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Brick Masonry Material Properties

Abstract: Brick masonry has a long history of reliable structural performance. Standards for the structural design of masonry that are periodically updated, such as the *Building Code Requirements for Masonry Structures* (TMS 402) and the *Specification for Masonry Structures* (TMS 602), advance the efficiency of masonry elements with rational design criteria. However, design of masonry structural members begins with a thorough understanding of material properties. This *Technical Note* is an aid for the design of brick and structural clay tile masonry structural members. Clay and shale units, mortar, grout, steel reinforcement, and assemblage material properties are presented to simplify the design process.

Key Words: brick, grout, material properties, mortar, reinforcement, structural clay tile.

SUMMARY OF RECOMMENDATIONS:

General
- This *Technical Note* is an aid for the design of brick and structural clay tile masonry structural elements
- Behavior of the combined materials determines the performance of the masonry as a structural element

Constituent Material Properties
- Clay and shale masonry units:
  - Specify units to meet the appropriate ASTM standard
  - For brick and structural clay tile unit compressive strengths, refer to Table 1
- Mortar:
  - Use mortar complying with ASTM C270
  - Select mortar Type based on recommendations listed for Type N, S and M mortars and *Technical Note* 8B
- Grout:
  - Use grout complying with ASTM C476
  - Use a non-shrink grout admixture to minimize shrinkage cracking in grout
- Steel reinforcement:
  - For steel reinforcement material yield and tensile strengths, refer to Table 3
  - Reinforcing bar grades above 60 ksi are not currently permitted by TMS Code
  - For ASTM material standards for reinforcement and metal accessories, refer to Table 4

Assemblage Material Properties
- Compressive strength:
  - Use the unit strength method or the prism test method in the TMS Specification to determine the compressive strength of the masonry assemblage
- Shear strength:
  - While not required for design, ASTM E519 may be used to determine shear strength of masonry
- Flexural tensile strength:
  - For the allowable flexural tensile stress for unreinforced masonry, refer to Table 6
  - For the modulus of rupture, refer to Table 7
- Elastic modulus:
  - For the elastic modulus of the masonry assemblage, refer to Equation 1
- Dimensional stability:
  - For coefficients of moisture expansion, creep and thermal movements, refer to Table 8

INTRODUCTION

The Masonry Society (TMS) has developed the *Building Code Requirements for Masonry Structures* (TMS 402) and the *Specification for Masonry Structures* (TMS 602). In this *Technical Note*, these documents are referred to as the TMS Code and the TMS Specification, respectively. The TMS Code and Specification are periodically revised by TMS and together provide design and construction requirements for masonry. The TMS Code and Specification apply to structural masonry assemblages of clay, concrete or stone units.

This *Technical Note* is a design aid for the TMS Code and Specification. It contains information on fired clay and shale units, mortar, grout, steel reinforcement and assemblage material properties. These are used in the initial stages of a structural design or analysis to determine applied stresses and allowable stresses. Material properties are explained to aid the designer in selection of materials and to provide a better understanding of the structural properties of the masonry assemblage based on the materials selected.

CONSTITUENT MATERIAL PROPERTIES

Because brick masonry is bonded into an integral mass by mortar and grout, it is considered to be a homogeneous construction. It is the behavior of the combination of materials that determines the performance of the masonry as a structural element. However, the performance of a structural masonry element is dependent upon the properties of the constituent materials and the interaction of the materials as an assemblage. Therefore, it is important to first consider the properties of the constituent materials: clay and shale units, mortar, grout, and steel reinforcement. This will be followed by a discussion of the behavior of their combination as an assemblage.

