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RÉSUMÉ

On a étudié neuf briques d'argile canadienne en vente dans le commerce et ayant différentes fiches de durabilité au gel dans le but d'améliorer les critères d'évaluation de la résistance au gel et les méthodes de contrôle de la qualité. L'influence des matières premières, des méthodes de coffrage et du gradient de chaleur dans le four a été examinée. Ce document décrit les méthodes générales d'échantillonnage et d'essais qui ont été utilisées.

On a étudié neuf briques d'argile canadienne en vente dans le commerce et ayant différentes fiches de durabilités au gel dans le but d'améliorer les critères d'évaluation de la résistance au gel et les méthodes de contrôle de la qualité.

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Frost-Durability Study on Canadian Clay Bricks I. Introduction and Sampling

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ABSTRACT

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Nine commercially marketed Canadian clay bricks of diverse frost-durability records were studied with the objective of improving frost-resistance evaluation criteria and quality-control methods. The effects of raw materials, forming methods, and heat gradient in the kiln were investigated, and the general sampling and testing procedures that were followed are described in this paper.

1. INTRODUCTION

In Canada the principal cause of deterioration of masonry is the freezing and thawing of clay bricks in the presence of moisture. Repairs are costly and there is no assurance that deterioration will not recur. Although present brick specifications are concerned with durability, the specified tests are time-consuming and the results are not reliable. There is little soundly based guidance to help manufacturers improve their products, to aid designers in choosing suitable bricks, or to enable standards-writing committees to specify minimum requirements for desired performance.

The Clay Brick Association of Canada and the Division of Building Research, National Research Council Canada, established a joint industrial Re-

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search Fellowship Program in 1978 to investigate the durability of clay bricks and the causes of failure. Particular attention was given to the need to identify the pertinent physical and mineralogical properties that are responsible for failure, to establish criteria for product improvement, to improve quality control, and to provide better and faster tests for the durability of clay bricks. An extensive literature survey was conducted on the subject of frost durability of clay bricks and will be published separately.

2. EXPERIMENTAL

The experimental program consisted of a study of nine types of commercially marketed clay bricks manufactured by six plants. The plants produce about 50% of all bricks made in Canada. The bricks were chosen mainly on the basis of their performance in service. Other important considerations were raw-material compositions, forming methods, and heat gradients in the kiln. The manufacturing processes of the nine types of bricks studied are summarized in Table 1, along with their past durability records in service. Most bricks studied in this program were made of hard shales of different chemical compositions. Barium carbonate is a common additive to reduce efflorescence. Whereever there is a lack of plasticity, the raw material is subjected to natural weathering and bentonite is added. All products studied, except one, were fired in tunnel kilns with natural gas, the exception being a downdraft periodic kiln fired with oil. Only two products studied were treated under some reducing atmosphere in the kiln, i.e. "flashing", in order to induce colour variation; all others were fired under oxidizing atmosphere.

Brick type Nos. 1, 2, 5, 6, 7, 8, and 9 were extruded bricks, each made from a different raw material. By comparing and studying properties of these bricks burnt at equal degrees of firing from the plants and laboratory, the effect of raw-material composition on the frost durability of clay bricks was investigated. Studies of brick types Nos. 3 to 5 showed the effect of different forming methods (i.e., soft mud, dry press, and stiff extrusion) on frost resistance of bricks made with similar raw materials. By sampling bricks from different positions in the kiln or kiln car, the heat gradient and its effect on the quality of bricks were evaluated.

The program was divided into three phases: (1) sampling of bricks in the production plants; (2) characterization of physical and chemical properties of sampled bricks; (3) development of laboratory techniques for determining frost durability. The general experimental procedure followed for each type of brick is shown in Table 2.

2.1 Brick sampling

2.1.1. Sampling from brick plants

The experimental work began with the sampling of products from brick plants and the documentation of the manufacturing process. Table 3 presents a list

TABLE 1

Summary of the manufacturing process of bricks studied

Brick No.	Plant No.	Raw materials	Additives	Forming method	Firing process	Durability record
1	1	shale	barium carbonate	stiff extrusion	oil-fired periodic kiln	good
2	2	weathered shale	bentonite, barium carbonate, lignosol	stiff extrusion	gas-fired tunnel kiln	good
3	3	shale and clay	barium carbonate	soft mud	gas-fired tunnel kiln	good
4	3	shale and clay	barium carbonate	dry press	gas-fired tunnel kiln	unknown
5	3	shale and clay	barium carbonate	stiff extrusion	gas-fired tunnel kiln	few failures
6	4	shale	barium carbonate	stiff extrusion	gas-fired tunnel kiln	many failures
7	5	shale	barium carbonate	stiff extrusion	gas-fired tunnel kiln	good
8	5	surface shale	barium carbonate	stiff extrusion	gas-fired tunnel kiln	many failures[a]
9	6	clay and calcined grog	barium carbonate, manganese oxide	stiff extrusion	gas-fired tunnel kiln	some failures

[a]Brick No. 8 possesses a good durability record in service, but other products using the same raw materials and similar processes have had extensive failures under frost attack.

of the manufacturing-process variables recorded during plant sampling. Since only a particular batch of bricks manufactured from a specific production was sampled, the day-to-day variations in the manufacturing process were not studied. However, production runs from which test bricks were obtained were representative of the normal production for the particular plant. In some cases, sampling had to be repeated due to abnormalities, such as excessive cracking in the extruded column and slowdowns in the kiln schedule.

