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Sustainability and Innovation for the Future

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DURABILITY ASSESSMENT OF CONSOLIDATION EFFECT ON SANDSTONE MONUMENTS

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INTRODUCTION

DEGRADATION PATTERNS ON THE SANDSTONE WALLS OF ST. LEONARD'S CHURCH

Five types of stone deterioration patterns
(ICOMOS-ICS glossary):

Crack & deformation

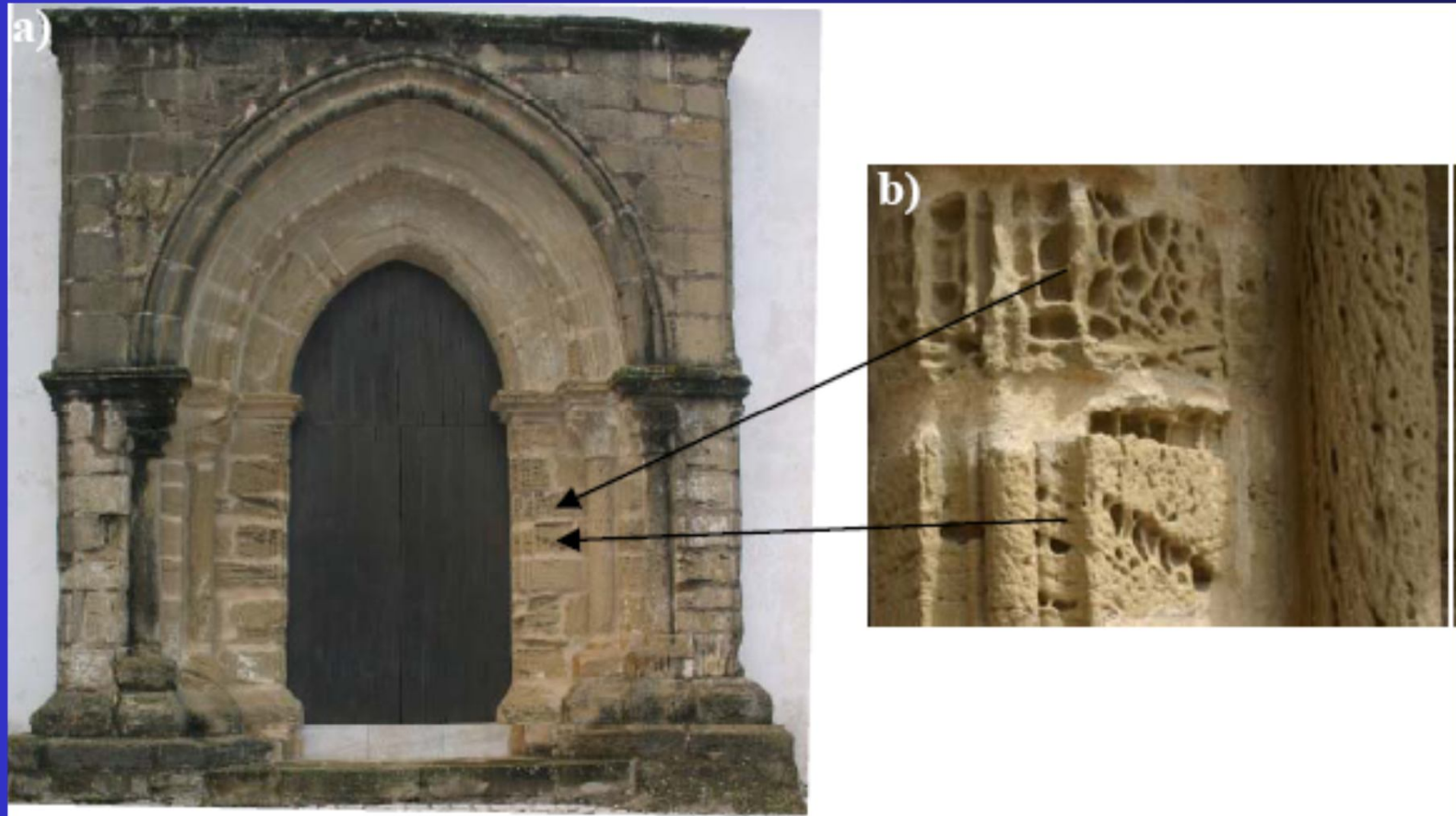
Detachment

Features induced by material loss

Discoloration & deposit

Biological colonization.

