DETERIORATION OF BRICKS WITH AND WITHOUT PERFORATIONS DUE TO SALT CRYSTALLIZATION

DETERIORAMENTO DI MATTONI PIENI E FORATI DOVUTO A CRYSTALLIZZAZIONE SALINA

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ABSTRACT The scope of this research is to compare the behaviour of bricks, with and without perforations, by means of salt crystallization tests developed in our laboratory.
The tests were carried out on bricks with different volumes of perforations prepared for this purpose from the same clay and by the same manufacturing process.
This study tries to demonstrate how differences in behaviour are related to the structure of the material, which in turn is dependent on the manufacturing process.

La presente ricerca ha lo scopo di confrontare il comportamento di mattoni pieni e di mattoni forati alla cristallizzazione utilizzando una procedura di prova messa a punto degli Autori.
Le prove vengono eseguite su mattoni con varia percentuale di fori appositamente prodotti con la medesima argilla e secondo un unico processo di produzione.
La ricerca si occupa in particolare di mettere in evidenza come le differenze di comportamento siano legate alla struttura del materiale, sulla quale influisce il processo di trafilatura, essicazione e cottura.

1. INTRODUCTION

The deterioration of bricks due to the crystallization of soluble salts within their matrix is one of the most important factors in the decay of masonry. The phenomenon is of major importance in cases such as the buildings in the city of Venice, but can also be found in various degrees of "virulence" all over the world.

This type of decay is characterized by the flaking, powdering and in some cases exfoliation and delamination of the brick or other porous building material. The mechanism through which this occurs is essentially one of mechanical stress induced by the growth of crystals (1,2,3,4,5).

The aim of this study is to compare the behaviour of perforated bricks, --two types with different volumes of perforations--, with that of solid bricks, --two types of current production and one experimental type using the same clay and manufacturing conditions of the perforated bricks--, with respect to their resistance to salt crystallization tests. The degree of influence of the different factors such as the presence of perforations, the clay used and firing conditions can thus be established.

2. MATERIALS

All the bricks used in this study are facing bricks and will be designated according to the following scheme:

- F perforated brick of current production
- SF experimental perforated brick with fewer holes than F manufactured from the same clay and under the same conditions as F
- P_1 experimental solid brick manufactured from the same clay and under the same conditions as bricks F and SF
- P_2 solid hand-made-looking brick of current production
- P_3 solid hand-made-looking brick of current production

Dimensions and coring arrangements of these bricks are given in Figure 1.

