FROST DURABILITY OF CANADIAN CLAY BRICKS

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ABSTRACT Some methods were used to assess the frost durability of clay bricks. Expansion on freezing of saturated bricks provides a valid test for the assessment of their durability. Although criteria based on saturation coefficient and specific surface area are useful, they depend on the raw materials and the manufacturing processes. The optimum firing condition can be estimated from a plot of saturation coefficient against specific surface area. Quality control can be improved if both absorption and saturation coefficient are used together. The current quality control test involving 48 hours can be reduced to one hour or less using short-term absorption tests.

1. INTRODUCTION

In Canada, the principal cause of masonry deterioration is the freezing and thawing of clay bricks. Although current brick specifications contain durability criteria, the tests are time-consuming and the results are not reliable. An Industrial Research Fellowship Program was sponsored jointly by the Clay Brick Association of Canada and the Division of Building Research of the National Research Council of Canada, in 1978. The purpose of the program was to identify the pertinent physical and mineralogical properties that are responsible for failure in order to establish criteria for product improvement, to improve quality control and to provide a better and faster test for the frost durability of clay bricks. Nine types of commercially marketed bricks manufactured by six plants were studied. The program included a study of the effects of raw materials, forming methods and heat gradient in kilns. The highlights of the program from 1978 to 1982, and information pertinent to manufacturers, are presented here.

2. MICROSTRUCTURAL CHARACTERISTICS AND DURABILITY

The microstructural properties that may be relevant to the durability of clay bricks, i.e. saturation coefficient, specific surface area and pore structure, are described below.

2.1 Saturation Coefficient

Saturation coefficient is the ratio of the twenty-four hours cold water absorption value to the five hours boiling absorption value of a brick. It is an approximate indication of the space available in the brick to accommodate the expansive pressure of freezing water. The lower the saturation coefficient, the more space there is for the freezing pressure to be relieved; thus it is less likely that the brick will be damaged. The saturation coefficient is traditionally used as a measure of durability in brick specifications and quality control. The development of saturation coefficient with respect to heat work (combined effect of peak temperature and soaking time), as measured by the shrinkage of firechek keys (1), expressed in the arbitrary BRI unit, is shown in Figure 1 for various Canadian brickmaking materials and in Figure 2 for bricks made of the same raw material but by different forming methods. These figures indicate that the critical saturation coefficient required for frost resistance depends on the raw materials and the manufacturing process and varies from brick to brick.

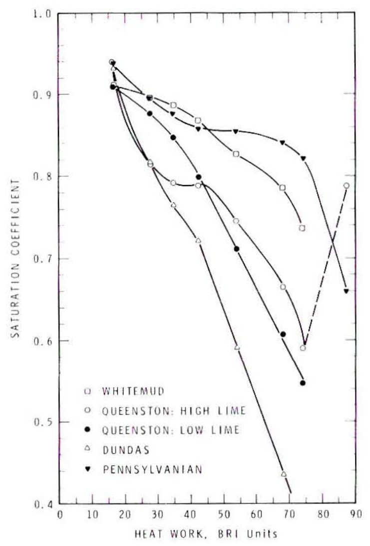

FIGURE 1
SATURATION COEFFICIENT OF BRICKS MADE OF VARIOUS CANADIAN BRICKMAKING MATERIALS AS A FUNCTION OF HEAT WORK

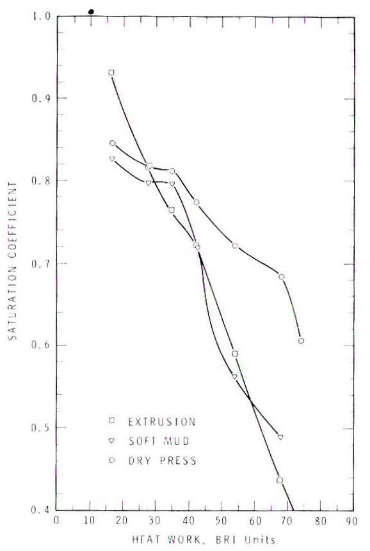

FIGURE 2
SATURATION COEFFICIENT OF BRICKS MADE OF THE SAME RAW MATERIAL BUT BY DIFFERENT FORMING METHOD AS A FUNCTION OF HEAT WORK