Between 150 and 200 bricks were sampled from each production run, including about 20 green bricks. Unburnt green bricks were sampled at the end of the forming process, most of them prior to (but some after) drying, such as in the case of soft mud bricks. Out of the nine types of bricks studied, green bricks were obtained for all except type No. 9. During sampling the entire manufacturing process up to the stage of forming was monitored and documented for at least 2 h before green bricks were sampled for testing to ensure representa-

TABLE 2

Experimental procedure

Sampling

Green bricks — *Burnt bricks*

Analyses
chemical
mineralogical
thermal
particle size

Laboratory firing — *Plant-fired*

Characterization (I)
suction rate,
water absorption,
saturation coefficient,
density

Samples selected
(12–20)

Characterization (II)
microhardness,
pore structure
(total porosity, pore-size distribution),
specific surface area

Durability tests
freeze–thaw exposure,
freezing expansion,
ultrasonic pulse velocity

tive samples. Whenever possible, the kiln car in top condition was selected and the history of such a car was followed and documented for both green and burnt bricks, and samples were taken from this selected car. Burnt bricks were collected just before packaging. The sampling procedure for the burnt bricks took into account the different degrees of firing associated with the temperature gradient of the kiln. Samples from the low and high extremes of the temperature gradient were always taken. Firechek keys were used to determine the degree of heat work, i.e., the temperature/time profile of the firing curve, on the sample burnt bricks (Newman, 1979). The higher the key reading in the arbitrary BRI unit, which means higher firing shrinkage of the ceramic firechek key, the greater is the resulting heat work. The use of the firechek key offered the opportunity to study the bricks at the same degree of firing, both in the plant and in the laboratory.

TABLE 3

List of process variables documented during plant sampling

PRODUCT:	PLANT:
DATE:	
A. Field data:	*D. Drying:*
Sample No.	Sample No.
Raw materials	Push rate
Location of deposit	Dryer No.
Description of deposit	Temp.
	RH
B. Processing data:	Moisture
Sample No.	Strength
Mix formula	Shrinkage
Additives	Comment
Grinding proc./equip.	
Screens	*E. Firing:*
Particle size	Sample No.
Moisture	Push rate
Comment	Kiln No.
	Firing curve
C. Forming:	Atmosphere
Sample No.	Fuel
Tonnage	Shrinkage
Water	Comment
Consistency	
Admixture	
Vacuum	
Oil pressure	
Power	
Penetrometer	
Moisture	
Comment	

2.1.2 Laboratory firing of green bricks

Because it was desirable to study the behaviour of the same bricks over a much wider range of properties, laboratory-fired samples were included in the experimental program. In this way, a large number of samples could be quickly produced covering the range from badly underfired to overfired, enabling comparison of bricks of different raw materials or forming methods subjected to equal heat treatment. The sampled green bricks from the plants were used as the starting materials for the laboratory-firing program so that the final products would be as similar as possible to the plant samples. The plant sampling program for this work covered only bricks from one production run in each plant.

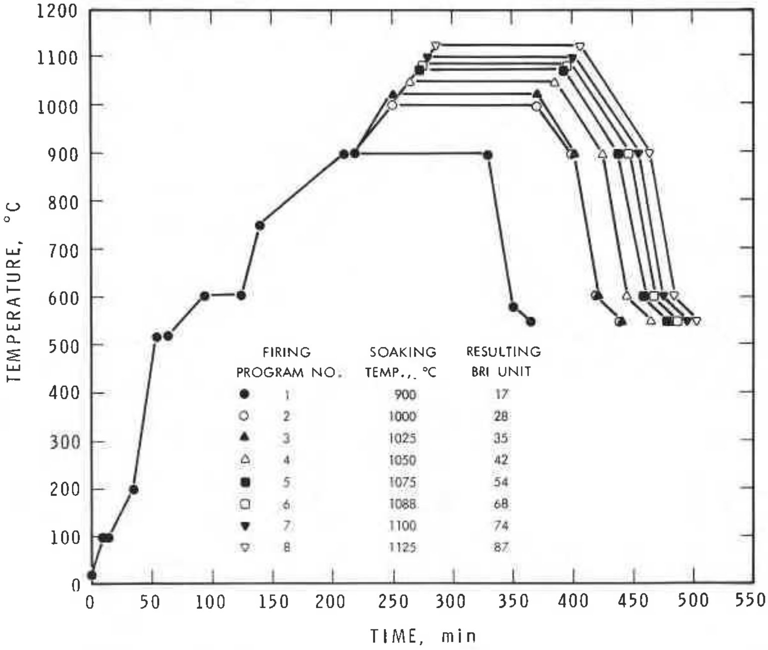

Fig. 1. Laboratory-firing curves for sampled green bricks.

