CEES 2021 INTERNATIONAL CONFERENCE
CONSTRUCTION, ENERGY, ENVIRONMENT & SUSTAINBILITY
GT1 – Session 1 - Construction Materials and Technologies

CEES 2020

12 – 15 OCTOBER 2021
COIMBRA | PORTUGAL

INTERNATIONAL CONFERENCE
CONSTRUCTION, ENERGY
ENVIRONMENT & SUSTAINABILITY

MONITORING DEGRADATION PATTERNS OF SANDSTONE MONUMENTS AFTER CONSOLIDATION TREATMENTS

Marco Ludovico-Marques

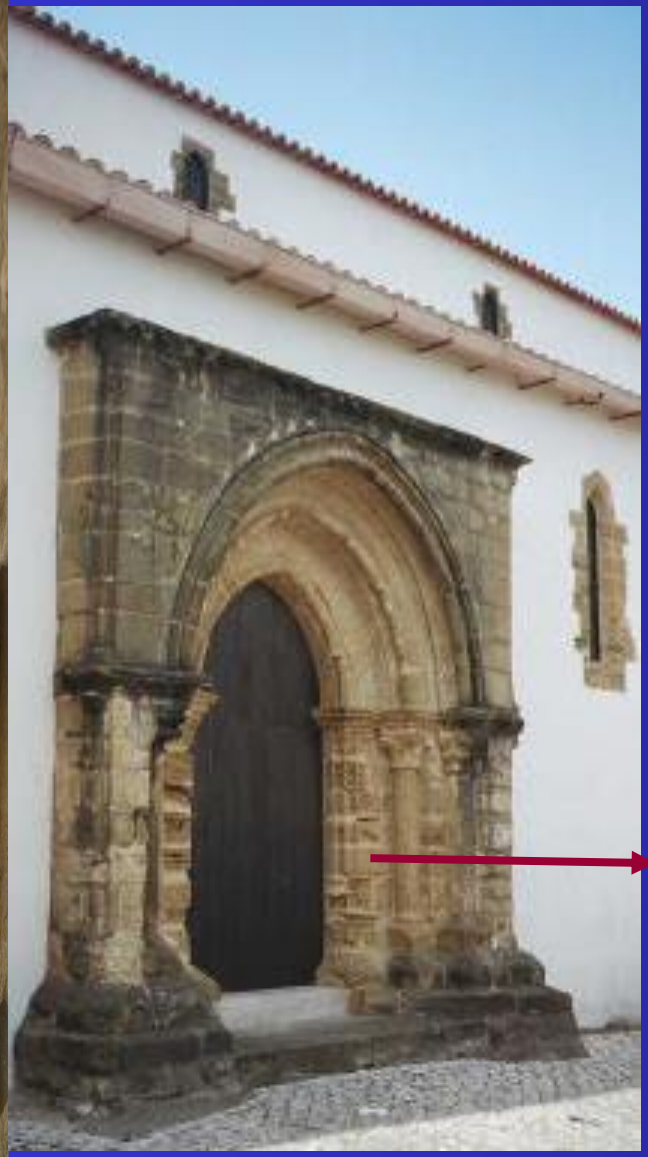
INCITE/IPS/ESTB

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

INTRODUCTION

- A major role is played by scientific conservation in a sustainable cultural heritage preservation.
- Environmental value of suitable conservation actions.
- Contribution to the creation of a sustainable habitat.

INTRODUCTION



St. Leonard's Medieval Church

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

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

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

- **Crack & deformation**
- **Detachment**
- **Features induced by material loss**
- **Discoloration & deposit and biological colonization.**

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

STONE DEGRADATION PATTERNS ON BUILT HERITAGE OF ATOUGUIA DA BALEIA VILLAGE

- **Sandstones use is common in traditional buildings in west region of Portugal, (Peniche and Lourinhã).**
- **Deterioration due to material loss (honeycomb weathering) is the worst pattern of stone degradation on St. Leonard's church, due to sea vicinity.**
- **Discoloration & deposits features such as efflorescences, are not visible in monuments facades. However chlorides predominate over sulphates as found in dissolution waters of tiny sandstones samples.**
- **Detachment of scales visible in the vaults of St. Leonard's church façades.**
- **The biological colonization has been found in superficial extent. Black fungi were located close to the zones exposed to water movement and lichens were visible on north and south façades linked to blistering and detachment forms of degradation.**

