ALTERATION OF THE MECHANICAL PROPERTIES OF MASONRY PRISMS DUE TO AGING.

EFFETTI DELL'INVECCHIAMENTO SULLE PROPRIETA' MECCANICHE DI PRISMI IN MURATURA

L. BINDA *, G. BARONIO *

* Associate Professor, Politecnico di Milano, 20133 Milano, Italy

ABSTRACT Brick and mortar decay due to salt crystallization has been previously investigated by the Authors.
Brick-masonry prisms (25x52x60cm.) built with different types of mortar (lime-pozzolana, lime-cement and fiber reinforced cement with additive) have been submitted to a crystallization procedure set up by the Authors.
The variation of their mechanical characteristics (strength and deformability) has been measured by compression tests carried out on altered and unaltered prisms.
The influence of absorption characteristics of brick and adhesion of mortar has been taken into account. Bond strength tests and measurement of dimensional variation of brick and mortar have been accomplished.

Gli autori, dopo aver esaminato separatamente sia sui mattoni che sulle malte l'alterazione determinata dalla cristallizzazione salina, hanno sottoposto a tale trattamento alcuni muretti in laterizio aventi dimensioni 25x52x60 cm , confezionati con diversi tipi di legante: calce e pozzolana, calce e cemento, cemento additivato con emulsione di resine acriliche.
La variazione delle proprietà meccaniche (resistenza e deformabilità) è stata misurata mediante prove di compressione su prismi alterati e non alterati.
E' stata presa in considerazione l'influenza delle caratteristiche di assorbimento dei mattoni e delle malte mediante prove di aderenza e misura delle variazioni dimensionali dei materiali in ambiente umido..

1. INTRODUCTION

The efflorescence phenomenon is prevalent in coastal regions due to the ubiquity of sodium chloride. In other regions calcium, sodium and/or magnesium sulfate can be present in the soil or generated by chemical attacks due to athmospheric pollution.
It is well known that salt crystallization may produce mechanical disruption of the materials , as well as damage the aestetics of buildings.
Alteration phenomena are particularly evident in ancient monuments which need restoration works.

In recent papers (1,2)the Authors have studied the behaviour of bricks and

mortars in salt crystallization. A test adapted to the case of northern Italy weather conditions had been set up (3).
The durability of bricks and mortars have a high influence on masonry resistance to aggressive agents. Besides workmanship, and adhesion between brick and mortar , are factors affecting the water penetration and therefore are to be taken into account (4,5,6).

The aim of this work is to point out the importance of the choice of mortar in brick-masonry, in order to increase the durability of buildings.
Masonry prisms (wallettes) have been manufactured with a single type of brick and three different mortars, then they have been subjected to the crystallization test. The variation of their mechanical properties (strength and deformability) has been measured by compression tests. Treated and untreated prisms have been compared.

2. MATERIAL PROPERTIES.

Manufactured face-bricks , made of a very moist clay, have been used. They have been extruded, then cut in suitable dimensions (25x12x5.5 cm) and thrown by hand in a mould previously sanded. Subsequently they were dried in drying sheds for 48 hours. The drying air temperature varied from 110°C at the entrance of bricks in the sheds to 45°C at the exit. The moisture content of the clay dropped from 31÷32% to 4÷5%. Bricks were then fired in a Hoffman kiln for 48÷60 hours at 900°C. The kiln used methane as combustible gas.
α-quartz, plagioclase, hematite (minor component) represented the mineralogical composition of the bricks. Their microstructure was studied scanning electron microscopy in fractured surface (Fig.1). The bricks had a highly