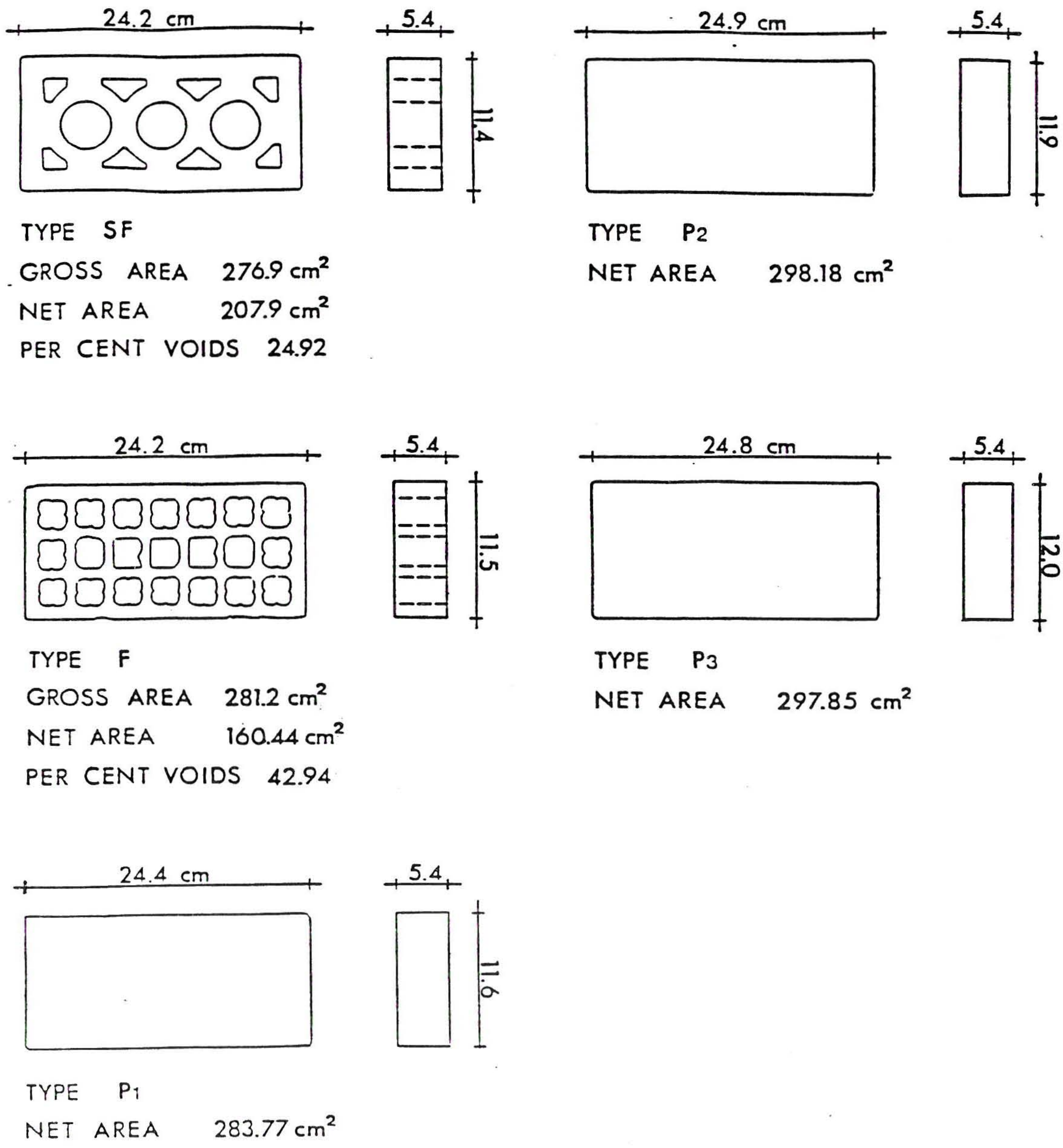

Fig 1 Dimensions and coring patterns of bricks

The composition of the clays used in the manufacturing of these bricks is listed in Table I.

Table I Chemical and Mineralogical Compostion of Clays

	F, SF & P_1	P_2	P_3
SiO_2	52.20 %	64.23 %	51.56 %
Al_2O_3	15.68	15.57	11.87
Fe_2O_3	4.46	6.55	5.36
CaO	11.11	2.63	11.95
MgO	0.99	0.71	2.25
CO_2	7.55	1.49	8.95
SO_3	0.02	0.03	0.01
Na_2O	0.78	1.45	1.11
K_2O	1.65	1.78	1.67
Ignition loss	13.02	3.98	13.35
HCl Ins. Res.	68.61	86.65	68.00
Minerals	α-Quartz	α-Quartz	α-Quartz
	Calcite	Plagioclase	Calcite
[in decreasing	Plagioclase	Chlorite	Plagioclase
order of	Muscovite	Illite	Chlorite
concentration]	Montmorillonite		Muscovite
	Chlorite		Dolomite

The F, SF and P_1 bricks were extruded and then dried in drying sheds for 48 hours. The drying air entered at 110°C and left the drying shed at 45°C. The moisture content of the clay dropped from 25% to 3-4% during this process. The bricks were then fired in a tunnel kiln at 950°C for 48 hours. The vertical temperature gradient in the kiln was less than 20-25°C.

The P_2 and P_3 bricks were prepared by the soft-mud method. The P_2 bricks were dried under the same conditions as the F, SF and P_1 bricks, the moisture content in the clay changing from 31-32% to 4-5%. They were then fired in a Hoffman kiln for 48-60 hours at 900°C. The P_3 bricks were also dried for 48 hours with a maximum air temperature of 90°C, the moisture content in the clay changing from 29-30% to 4-5%. They were then fired in a tunnel kiln for 42-44 hours at 1020°C. All kilns used methane as the combustion gas.

The fired bricks were studied by their mineralogical composition, given in Table II, and also by their water absorption characteristics. The latter are described by the water absorption coefficient, measured according to test No. II-6 of the 25-PEM/RILEM standard (6), absorption in cold and boiling water and the saturation coefficient as defined by ASTM standard C-67 (7). The results of these measurements are reported in Table III.