INTRODUCTION



St. Leonard's Medieval Church

EXPERIMENTAL PROGRAMME

MINERALOGICAL CHARACTERIZATION

- Four varieties of sandstones (A, B, C, M).
- **Lithic arkose with carbonate cement according to Folk (1974).**
- The varieties C and **M** have around 20-25% carbonates and 40-51% quartz.

PREPARATION OF SPECIMENS

- Samples were extracted from stone masonry walls close to the built heritage.
- **Similarity to the stones in the monuments: appearance, mineralogical composition, texture and structure.**
- Specimen sizes: 5x5x5 [cm] and 5x5x10 [cm]

EXPERIMENTAL PROGRAMME

CONSOLIDATING PRODUCTS

- Treatment of stones were carried out in a laboratory environment and in the monument
- **Evaluation of the viability of two ethyl silicate consolidating products on stones:**
 - Tegovakon V (TG) and Redur 420 (R)**
- Selection criteria: commercial availability and reasonable costs.
- **TG is produced by Goldschmidt in a single component**
(Before application: unit weight of 0.95 ± 0.02 g/cm³ at 25°C
After application: dry residue of 34% after evaporation of solvents at 20°C and 60% of RH).
- R is manufactured by Promasil in a single component
(Before application: unit weight of 0.83 ± 0.02 g/cm³
After application: dry residue of 17% after evaporation of solvents at 20°C and 60% of RH).

EXPERIMENTAL PROGRAMME

CONSOLIDATION PROCEDURES

- . 5 cm-long cubic samples.
- . Applications step by step by immersion and capillarity over all stone mass (Ludovico-Marques, 2008).
- . The amounts of absorbed products were around 5% of mass content in variety M.
- . Drying at room temperature and RH of Laboratory (Civil Engineering Department of FCT-UNL).
- . A dry residue of about 40% of TG and 25% of R after evaporation of solvents during 8 weeks.
- . Capillarity procedure was followed on samples used to carry out drying tests. Capillarity height reached 2.5 cm and the amounts of absorbed products were around 3% of mass content.

EXPERIMENTAL PROGRAMME

PROCEDURES FOR PHYSICAL TESTS

- Porosity and density on sandstone samples following the Recommendations of RILEM (1980) and EN1936 (1999).
- **Four varieties samples exhibit similar values of porosity to the historical building stones, ranging from 3.6% (variety A) to 12.7% (variety C) and 18.5% (variety M).**
- Pore size distribution of sandstone varieties M was obtained by mercury intrusion porosimetry. Microporosity settled as the percentage of pores radii lower than 7,5 μm (Pellerin, 1980), is 75-81% in variety M.
- **Drying tests were carried out on top face of sandstone cubic samples of variety M before and after treatments, following the Recommendations of NORMAL 29/88 (1991) and RILEM (1980) at laboratory environment of 20 ± 2 ° C and $55 \pm 10\%$ of RH.**
- RILEM (1980) water absorption under low pressure test procedure was carried out on prismatic and cubic sandstone samples. After consolidation treatments was only applied on cubic samples.

EXPERIMENTAL PROGRAMME

PROCEDURES FOR MECHANICAL TESTS

The uniaxial compression tests on the sandstones used a Seidner servo-controlled press, model 3000D:

- Load capacity up to 3000kN and a piston stroke of 50 mm.
- Tests carried out under axial displacement control at a rate of 10 mm/s on cubic specimens of variety M.

