Technical Notes 39 - Testing for Engineered Brick Masonry- Brick and Mortar
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Abstract: Testing of brick, mortar and grout is often required prior to and during construction of engineered brick masonry projects. The tests involve a combination of laboratory and field procedures which are described in various ASTM standards. The extent of testing is a decision made by the engineering or architectural firm responsible for the masonry design, and may consist of only a few laboratory tests to determine the properties of the brick units, or may involve extensive laboratory and field sampling and testing. This *Technical Notes* describes the testing of materials; other issues in this series describe testing of brick masonry assemblages.

Key Words: **brick**, **engineered brick masonry**, grout, mortar, **quality control**, **testing**.

INTRODUCTION

The use of engineered brick masonry in the construction of loadbearing structures requires that the standard methods for determining the physical properties of both the materials and the masonry assemblages be strictly followed. The standards and specifications for engineered brick masonry are based, for the most part, on the results of American Society for Testing and Materials (ASTM) methods of testing.

It is not the intent of this *Technical Notes* to supersede the various applicable ASTM standards, but to supplement them. The ASTM standards have been carefully developed by balanced technical committees composed of people experienced and knowledgeable in their chosen fields. Therefore, if the prescribed methods of tests are not adhered to, inaccurate and inconsistent test data and erroneous conclusions can result. This can be quite serious when the design of a masonry bearing wall structure is based on such tests, or when such tests are used as quality controls during construction.

This *Technical Notes* covers testing of masonry materials for obtaining information needed to determine design properties for engineered brick masonry. Additional testing required for assessment of material compliance to various ASTM specifications is not included. In addition, field testing of brick, mortar and grout for quality control is discussed.

This *Technical Notes is* the first in a series on testing. Other *Technical Notes* in this series discuss the construction, preparation and testing of masonry assemblages (in the laboratory); and the sampling, preparation and handling of jobsite test specimens for the purpose of quality control of the construction.

ENGINEERED BRICK MASONRY STANDARDS

There are several standards used in the United States for the design of brick masonry structures, all of which contain some requirements for testing of masonry materials or assemblages. Likewise, other standards and building codes require testing in order to establish various design parameters.

In addition to predesign and preconstruction testing, testing for the purpose of quality control is often implemented. *Building Code Requirements for Masonry Structures* (ACI 530 / ASCE 5 / TMS 402-99) and *Specification for Masonry Structures* (ACI 530.1/ ASCE 6 / TMS 602-99) [3], known as the MSJC Code and Specifications, contain several quality assurance requirements. For example, the MSJC Code and Specification require that the initial rate of absorption (IRA) of brick at the time of laying not exceed 1 gram per sq in. per min. ASTM C 62, ASTM C 216 and ASTM C 652 also recommend that the limit on IRA be 30 g/30 in.^{2}/min. The determination of this property may be made in the laboratory on oven-dry brick, or at the construction site as a field test. The tests outlined within this *Technical Notes* are those which are most commonly performed to satisfy the requirements of the MSJC Code and Specification.

TESTING STANDARDS

The ASTM standards which are most frequently utilized when testing brick masonry materials should be readily available to all laboratory personnel, and to individuals involved in field testing. The applicable standards are as follows:

Clay Masonry Units	-ASTM C 67, Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile
Mortar	-ASTM C 270, Standard Specification for Mortar for Unit Masonry

-ASTM C 91, Standard Specification for Masonry Cement
-ASTM C 109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)
-ASTM C 780, Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry

Grout -ASTM C 476, Standard Specification for Grout for Masonry
-ASTM C 1019, Standard Test Method for Sampling and Testing Grout

For the most part, these standards provide clear and concise explanations of the procedures for sampling and testing masonry materials; however, for the novice, some areas may present some confusion. The following sections will explain some of the procedures required by the various ASTM standards.