Table II Mineralogical Composition of Fired Bricks

F, SF & P_1	P_2	P_3
α-Quartz Plagioclase Diopside (m) Hematite (m) Gehlenite (tr)	α-Quartz Plagioclase Hematite (m)	α-Quartz Plagioclase Calcite (m) Gehlenite (m) Diopside (m) Muscovite (m)

(m) minor component; (tr) trace component

Table III Water Absorption Characteristics of Fired Bricks

	Water Abs.Coeff. $kg/m^2s^{0.5}$	% Absorption cold water 24h	% Absorption boiling water 5h	Saturation Coefficient
F	0.073	9.9 ± 0.1	11.2 ± 0.2	0.887 ± 0.02
SF	0.089	10.4 ± 0.3	11.9 ± 0.5	0.870 ± 0.02
P_1	0.056	10.9 ± 0.2	10.8 ± 0.3	1.010 ± 0.02
P_2	0.380	13.2 ± 0.2	18.5 ± 0.3	0.714 ± 0.02
P_3	0.112	15.5 ± 0.2	16.2 ± 0.3	0.955 ± 0.02

The highest porosity, given by the % water absorption, occurs in the two bricks prepared by the soft-mud method, P_2 and P_3. The highest water absorption coefficient, i.e., the fastest water absorption rate, corresponds to brick P_2, indicating the presence of larger pores, or a higher incidence of such pores. On the other hand, the three extruded bricks, F, SF and P_1, have the lowest porosity.

The microstructure of the bricks was studied by scanning electron microscopy in fractured surface. Figures 2, 3 and 4 correspond to photomicrographs of the F, SF and P_1 bricks, all three prepared from the same clay and under the same manufacturing conditions. All three present a well vitrified matrix with the laminated microstructure characteristic of the extrusion process. Figure 5 shows the appearance of a fractured surface from a P_2 brick, and Figure 6 corresponds to P_3. The difference in the amount of vitrification can be seen clearly. Brick P_2 has a highly vitrified matrix in which the large pores are very evident. On the other hand, P_3 is the least vitrified of all bricks, which can be explained due to the fact that even though it was fired at a higher temperature, its residence time in the kiln was shorter. The presence of residual calcite in the fired P_3 brick, implies that the temperature in the interior of the brick did not exceed 850°C (8,9).

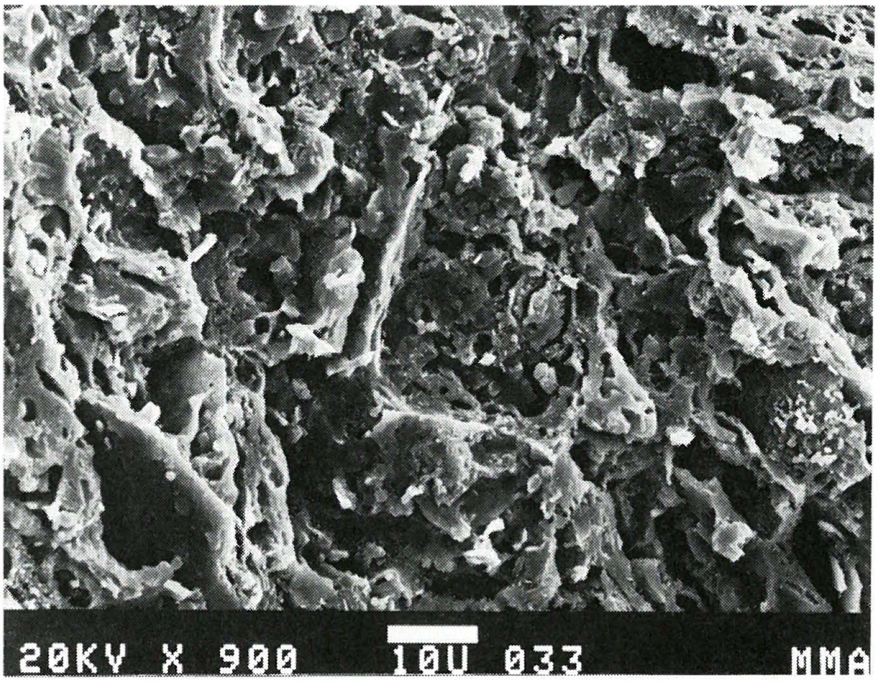

Fig 2 SEM photomicrograph of a fractured surface of an F brick. Note the oriented pores due to the extrusion process.