EXPERIMENTAL PROGRAMME

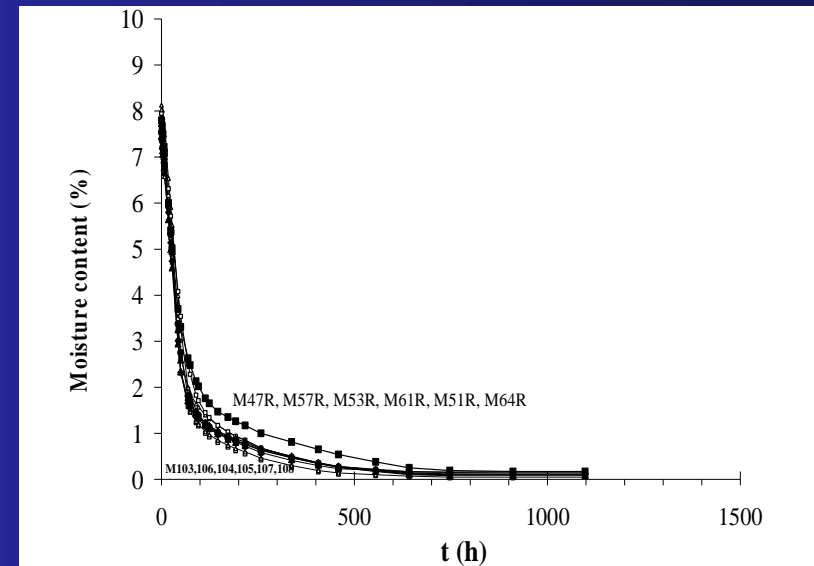
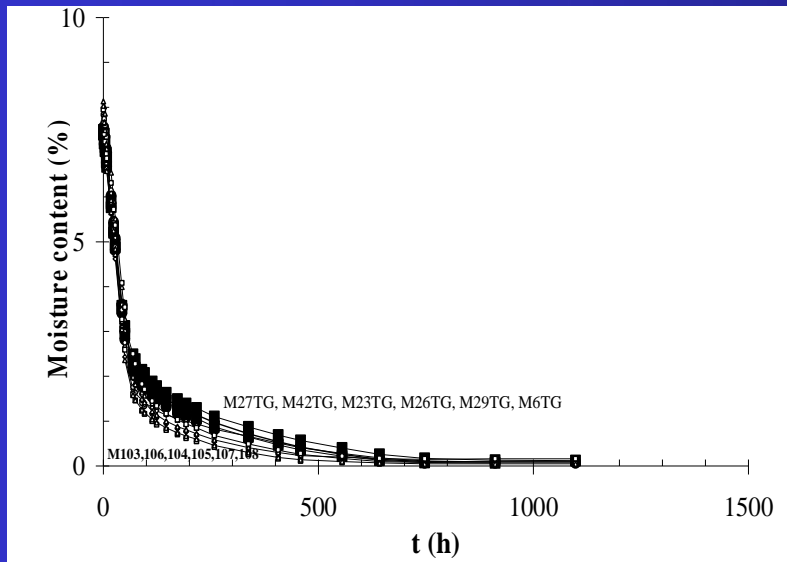
PROCEDURES FOR DURABILITY TESTS

- Crystallization tests by total immersion were carried out following RILEM V.1a, b, V.2 (1980) [6] and EN 12370 [10], replacing sodium sulphate solutions by sodium chloride solutions.
- Salt crystallization-dissolution ageing tests were carried out in an automatic ageing chamber prototype.



ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (DI)



ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (DI)

Variety	Drying Index Average \pm SD (CV %)
M	0.10 \pm 0.01 (9.80)