BRICK TESTING FOR ENGINEERED BRICK MASONRY

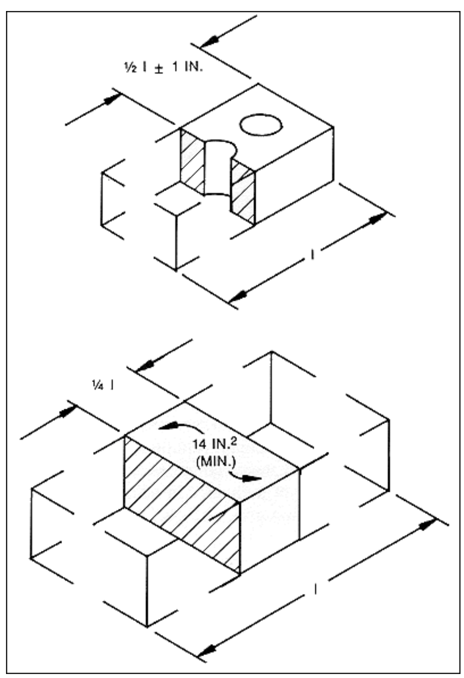
The strength of brick varies considerably, depending on raw material, method of manufacture and degree of firing. The range in compressive strength is on the order of 2000 psi to in excess of 20,000 psi. The MSJC Code does not dictate minimum compressive strength requirements for brick, but since the allowable stresses and elastic moduli of masonry are a function of compressive strength of brick, testing to determine compressive strength is required.

For the determination of unit compressive strength, f'_b, the procedures given in ASTM C 67 [1] should be followed.

The initial rate of absorption (IRA) is another important property. If the IRA of brick exceeds an acceptable upper limit, problems with excessive shrinkage of mortar and grout, and poor bond, are apt to occur. The procedures for determining the IRA, in the laboratory and in the field, are contained in ASTM C 67.

Compressive Strength

Specimen Size. ASTM C 67 requires that the specimen be full height and width, and approximately one-half of a brick in length, plus or minus 1 in. (25 mm). For example, an 8-in. (200 mm) long brick may be tested using a piece of brick with a length between 3 and 5 in. (75 and 125 mm). However, if the testing machine being used is not capable of providing sufficient force to crush the approximate half-brick, a piece of brick having a length of one-quarter of the original full brick length may be used, so long as the total cross-sectional area is not less than 14 in.^{2} (90 cm^2), see Figure 1.



Compressive Strength Specimens
FIG. 1

Although ASTM C 67 does not specifically state the method in which the samples are to be obtained, it has been common practice to use pieces of brick which are left over from modulus of rupture tests. If modulus of rupture tests are not being performed, then sawing the units to the desired size is acceptable. A minimum of five specimens is required.

The compressive strength test specimens should be oven-dried. The amount of moisture in the brick can affect its compressive strength - the higher the moisture content, the lower the apparent strength. Therefore, by drying the specimens before testing, one variable that can affect the results is eliminated. If they are wet-cut with a masonry saw, the drying should follow the cutting. If a wet capping material, such as high-strength gypsum, is used, it is generally agreed that the small amount of moisture absorbed by the specimens will not make additional oven drying necessary. The 24-hr curing period in laboratory air will suffice.

Capping Specimens. The importance of careful capping procedures cannot be over-emphasized. Brick units, by their inherent nature, are not perfectly formed and their bearing surfaces may not be parallel and free from surface irregularities. The purpose of capping the bearing surfaces is to assure reasonably parallel and smooth opposite bearing surfaces; thus reducing the likelihood of uneven bearing and stress concentrations, and the resulting premature failure of the test specimen.

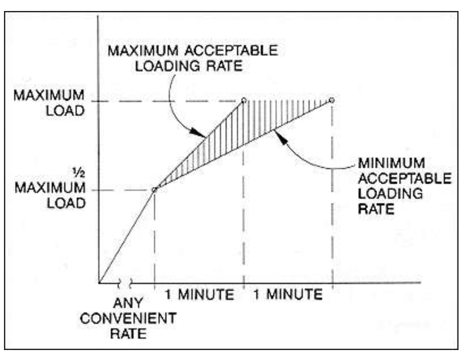
Laboratory technicians responsible for capping compressive test specimens should be thoroughly familiar with the capping procedures prescribed in ASTM C 67. Poor caps, resulting from careless capping techniques, can result in erratic test results and a lowering of the apparent compressive strengths of the specimens.

Placing Specimens in Testing Machine. The requirement in ASTM C 67 that the specimen be centered under the spherical upper bearing block within 1/16 in. (1.6 mm) is not a capricious one. The introduction of an eccentric load, if the specimen is not carefully centered, can result in a lower apparent compressive strength for the test specimen. It should be understood, however, that this requirement assumes that the specimen is symmetrical about both horizontal axes or its center of gravity. For symmetrical specimens, the center of gravity will be the geometrical center of the unit. Such is not the case with unsymmetrical test specimens. Therefore, the centers of gravity of unsymmetrical specimens should be determined and marked, and it is those marks that should be aligned with the center of the upper bearing block.