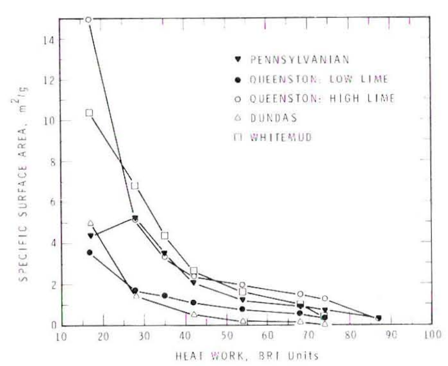

FIGURE 3
SPECIFIC SURFACE AREA OF BRICKS MADE OF VARIOUS CANADIAN BRICKMAKING MATERIALS AS A FUNCTION OF HEAT WORK

Although the saturation coefficient criterion has some merit, it fails, by itself, to take this variation into account. As can be seen from these results, Canadian Standard CSA A82.1 is of questionable value since five out of the nine products studied achieved a saturation coefficient of 0.88 when fired to about 900°C. These underfired bricks have the specified saturation coefficient and will pass the CSA Standard but they do not possess adequate durability characteristics to withstand either laboratory freeze-thaw tests or natural weathering.

2.2 Specific Surface Area

Typically, the specific surface area value of burnt Canadian clay bricks is between 0.5 and 3.0 m^2/g. Litvan (2) found that the specific surface areas of twenty-seven bricks collected from different masonry structures correlated well with their field performance. Further results from the Fellowship research indicate that durability can be assessed on the basis of specific surface area measurement. But the effect of raw materials and manufacturing processes must be considered. Figure 3 shows the variation of specific surface area of extruded bricks made from different raw materials with respect to heat work. The region of heat work between 35 and 70 BRI units corresponds to peak firing temperatures between 1030°C and 1080°C. This is where the durability of the five bricks develops. It can be seen that the curves are apart and do not cross in this region. Thus, Figure 3 reveals that the critical surface area corresponding to the durable limit of each product may vary. Similarly, Figure 4 indicates that different manufacturing processes may also result in different critical surface areas for equal durability, even though the same raw materials were used. Thus the relative durability of bricks manufactured from raw materials of different composition and by different processes cannot be predicted solely on the basis of a direct comparison of the absolute value of the specific surface area. Specific surface area is useful for quality control purposes only when applied to a particular raw material formed by the same process.

2.3 Pore Structure

References in the literature suggest that the existence of coarse pores (greater than 1 micron) result in an enhancement of durability whereas the intermediate pore sizes (say,

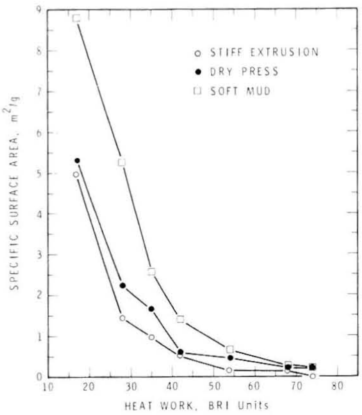

FIGURE 4
SPECIFIC SURFACE AREA OF BRICKS MADE OF THE SAME RAW MATERIAL BUT BY DIFFERENT FORMING METHOD AS A FUNCTION OF HEAT WORK

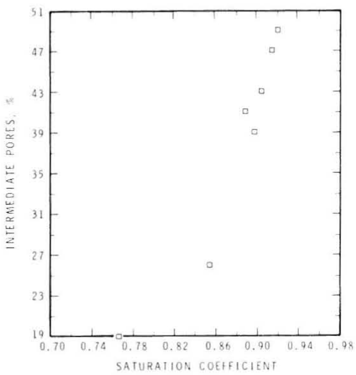

FIGURE 5
RELATIONSHIP BETWEEN THE AMOUNT OF INTERMEDIATE SIZE PORES AND SATURATION COEFFICIENT OF BRICKS FROM PROJECT BP

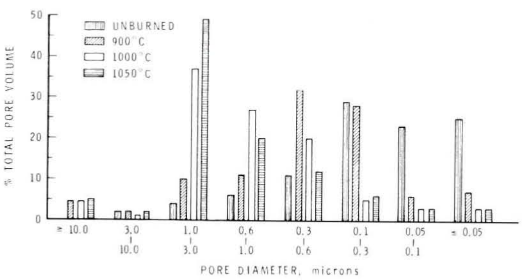

FIGURE 6
EFFECT OF FIRING TEMPERATURES ON PORE SIZE DISTRIBUTION

between 0.1 and 1 micron) have a lower frost resistance (2,3,4). In natural weathering conditions, coarse pores are rarely filled with water because, although they are easily filled with water, it dries out quickly. Small pores do not fill or dry easily. Since water in small pores does not freeze until very low temperatures are reached, it has very little effect on the frost susceptibility of bricks. Intermediate pores are most susceptible to freeze-thaw action since they are most frequently filled with water and the water dries more slowly than in larger pores. This detrimental effect is illustrated in Figure 5, which shows that the saturation coefficient is proportional to the amount of intermediate-sized pores in bricks, as determined by mercury intrusion porosimetry. In general, large pores lower the saturation coefficient, whereas small pores increase it. It is perhaps feasible to use pore structure as a durability test, but more analysis is needed.