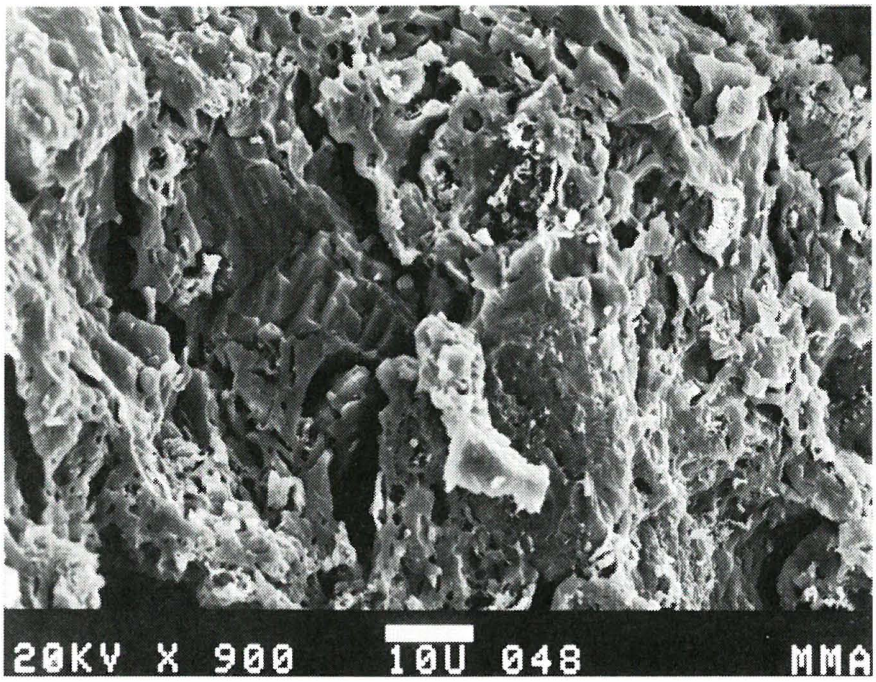

Fig 3 SEM photomicrograph of a fractured surface of an SF brick.

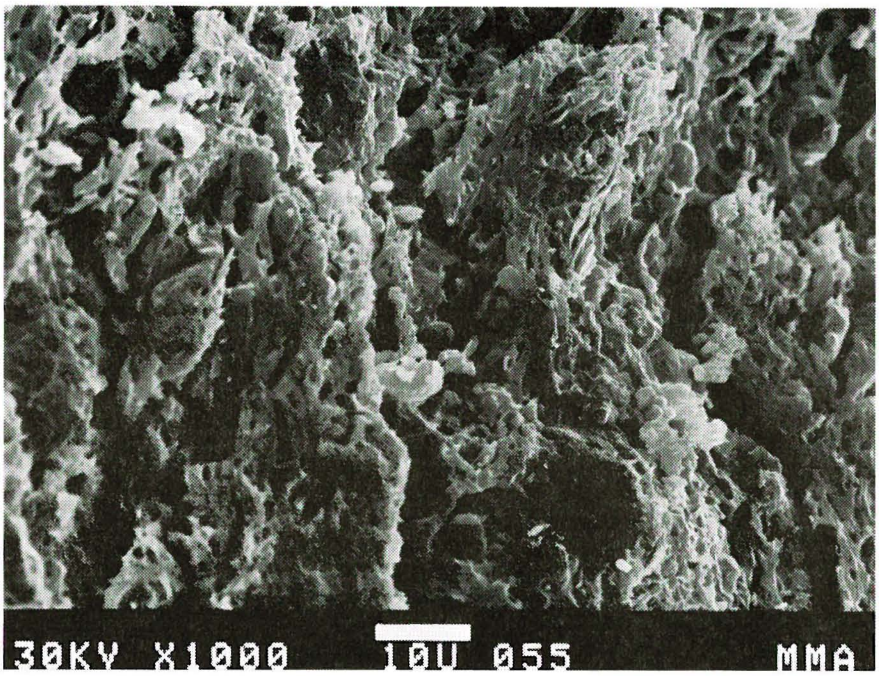

Fig 4 SEM photomicrograph of a fractured surface of a P_1 brick. Notice the laminated microstructure due to the extrusion process.