To determine the center of gravity for an unsymmetrical test specimen, a small steel rod, 1/8 in. to 1/4 in. (3 to 8 mm) in diameter, may be used. The location of the center of gravity is determined by finding the balance point of the brick specimen. To place the specimen over the rod in the exact position such that it balances perfectly is difficult, but a very good estimate of this location is not hard to achieve.

Speed of Testing. The speed of testing specified in ASTM C 67 should be adhered to, primarily for the purpose of obtaining consistent results. Past experience on the effect of the rate of loading on the compressive strength of specimens has shown that, as the rate increases, there can be significant increases in the apparent compressive strengths of the specimens. The requirements of ASTM C 67, while not particularly specific, do provide a moderate rate of loading which, if followed, will produce consistent results that will represent more accurately the true compressive strengths of the specimens.

ASTM C 67 specifies that the specimen should be loaded to one-half of the expected maximum load, and then the rate should be adjusted such that the test is completed in not less than one minute and not more than two minutes. For this reason, it is a good idea to do one or two preliminary tests to get an estimate of the maximum strength. Figure 2 illustrates the time vs. loading criteria of ASTM C 67.



Compressive Test Loading Rate
FIG. 2

Determination of Minimum Net Area (Percent Voids). There are two reasons for determining the void area of brick: the first reason is to obtain the percentage of voids (percentage coring) in order to assess whether the brick will be classified as solid or hollow brick; the second reason is to obtain the average net cross-sectional area for determination of net area compressive strength of the units. ASTM C 216 and C 62 for solid brick, and ASTM C 652 for hollow brick require calculation of *gross* area compressive strength.

If the net area compressive strength is required, the section "Measurement of Void Area in Cored Units" in ASTM C 67 should be followed. To perform these measurements, a sample of ten brick is specified by ASTM C 67. Following the procedure in this section, the cores are filled with sand. The sand is then placed in a graduated cylinder to determine the volume. Using the equation given in ASTM C 67 for percent void area, the void area can be determined. The net area can be determined by subtracting the void area from the gross area.

Calculation and Report. The compressive strength is determined by dividing the maximum compressive load by the gross cross-sectional area of the specimen. If the net area compressive strength is required, the net area, as determined in the previous section, must be used to obtain the desired results. Since five specimens are used, the arithmetic average should be determined.

Initial Rate of Absorption

The initial rate of absorption (IRA) is an important property of brick because it affects mortar and grout bond. Brick IRA and mortar retentivity should be considered when selecting brick and mortar type. If the initial rate of absorption is over 1 gram per minute per in^2, brick will absorb moisture from the mortar or grout at a rapid rate, and may impair the strength and extent of the bond. Thus, determining the IRA is important.

In the laboratory, the IRA is measured using brick which are oven-dried to equilibrium. The IRA of a dry brick is apt to be higher than one which contains some moisture. The field test for initial rate of absorption is performed on brick in their field condition, i.e., no attempt is made to dry the units. The laboratory test will give an idea of the order of magnitude of the IRA and the field test can be used to determine if additional wetting is necessary.

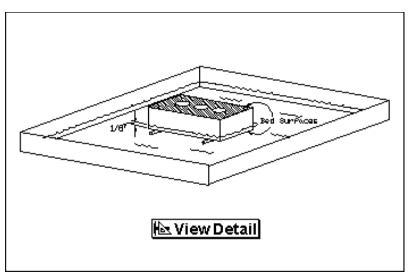
Laboratory Procedure. As previously mentioned, the laboratory procedure is performed on oven-dried specimens. Five full-size specimens are required. The technician performing the test should be aware that the larger the tray size, the less effect the absorption has on the water level. ASTM C 67 requires a tray with a cross-sectional area of at least 300 $in.^2$ (1935.5 cm^2). For a brick with an IRA of 40 g/min/30 $in.^2$, the water level would drop less than 1/100 in., which is hardly measurable. Nevertheless, ASTM C 67 provides recommendations on maintaining the water level. Figure 3 illustrates the tray with a brick positioned for testing. The method is relatively straightforward and easy to perform. The results are reported in grams of water gained per 30 sq in. when the brick are immersed in 1/8 in. (3 mm) of water for 1 min. The calculation of IRA is as follows:

$$IRA = 30\,W / LB \qquad \text{(Eq. 5)}$$

where:

- W = actual gain in weight of specimen in grams,
- L = length of specimen, in in. and
- B = width of specimen, in in.