During the firing of a brick, its durability is improved because the total porosity is reduced by grain growth and particle fusing. Also, as the firing temperature increases, coarsening of the pores takes place, as shown in Figure 6. By comparing water absorption results and the total theoretical porosity determined by mercury intrusion porosimetry, the following important conclusions can be drawn: a) Some bricks are easier to saturate than others. For example, after soaking for one hour in water, bricks from projects BP and NW achieved the highest level of saturation, i.e. 80%, whereas HC and VD bricks had the lowest degree of saturation, i.e. below 60%. b) Bricks fired at higher temperatures (thus with greater frost resistance) are more difficult or slower to saturate by soaking in water than those fired at lower temperatures. Such different rates of saturation have an important practical significance in considering the weatherability of bricks in service.

3. FREEZING EXPANSION AS A FROST DURABILITY TEST

It is desirable to establish a test method that is fast and reliable. One promising method is to measure expansion

of a wet brick specimen during freezing. The method involves measuring the expansion of a small (8 mm in diameter × 13 mm in length) vacuum-saturated brick specimen during one cycle of freezing and thawing that could be carried out in a few hours. It is based on the concept that expansion is caused by the stress developed when the water freezes, and that there is a relation between the difference in freezing expansion and thawing shrinkage (called residual expansion) and the damage suffered (Figure 7). The results obtained rated samples of known relative durability in the proper order. Figure 8 presents the residual expansion plotted against the total expansion on freezing of seventy-seven bricks. Higher freezing expansion is accompanied by larger residual expansion in general. This behaviour becomes more pronounced as the freezing expansion exceeds the 0.15% level. Using 0.10% expansion as the threshold, the prediction is 100% accurate with 15% rejection of possibly durable products. Taking 0.15% as the threshold value, the prediction of non-durable products is 93% correct with a 2% rejection of possibly durable products. Since there is a reasonable correlation between the freezing expansion and the residual expansion, the method can be simplified by measuring the residual expansion after freeze-thaw tests. This correlation improves with specimens of larger size.

The freezing expansion test also provides information on the effect of the manufacturing process on the frost resistance of bricks. There is an indication that beyond a critical saturation level, which lies between 75 and 80%, extruded clay bricks show a marked increase in freezing expansion, whereas bricks made from dry-press and soft mud methods do not, as can be seen in Figure 9. This behaviour in extruded bricks may be related to the pore structure.

4. OPTIMIZATION OF BRICK FIRING

Where frost durability is concerned, firing is the most important process in the production of clay bricks. Since frost resistance increases with greater heat work, it is advantageous for the industry to optimize the firing conditions. An empirical laboratory procedure was developed that estimates the optimum heat work for a given brick, based on saturation coefficient, specific surface area and the heat work. The specific surface areas of fired samples at different heat works are plotted against the corresponding saturation coefficients, as shown in Figure 10. The result could be described

