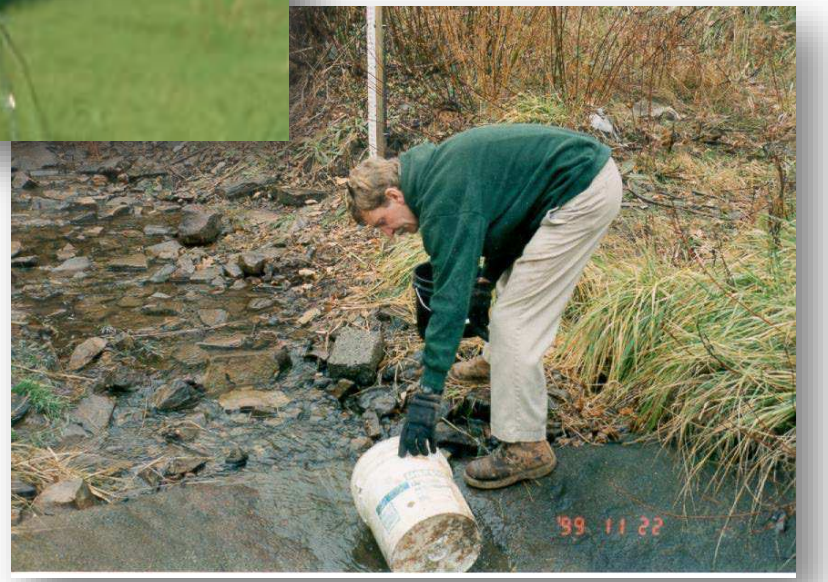
Mortar	Type	Average Compressive Strength at 28 days, min, psi (MPa)	Water Retention, min, %	Air Content, max, %[B]	Aggregate Ratio (Measured in Damp, Loose Conditions)
Cement-Lime	M	2500 (17.2)	75	12	
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14[C]	
	O	350 (2.4)	75	14[C]	
Mortar Cement	M	2500 (17.2)	75	18	Not less than 2 ¼ and not more than 3 ½ times the sum of the separate volumes of cementitious materials
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20[D]	
	O	350 (2.4)	75	20[D]	
Masonry Cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20[D]	
	O	350 (2.4)	75	20[D]	

Water

- Potable, clean
- No deleterious materials
- Generally, municipal water is used

- Workability is one of the most important properties of mortar
- Water content is at the discretion of mason and mason tender

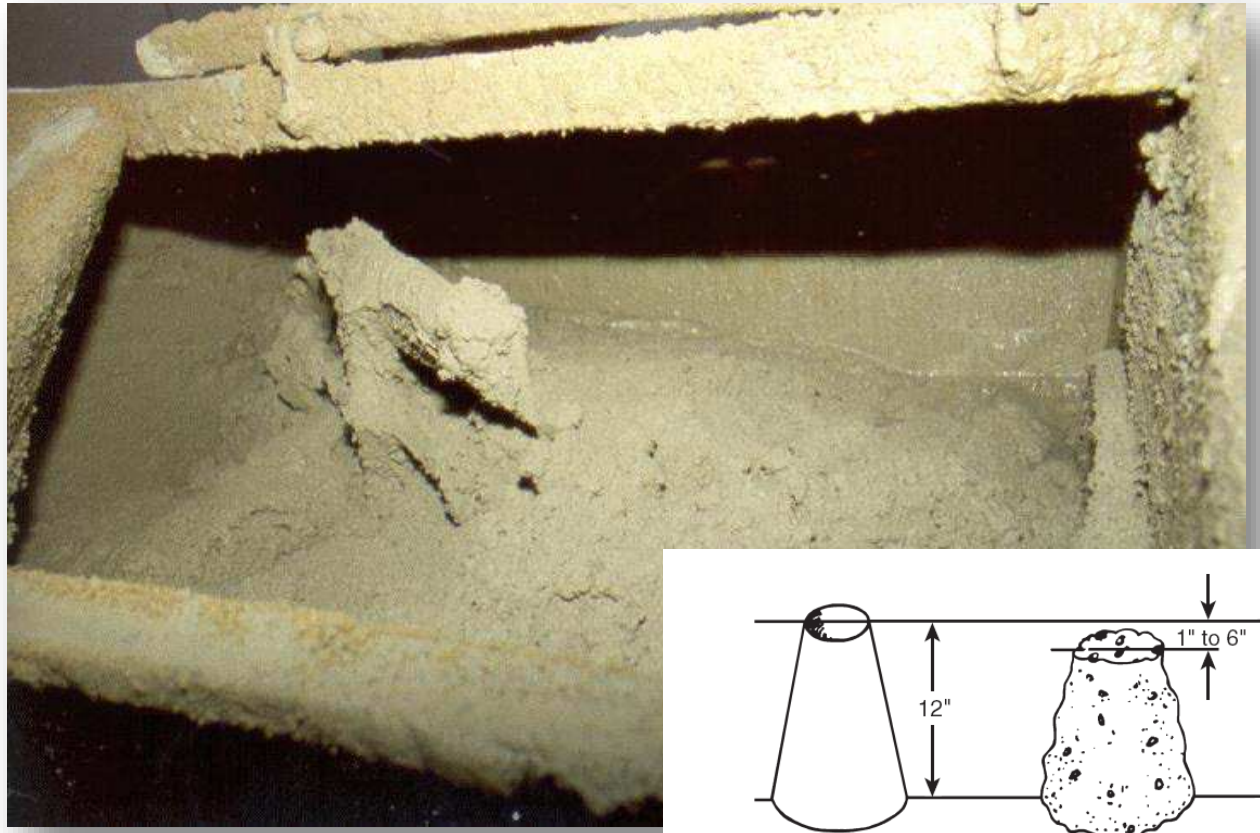
Generally, same source as drinking water