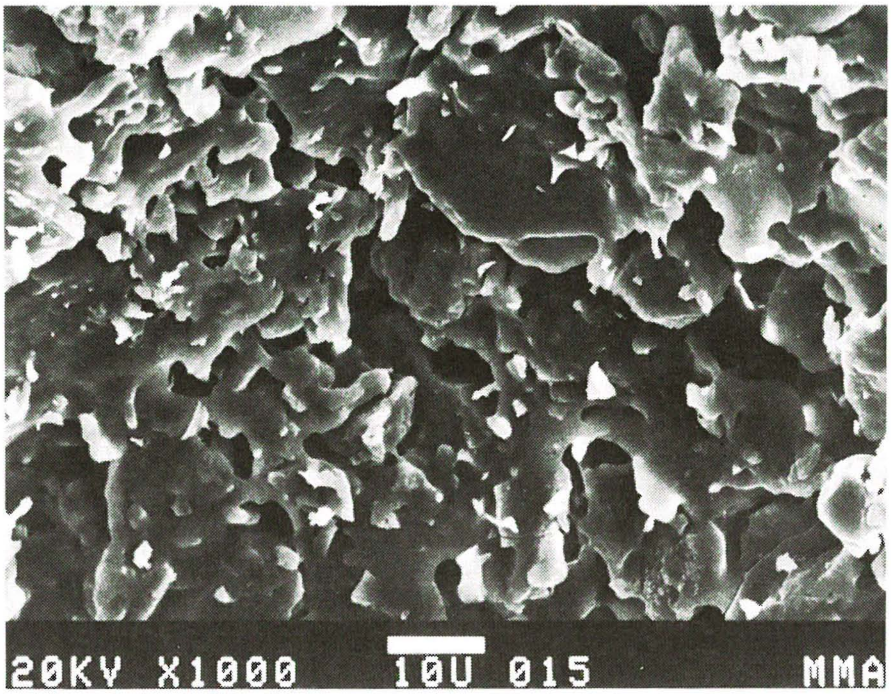

Fig 1 SEM photomicrograph of a fractured surface of brick. Notice the highly vitrified matrix and the large size of pores.

vitrified matrix in which large pores was clearly evident.
Water absorption characteristics are reported in Table II (ASTM standard C67(7).
The stress-strain relationships of bricks are plotted in Figure 2, where the anisotropic behaviour of the material is clear. Owing to the manufacturing process, the mechanical and physical properties of a brick vary from the outer to the inner part. In Figure 3 are plotted the changes of the elastic modulus for different loads in specimens taken from the same brick.

Three types of mortars of various strength and deformability were used in order to study their influence on the behaviour of masonry prisms. The mix proportions as well as the compressive and flexural strength are given in Table I.

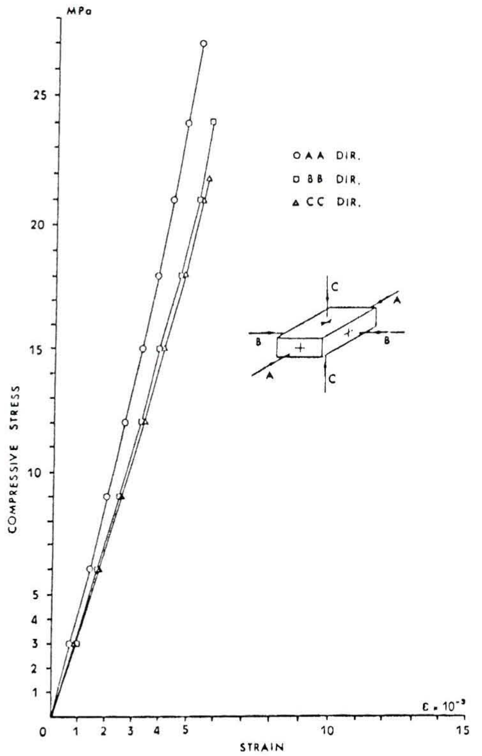

Fig 2 Stress-strain curves of bricks

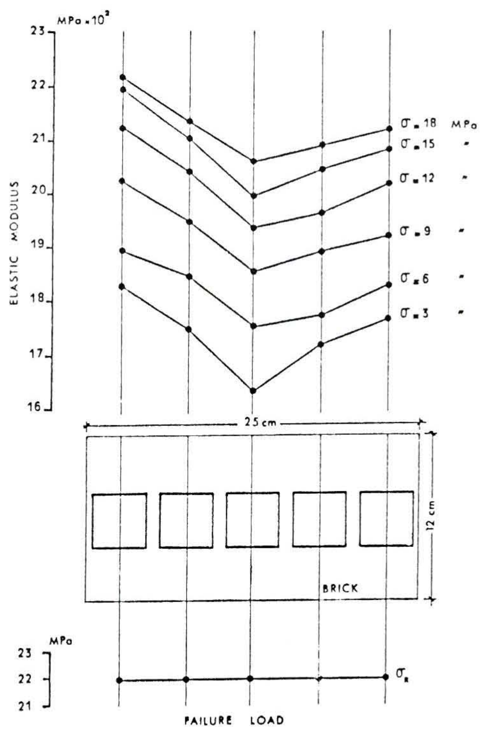

Fig 3 Elastic modulus and failure load in different positions

Properties were measured on 20 specimens of 4x4x16 cm for each mortar manufactured and cured following ASTM standard C348-349 (7).
Some physical properties of mortars are described in Table II.
In Figure 4 are plotted the stress-strain relationships due to compression test of the three different mortars, as mean values of 20 specimens. In the same figure the behaviour of bricks, in direction normal to bed face, is represented as mean value of a sample of 50 specimens.