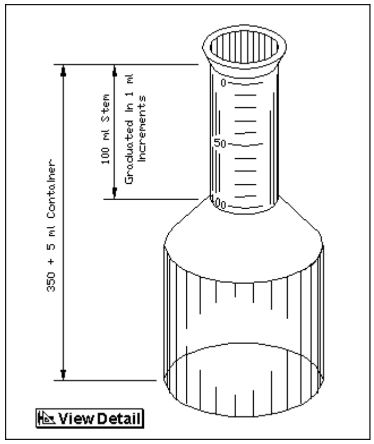
What some laboratory technicians fail to realize, however, is that the above equation is for specimens that are *not* cored. If the test specimens are *cored* brick, or are non-prismatic, the *net* area must be substituted for LB in Eq. 5.



Determination of IRA
FIG. 3

Field Procedures. Brick units on the jobsite may have a different rate of absorption than that of the same units tested for IRA in the laboratory. The IRA may be lower due to moisture which brick absorb after leaving the manufacturing plant. Two tests are available for field determination of brick absorption. One is an ASTM procedure, described in ASTM C 67, which measures quantitatively the absorption rate. The other is an approximate, but effective, test which is not covered by an ASTM standard, and yields a qualitative indication of the bricks' absorption rate and necessity for wetting prior to use.

ASTM Field Method for IRA - This method is described in detail in ASTM C 67, and is accomplished through volumetric means rather than by weight measurements. Using this method, the brick are placed in a pan of water for 1 min. removed and the quantity of water remaining in the pan is measured using a pycnometer (Fig. 4). The pycnometer is used to measure the initial quantity of water to be placed in the pan. The difference in the original amount of water and the quantity remaining after placement of the brick into the pan for 1 min is the amount absorbed by the brick. It is very important to use the correct size pan and to wet and drain the pan prior to testing.



Pycnometer
FIG. 4

Test for Wetting Brick - The following test is useful for determining the necessity of wetting brick prior to use:

A circle, approximately 1 in. (25 mm) in diameter, is drawn on the bed surface of the brick, using a wax pencil and a twenty-five-cent coin as a guide. Twenty drops of water are placed into the circle using an eyedropper. If, after 90 seconds, all of the water has been absorbed, wetting the brick prior to placement is recommended.

MORTAR TESTING FOR ENGINEERED BRICK MASONRY

Technical Notes 8 Series discusses the various types of mortar, properties and mix designs. Also, ASTM C 270, Specification for Mortar for Unit Masonry, gives both prescriptive and performance requirements for mortar. Another standard specification for mortar, BIA M1-88, provides recommendations on selection proportions and test requirements of portland cement-lime mortars. This section will outline the various mortar tests which are important when designing and building engineered brick masonry elements.

