Frost action on brick work

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SUBJECT FROST ACTION ON BRICK WORK

Frost action appears to be an important source of damage to masonry materials. B. Butterworth, at the Building Research Station of Great Britain has been concerned with problems of the weathering of structural clay products for many years, and in his opinion (1), "In cold and wet climates, frost is one of the main causes of the decay of porous building materials, including fired clay." The fact that the present specification of the American Society for Testing Materials for clay and shale bricks (C62-50) requires that bricks be resistant to a standard freezing test, or have certain properties which are related to frost resistance, indicates that this is an important consideration in the use of building bricks in the United States and elsewhere, where the specification is used (it is the basis of the present Canadian C.S.A. specification for clay or shale bricks.)

As you have pointed out in your note, severe frost damage to brickwork seems to occur, generally, only in locations where the brickwork is unusually damp when freezing weather prevails. This has been observed by many persons interested in the subject. That the amount of damage done to most materials in freezing depends to a great extent on their degree of dampness has been shown by W.N. Thomas (2) of the British Building Research Station. Thomas studied the effects of freezing certain building stones and ceramic tiles under various conditions; he used, as an index of damage done to the materials by freezing, decrease in E (stress-strain relationship). Thus, for a particular type of fired clay roofing tile, Thomas found that one freezing in air at -10°C produced a reduction in E (stress-strain relationship) of 0 per cent at 80 per cent of complete saturation, 3 per cent at 90 per cent saturation, and 7 per cent reduction in E at 100 per cent saturation of the tiles, which illustrates clearly the effect of degree of saturation of a material on the damage caused by freezing.

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(1) B. Butterworth "The Frost Resistance of Fired Clay - A Perennial Problem" The Brick Builder - September, 1952.

(2) W.N. Thomas "Experiments on the Freezing of Certain Building Materials" Building Research Technical Paper No. 17 H.M.S.O. 1938.

Parapet walls, being in exposed locations and not heated on the interior surface, are often in a damper condition, probably, than the walls proper; this is undoubtedly a reason for the decay often observed in parapet walls, as you have mentioned in your note. In addition, they are probably subjected to a greater number of, and more rapid, cycles of freezing and thawing than the main walls. The rate of freezing is an important aspect of frost damage, as another part of the work of Thomas, mentioned above, has shown.

Damage to brickwork in chimneys, and in walls at or near grade line, may be caused in many cases by the crystallization of salts, the damage often resembling closely that of frost action. Salts in solution may move by capillarity into the foundation of a building from the soil, and if there is no damp course (such as thin metal sheet) between the foundation and the walls, evaporation of the moisture may take place from the walls above grade, and crystallization of the salts takes place, either in or on the masonry wall. In the former case it may be capable of disintegrating the masonry. Similarly, in chimneys, gases containing sulphur compounds formed in the combustion of the fuel may permeate the chimney, and form salts which may cause disintegration by crystallization. Or they may react in solution with hydrated portland cement products to cause decay. This latter action has been described (3) as follows:, "As another example of crystal transformation causing disruption, there may be cited the action of calcium sulphate solutions (or other soluble sulphates) on the hydrated alumina compounds present in set Portland cement. The compound $4CaO.\ Al_2O_3.\ 13H_2O$ or certain solid solutions which it forms, reacts with calcium sulphate to form $3CaO.\ Al_2O_3.\ 3CaSO_4.\ 32H_2O$..... The increase in solid volume which results is accomodated not by growth into existing pore spaces but by an outward thrust causing disruption of the solid mass."

It is felt that your contention that in actual practice damage to brickwork from frost is to a much greater extent governed not by the properties of the materials themselves, but by how they are employed in building (such as in the use of parapet walls or other means of bringing about relatively severe exposure) is, to a certain extent a reasonable one. This appears to be the view of B. Butterworth (1) with reference to conditions in Great Britain, "In a temperate climate such as that of the British Isles and much of Western Europe, frost does not normally damage fired clay except where it is fully exposed to the weather, without damp-proof membranes to prevent free absorption of rain water, and without the protective influence of heat flowing from the interior of a building and tending to dry and warm the walling materials ..... In the external walls of a building with normal protection from a roof, a situation that may conveniently be considered as 'normal exposure', the risk of damage from frost is negligible. Bricks that are not damaged when exposed in a wet state to the frosts of one winter, as they may be whilst a building is being built, should withstand freezing indefinitely in normal exposure."