Eight masonry prisms (25x52x60 cm) were prepared for each type of mortar. The joints were 1 cm thick. Prisms were manufactured by a mason (to get the same conditions as actual walls) at 20°C and 50% R.H. They were cured at 20°C and

TABLE I Mix proportions, compressive and flexural strength of mortars

Mortar	mix proportions by volume pozzolana (or cement)-lime-sand	water/ binder	compressive strength MPa	flexural strength MPa
M1 pozzolana-lime	1 : 4 : 9.28	0.54	0.7	3.0
M2 cement-lime	1 : 3 : 5	0.50	3.9	12.7
M3 high strength cement and emuls. of acrylic resins	1 : 0 : 1.5	0.42	16.0	95.4

TABLE II Physical properties of bricks and mortars

Material	bulk density (Kg/m^3)	% Absorption cold water 24h	I.R.A. initial rate of absorption ($Kg/m^2 min$)	capillary rise coefficient ($Kg/m^2 s^{0.5}$)
Brick	1730	13.2	3.32	0.38
M1	1752	15.24	1.79	0.20
M2	1842	12.59	0.71	0.18
M3	1902	2.27	0.04	0.0015

95% R.H. for a minimum of 90, 60 and 28 days respectively for the lime-pozzolana (MU1), lime-cement (MU2) and fiber reinforced cement (MU3) mortar.
MU1 wallettes could simulate the behaviour of an old brickmasonry usually built with lime or lime-pozzolana mortar; MU3 were manufactured with a high strength mortar in order to study the influence of its rigidity on the durability of masonry.

3. EXPERIMENTAL STUDIES

The crystallization test used in this work was carried out to reproduce in laboratory the damage on masonry caused by thermodynamic conditions of weather in the north of Italy. The test, described elsewhere (3), consists in repeated cycles of immersion of a specimen for a time t_1 in a saturated solution of sodium sulfate, followed by an evaporation for a time t_2 under controlled

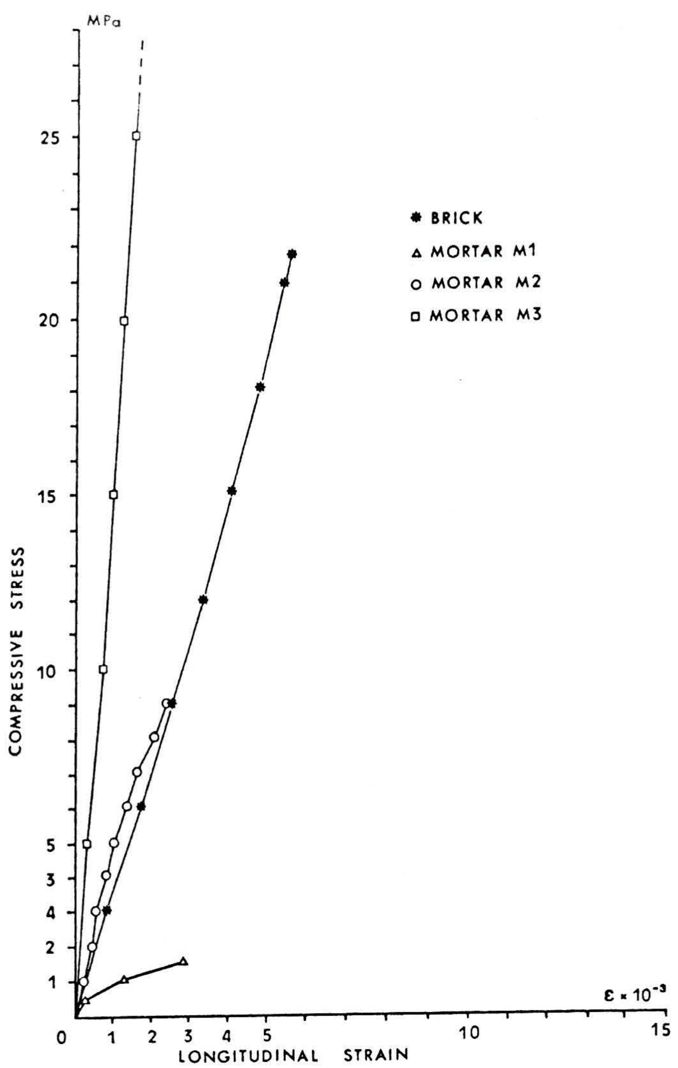

Fig 4 Stress-strain diagrams of brick and mortars

thermodynamical conditions.