Clay and Shale Masonry Units

There are many variables in the manufacturing of clay and shale masonry units. Primary raw materials include surface clays, fire clays, shales or combinations of these. Units are formed by extrusion, molding or dry-pressing and are fired in a kiln at temperatures between 1800 and 2100 °F (980 and 1150 °C). These variables in manufacturing produce units with a wide range of colors, textures, sizes and other physical properties. Clay and shale masonry units are most frequently selected as a construction material for their aesthetics and long-term performance. Consequently, material standards for clay and shale masonry units contain requirements to ensure that units meet a level of durability and visual and dimensional consistency. Material standards for brick and structural clay tile include the following: ASTM C216 (facing brick), ASTM C62 (building brick), ASTM C652 (hollow brick), ASTM C1405 (single fired glazed brick), ASTM C1088 (thin veneer brick), ASTM C212 (structural clay facing tile), ASTM C34 (structural clay loadbearing tile), and ASTM C56 (structural clay non-loadbearing tile). All of these units may be used in structural elements of building construction except ASTM C1088 (thin veneer brick) and ASTM C56 (structural clay non-loadbearing tile).

While brick and structural clay tile are both visually appealing and durable, they are also well-suited for many structural applications. This is primarily due to their variety of sizes and very high compressive strength. The material properties of brick and structural clay tile that have the most significant effect upon structural performance of the masonry are compressive strength and those properties affecting bond between the unit and mortar, such as rate of water absorption and surface texture.

Unit Compressive Strength. The compressive strength of brick or structural clay tile is an important material property for structural applications. In general, increasing the compressive strength of the unit will increase the masonry assemblage compressive strength and elastic modulus. However, brick and structural clay tile are frequently specified by material standards rather than by a particular minimum unit compressive strength. ASTM material standards for brick and structural clay tile require minimum compressive strengths to ensure durability, which may be as little as one-fifth the actual unit compressive strength.

A 1993 Brick Institute of America survey of U.S. brick manufacturers resulted in a data base of unit properties [Ref. 6]. A subsequent survey of structural clay tile manufacturers was conducted. The compressive strengths of brick and structural clay tile evaluated in these surveys are presented in Table 1. As is apparent, all types of brick and structural clay tile typically exhibit compressive strengths considerably greater than the ASTM minimum requirements. Compressive strength of brick and structural clay tile is determined in accordance with ASTM C67/C67M, *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile*.

Compressive strength testing is conducted with the brick unit oriented horizontally, as if it were laid on the bed joint. Compressive strength is not a requirement for thin brick, as these units would never be used in a loadbearing application. Therefore, compressive strength is excluded as a requirement from the ASTM C1088 standard.

TABLE 1

Brick and Structural Clay Tile Unit Compressive Strengths[a]

Unit Type			Mean Unit Compressive Strength, psi (MPa)	Standard Deviation of Compressive Strength, psi (MPa)
Solid Brick[b]	Forming method	Extruded	11,305 (77.9)	4464 (30.8)
		Molded	5293 (36.5)	1822 (12.6)
	Raw material[c]	Fire clay	15,346 (105.8)	5065 (34.9)
		Shale	11,258 (77.6)	3487 (24.0)
		Other[d]	9169 (63.2)	3988 (27.5)
Hollow Brick			6736 (46.4)	2447 (16.9)
Structural Clay Tile	Vertical coring		10,057 (69.3)	5578 (38.5)
	Horizontal coring		5119 (35.3)	2067 (14.3)

a. Based on gross area.
b. Solid brick are allowed to have up to 25% void area.
c. Extruded only.
d. Made from other materials or a combination of materials.

Unit Texture and Absorption. Unit texture and absorption are properties that affect the bond strength of the masonry assemblage. In general, mortar bonds better to roughened surfaces, such as wire- or blade-cut surfaces, than to smooth surfaces, such as die skin surfaces. Cores or frogs provide a means of mechanical interlock. The bond strength of sanded surfaces is dependent upon the amount of sand on the surface, the sand's adherence to the unit and the absorption rate of the unit at the time of laying.

In practically all cases, mortar bonds best to a unit whose suction at the time of laying is less than 30 g/min/30 in.^{2} (1.55 kg/min/m^2). Generally, molded units will exhibit a higher initial rate of absorption than extruded or dry-pressed units. Unit absorption at the time of laying is an alterable property of brick and structural clay tile. In accordance with the TMS Specification, units with an initial rate of absorption in excess of 30 g/min/30 in.^{2} (1.55 kg/min/m^2) should be wetted to reduce the rate of water absorption of the unit prior to laying. In addition, suction of very absorptive units may be accommodated by using highly water-retentive mortars.