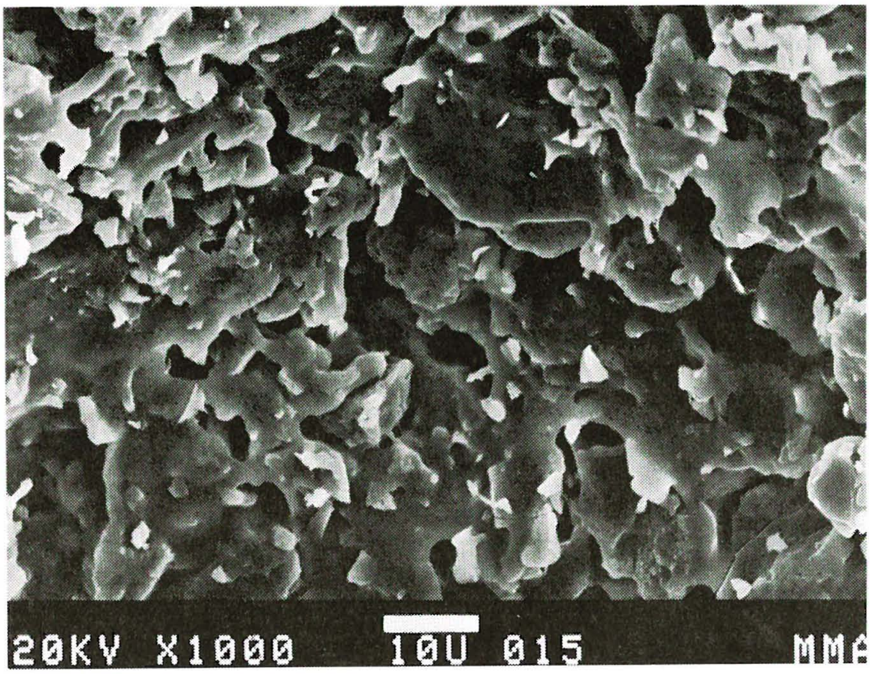

Fig 5 SEM photomicrograph of a fractured surface of a P_2 brick. Notice the highly vitrified matrix and the large size of the pores.

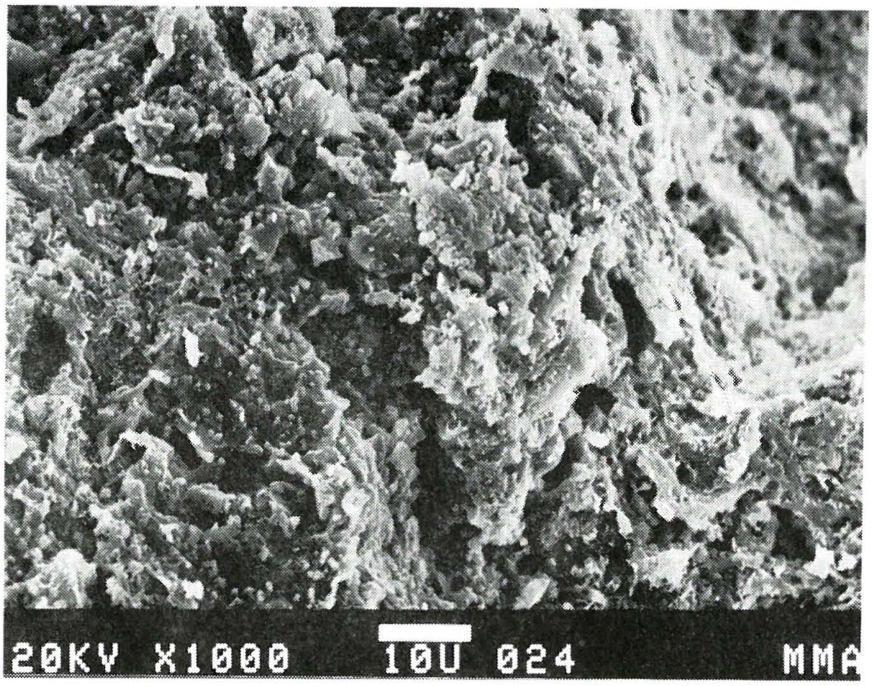

Fig 6 SEM photomicrograph of a fractured surface of a P_3 brick. Notice the poor vitrification of the matrix.