Specimens of bricks and mortars (4x4x16), together with masonry prisms (25x52x60 cm), have been subjected to the above mentioned test. Only t_1 and t_2 values were changed because of the influence of different dimensions of specimens on absorption and evaporation time. The behaviour of the material will be described in the following section.
Masonry prisms have undergone tests of crystallization and compression. The results of their mechanical behaviour have been compared to the ones obtained on untreated specimens of the same type and dimensions. Some of the mechanical tests were achieved on a compression machine at a constant rate of loading (1.5 N/mm^2.min.). In order to follow the behaviour of the masonry during failure loading, some tests were carried out on a hydraulic servo-controlled machine MTS (Material Testing System) at a costant rate of displacement.
In both cases the spherical swivel of the machine was blocked after contact with the press rigid platens and the bearing parallel surfaces of the test piece (8). Displacements of the load bearing platens of the testing machine have been registered; measurement bases,to measure vertical and horizontal displacements, were put in place on the test piece.

4. RESULTS AND DISCUSSION

Masonry materials were at first submitted to crystallization test. Because of the small dimension of specimens, the cyles were arranged in the following way:
- 2h immersion in a saturated solution of sodium sulfate;
-46h drying at 20°C and 50% R.H.

Soon after the first cycle M1 mortar (lime-pozzolana) showed some spalling. The test was stopped at the second cycle, after 96h; the mortar had reached a total destruction (Figure 5). These mortars had the highest porosity (Table II).
M2 mortar started to crack after 5 cycles and almost splitted in the middle after 6 cycles, with some additional laminations on the top of the specimens. The test was stopped after a total time of 288h. In Figure 6 the failure mechanism of mortars is shown.

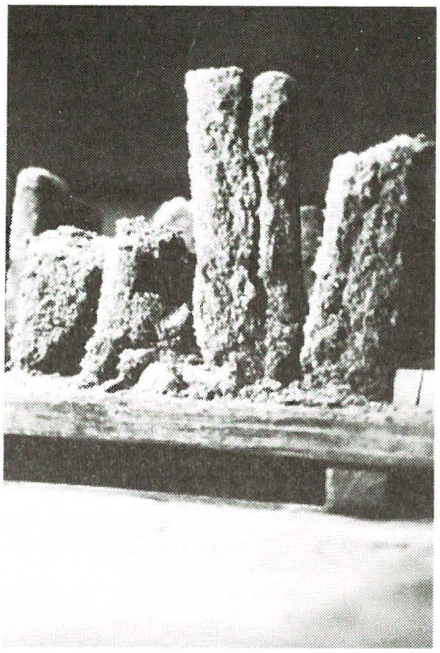

Fig 5 Alteration of lime-pozzolana mortar M1

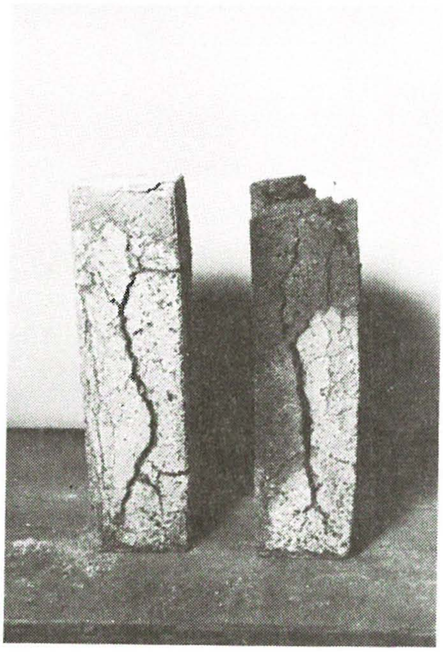

Fig 6 Alteration of lime-cement mortar M2

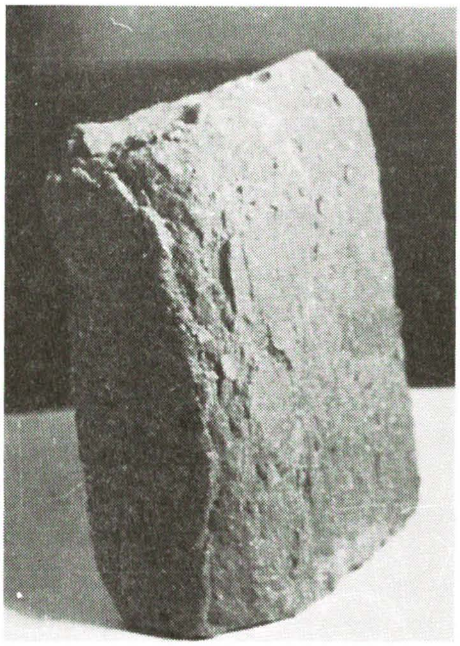

Fig 7 Alteration of bricks after 30 cycles.