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

- **Four typologies of sandstones** (A, B, C, M).
- **The varieties C and M have about 20-25% carbonates and 40-51% quartz.**

  (Lithic arkose with carbonate cement (Folk, 1974))
- **Similarity to the stones in the monuments (aesthetic, mineralogical composition, texture and structure) was considered in order to collect samples from stone masonry walls near to the built heritage.**
- **5cm-long cubic specimens**
- **Open porosity range: 3.6% (A) - 12.7% (C) and 18.5%(M)**

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

CONSOLIDATING PRODUCTS

. Tegovakon V (TG) and Redur 420 (R)

. Commercially available with reasonable costs.

. TG
Manufacturer: Goldschmidt
Single component
Before application: unit weight of 0.95±0.02 g/cm3 at 25ºC.
After application: dry residue of 34% after evaporation of solvents at 20ºC and 60% of RH.

. R
Manufacturer: Promasil
Single component.
Before application: unit weight of 0.83±0.02 g/cm3.
After application: dry residue of 17% after evaporation of solvents at 20ºC and 60% of RH.

(Treatment of stones were carried out in a laboratory environment and in the monument)

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

CONSOLIDATION PROCEDURES

. Applications by immersion and/or capillarity over all stone mass (Ludovico-Marques, 2008).

. Drying at room temperature and RH of Laboratory.

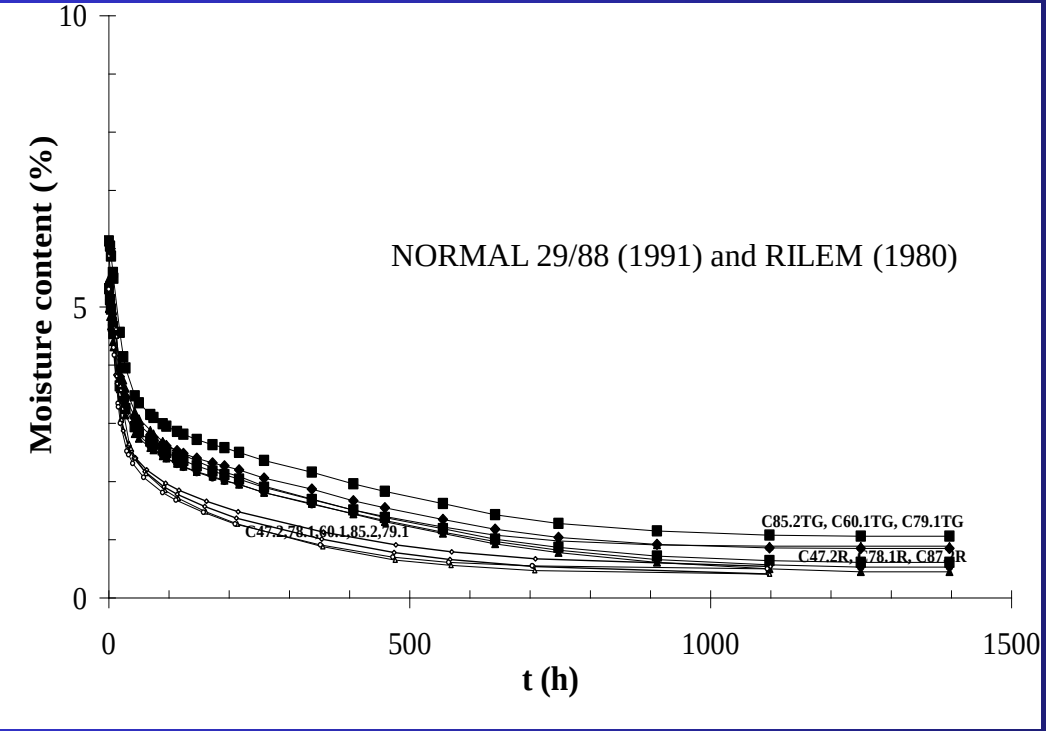
. A dry residue after evaporation of solvents during 8 weeks, of around: 40% of TG and 17-25% of R.

. Karsten pipe method was used to apply R on a sandstone block at right side of south portal below the vault (an absorption of 1.1 kg/m^2 per application).