The green bricks obtained during the plant sampling period were sealed in plastic bags and taken to the laboratory, where the two ends of the brick were sliced and then cut with a band saw into bars measuring 16.5×16.5×100 mm. The cut samples were stored in a room controlled at 21°C and 40% relative humidity. In the laboratory-firing program each type of brick underwent seven or eight different heat treatments. These firing schedules had identical firing and cooling profiles below 900°C and differed primarily in the temperature used in the 2-h soaking period. Figure 1 shows eight laboratory-firing curves with their respective soaking temperature and the corresponding index of heat work in the arbitrary BRI unit for firechek keys. Figure 2 shows the relationship between the soaking temperatures and the resulting heat work in the laboratory-firing program.

The samples were fired on end at an airflow of 2000 cm^3/min in a Rapid Temp 1500 D(C) furnace with Kanthal heating elements on the side walls and a MicRion microprocessor temperature controller. The working dimensions of the furnace were 254 mm×254 mm×254 mm.

The reproducibility for identical, programmed firing curves was ±1 BRI units on the firechek key measurement at low temperatures, i.e., firing Nos. 1 to 3, and ±4 BRI units at the highest-temperature firing. The reproducibility of the fired keys was ±1 BRI unit. The temperature gradient associated with the furnace depended on the firing temperature. At low temperatures the tem-

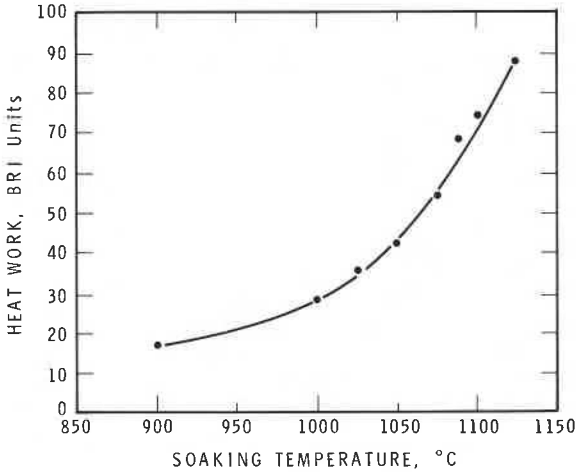

Fig. 2. Relationship between the soaking temperatures and the resulting heat works in the laboratory-firing program.

perature gradient was practically nil, and the resulting key measurements in BRI units for the front, back, right, and left sides were 15, 16 and 17, respectively. For Firing Program 5 (soaking at 1075°C), the key measurements for the front, centre, and left side close to the wall were 53, 54 and 58, respectively. For Program 6 (soaking at 1088°C) the key measurements for the front and centre and the right and left sides were 64, 74, 77 and 78, respectively.

The laboratory-fired specimens were required to be similar and representative in properties to the corresponding plant products and were intended to provide a series of samples of graded durability for evaluating the test methods. They also were intended to provide the basis for establishing a new method for determining the optimum firing conditions for a given brick, and to assess quickly and economically the effects of variations in the raw materials.

2.2 Characterization of properties of sampled bricks

2.2.1 Green bricks

Chemical, mineralogical, and thermal analyses were carried out on the sampled green bricks in order to characterize the raw materials. Moisture content, specific surface area, pore structure, and particle-size distribution were also determined. The experimental details and results will be reported in later parts of this series.

2.2.2 Burnt bricks

The 1-h, 4-h, and 24-h cold absorption, the 5-h boiling absorption, and the saturation coefficients based on them were determined on all sampled burnt bricks and on the laboratory-fired samples. The bulk density, apparent porosity, and apparent specific gravity were also measured on most of the burnt plant and laboratory samples. In addition, the initial rate of absorption was determined on all burnt plant samples and a short-term 1-min cold absorption was measured on all laboratory-fired samples. Based on the 1-h cold absorption and the saturation coefficient, 12 to 20 samples from each type of bricks studied were selected for further testing. These bricks underwent the following physical tests: microhardness, specific surface area, and pore structure. Subsequently, the freeze–thaw behaviour of the selected samples was studied by length change and ultrasonic pulse-velocity measurements. The experimental procedures and results are presented in the respective papers.

2.3 Development of frost-durability quality-control tests

Based on the analyses of the results from the characterization and freeze–thaw tests, various evaluation methods and quality-control criteria pertinent to the frost durability of clay bricks were established.

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