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(3) F.M. Lea and R.W. Nurse "Problems of Crystal Growth in Building Materials" Discussions of the Faraday Society No. 5, 1949.

In previous work, Butterworth (4) showed that in Great Britain a high degree of saturation by outdoor exposure was reached in roofing tiles and bricks, the latter being exposed in simulation of parapet walls. The water content of these materials often exceeded that which they would absorb during 24 hours immersion at room temperature. However, he has noted (1) that "Only a few measurements of the water content of bricks cut from normal external walls have been made at the Building Research Station, but these showed very low water contents, even in the depths of winter."

The present (C62-50) specification of the A.S.T.M. for building brick of clay or shale makes recognition of differences in degree of exposure of brickwork, and classified bricks into 3 grades according to the severity of exposure in which they are to be used. These are grades SW, MW and NW. The first grade covers "Brick intended for use where a high degree of resistance to frost action is desired and the exposure is such that the brick may be frozen when permeated with water. As a typical example, brick used for foundation courses and retaining walls in portions of the United States subject to frost action should conform to this grade." Grade MW bricks are "intended for use where exposed to temperatures below freezing but unlikely to be permeated with water ..... as a typical example, brick used in the face of a wall above grade." Grade NW are bricks "intended for use as back-up or interior masonry, or if exposed, for use where no frost action occurs ....."

It is thought that the A.S.T.M. classification of bricks, with respect to durability against frost action, is based on the idea that bricks which are resistant to 50 cycles of a standard (and severe) freezing and thawing test are adequately resistant to any conditions they will meet in service with respect to frost action.

The A.S.T.M. freezing test (C67-50) consists of immersing the bricks in water at room temperature for 48 hours, after which they are placed, on edge, and standing in ½ inch of water, in trays. The trays and bricks are put in a freezing chamber, at a temperature not higher than 16°F, for 20 hours. They are removed after this time and immersed in water at room temperature for four hours. The freezing is then repeated. After every third such cycle the bricks are dried and weighed and the loss in weight by the treatment is determined.

However, if the bricks have certain combinations of physical properties, the freezing test need not be applied.

For the A.S.T.M. grade SW bricks, the properties required are essentially as follows:

Minimum compressive strength 3000 psi
Maximum water absorption (5 hour boiling) 17%
Maximum Saturation Coefficient 0.78

However, even if bricks have a saturation coefficient greater than 0.78, they may qualify for grade SW if their compressive

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(4) B. Butterworth "The Absorption of Water by Clay Building Bricks and Related Properties - Part II" Trans. Brit. Cer. Soc. Vol. 44-45, 1945 - 46.

strength is greater than 8000 psi or their water absorption, by 24 hour submersion, is less than 8 per cent.

In addition, as mentioned previously, the above requirements do not apply if bricks can withstand, without breakage and loss in dry weight greater than 1.0 per cent, the standard A.S.T.M. freezing and thawing test of 50 cycles.

These physical requirements of bricks are thought to have been set up on the basis of results of a study made by McBurney and Lovewell (5) on relationships between compressive strength, water absorption and saturation coefficient, and the resistance of bricks to 51 cycles of a freezing and thawing test. They studied a very large number of bricks from many manufacturers in the United States.

For bricks over 2500 psi compressive strength and less than 0.80 saturation coefficient (cf ASTM SW requirements of 3000 and 0.78), McBurney and Lovewell found that only one brick out of 61 in this range of properties was unsatisfactory in their freezing test (i.e. it had breakage or loss in weight of more than 3 per cent).

For bricks of saturation coefficient less than 0.8 and 5 hour absorption (boiling water) of less than 18% they found no bricks out of 46 in this range of properties to be unsatisfactory in the freezing test. Above this range of absorption and saturation coefficient, many bricks were unsatisfactory in the test.

For bricks over 8000 psi compressive strength, they found that only four out of 66 failed to resist satisfactorily the 51 cycles of freezing and thawing.

Their conclusions were as follows, "The combination, not less than 2500 lb. per sq. in. compressive strength with an absorption ratio (Saturation coefficient) of not more than 0.80 or a compressive strength of not less than 6000 lb. per sq. in. with an absorption ratio of not more than 0.85 insures the withstanding of 51 cycles of freezing and thawing."