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (DI)



NORMAL 29/88 (1991) and RILEM (1980)

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (DI)

Variety	Drying Index Average ± SD (CV %)
C	0.17 ± 0.01 (5.88)

Consolidating product	Drying Index Average ± SD (CV %)
TG	0.29 ± 0.01 (3.45)
R	0.25 ± 0.01 (4.00)

Major increase

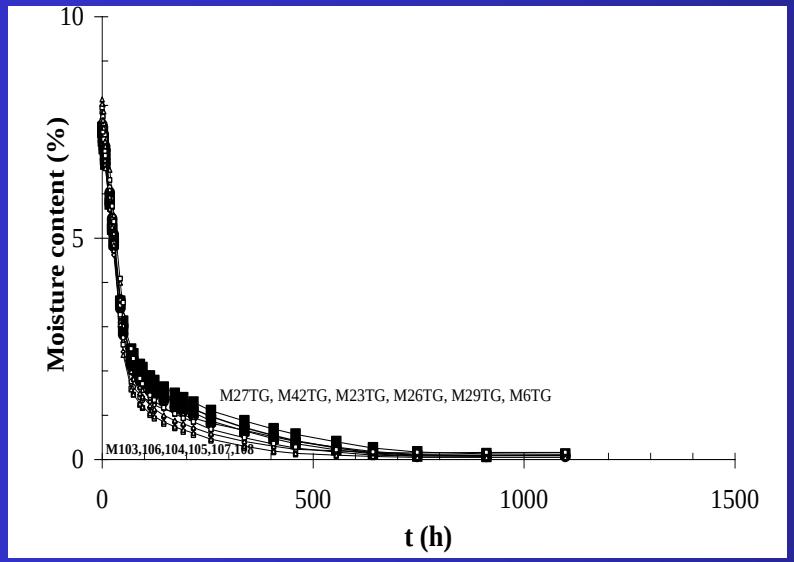
71% on TG

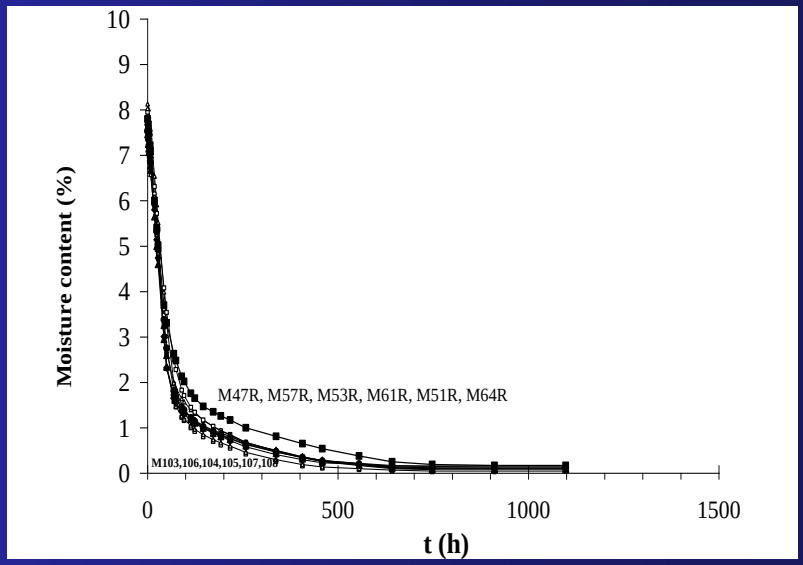
47% on R

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (DI)





NORMAL 29/88 (1991) and RILEM (1980)

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (DI)