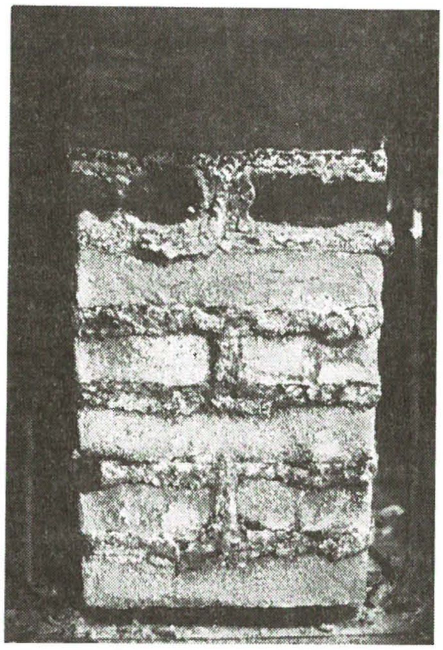

Fig 8 Major efflorescence on mortar joints of MU1 prisms.

Bricks started to flake after about 8 cycles and their sanded sides were the first to be affected (Fig.7). After 32-33 cycles (1584h) they underwent greater delamination with meaningful structural damage.

MU1 prisms were subjected, after three months of curing, to 7 cycles (1176h). Efflorescences appeared soon after immersion mainly on mortar joints (Fig.8). At the third cycle alteration of joints was already evident. During every cycle at the second day of exposure some pieces of mortar started spalling: they were 1÷2 cm thick. Meanwhile bricks remained unaltered almost up to the last cycle. The test had to be stopped because of the extreme degradation of mortar joints (Fig.9). As for masonry materials, the behaviour of MU1 units can be explained by the high porosity of mortars; in fact water evaporation took place with preference through mortar joints.

The stress-strain diagrams of Figure 10 show the behaviour of some treated and untreated units subjected to compression tests at a constant rate of loading. The strains given therein are those obtained by measurement of the displacement of the bearing platens of the testing machine. The great deformability of the altered masonry for low values of stress is due to the squeezing of cracked and powdered mortar out of the joints.

Starting from about 3 MPa, material locking is evident up to failure load, which has a value only 10÷15% less than the one of untreated masonry prisms.

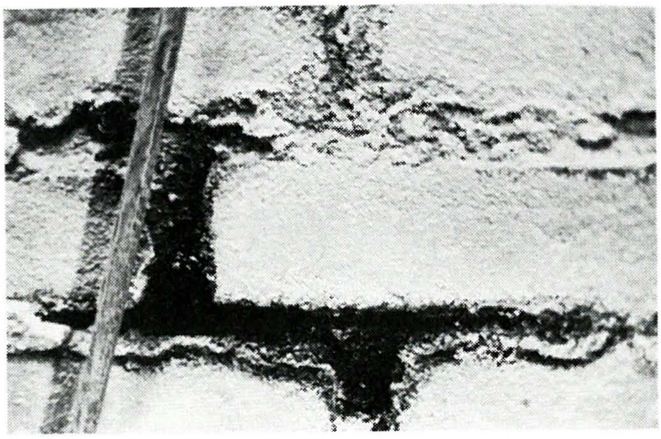

Fig 9 Deterioration of mortar joints of MU1 prisms.

The crystallization test of MU2 wallettes was carried out after 60 days of curing. At first efflorescences appeared on mortar joints, then they became more and more manifest on brick surface. At the 4th cycle bricks started to flake, while mortar remained apparently unaltered. A slight degradation of mortar joints began at the 7th cycle, while delamination of bricks went on. The flakes were about 1.5÷2 mm thick. At the 15th cycle a remarkable alteration appeared on the external surface of bricks. The loss of section area was about 10% , which is a particularly hight rate for the lowest and highest immersed courses.