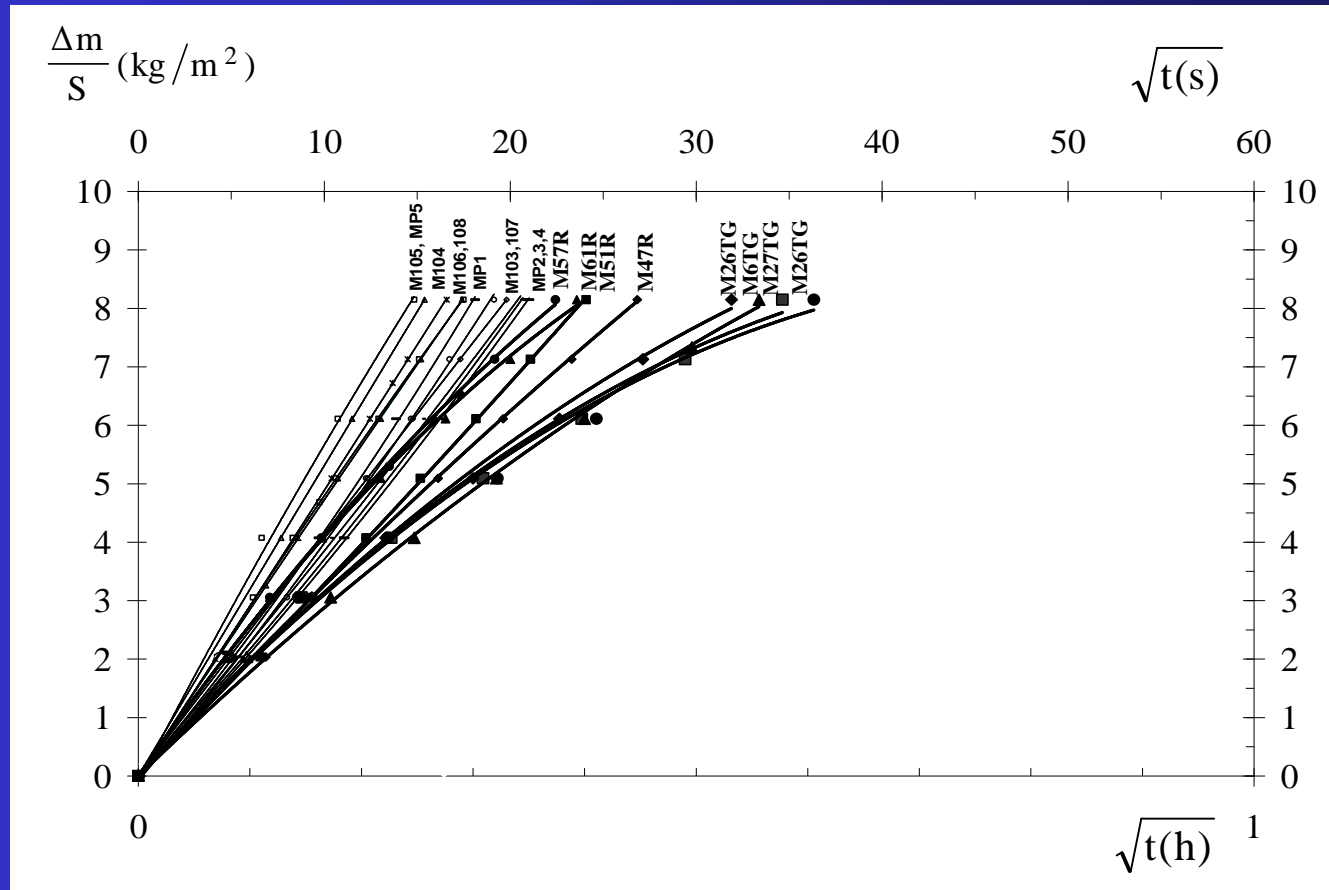
Consolidating product	Drying Index Average \pm SD (CV %)
TG	0.12 \pm 0.01 (8.33)
R	0.11 \pm 0.01 (9.09)

Minor increase

20% on TG

10% on R

ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME PHYSICAL BEHAVIOUR (k)



ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (k)

Consolidants	Water absorption coefficient, k (kg/m ² /√h) Average ± SD (CV %)
NT	24.0 ± 1.6 (6.8)
TG	12.6 ± 1.0 (8.2)
R	20.9 ± 1.9 (8.8)