Mortar

The material properties of mortar that influence the structural performance of masonry are compressive strength, bond strength and elasticity. Because the compressive strength of masonry mortar is less important than bond strength, workability and water retentivity, the latter properties should be given principal consideration in mortar selection. Mortar materials, properties and selection of masonry mortars are discussed in the *Technical Note* 8 Series. Mortar should be selected based on the design requirements and with due consideration of the TMS Code and TMS Specification provisions affected by the mortar selected.

Laboratory testing indicates that masonry constructed with portland cement-lime mortar exhibits greater flexural bond strength than masonry constructed with masonry cement mortar or air-entrained portland cement-lime mortar of the same Type. This behavior is reflected in the TMS Code's allowable flexural tensile stresses for unreinforced masonry, which are based on the mortar Type and mortar materials selected. In addition, no masonry cement mortar of any Type is permitted in partially grouted elements in structures assigned to Seismic Design Categories D, E or F. However, masonry cement mortars are permitted for use in fully grouted elements in structures within these seismic design categories.

Other TMS Code and Specification provisions do not differ among mortar formulations (portland cement-lime mortars, mortar cement mortars, masonry cement mortars and air-entrained portland cement-lime mortars) of the same Type. These include provisions for the modulus of elasticity of the masonry and the unit strength method of verifying that the specified compressive strength of masonry is supplied. Following is a general description of the structural properties of each Type of mortar permitted by the TMS Code and TMS Specification.

Type N Mortar. Type N mortar is specifically recommended for chimneys, parapet walls and exterior walls subject to severe exposure. It is a medium bond and compressive strength mortar suitable for general use in exposed masonry above grade. Type N mortars are not permitted in structures assigned to Seismic Design Categories D, E or F.

Type S Mortar. Type S mortar is recommended for use in reinforced masonry and unreinforced masonry where maximum flexural strength is required. It has a high compressive strength and a high tensile bond strength with most brick units.

Type M Mortar. Type M mortar is specifically recommended for masonry below grade and in contact with earth, such as foundation walls, retaining walls, sewers and utility holes. It has high compressive strength and better durability in these environments than Type N or S mortars.

For compliance with the TMS Specification, mortars should conform to the requirements of ASTM C270, *Standard Specification for Mortar for Unit Masonry*, per laboratory testing. Field sampling of mortar for quality control should follow the procedures given in ASTM C780, *Standard Test Methods for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry*. Field testing is intended only to monitor mortar consistency, not to confirm compliance with the compressive strength requirements of ASTM C270. Reference *Technical Note* 8B for more information.

Grout

Grout is used in brick masonry to fill cells of hollow units or spaces between wythes of solid unit masonry. Grout increases the compressive, shear and flexural strength of the masonry element and bonds steel reinforcement and masonry together. For compliance with the TMS Specification, grout that is used in brick or structural clay tile masonry should conform to the requirements of ASTM C476, *Standard Specification for Grout for Masonry*. Grout proportions of portland cement or blended cement, hydrated lime or lime putty, and coarse or fine aggregate are given in Table 2.

TABLE 2

ASTM C476 Grout Proportions by Volume

Grout Type	Portland Cement or Blended Cement[a]	Hydrated Lime or Lime Putty	Fine Aggregate[b]	Coarse Aggregate[b]
Fine	1	0–1⁄10	2¼ to 3 times the sum of the volumes of the cementitious materials	None
Coarse	1	0–1⁄10	2¼ to 3 times the sum of the volumes of the cementitious materials	1 to 2 times the sum of the volumes of the cementitious materials

a. Includes a selection of cement types from ASTM C150/C150M, *Standard Specification for Portland Cement*, C595/C595M, *Standard Specification for Blended Hydraulic Cements*, and C1157/C1157M, *Standard Performance Specification for Hydraulic Cement*, which are listed in ASTM C476, Section 3.1.1.

b. Aggregate measured by volume in a damp, loose condition.