The test was stopped for two prisms and went on for the remaining two up to 21 cycles, when the loss of section area was about 25% less than the original one.

Compression tests at a constant rate of loading were carried out on untreated prisms and on prisms tested for 15 cycles; the stress-strain curves are plotted in Figure 11. Treated units show at first greater deformability, then a

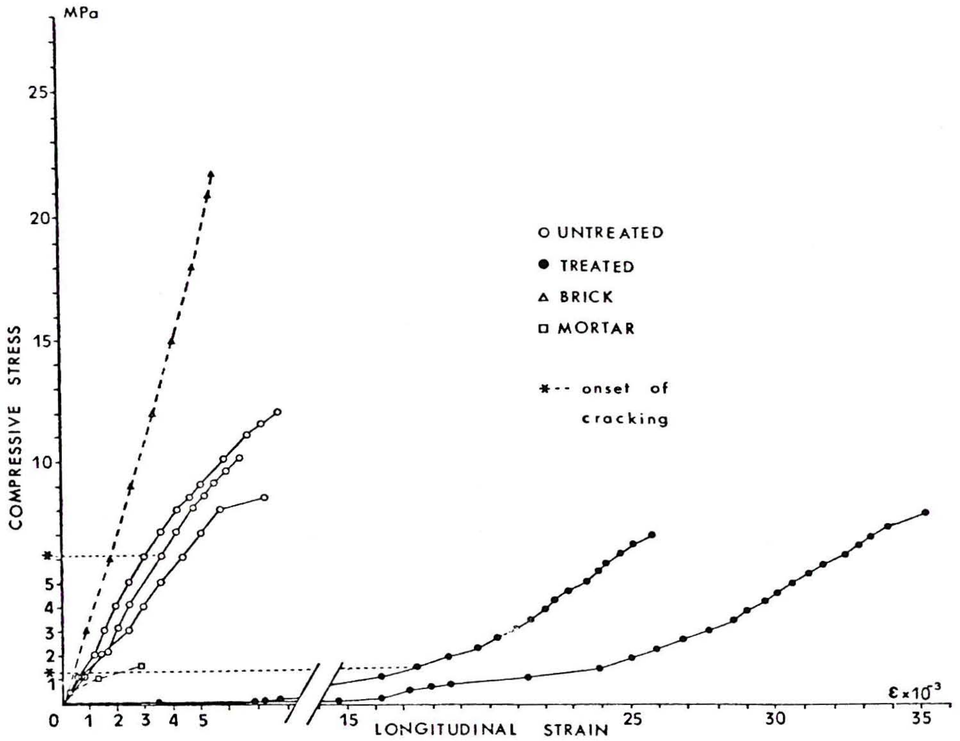

Fig 10 Stress-strain curves for MU1 prisms

slight locking, finally an increase in strength of 3.3%.

MU3 prisms underwent the crystallization test after 28 days of curing. Because of the very low absorption of mortar the saturated solution of Na_2SO_4 penetrated into the bricks only through their lateral surfaces.
Brick delamination started also in this third case at the 4th cycle, and went on, while mortar remained completely unaltered. The test was stopped at the 9th cycle when alteration of the first and last immersed course was evident with a loss of 10% of the cross section of the original area.
This time efflorescences appeared only on external surface of bricks and were more evident near horizontal mortar joints. In corrispondence with this phenomenon it was possible to notice the lack of bond probably caused by high brick IRA as well as by mortar shrinkage.
The crystallization test is still going on in some MU3 prisms.
The stress-strain diagrams of treated and untreated units are given in Fig.12. A slight increase in strength , but smaller longitudinal strains can be noticed for treated prisms.

In order to observe their post failure behaviour, six MU2 specimens were tested under a constant strain rate of 1.73×10^{-3} mm/m.s.Of the six specimens, two were untreated, two had previously undergone 9 cycles of the crystallization test and the remaining two 21 cycles.
The results are plotted in Figure 13. Their behaviour is similar to that of Figure 10; all the prisms show a brittle type of failure. In comparison with untreated units, the ones subjected to nine cycles give smaller deformation and an increase in strength; on the contrary the ones submitted to 21

cycles show greater ductility but lower strength (17.5%).

Other compression tests under constant strain rate were carried out on some MU3 prisms. Treated masonry were subjected to 9 cycles of crystallization test. Here again the salt absorbed by masonry caused an improvement in brittleness, as it can be seen from Figure 14.
Some crystallization tests are still going on for MU3 prisms, to further establish the influence of greater alteration on their mechanical behaviour.