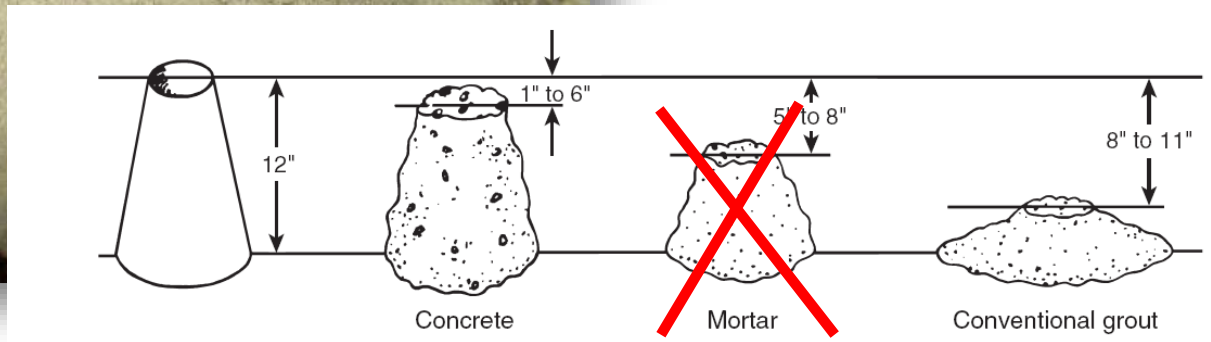


Water from other sources may be acceptable

How much water?