The amount of mixing water and its migration from the grout to the brick or structural clay tile will determine the compressive strength of the grout and the amount of grout shrinkage. Tests indicate that the total amount of water absorbed from grout by hollow clay units appears to be more dependent on the initial water content of the grout than the absorption properties of the unit [Ref. 4]. Grouts with high initial water content exhibit more shrinkage than grouts with low initial water content. Consequently, use of a non-shrink grout admixture is recommended to minimize the number of flaws and shrinkage cracks in the grout while still producing a grout slump of 8 to 11 in. (200 to 280 mm), unless otherwise specified.

The TMS Specification requires grout compressive strength to be at least equal to the specified compressive strength of masonry, f'_m, but not less than 2000 psi (13.8 MPa) as determined by ASTM C1019, *Standard Test Method for Sampling and Testing Grout for Masonry*. In general, the compressive strength of ASTM C476 grout by proportions will be greater than 2000 psi (13.8 MPa). Prediction of the actual compressive strength of grout that is proportioned in accordance with ASTM C476 is difficult because of the many possible combinations of materials, types of materials and construction conditions. However, ASTM C476 grout by proportions tends to result in higher actual strengths than specified compressive strength requirements due to higher cement contents.

Steel Reinforcement

Steel reinforcement for masonry construction consists of bars and wires. Reinforcing bars are used in masonry elements such as walls, columns, pilasters and beams. Wires are used in masonry bed joints to reinforce individual masonry wythes or to tie multiple wythes together. Bars and wires have approximately the same modulus of elasticity, which is given in the TMS Code as 29,000 ksi (200,000 MPa). In general, wires tend to achieve greater tensile and ultimate strength and behave in a more brittle manner than reinforcing bars. Common bar grades, wire types, and their yield and tensile strengths permitted by the TMS Code are given in Table 3. Reinforcing bar grades above 60 ksi are not currently permitted by the TMS Code. Research is ongoing to determine the feasibility for use of higher grade bars.

As stated in the TMS Specification, steel reinforcement and accessories for masonry assemblies should comply with one of the material standards given in Table 4.

TABLE 3

Steel Reinforcement Materials Yield and Tensile Strengths[a]

Type	ASTM Specification	Grade or Type	Minimum Yield Strength, ksi (MPa)	Minimum Tensile Strength, ksi (MPa)
Bars	A615/A615M	40	40 (280)	60 (420)
		60	60 (420)	80 (550)
	A706/A706M	60	60 (420)	80 (550)
	A996/A996M	40	40 (280)	70 (500)
		50	50 (350)	80 (550)
		60	60 (420)	90 (620)
Steel Wire for Joint Reinforcement and Ties	A1064/A1064M	Smooth	70 (485)	80 (550)
		Deformed	75 (515)	85 (585)
Steel Wire for Welded Wire Reinforcement	A1064/A1064M	Smooth or Deformed	70 (485)	80 (550)
Stainless Steel Wires	A580/A580M	AISI Type 304 or 316	45 (310)	90 (620)

a. From TMS 402/602-22 [Ref. 3].

TABLE 4

ASTM Material Standards for Reinforcement and Metal Accessories[a]

Reinforcement Type or Accessory	ASTM Specification
Deformed Steel Reinforcing Bars	A615/A615M, A706/A706M, A767/A767M, A775/A775M, A996/A996M
Deformed Glass Fiber Reinforced Polymer Bars	D7957/D7957M
Joint Reinforcement	A951/A951M
Stainless Steel Joint Reinforcement	A580/A580M Type 304 or 316 stainless steel wire fabricated in accordance with A951/A951M[b]
Veneer Wire Reinforcement[c]	A1064/A1064M knurled per A951/A951M, A580/A580M knurled per A951/A951M[b], A1064/A1064M (deformed)
Deformed Wire	A1064/A1064M, A1022/A1022M
Welded Deformed Wire Reinforcement	A1064/A1064M
Plate and Bent Bar Anchors	A36/A36M, A480/A480M, A666/A666M
Sheet Metal Anchors and Ties	A1008/A1008M, A480/A480M, A240/A240M
Wire Ties	A1064/A1064M, A580/A580M
Bent Bar Anchor Bolts	A36/A36M, F1554
Headed Anchor Bolts	A307 Grade A, F1554

a. From TMS 402/602-22 [Ref. 3].