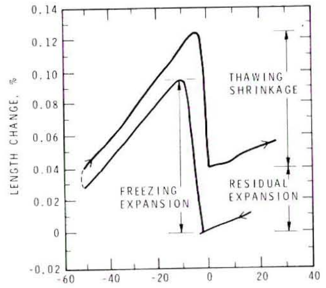

FIGURE 7

TYPICAL EXPERIMENTAL LENGTH CHANGE RESULTS FROM THERMOMECHANICAL MEASUREMENT

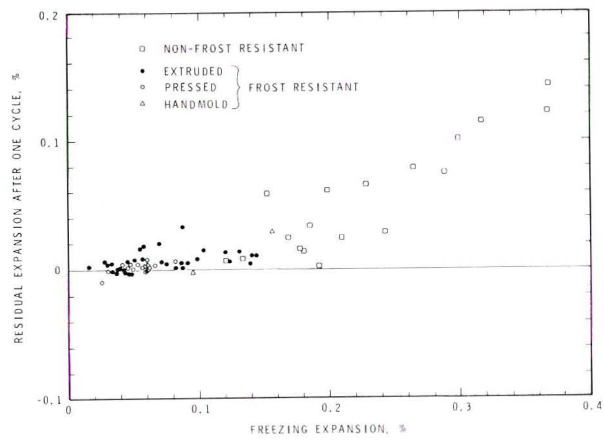

FIGURE 8

RELATIONSHIP BETWEEN RESIDUAL EXPANSION AND FREEZING EXPANSION OF FROST RESISTANT AND NON-FROST RESISTANT BRICKS

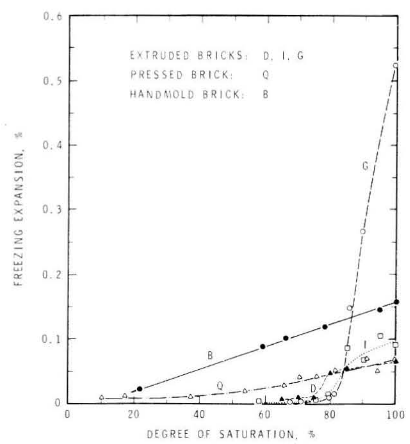

FIGURE 9

EFFECT OF MANUFACTURING METHODS ON FREEZING BEHAVIOR OF CLAY BRICKS

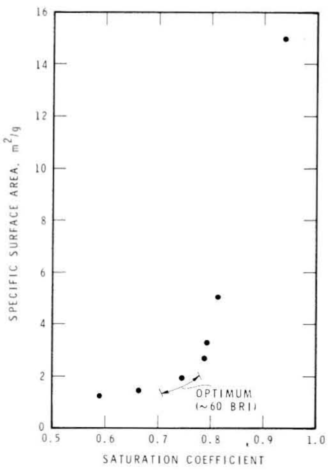

FIGURE 10

ESTIMATION OF OPTIMUM FIRING CONDITION FOR PROJECT VD BASED ON SPECIFIC SURFACE AREA AND SATURATION COEFFICIENT

by two intersecting lines. The optimum heat work and firing condition are approximately those corresponding to the intersection of the two lines. This optimum value can be more clearly defined by the derivative of the curve of specific surface area with respect to saturation coefficient. This method could also be used to assess the intrinsic tolerance of a brickmaking material to frost action or to indicate how much improvement could be achieved in a product by modifying the present process.

5. QUALITY CONTROL

The procedures for the present quality control tests have limitations, since they are based on tests for absorption characteristics and saturation coefficients which are time-consuming and depend on the variation in raw materials. Thus, the maximum allowable and the optimum values of absorption and saturation coefficients must be established for each product.

5.1 Short-Term Absorption Tests

Correlation between the short-term absorption and the saturation coefficient has been found, as shown in Figures 11 and 12. The degree of correlation is a function of the mixing or homogeneity of the raw materials: it is best when only one source of consistent raw material is used (Figures 13 and 14) and is poor when different materials are blended (Figure 15). Thus, the standard quality control tests could be shortened considerably from the usual forty-eight hours (required in the case of saturation coefficient) to within an hour by using short-term absorptions, such as one minute or one hour cold absorptions. In order to ensure best correlation, the short-term absorption tests should be done with half bricks or a fraction of a whole brick in order to avoid the "tight-skin effect" which increases the scattering of data. Although the initial rate of absorption could be measured in a minute, it has a poorer correlation than the one hour absorption tests and is more affected by surface texture.

5.2 Absorption and Saturation Coefficient

Cold absorption and saturation coefficients have been used separately for quality control, but their values vary depending on the raw material. The inadequacy of using either one independently for quality control can be seen