- Enough to provide good workability

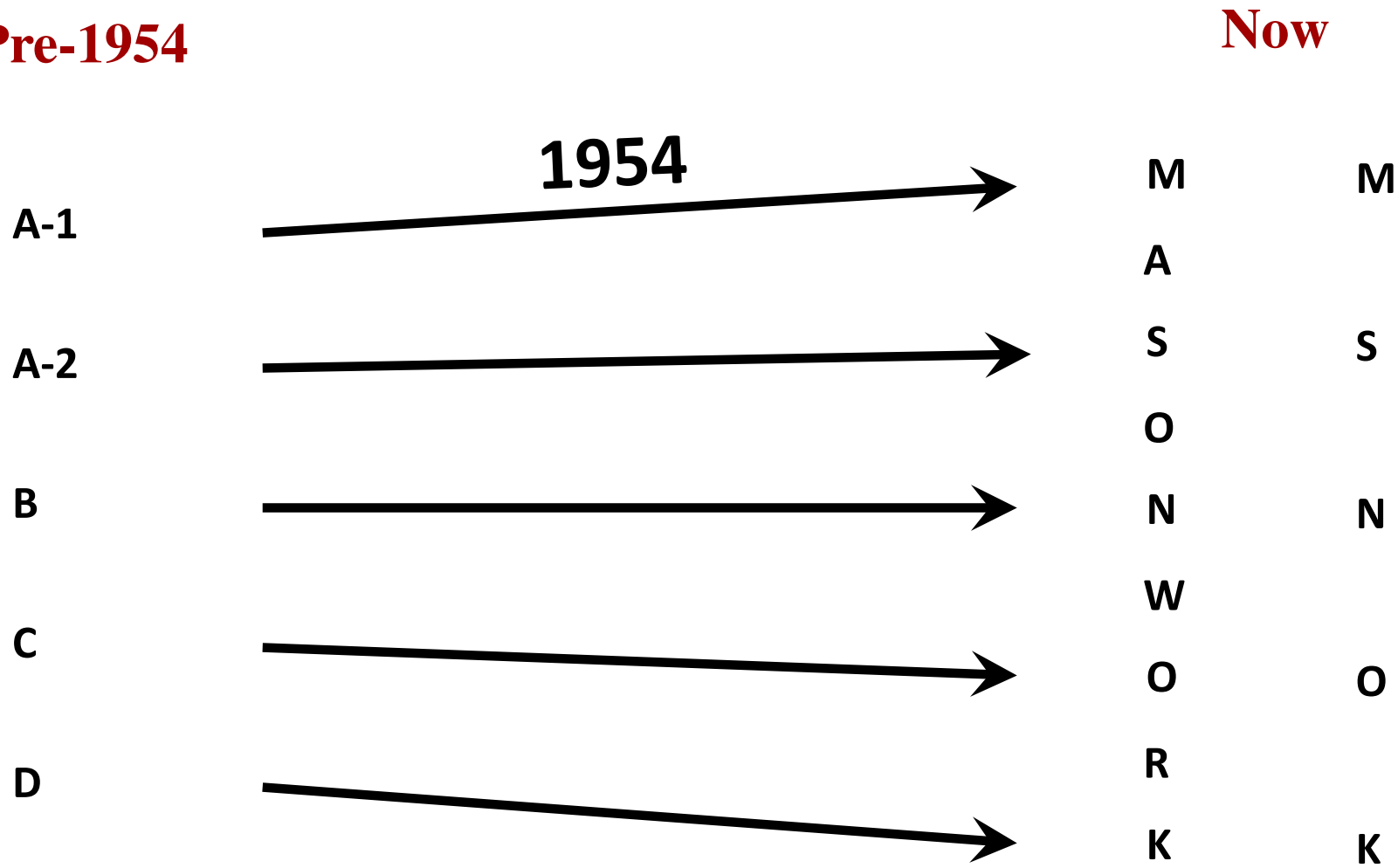




Admixtures

- May only be used when specified or approved
- Examples include (most are per ASTM C1384):
  - Set accelerator/retarder
  - Water repellent
  - Workability enhancer
  - Bond enhancer
  - Antifreeze (typically not permitted)
  - Pigments (ASTM C979)
- Avoid chlorides unless explicitly permitted

Mortar Types



Specifying Mortar

- Proportion Specification
  - Easiest, most common
  - No laboratory testing required
  - Recipe (by volume)
  - ASTM C270, Table 2

- Property Specification
  - Preconstruction laboratory testing required
  - Minimum compressive strength, water retention, air content
  - ASTM C270, Table 1

Specifying by Proportion: Cement and Lime

	Proportions, by Volume		
Mortar Type	**Cement**	Lime	Sand
M	1	¼	2 ¼ to 3 times cement and lime volumes
S	1	¼ to ½	
N	1	½ to 1 ¼	
O	1	1 ¼ to 2 ½	

Common Type N mortar contains: **1 part cement + 1 part lime** and sand

Specifying by Proportion: Sand Content

How much sand? 2-1/2 to 3 parts

- Volume of sand is determined by the sum of the volume of cementitious materials
- Cement and lime are both cementitious
- 1 part cement + 1 part lime = 2 parts cementitious materials
- So sand volume is allowed to be between:

$2 \times 2\,{}^{1}/_{4} = 4\,{}^{1}/_{2}$ and $2 \times 3 = 6$

Specifying by Proportion: Parts by Volume

- One bag of portland cement (94 lb) equals 1 cubic foot of material
- One bag of lime (40 lb or 50 lb) is typically taken to be equal to 1 cubic foot of material
- For our Type N mortar example, we have 2 cubic feet of cementitious material, so we need 4 ½ to 6 cubic feet of sand
- Proportions would be given as 1:1:6 (cement: lime: sand)

Specifying by Proportion: Masonry or Mortar Cement

Mortar Type	Masonry/Mortar Cement			Portland Cement	Sand
	M	S	N		
M	1				2 ¼ to 3 times total cement volume
M			1	1	
S		1			
S			1	½	
N			1		
O			1		

Proportion Specifications

TABLE 2 Proportion Specification Requirements

NOTE 1—Two air-entraining materials shall not be combined in mortar.

Mortar	Type	Proportions by Volume (Cementitious Materials)								Aggregate Ratio (Measured in Damp, Loose Conditions)
		Cement[A]	Mortar Cement			Masonry Cement			Hydrated Lime or Lime Putty	
			M	S	N	M	S	N		
Cement-Lime	M	1	...	...	...	...	...	...	¼	
	S	1	...	...	...	...	...	...	over ¼ to ½	
	N	1	...	...	...	...	...	...	over ½ to 1¼	
	O	1	...	...	...	...	...	...	over 1¼ to 2½	
Mortar Cement	M	1	...	...	1	...	...	...	...	Not less than 2¼ and not more than 3 times the sum of the separate volumes of cementitious materials
	M	...	1	...	...	...	...	...	...	
	S	½	...	...	1	...	...	...	...	
	S	...	...	1	...	...	...	...	...	
	N	...	...	...	1	...	...	...	...	
	O	...	...	...	1	...	...	...	...	
Masonry Cement	M	1	...	...	...	...	...	1	...	
	M	...	...	...	...	1	...	...	...	
	S	½	...	...	...	...	...	1	...	
	S	...	...	...	...	...	1	...	...	
	N	...	...	...	...	...	...	1	...	
	O	...	...	...	...	...	...	1	...	