b. Stainless steel joint reinforcement and veneer wire reinforcement are not directly covered in ASTM A951/A951M. Minimum yield and tensile strength values are used to identify which wire conforming to A580/A580M can be used to fabricate stainless steel joint reinforcing. See Table 3.

c. Joint reinforcement is permitted to be used as veneer wire reinforcement.

ASSEMBLAGE MATERIAL PROPERTIES

The properties of the constituent materials discussed previously combine to produce the brick or structural clay tile masonry assemblage properties. Following is a discussion of the material properties of the masonry assemblage.

Compressive Strength

Perhaps the single most important material property in the structural design of masonry is the compressive strength of the masonry assemblage. The specified compressive strength of the masonry assemblage, f'_m, is used to determine the allowable axial and flexural compressive stresses, shear stresses, and anchor bolt loads given in the TMS Code.

The compressive strength of the masonry assemblage can be evaluated by the properties of each constituent material, termed in the TMS Specification the "unit strength method," or by testing the properties of the entire masonry assemblage, termed the "prism testing method." These methods are generally not used to establish design values; rather, they are used by the contractor to verify that the masonry achieves the specified compressive strength, f'_m. In certain cases, prism strength testing may be used to establish design strength where there is a need for values higher than provided in the unit strength tables.

Unit Strength Method. A benefit of verifying compliance of the compressive strength of masonry by unit and mortar properties is the elimination of prism testing. Each of the materials in the masonry assemblage must conform to the ASTM material standards mentioned in previous sections of this *Technical Note*. For compliance with these material standards, the compressive strength of the unit and the proportions or properties of the mortar and grout must be evaluated. Not surprisingly, there have been attempts by numerous researchers to accurately correlate the assemblage compressive strength with unit, mortar and grout compressive strengths.

Testing an assemblage of three materials produces a large scatter of compressive strengths covering all possible combinations of materials. Therefore, estimates of the masonry assemblage compressive strength based on unit and mortar properties are necessarily conservative. The correlations provided in the TMS Specification, shown in Table 5, between unit compressive strength, mortar type and the masonry assemblage compressive strength, represent a lower bound to experimental data. In addition, the TMS Specification unit strength method does not directly address variable grout strength, multiwythe construction or the influence of joint reinforcement on the compressive strength of the masonry assemblage. Consequently, compliance with the specified compressive strength of masonry by prism testing will always produce a more accurate and optimum use of brick or structural clay tile masonry's compressive strength than the unit strength method.

The designer should not overlook the conservative nature of Table 5. A comparison of the predicted assemblage compressive strength by the unit strength method in the TMS Specification and a database of actual brick masonry prism test results [Ref. 2] reveals this conservatism. The average compressive strength of prisms of solid brick units was found to be about 1.7 times the masonry assemblage compressive strength predicted by Table 5. The average compressive strength of prisms of hollow units ungrouted and grouted was found to be 1.9 and 1.4 times the compressive strengths predicted by Table 5, respectively.

TABLE 5
Unit Strength Method of f'_m Compliance in the TMS Specification

Net Area Unit Compressive Strength, psi (MPa)		Net Area Assemblage Compressive Strength, psi (MPa)
Type M or S Mortar	Type N Mortar	
1700 (11.72)	2100 (14.48)	1000 (6.90)
3350 (23.10)	4150 (28.61)	1500 (10.34)
4950 (34.13)	6200 (42.75)	2000 (13.79)
6600 (45.51)	8250 (56.88)	2500 (17.24)
8250 (56.88)	10,300 (71.02)	3000 (20.69)
9900 (68.26)	—	3500 (24.13)
11,500 (79.29)	—	4000 (27.58)

Prism Test Method. Prism testing of brick or structural clay tile masonry assemblage provides a number of advantages over constituent material testing alone. The primary benefit of prism testing is a more accurate estimation of the compressive strength of the masonry assemblage. Another benefit of prism testing is that it provides a method of measuring the quality of workmanship throughout the course of a project. Low prism strengths may indicate mortar mixing error, poor quality grout or improper testing. Where a low value for prism testing results, additional testing of the constituent materials is generally necessary to ascertain which component is responsible for the understrength result.