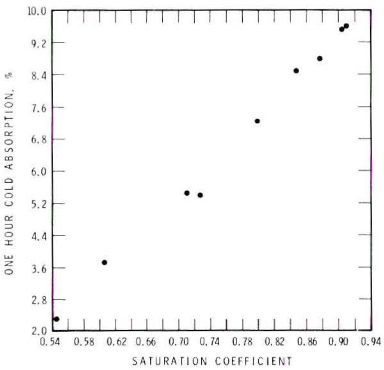

FIGURE 11

CORRELATION BETWEEN ONE HOUR COLD ABSORPTION AND SATURATION COEFFICIENT FOR BURNT BRICKS FROM PROJECT R

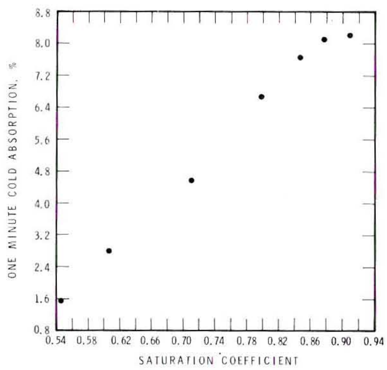

FIGURE 12

CORRELATION BETWEEN ONE MINUTE COLD ABSORPTION AND SATURATION COEFFICIENT FOR BURNT BRICKS FROM PROJECT R

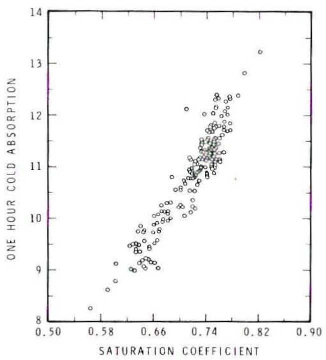

FIGURE 13

RELATIONSHIP BETWEEN SATURATION COEFFICIENT AND ABSORPTION OF BRICKS MADE FROM A SINGLE SOURCE OF RAW MATERIAL

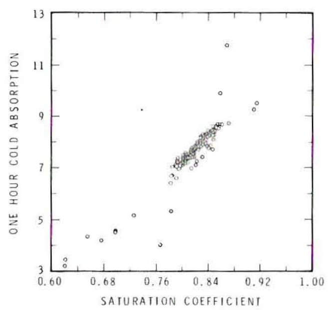

FIGURE 14

RELATIONSHIP BETWEEN SATURATION COEFFICIENT AND ABSORPTION OF BRICKS MADE WITH ADDITIVES INTRODUCED IN SLURRY

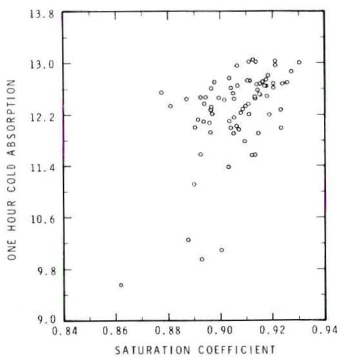

FIGURE 15

RELATIONSHIP BETWEEN SATURATION COEFFICIENT AND ABSORPTION OF BRICKS MADE FROM BLENDING A SHALE AND A CLAY

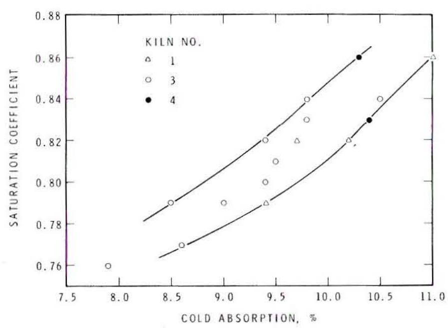

FIGURE 16

PROPERTIES OF BRICKS PRODUCED IN A PLANT OVER A PERIOD OF THREE MONTHS

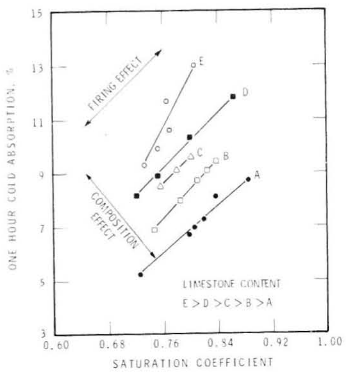

FIGURE 17

VARIATION IN RAW MATERIALS ELUCIDATED BY PLOTTING COLD ABSORPTION VS SATURATION COEFFICIENT

in Figure 16. In a production plant, bricks of similar saturation coefficient but different absorption values, and similar absorption but different saturation coefficient values are both produced. These bricks have different properties. Thus, it is recommended that absorption and saturation coefficients be used in conjunction, since this composite relationship not only reveals the quality of the particular brick produced but also the "history" of the brick, such as the original raw material composition and the resulting firing condition, as shown in Figure 17.

6. CONCLUSIONS

Present Canadian durability standards for clay bricks are questionable. Evaluation criteria based on saturation coefficient and specific surface area must be established for each product because they vary according to the different raw materials and manufacturing processes. The optimum firing condition can be estimated by plotting the specific surface area against saturation coefficient at different degrees of firing. Freezing expansion seems to provide a valid durability test for clay bricks independent of the composition and process variables. In the absence of the criteria mentioned above, quality control should be based on both absorption and saturation coefficient. Current quality control tests based on saturation coefficient can be shortened by the one minute or one hour absorption test.

7. ACKNOWLEDGEMENT

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