[A]Includes Specification C150/C150M, C595/C595M, and C1157/C1157M cements as described in 4.1.1.

Specifying by Property

Mortar	Mortar Type	Compressive Strength, psi	Water Retention, %	Air Content,%	Sand
Type and Combination of Cementitious Materials	M S N O	2500 1800 750 350	75	12 or 14* (cement-lime) 18 or 20* (masonry cement or mortar cement)	Range of parts by volume of $2^{1}/_{4}$ to $3^{1}/_{2}$ times sum of cementitious materials

*When structural reinforcement is incorporated in mortar made with:

- Cement-lime, the maximum air content shall be 12%.
- Masonry cement or mortar cement, the maximum air content shall be 18%.

Comparing Mortar Types

Mortar Type

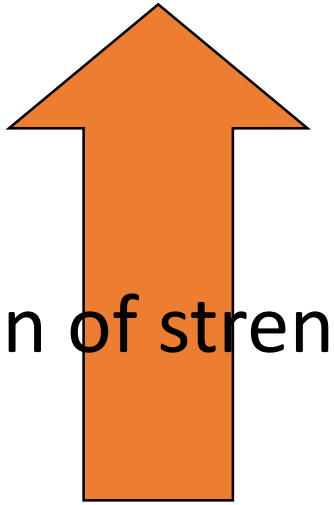
Higher Strength

M

S

N - good combination of strength and workability

O



Better Workability

Mortar Compressive Strength

- By itself, not the best indicator of mortar acceptability
- Mortar quality and masonry quality are most dependent on the workability of the mortar and the mason's ability to place it
- Mortar compressive strength should only be as high as necessary
- Mortar with higher strengths than specified **may not be substituted without approval**

Mortar Compressive Strength NOT Recommended for Field Testing

- **Will almost always appear to be low**
- Compressive strength test doesn't tell whether mortar was mixed to comply with proportions of ASTM C270
- Results are affected by many variables:
  - Weather
  - Curing of specimens
  - Specimen geometry
- Identifies batch-to-batch variations, but not necessarily a change in proportions
- A better option is mortar-aggregate ratio test (ASTM C780)

Mortar Mixing

End goal of mixing is good workability

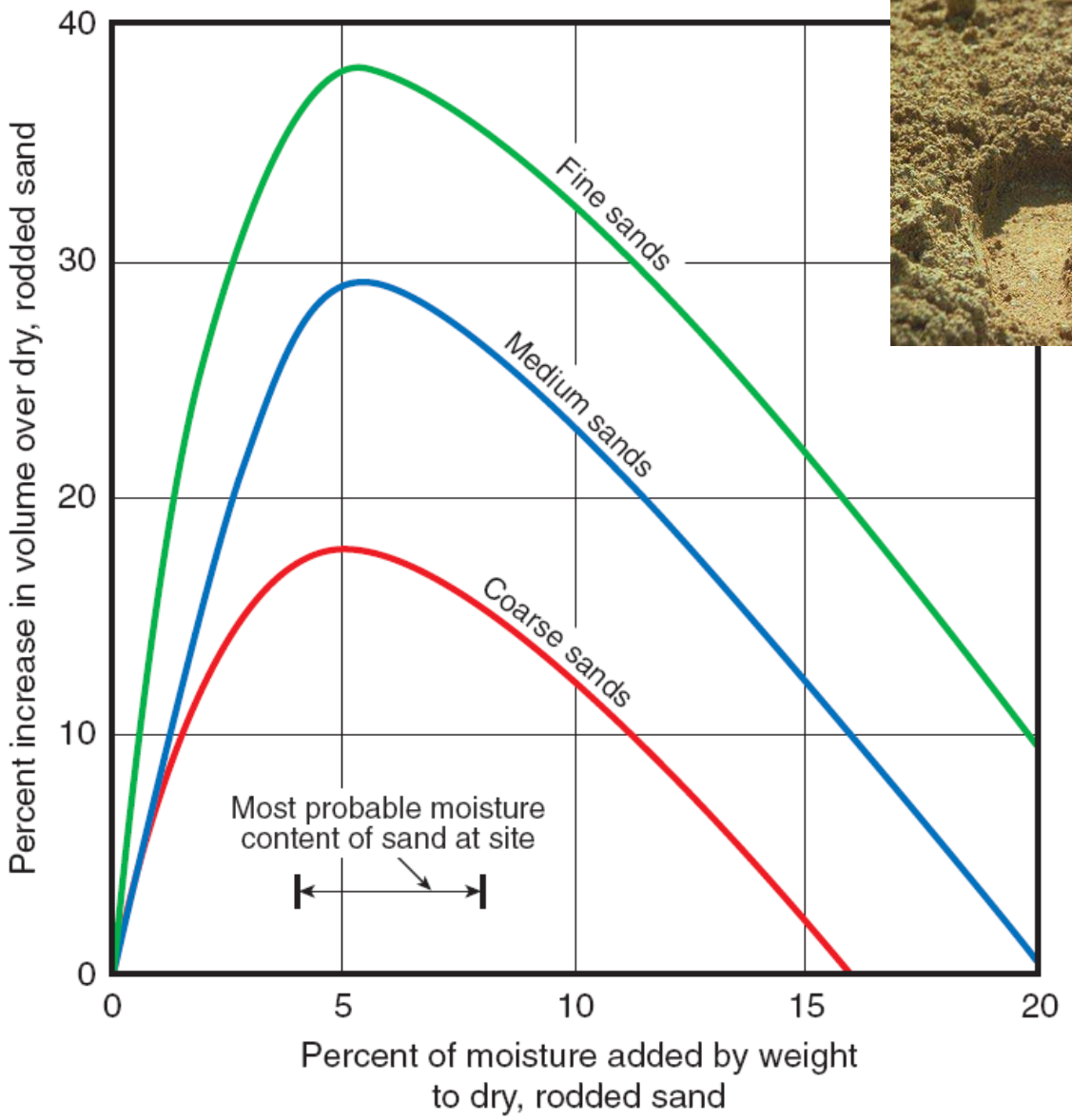
But first, materials must be batched properly…