The TMS Specification permits testing of masonry prisms to show conformance with the specified compressive strength of masonry, f'_m. In addition, the material components must meet the appropriate standards of quality. Masonry prisms are tested in accordance with ASTM C1314, *Standard Test Method for Compressive Strength of Masonry Prisms*. According to this standard, a set of prisms is required for each combination of materials and each test age at which the compressive strength of masonry is to be determined.

Shear Strength

The shear strength of a masonry assemblage may be separated into four parts: 1) the shear strength of the unit, mortar and grout assemblage; 2) the effect of the shear span-to-depth ratio, M/Vd_v; 3) the enhancement of shear strength due to compressive stress; and 4) the contribution of shear reinforcement in the masonry assemblage. All four phenomena are represented in the allowable shear stresses provided in the TMS Code. However, only the first and fourth items are controlled by material properties. The second and third items vary with member size and applied loads.

The shear strength of the masonry assemblage is directly related to the properties of the unit, mortar and grout.

Shear failure of a unit-mortar assemblage is by splitting of units, step-cracking in mortar joints or a combination of the two. Unit splitting strength is increased by increasing the compressive strength of the unit. In general, unit splitting is not a common shear failure mode of brick or structural clay tile masonry. Unit splitting occurs in masonry assemblages of weak units and strong mortar and may also occur in shear walls that are heavily axially loaded. Cracking in mortar joints is the more common shear failure mode for brick and structural clay tile masonry assemblages. Mortar joint failure occurs by sliding along bed joints and separation of head joints. Mortar joint shear failure is affected by bond strength and the frictional characteristics between the mortar and the unit. In general, a unit–mortar combination that provides greater bond strength will also provide greater shear strength. Grouting the masonry assemblage will also increase shear strength by providing a shear key between courses. The shear strength of a masonry assemblage may be evaluated in accordance with ASTM E519, *Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages*. The contributions of unit, mortar and grout to the allowable shear stresses stated in the TMS Code are based on ASTM E519 tests of masonry assemblages.

Steel reinforcement may be added to the masonry assemblage to increase shear strength. Shear reinforcement should be provided parallel to the direction of the applied shear force. The TMS Code also requires a minimum amount of reinforcement perpendicular to the shear reinforcement of one-third the area of shear reinforcement.

Flexural Tensile Strength

The flexural tensile strength of the masonry is neglected in the design of reinforced brick and structural clay tile masonry assemblages. However, cracking of an unreinforced brick or structural clay tile masonry member constitutes failure and must be avoided. Thus, flexural tensile strength is an important design consideration for unreinforced masonry. Flexural tensile strength is the bond strength of masonry in flexure. It is a function of the type of unit, type of mortar, mortar materials, percentage of grouting of hollow units and direction of loading. Workmanship is also very important for flexural tensile strength, as unfilled mortar joints or dislodged units have no mortar-to-unit bond strength.

Allowable flexural tensile stresses stipulated in the TMS Code for allowable stress design of masonry are given in Table 6. Modulus of rupture values for strength design of masonry are given in Table 7.

Flexural tensile strength may be evaluated by testing small-scale prisms in accordance with ASTM E518, *Standard Test Methods for Flexural Bond Strength of Masonry*, or ASTM C1072, *Standard Test Methods for*

Measurement of Masonry Flexural Bond Strength, but these results may not directly correlate with the allowable flexural tensile stresses in the TMS Code.