6. CONCLUSIONS

The selection of a proper brick with its fittest mortar is of great importance. Useful information on this matter was also supplied by the mechanical

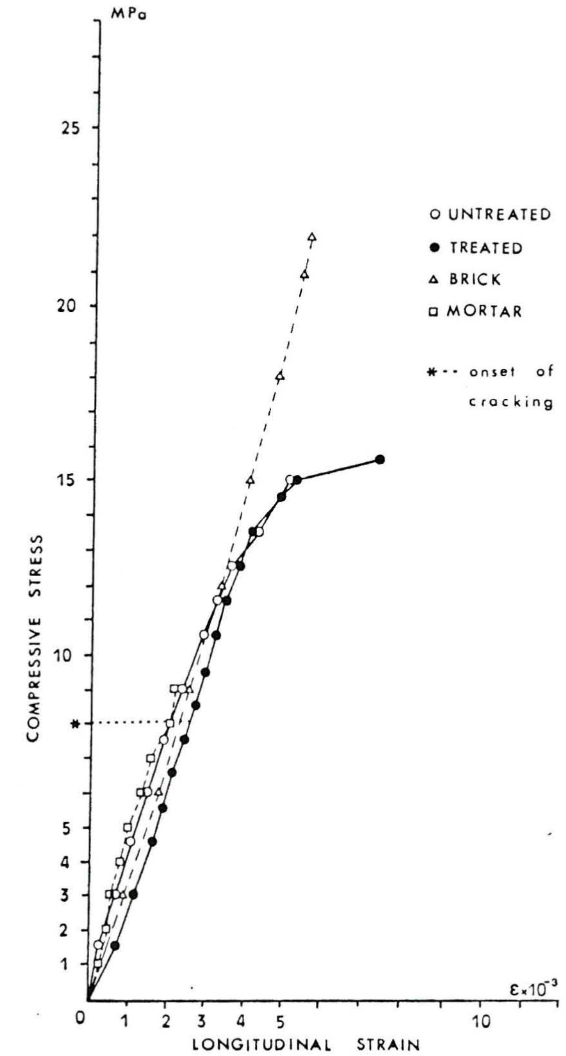

Fig 11 Stress-strain curves for MU2 prisms

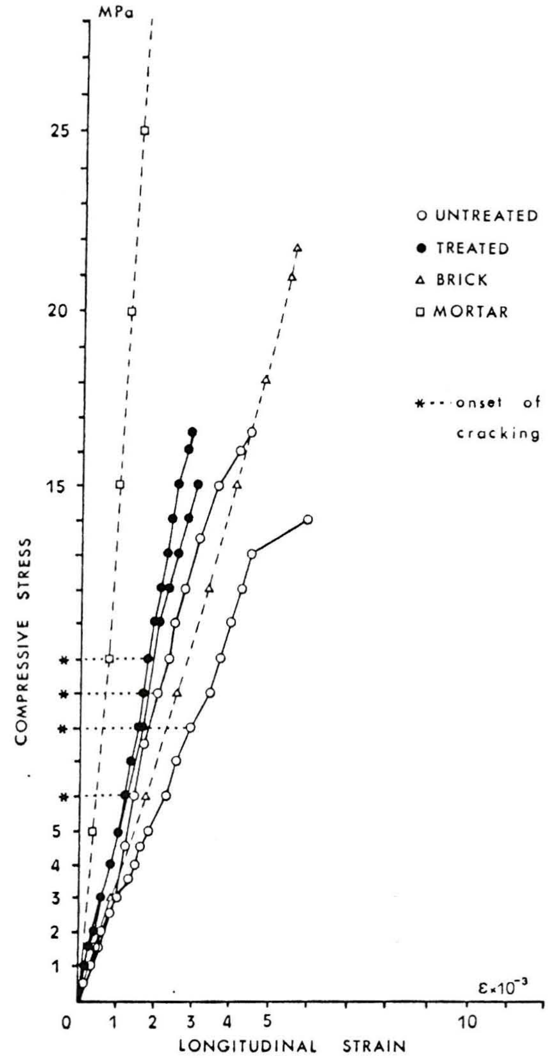

Fig 12 Stress-strain curves for MU3 prisms

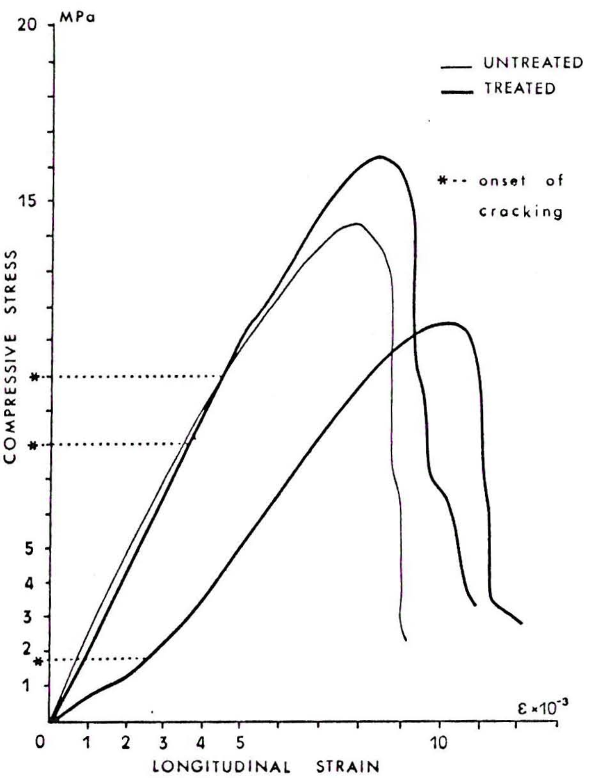

Fig 13 Stress-strain relashionships for MU2 prisms

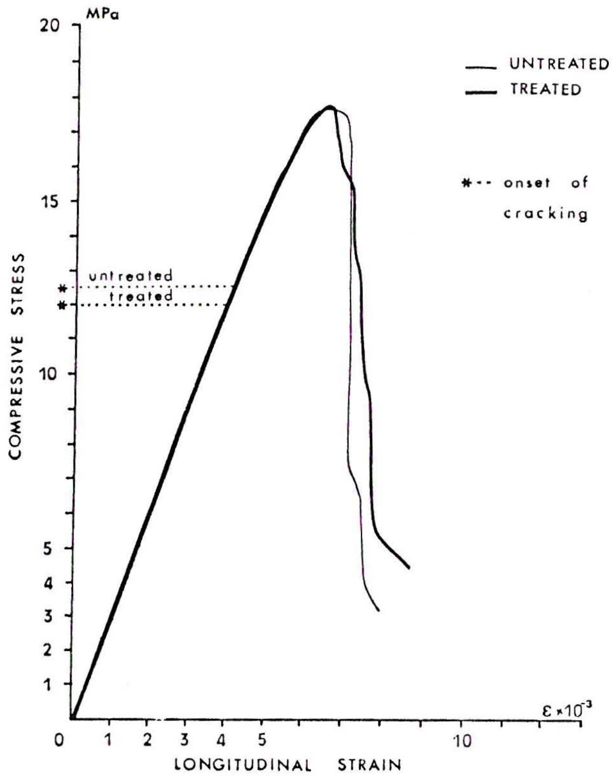

Fig 14 Stress-strain relashionships for MU3 prisms

properties of untreated masonry prisms.
The units made of lime-pozzolana mortar show some ductility and a failure which develops gradually, with a low strength.
The use of fiber-reinforced cement mortar induced an elastic-brittle behaviour with explosive failure and an increase in strenght.

The influence of porosity, undirectly measured through absorption (%) can be explained as follows:

- mortar with high absorption (M1), undergoes alteration while bricks are still intact; the masonry (MU1) fails when subjected to a few cycles of crystallization test;
- highly absorbent bricks, even when joined with high strength and rigid mortars allow water to penetrate into the masonry. It causes a deep alteration in bricks. In fact when IRA (Initial Rate of Absorption) of brick is too high (more than 2 Kg/mm^2m min), it may destroy the intimate contact between mortar and brick because of dilatation of bricks, shrinkage of mortars, etc.. In this way some capillary planes are left at brick line (9) (10). Water penetration is then possible through those planes and alteration of masonry (freeze-thaw, efflorescences, leakage) becomes easier (MU3);
- after a certain number of crystallization cycles, MU2 and MU3 units undergo an increase in strength and become more brittle;
- when phisico-mechanical properties (porosity and deformability) of bricks and mortars are similar there is a kind of gradual and homogeneous alteration on masonry, which presents a more ductile behaviour with gradual failure (MU2

prisms)

Before building a masonry it is necessary to measure the compatibility and durability of materials to get good results.
High-strength, rigid mortars or highly vitrified bricks may not be useful to obtain a masonry resistant to aggressive environment.

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