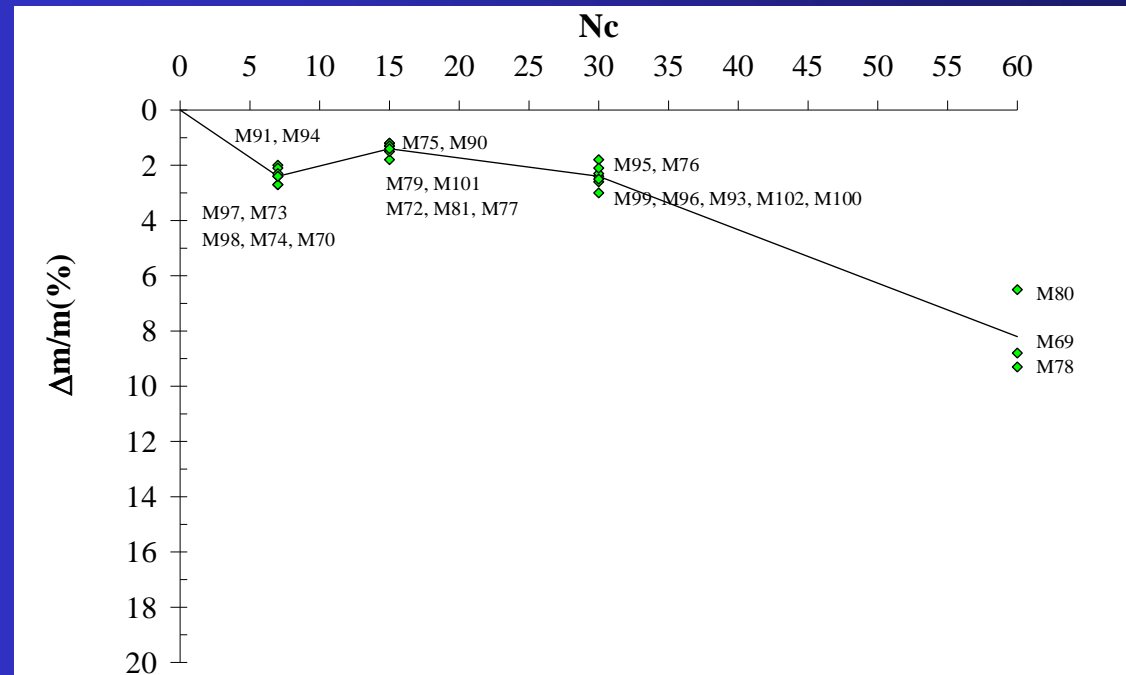
Significant decrease

48% on TG

13% on R

ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

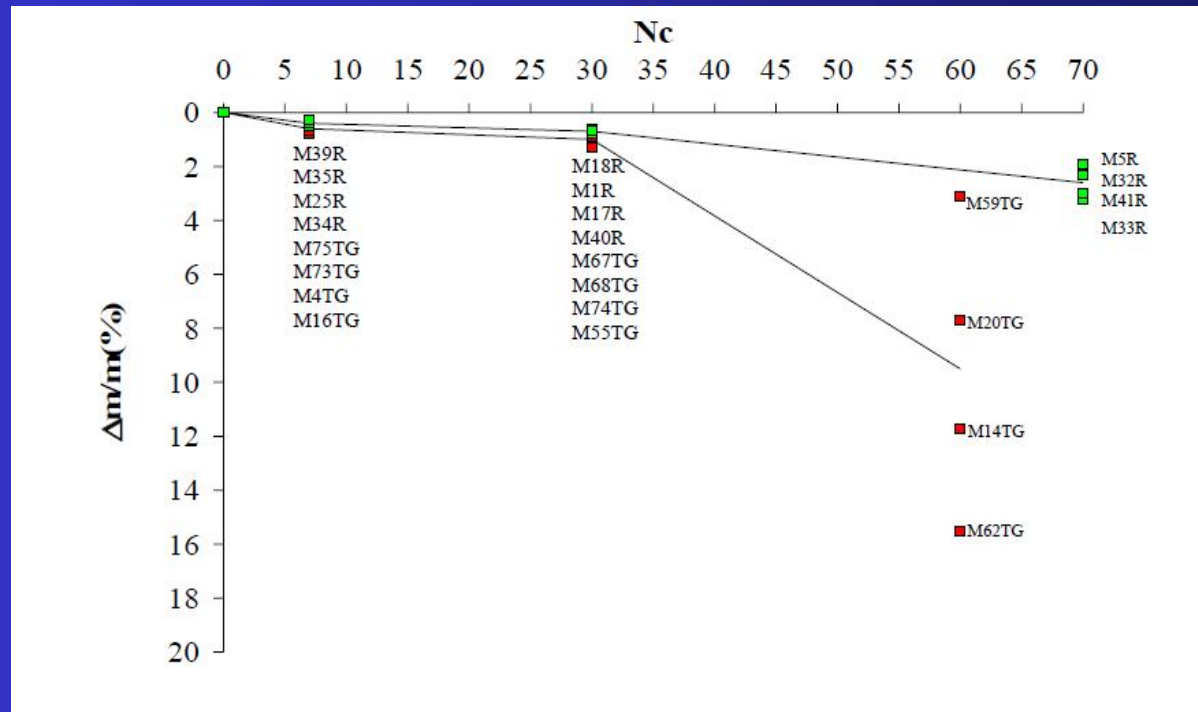
DURABILITY ASSESSMENT BY SALT CRYSTALLIZATION DISSOLUTION ARTIFICIAL AGEING TESTS