TABLE 6

TMS Code Allowable Flexural Tensile Stress for Unreinforced Masonry, psi (kPa)[a]

Direction of Stress	Masonry Type	Mortar Type			
		Portland Cement/Lime or Mortar Cement		Masonry Cement or Air-Entrained Portland Cement/Lime	
		M or S	N	M or S	N
Normal to bed joints	Solid units	53 (366)	40 (276)	32 (221)	20 (138)
	Hollow units ungrouted[b]	33 (228)	25 (172)	20 (138)	12 (83)
	Hollow units fully grouted[b]	65 (448)	63 (434)	61 (420)	58 (400)
Parallel to bed joints in running bond	Solid units and hollow units fully grouted	106 (731)	80 (552)	64 (441)	40 (276)
	Hollow units ungrouted and partially grouted	66 (455)	50 (345)	40 (276)	25 (172)
Parallel to bed joints in masonry not laid in running bond	Continuous grout section parallel to bed joints	133 (917)			

a. Not applicable to structural clay tile unit masonry (ASTM C34, C56, C126 or C212).
b. For partially grouted masonry, allowable stresses shall be determined on the basis of linear interpolation between hollow units that are fully grouted and ungrouted hollow units based on percentage of grouting.

TABLE 7

TMS Code Modulus of Rupture, fr, psi (kPa)[a]

Direction of Flexural Tensile Stress	Masonry Type	Mortar Type			
		Portland Cement/Lime or Mortar Cement		Masonry Cement or Air-Entrained Portland Cement/Lime	
		M or S	N	M or S	N
Normal to bed joints	Solid units	133 (919)	100 (690)	80 (552)	51 (349)
	Hollow units ungrouted[b]	84 (579)	64 (441)	51 (349)	31 (211)
	Hollow units fully grouted[b]	163 (1124)	158 (1089)	153 (1055)	145 (1000)
Parallel to bed joints in running bond	Solid units and hollow units fully grouted	267 (1839)	200 (1379)	160 (1103)	100 (689)
	Hollow units ungrouted and partially grouted	167 (1149)	127 (873)	100 (689)	64 (441)
Parallel to bed joints in masonry not laid in running bond	Continuous grout section parallel to bed joints	335 (2310)			

a. Not applicable to structural clay tile unit masonry (ASTM C34, C56, C126 or C212).
b. For partially grouted masonry, modulus of rupture values shall be determined on the basis of linear interpolation between hollow units that are fully grouted and ungrouted hollow units based on percentage of grouting.

Elastic Modulus

The elastic modulus of the masonry assemblage, in combination with the moment of inertia of the section, determines the stiffness of a brick or structural clay tile masonry structural element. Elastic modulus is the ratio of applied load (stress) to corresponding deformation (strain). The elastic modulus is roughly proportional to the compressive strength of the masonry assemblage. Testing of brick masonry prisms indicates that the elastic modulus of brick masonry falls between 700 and 1200 times the masonry prism compressive strength [Ref. 5]. Therefore, the lower bound of the test data is used to calculate the elastic modulus of the masonry assemblage per TMS Code (Equation 1).

$$E_m = 700\, f'_m \qquad \text{Eq. 1}$$

The elastic modulus of grout is computed as 500 times the compressive strength of the grout in accordance with the TMS Code. In general, the elastic modulus of grout and the elastic moduli of brick or structural clay tile and mortar masonry assemblages are comparable and are often considered equal for design calculations. However, the TMS Code recommends that the method of transformation of areas based on relative elastic moduli be used for computation of stresses in grouted masonry elements.

Dimensional Stability

Dimensional stability is also an important property of the masonry assemblage. Expansion and contraction of the brick or structural clay tile masonry may exert restraining stresses on the masonry and surrounding elements. Material properties that affect dimensional stability of clay and shale unit masonry are moisture expansion, creep and thermal movements. Effects of these phenomena may be evaluated by the coefficients provided in the TMS Code, which are listed in Table 8. The coefficients in Table 8 represent average quantities for moisture expansion and thermal movements and an upper-bound value for creep. Moisture expansion and thermal expansion and contraction are independent and may be added directly. The magnitude of creep of clay or shale unit masonry will depend upon the amount of load applied to the masonry element.