Batching

- Volume proportions
- Consistent addition of materials to mixer
- A cubic foot box helps “accurately maintain specified proportions”
- Water determined by mason and mason tender together
  - Enough for good workability

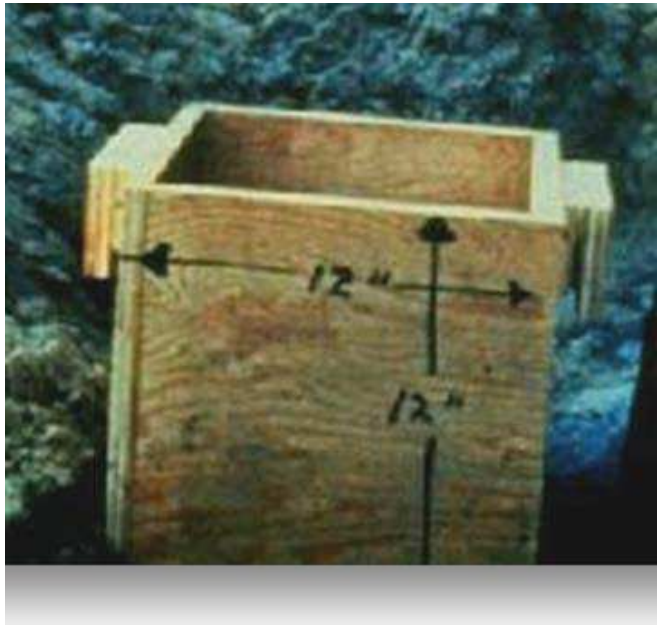
Aggregate

- Moisture content affects volume
- Measured by volume in damp, loose condition
- Footprint shows “bulking” or “fluffing” effect



Importance of Measuring Sand

- Measure sand accurately each time
  - Sand moisture content affects volume
  - Keep sand damp and loose



Use volumetric measure: 5 gal. bucket, cubic foot box

Field Mortar Proportioning

Mortar Mixing

- Mechanical mortar mixing is best (paddle type)
- Use mortar mixer, not concrete mixer
- Mortar should be discarded if it:
  - Is older than 2-1/2 hours (following initial mixing)*
  - Has begun to stiffen
- 2-1/2 hours is the maximum useful life of mortar under usual conditions
- 2 hour maximum recommended in hot weather

*Ready mix mortar may be exempted from this requirement

Mortar Mixing

- It is better to over-mix rather than under-mix
- Thorough blending of materials is important
- Consistency is key
- One person dedicated to mixing is best to provide consistent mortar throughout the job

Two Common Types of Mixers

Paddle/Plaster Mixer
The drum is stationary and the blades rotate through the mortar materials for thorough mixing.

Drum/Barrel Mixer
The drum rotates and the material is carried to the top of the rotation and drops down to achieve mixing.

Alternate Mixing – Silo Mixes

Silo mixing suited to factory pre-blended mortar materials

ASTM C1714, Standard Specification for Preblended Dry Mortar Mix for Unit Masonry

Mortar meets requirements of C270

Some systems:

- Are self-contained and introduce water to the dry mortar mix in an auger screw at the base of the silo
- Discharge the dry mortar mix into a conventional mixer and mechanical mixing occurs as usual

Pre-blended mortar requires that a manufacturers certification of the type of mortar be provided (delivery tickets)

Hand Mixing… Can Be Allowed

- Small amounts of mortar can be hand mixed only if approved in writing by the specifier
- Hand mixing requires written procedures
- Better blending with mechanical mixing
- It is difficult to incorporate air into mixtures with hand mixing