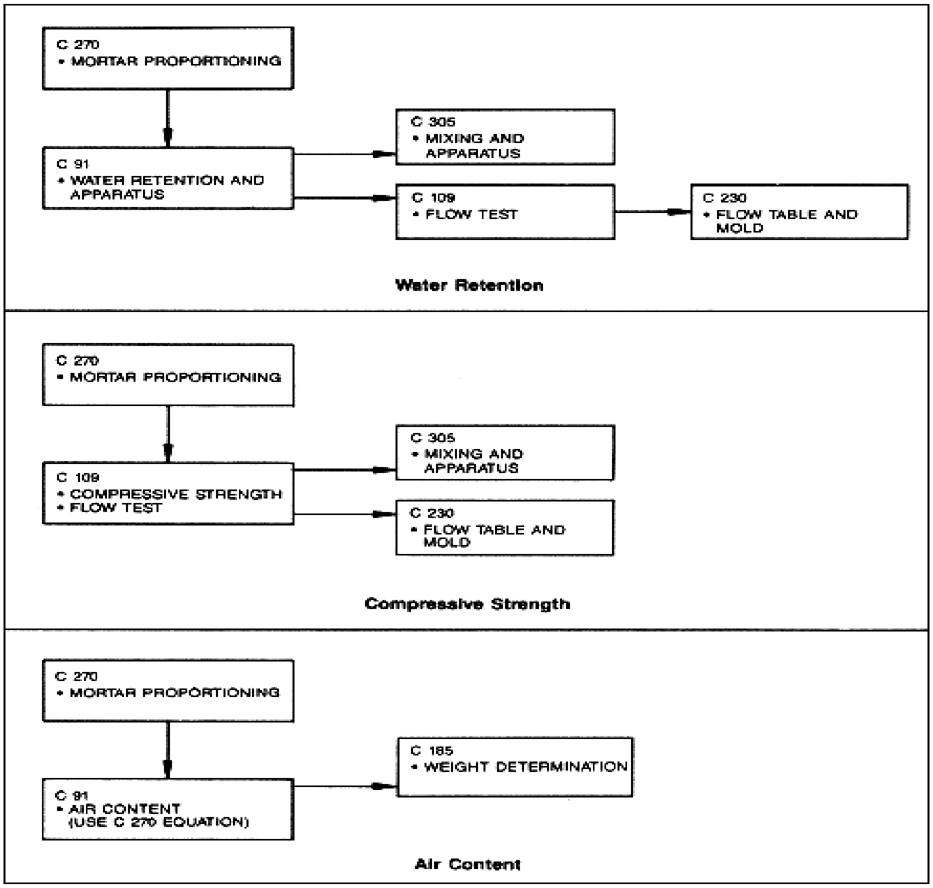
Laboratory Testing of Mortar

Laboratory testing of mortar is performed in accordance with ASTM C 270 [2]and other standards referenced in ASTM C 270. *The tests are performed on mortar samples which are prepared in the laboratory.* ASTM C 270 is *not* a specification to determine mortar strength and properties through field testing. The amount of testing required by ASTM C 270 depends on the method in which the mortar is specified, i.e., proportion or property specification. If the mortar is specified by the proportion specifications, there are *no* testing requirements for mortar. For mortars specified by the property specifications, water retention, compressive strength and air content tests must be performed.

The following sections describe the methods of tests for mortar which are specified by the *property specifications.*

Water Retention. ASTM C 270 refers to the procedures of ASTM C 91 for water retention determination, except that the laboratory-mixed mortar shall be of the same materials and proportions to be used in the construction. Since the water content of mortar used on the jobsite varies somewhat, and is not a specified quantity, the laboratory technician should proportion the cementitious materials and sand in accordance with the job specification and add sufficient water to bring the flow up to 110 +/- 5%.

To perform the water retention tests, the technician should review ASTM C 91 on Water Retention, ASTM C 305 on Mechanical Mixing, and ASTM C 109 on Performing Flow Tests. The flow test apparatus must meet the specifications of ASTM C 230. The chart in Fig. 5 indicates the ASTM standards relative to water retention testing of mortar specified by the *property specifications.*



Related ASTM Standards for Property Specifications
FIG. 5

Compressive Strength. Compressive strength testing of laboratory-prepared mortar is required under the ASTM C 270 property specifications. To determine compressive strength, samples are to have the same proportions as in the actual construction. As with the water retention test, the amount of water to be used is not clearly stated; therefore, it is recommended that sufficient water be used to bring the flow to 110 +/- 5%. As shown in Fig. 5, other associated ASTM standards which must be used are ASTM C 109, C 305 and C 230.

The technician should become familiar with the procedures of ASTM C 109 for specimen molding and load application since these procedures must be followed closely in order to obtain reliable results.

Air Content. Air content determination is the third and last property which must be assessed for mortars specified under the property specifications. The air content is determined using a weight-volume relationship to determine the absolute volume of solids and water. ASTM C 91 and ASTM C 185 are used to determine air content, except that the equation for percent air content is given in ASTM C 270. The equation for air-free mortar density is:

$$D = \frac{(W_1 + W_2 + W_3 + W_4 + V_w)}{\frac{W_1}{P_1} + \frac{W_2}{P_2} + \frac{W_3}{P_3} + \frac{W_4}{P_4} + V_w} \quad \text{(Eq. 2)}$$

and the volume of air in percent is

$$A = 100 - \frac{W_m}{4D} \quad \text{(Eq. 3)}$$

where: W1 = weight of portland cement, g,

W_2 = weight of hydrated lime, g,

W_3 = weight of masonry cement (if used), g,

W_4 = weight of sand, g,

V_w = volume of water used, mL,

P_1 = unit weight of air-free portland cement, g/cm^3,

P_2 = unit weight of air-free hydrated lime, g/cm^3,

P_3 = unit weight of air-free masonry cement (if used), g/cm^3,

P_4 = unit weight of air-free sand, g/cm^3,

W_m = weight of 400 mL of mortar, g.