"Likewise the combination not more than 18 per cent water absorption by 5 hour boiling water with an absorption ratio of not more than 0.80, or a water absorption of not more than 12 per cent by 5 hour boiling with an absorption ratio not exceeding 0.85, insures the withstanding of 51 cycles of freezing and thawing."

The saturation coefficient or "absorption ratio" of McBurney and Lovewell was taken as the ratio of absorption by 48 hour submersion in cold water to that after 5 hour submersion in boiling water, whereas the A.S.T.M. saturation coefficient is the ratio of the absorption by 24 hour submersion in cold water to that after 5 hour submersion in boiling water.

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(5) J.W. McBurney and C.E. Lovewell "Strength, Water Absorption and Weather Resistance of Building Bricks Produced in the United States". A.S.T.M. Proc. Vol. 33, Part 2, 1933.

It seems, therefore, that the A.S.T.M. requirements of properties for grade SW bricks are based on ensuring that the bricks will withstand 50 cycles of freezing and thawing.

In the case of grade MW bricks, it is more difficult to find the basis for the requirements which have been set by the A.S.T.M. That is, with respect to the work of McBurney and Lovewell.

For grade MW the required physical properties are essentially as follows:

Minimum compressive strength 2500 psi
Maximum water absorption (5 hour boiling) 22%
Maximum saturation coefficient 0.88

However, bricks may have higher saturation coefficients than 0.88 if the compressive strength is greater than 8000 psi, or the water absorption is less than 8 per cent by 24 hour immersion. In addition, bricks for grade MW need not meet the requirements for water absorption and saturation coefficient if they withstand a freezing and thawing test of 50 cycles with no breakage and not more than 3.0 per cent loss in dry weight (1.0 per cent for grade SW).

Using the data of McBurney and Lovewell for bricks greater than 2500 psi compressive strength and less than 0.85 saturation coefficient (cf A.S.T.M. 2500 psi and 0.88 saturation coefficient for grade MW), 25 out of 139 bricks in this range of properties were found unsatisfactory in the freezing test.

Of bricks less than 0.85 in saturation coefficient and up to 21% absorption by 5 hour boiling (cf A.S.T.M. 22% and 0.88) McBurney and Lovewell found that 24 bricks out of 119 in this range of properties were unsatisfactory in the freezing and thawing test.

It seems almost certain that any brick which meets the requirements of physical properties as set up in A.S.T.M. grade SW will withstand 50 cycles of freezing and thawing. This seems to be the A.S.T.M. basis of judging the durability of bricks to severe exposure.

In the case of grade MW, however, it seems only that the chances are favourable that bricks meeting the physical property requirements will withstand 50 cycles of freezing and thawing (with an increased loss of weight allowed - 3% instead of the 1% for grade SW).

The problem, which has been raised in your note, of applying the same freezing test, essentially, to bricks to be used for quite different conditions of exposure, is worthy of consideration. However, as mentioned before, in winter construction a high degree of dampness may be present in walls which will be normally relatively dry in service.

In the A.S.T.M. specification (62-50 Explanatory Note) it is asserted that, "There is a reasonably close correlation between the performance of brick in the freezing-and-thawing test and under the agents of weathering in masonry structures, and at the present

time this test appears to be the best measure of the durability of brick."

"In classifying brick according to their resistance to the freezing-and-thawing test, they fall into three general groups as indicated in Table I of these specifications:

Grade SW which are not affected by the test, and whose appearance and structure remain unchanged.

Grade MW which are for the most part well-burned brick but may include some brick which change materially in appearance when exposed to weathering."

"The limits for absorption and saturation coefficient in the grade MW classification have been set to include the average production of those districts which do not grade or classify their kiln output beyond elimination of extremely underburned (salmon) brick. These 'kiln run' shipments frequently include a small percentage of brick which, on exposure to weathering, will lose their surfaces by powdering, flaking or spalling and thus produce an unsightly appearance of the exposed masonry surface."

For the conditions of exposure applying to a particular grade, it is considered that bricks qualifying for the A.S.T.M. classification of grades SW and MW should give satisfactory protection against frost damage. The problem may have arisen however, as suggested in your note, that the limits set in this specification are too stringent.