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

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

Minor increase

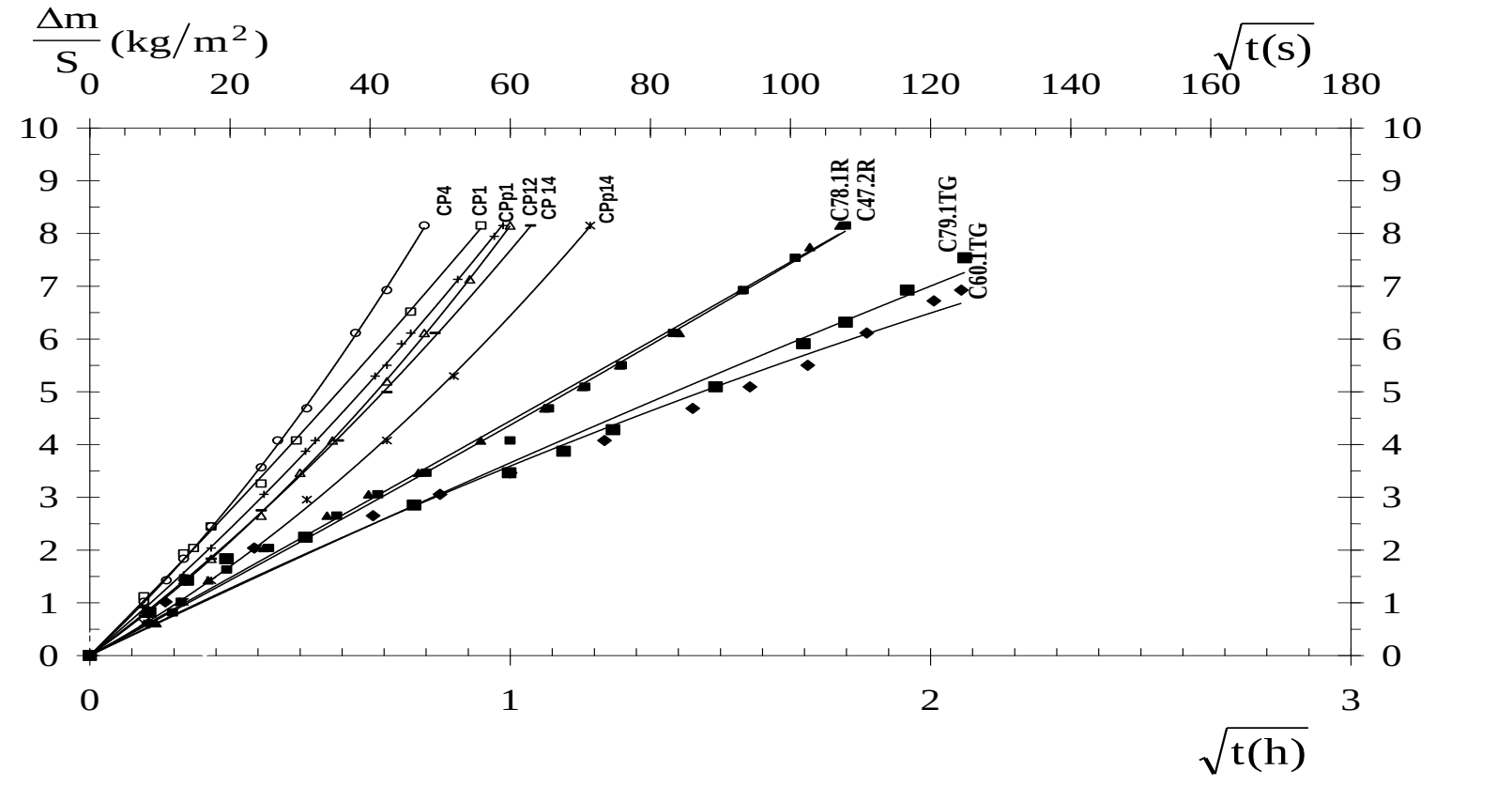
20% on TG

10% on R

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (k)



RILEM (1980)

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (k)

Variety	Water absorption coefficient, k ($kg/m^2/\sqrt{h}$) Average ± SD (CV %)
C	7.9 ± 0.9 (11.4)

Consolidating product	Water absorption coefficient, k ($kg/m^2/\sqrt{h}$)
TG	5.8
R	4.5