After 60 salt cycles the average mass loss of sandstone samples is about 8%

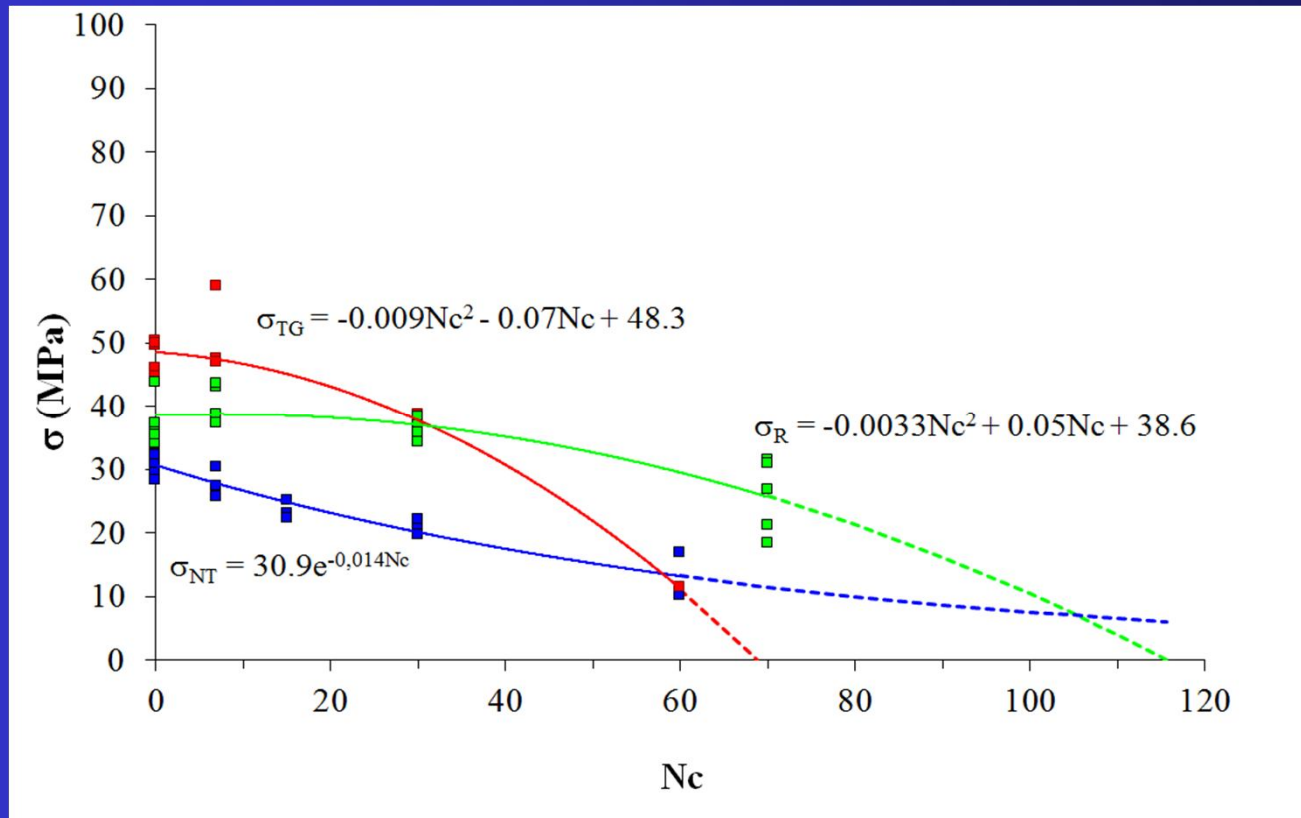
ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

DURABILITY ASSESSMENT BY SALT CRYSTALLIZATION DISSOLUTION ARTIFICIAL AGEING TESTS



After 30 salt cycles reduction of 50%
 After 60 salt cycles reduction higher on TG than NT
 After 70 salt cycles reduction on R less than NT

ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME DURABILITY ASSESSMENT BY SALT CRYSTALLIZATION DISSOLUTION ARTIFICIAL AGEING TESTS



Clear increment of about 26% on TG and 10% on R treatments before salt artificial ageing tests

ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

DURABILITY ASSESSMENT BY SALT CRYSTALLIZATION DISSOLUTION ARTIFICIAL AGEING TESTS

- NT decreased about 56% during 60 cycles
- TG treated specimens have an average reduction of circa 75%
- R treated have a minor reduction of about 18% to the initial values of non treated specimens at 70th cycle
- Compressive strength data of NT specimens extrapolated for more than 100 cycles decreased to about 30% of the initial values.
- At 115th cycle the compressive strength should be less than 30% of its value before salt ageing, being higher than its value on R treated specimens that is null.

CONCLUSIONS

- On sandstone specimens were applied two ethyl silicates (TG and R).
- Minor harmful characteristics of the R applications on M variety of sandstones and a better consolidation effect of TG.
- Salt crystallization artificial ageing tests highlighted good durability of R applications and a worst behavior of TG treatments.

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THANK YOU