TABLE 8

TMS Code Dimensional Stability Coefficients for Clay and Shale Unit Masonry

Material Property	Coefficient
Irreversible moisture expansion	3×10^{-4} in./in. (3×10^{-4} mm/mm)
Creep	0.7×10^{-7} per psi (0.1×10^{-4} per MPa)
Thermal expansion and contraction	4×10^{-6} in./in./°F (7.2×10^{-6} mm/mm/°C)

SUMMARY

This *Technical Note* contains information about the material properties of brick and structural clay tile masonry. This information may be used in conjunction with the TMS Code and Specification to design and analyze structural masonry elements. Typical material properties of clay and shale masonry units, mortar, grout, reinforcing steel and combinations of these are presented.

> *The information and suggestions contained in this* Technical Note *are based on the available data and the experience of engineering staff and members of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information discussed in this* Technical Note *are not within the purview of the Brick Industry Association, and must rest with the project architect, engineer and owner.*

REFERENCES

1. *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA, 2024:

Volume 1.03

A240/A240M	Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
A480/A480M	Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip
A580/A580M	Standard Specification for Stainless Steel Wire
A666/A666M	Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar
A1008/A1008M	Standard Specification for Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, Required Hardness, Solution Hardened, and Bake Hardenable

Volume 1.04

A36/A36M	Standard Specification for Carbon Structural Steel
A615/A615M	Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
A706/A706M	Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement
A767/A767M	Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
A775/A775M	Standard Specification for Epoxy-Coated Steel Reinforcing Bars
A951/A951M	Standard Specification for Steel Wire for Masonry Joint Reinforcement
A996/A996M	Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement
A1022/A1022M	Standard Specification for Deformed and Plain Stainless Steel Wire and Welded Wire for Concrete Reinforcement
A1064/A1064M	Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

Volume 1.09

A307	Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength
F1554	Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength

Volume 4.01

C150/C150M	Standard Specification for Portland Cement
C595/C595M	Standard Specification for Blended Hydraulic Cements
C1157/C1157M	Standard Performance Specification for Hydraulic Cement

Volume 4.05

C34	Standard Specification for Structural Clay Loadbearing Wall Tile
C56	Standard Specification for Structural Clay Nonloadbearing Tile
C62	Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale)
C67/C67M	Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile
C126	Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units
C212	Standard Specification for Structural Clay Facing Tile
C216	Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)
C270	Standard Specification for Mortar for Unit Masonry
C476	Standard Specification for Grout for Masonry
C652	Standard Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale)
C780	Standard Test Methods for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
C1019	Standard Test Method for Sampling and Testing Grout for Masonry
C1072	Standard Test Methods for Measurement of Masonry Flexural Bond Strength
C1088	Standard Specification for Thin Veneer Brick Units Made from Clay or Shale
C1314	Standard Test Method for Compressive Strength of Masonry Prisms
C1405	Standard Specification for Glazed Brick (Single Fired, Brick Units)
E518/E518M	Standard Test Methods for Flexural Bond Strength of Masonry
E519/E519M	Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages

Volume 15.03

D7957/D7957M	Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

2. Atkinson, R.H., “Evaluation of Strength and Modulus Tables for Grouted and Ungrouted Hollow Unit Masonry,” Atkinson-Noland and Associates Inc., Boulder, Colorado, November 1990, 47 pp.

3. *Building Code Requirements and Specification for Masonry Structures* (TMS 402/602-22), The Masonry Society, Longmont, Colorado, 2022.

4. Kingsley, G.R., et al., “The Influence of Water Content and Unit Absorption Properties on Grout Compressive Strength and Bond Strength in Hollow Clay Unit Masonry,” *Proceedings 3rd North American Masonry Conference*, The Masonry Society, Boulder, Colorado, June 1985, pp. 7:1-12.

5. Plummer, H.C., *Brick and Tile Engineering*, Brick Institute of America, Reston, Virginia, 1977, 466 pp.

6. Subasic, C.A., Borchelt, J.G., “Clay and Shale Brick Material Properties - A Statistical Report,” submitted for inclusion, *Proceedings 6th North American Masonry Conference*, The Masonry Society, Boulder, Colorado, June 1993, 12 pp.