3. EXPERIMENTAL

The salt crystallization test used in this study was developed in our laboratory to reproduce the damage observed on masonry under such climate conditions as found in Milan and in most of the north of Italy. The test consists in repeated cycles of immersion of the whole brick in a saturated salt solution followed by an evaporation period. The rationale behind the choice of the experimental conditions has been discussed elsewhere (10).

Each cycle consists of a 2-hour immersion in a Na_2SO_4 saturated solution and then a 48-hour drying period at 20°C and 50% RH. For the case of the perforated bricks, to avoid undue evaporation through the manufactured holes, the bricks were stacked in a pile, separating each brick by means of a glass plate and the pile covered by a final glass plate with a weight on top to avoid the lifting up of the glass plates by the crystallizing salt. Figure 7 gives a diagram of this setup.

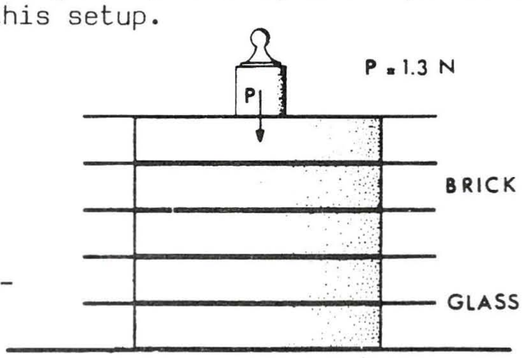

Fig 7 Experimental setup for salt-crystallization test for perforated bricks

4. RESULTS AND DISCUSSION

After the first 3-4 cycles, bricks P_3 showed the beginning of decay by flaking. After 22-24 cycles, major delamination occurred and some of the P_3 bricks began to fall apart.

Bricks P_2 on the other hand, started to flake after 8 cycles, the sanded sides of the bricks being the first to be affected, and the other sides flaking off after one more cycle. Major delamination with significant structural damage occurred after 32-33 cycles. The flakes obtained during the initial deterioration cycles for both these cases were about 1-1.5 mm thick.

Bricks P_1, SF and F formed minute flakes (about 4-5 mm in diameter and less than 1 mm thick) after 4-5 cycles, the location of the flakes usually corresponding to the presence of a dishomogeneity in the brick matrix. After 13-14 cycles, P_1 started forming significantly larger flakes, but still thinner than those obtained with the P_2 and P_3 bricks. The perforated bricks, F and SF, did not present any further progress in the deterioration up to the writing of this report (32 cycles).

The results obtained can be explained as a function of the composition, micro- and macrostructure of the bricks. Bricks P_3 show the smallest resistance to salt crystallization, which can be explained as a function of the very low vitrification of their matrix. Bricks P_2 being better vitrified, nearly doubled the number of cycles of bricks P_3 through which they could pass before deteriorating significantly. On the other hand, the three other bricks, also well vitrified, resisted much longer. This can be explained by the fact that these bricks were extruded, the pore sizes thus obtained being smaller than those obtained by the soft-mud method (11).

It would also appear that major damage to the bricks, which will be referred to as structural damage, such as occurs after 22-24 cycles for P_3 and 32-33 cycles for P_2, does not occur as soon for the perforated bricks, F and SF, which have surpassed 32 cycles without even losing major surface flakes, while P_1 started losing these after 13-14 cycles. The perforated bricks, due to the presence of the manufactured holes, could possibly accommodate a much higher amount of crystallized salt, --it could crystallize in these holes--, thus relieving the mechanical stress inside the pores of the brick matrix.

The experimental testing is still under progress to further establish the influence of the size, shape and coring arrangement for the perforated bricks and to study the final stages of structural deterioration for both solid and perforated bricks.

5. CONCLUSIONS

The results obtained in this study show once again how important firing conditions are to obtain a good quality brick. Not only is the firing temperature important, but the residence time of the brick in the kiln has to be adjusted to the clay mixture and manufacturing technique used, to obtain the most favourable combination of composition/microstructure in the fired brick (11).

Deterioration by flaking and delamination will result from the mechanical stress induced by salt crystallization, regardless of whether the material has a laminated structure or not. In our particular case, it was shown that the extruded bricks, which have a laminated microstructure, as can be seen in Figures 2 to 4, are much more resistant to major flaking than those prepared by the soft-mud method.

Perforated bricks appear to have an increased resistance to major salt deterioration, apparently due to the fact that part of the crystallizing salt can accumulate in the manufactured holes, thus decreasing the total content of salt in the brick matrix.

6. REFERENCES

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