The air-free unit weights of the various materials in Eq. 2 are equal to the specific gravity of the material times the unit weight of water (which is unity); thus, the unit weight is numerically equal to the specific gravity. The specific gravity for the various materials should be obtained from the manufacturers or determined by testing. Table 1 gives the approximate specific gravities for several mortar materials

TABLE 1
Approximate Specific Gravities of Various Mortar Materials

Portland Cement	3.15
Hydrated Lime	1.25
Sand	2.65

In performing the air-content tests, it is very important to weigh and measure the quantities accurately, since errors in weights and volumes would have significant impact upon the calculated air content.

Field Testing of Mortar

For purposes of quality control, field testing of mortar is sometimes required. Field testing should not be confused with laboratory testing, or be performed using the standards and procedures for laboratory testing of mortar. The appropriate standard for this type of testing is ASTM C 780 "Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry". The main purposes of field testing is to ensure that mortar is proportioned properly by the mixer operator, and to obtain an indication of variability or change in constituent materials, quality and performance.

There are several tests which are covered in ASTM C 780, not all of which are required. Eight tests are outlined in the Annexes of ASTM C 780 which are: A1) Consistency by Cone Penetration Test Method, A2) Consistency Retention of Mortars for Unit Masonry, A3) Initial Consistency and Consistency Retention or Board Life of Masonry Mortars Using a Modified Concrete Penetrometer, A4) Mortar Aggregate Ratio Test Method, A5) Water Content Test Method, A6) Mortar Air Content Test Method, A7) Compressive Strength of Molded Masonry Mortar Cylinders and Cubes and A8) Splitting Tensile Strength of Molded Masonry Mortar Cylinders.

The testing agency and the specifier should be aware that the compressive strength of mortar, as determined by field testing, *does not* have to meet the minimum compressive strength requirements of ASTM C 270.

The specifier must decide which of the eight tests is to be performed, then preconstruction testing of the materials can be performed in order to establish requirements for construction site-sampled mortar.

A complete discussion of the test procedures of ASTM C 780 is not within the scope of this *Technical Notes;* therefore, the technician in charge of performing the tests should become thoroughly knowledgeable with ASTM C 780 and its referenced documents.

GROUT TESTING FOR ENGINEERED BRICK MASONRY

The specification for grout for engineered brick masonry, ASTM C 476, does not require any laboratory testing. Experience with grout mixed in accordance with the provisions of ASTM C 476 has been extremely favorable, and grout, therefore, does not require extensive testing if mixed with the materials and in the proportions stipulated by the standard.

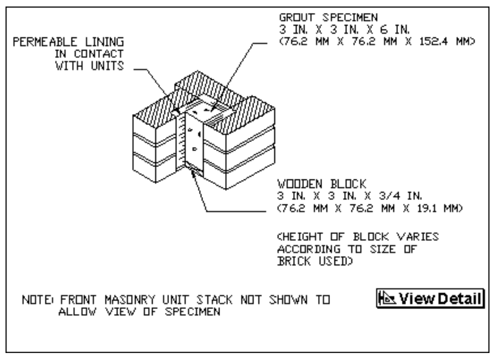
There is a relatively new standard for both field and laboratory sampling and compressive testing of grout used in masonry construction, entitled ASTM C 1019, "Standard Test Method for Sampling and Testing Grout".

Sampling and Testing Grout for Engineered Brick Masonry

According to ASTM C 1019, the use of the standard may be to select grout proportions by comparing test values or as a quality control test for uniformity of grout preparation during construction. The standard specification for grout, ASTM C 476, does not contain provisions for mixing grout to property specifications; therefore, the use of ASTM C 1019, at this time, for grout mix design is not advised. For purposes of quality assurance, the grout testing standard may be useful.

The specimens are prepared by using masonry units as forms (Fig. 6). The masonry units are those which are to be used in the project under construction or to be constructed. The laboratory technician may find it strange to use the brick units as forms, but the reason is to simulate the conditions of the grout after placement into the brick masonry element. Grout is placed with a high water/cement ratio, slump of 10 to 11 in. (250 mm to 275 mm), in order to facilitate consolidation and eliminate voids. Due to the absorptive nature of the masonry, the water content of the grout is reduced after placement.

The methods of sampling and testing, as described in ASTM C 1019, are easily accomplished; therefore, additional description and explanation will not be given in this *Technical Notes*.



Grout Mold Using 2 ¼ in. (152.4 mm)
High Standard Size Brick
FIG. 6

SUMMARY

This *Technical Notes* has discussed testing of brick, mortar and grout used in engineered brick masonry. Most laboratory and field tests are covered by ASTM standards. Testing agencies using these tests should be fully aware of the procedures and limitations, so that improper application and erroneous results are avoided.