- Mixing on ground not recommended
- Risk of contamination

Retempering is Good Practice

- Age and hot weather conditions can affect mortar properties
- Retempering = addition of water and remixing to restore plasticity/workability
- Water should be thoroughly reworked into mortar

Retempering – When to do it

- Mortar should be retempered with water when needed to maintain workability (but 2-1/2 hour age limit applies)
- Mortar that has begun to stiffen due to hydration should be discarded
- Exceptions
  - Hot weather limit: 2 hours instead of 2-1/2
  - *Not recommended* for colored mortar
    - Color may be affected
    - Solution: mix batches in amounts that can be used before retempering becomes necessary

Colored Mortar

Colored Mortar Pigments

- Mortar colors are generally mineral oxides or carbon black (ASTM C979)
- Dosages are based on weight of cement. Higher dosages yield more intense colors
- White cement allows for pastels, brighter and more intense colors, lower pigment dosages, or colored aggregates

Colored Mortar Pigment Dosages

Maximum percentages :

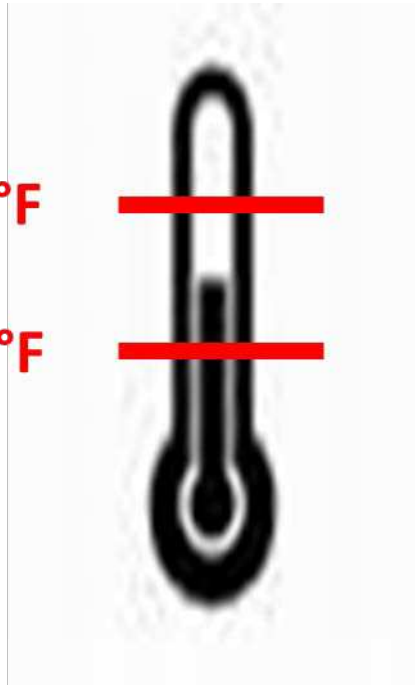
- Pigmented (portland) cement-lime mortar
  - Mineral oxide pigment 10%
  - Carbon black pigment 2%
- Pigmented mortar cement mortar or masonry cement mortar
  - Mineral oxide pigment 5%
  - Carbon black pigment 1%

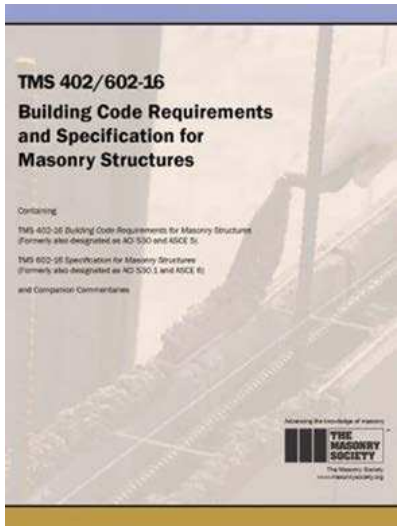
Colored Mortar Best Practices

- Uniform color from consistent practices: material source, manufacturer, and amount of each ingredient should remain the same for all colored mortar on the project
- Pre-blended colored mortars help maintain color consistency
- If jobsite blended, full batches should be used
- Retempering is not recommended as it can affect color

Hot & Cold Weather

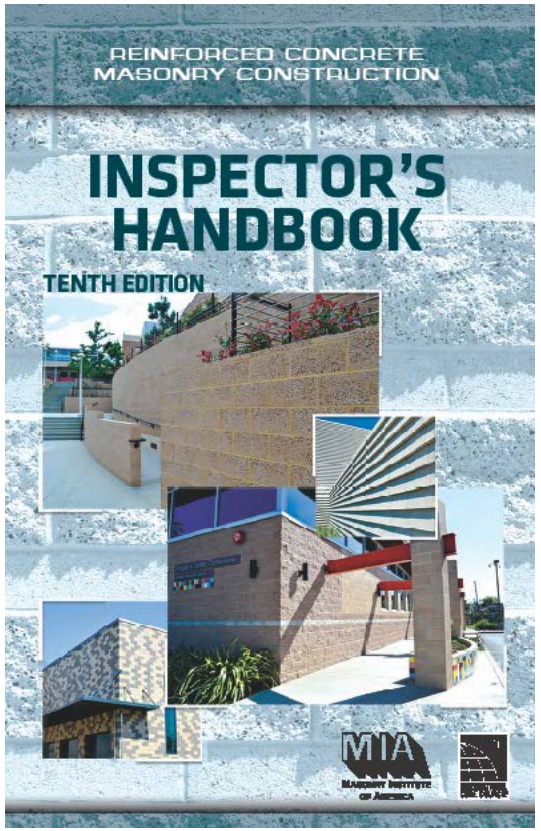
- "Normal" conditions – 40°F to 90°F
- Hot weather - above 100°F (or 90°F with an 8 mph)
- Cold weather – below 40°F
- In hot or cold weather, building new masonry may require special precautions during:
  - Preparation
  - Construction
  - Protection (immediately following construction)
- TMS 602 contains all the information you need





Hot and Cold Weather Construction Requirements

- What effect does weather have on masonry construction?
- Before, during, immediately after?
- Mortar and grout
  - Affects set time
  - Affects early age strength
  - Water demand
- Units
  - Affects absorption
  - Affects shrinkage
  - Affects unit placement



Hot Weather Mortar Mixing

- Cold water helps delay hydration
  - Use to mix mortar in hot weather to extend mortar life
  - Chipped ice can be used, but account for as part of water (by weight)
- Cool aggregate by:
  - Sprinkling aggregate piles with water to cause evaporative cooling
  - Shade aggregate piles
  - These are simple, effective methods to control temperature

Cold Weather Mortar Mixing

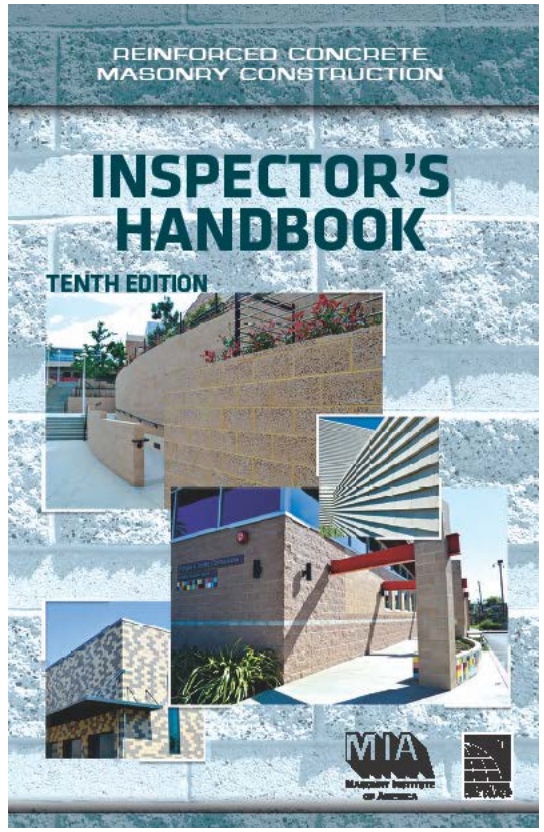
- Water can be heated in drums or barrels
  - Use water up to 140°F to mix mortar
  - Hotter water can initiate flash set of cement
- Sand can be heated in sand piles or with heated pipes
  - Use sand up to 140°F to mix mortar
  - Overheating sand can scorch it

Protecting Mixing Site

- Freshly mixed mortar should be neither too hot nor too cold
- In cold weather, an enclosure can help maintain temperature of mixing area
- In hot weather, shading the mixing area can prevent unwanted heat gain

Cold Weather Construction

Laying the Units	*Temperature Range ºF*			
	40º to 32º	32º to 25º	25º to 20º	20º and below
Temperature of the units to be at least 20º F	×	×	×	×
Do not lay glass units	×	×	×	×
Remove ice and snow from footings and installed masonry	×	×	×	×
Heat sand ***or*** mixing water for mortar 40ºF to 120ºF. Do not heat water or aggregates above 140ºF	×			
Heat sand ***and*** mixing water for mortar 40ºF to 120ºF (TMS 602 requirement)		×	×	×
Maintain mortar above freezing		×	×	×
Heat masonry surfaces to 40ºF			×	×
Windbreaks for excess of 15 mph			×	×
Provide enclosures & auxiliary heat to produce air temperature above 32ºF				×



Proprietary Mortars

- Proprietary mortars must be approved by the engineer or architect and accepted by building official, where applicable
- Handling and use of proprietary mortar should be in strict compliance with manufacturer's recommendations
  - C270 does not apply
- Proprietary mortars may or may not contain portland cement
- Extended life mortar standard, ASTM C1142, was withdrawn in 2019

Other/Specialty Mortars

- Repair mortar (tuck pointing), C270
  - Not for new construction – guidance in Appendix X3
- Mortar for adhered veneer, ANSI A118.1, 118.4, 118.15 (TMS 402/602-22)
  - Bedding mortars, may contain polymers for better bond
- Refractory mortars, F1097
  - Resistant to high temperature exposures, use ¼ in. or thinner joints
  - Non-portland cement systems: fire clay, calcium aluminate, sodium silicate
- Chemical-resistant mortars, C287, C395, C466
  - Protect against acid or alkali attack, use narrow joints
  - Not portland cement – sulfur, silicate, phenolic resin, furan, polyester, epoxy resin
- AAC mortars, C1660
  - Thin-bed adhesive mortar, use 1/16 to 1/8 in. thick joints
  - All C270 cements allowed, as well as C1600 rapid-hardening cements

Quality Assurance vs. Quality Control

Quality Assurance

- Think of it as more external
- Identify problems
- Owner/designer efforts to determine acceptability

Quality Control

- Think of it as more internal
- Prevent problems
- Materials producer/contractor efforts to make sure that their product is good, installed correctly

Quality Assurance for Mortar

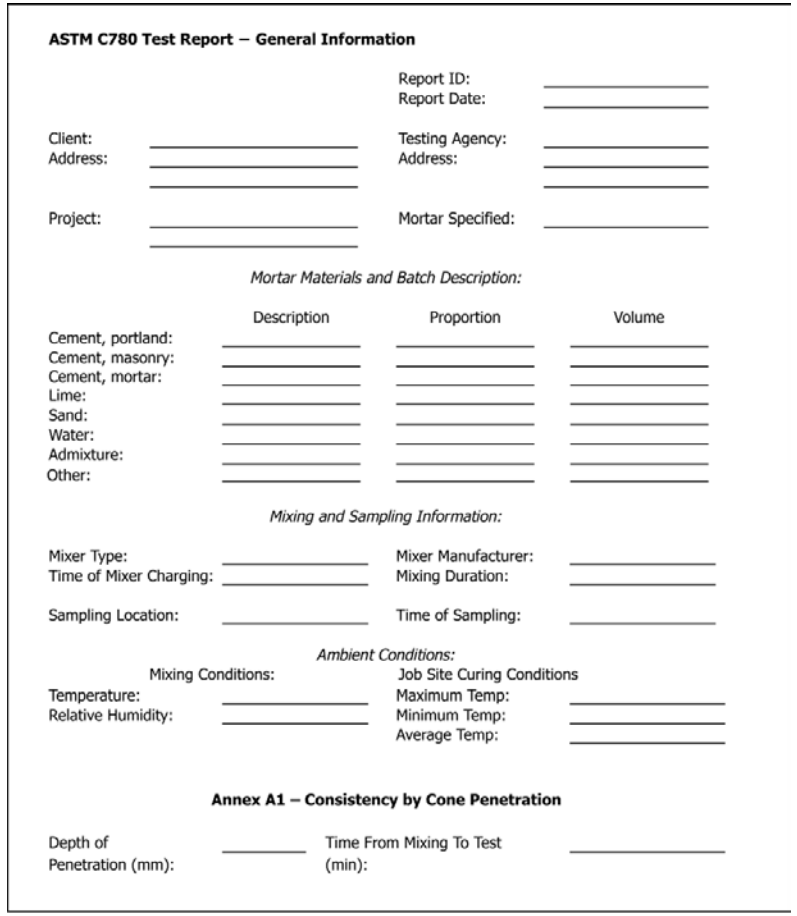
- QA = administrative and procedural requirements in the contract documents to assure that masonry is in compliance
  - Actions taken by owner to verify good quality
  - Level of QA varies with design and complexity of the project
  - TMS 402 assigns a Level 1, 2, or 3 depending on Risk Category
  - TMS 602 lays out minimum verification and (where required) special inspection requirements
    - Guidance on required/not, and periodic or continuous
    - Proportions of mortar
    - Preparation of mortar specimens, where required

Quality Control for Mortar

- QC = a comparison of the quality of work with established standards
  - Inspection, testing, evaluation, and corrective action, **when needed**
  - Tests may be required (ASTM C780)
    - Annex A1, consistency by cone penetration
    - Annex A2, consistency retention by cone penetration
    - Annex A3, initial consistency and retention, modified penetrometer
    - Annex A4, mortar aggregate ratio
    - Annex A5, air content
    - Annex A6, compressive strength

Submittals – Sample Report in C780

- Report results promptly to architect/engineer and contractor
- Furnish inspection reports to the same groups
- Provide summary of weather and other conditions under which inspection was made
- Report discrepancies
- Identify what portion of construction is represented
- Inspectors are not on every job, but when present, are only there to **observe and report**



ASTM C780 Test Report – General Information

Report ID: _____
Report Date: _____

Client: _____
Address: _____
_____

Testing Agency: _____
Address: _____
_____

Project: _____
_____

Mortar Specified: _____

Mortar Materials and Batch Description:

	Description	Proportion	Volume
Cement, portland:			
Cement, masonry:			
Cement, mortar:			
Lime:			
Sand:			
Water:			
Admixture:			
Other:			

Mixing and Sampling Information:

Mixer Type: _____
Time of Mixer Charging: _____

Mixer Manufacturer: _____
Mixing Duration: _____

Sampling Location: _____

Time of Sampling: _____

Ambient Conditions:

Mixing Conditions:
Temperature: _____
Relative Humidity: _____

Job Site Curing Conditions
Maximum Temp: _____
Minimum Temp: _____
Average Temp: _____

Annex A1 – Consistency by Cone Penetration

Depth of Penetration (mm): _____

Time From Mixing To Test (min): _____

This concludes The American Institute of Architects Continuing Education Systems Course

The Masonry Society

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