Decrease

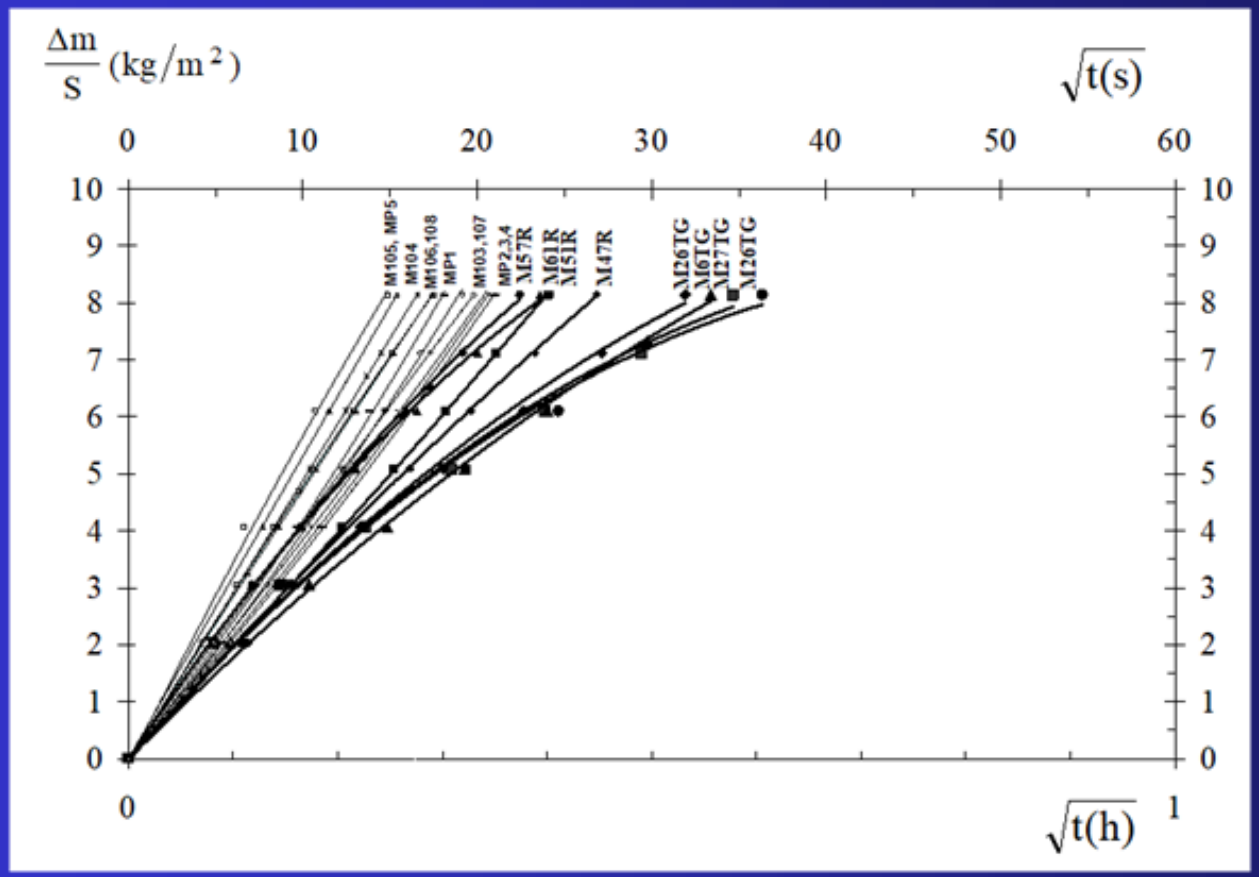
27% on TG

43% on R

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (k)



RILEM (1980)

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (k)

Variety	Water absorption coefficient, k ($kg/m^2/\sqrt{h}$) Average ± SD (CV %)
M	24 ± 0.9 (11.4)

Consolidating product	Water absorption coefficient, k ($kg/m^2/\sqrt{h}$)
TG	12.6± 1.0 (8.2)
R	20.9± 1.8 (8.8)

Decrease

48% on TG

13% on R

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

MECHANICAL BEHAVIOUR (UCS)

Variety	σ_c (MPa) Average ± SD (CV %)
C	57.5 ± 4.9 (8.5)

Consolidating product	σ_c (MPa) Average ± SD (CV %)
TG	72.2 ± 5.5 (7.6)
R	63.2 ± 2.9 (4.6)

Increase

26% on TG

10% on R

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

MECHANICAL BEHAVIOUR (UCS)

Variety	σ_c (MPa) Average ± SD (CV %)
M	57.5 ± 4.9 (8.5)

Consolidating product	σ_c (MPa) Average ± SD (CV %)
TG	48.1 ± 2.3 (4.8)
R	35.9 ± 1.4 (4.0)

Increment

56% on TG

21% on R

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

- **Salt crystallization-dissolution ageing tests were carried out in an automatic ageing chamber prototype (M typology).**

RILEM V.1a, b, V.2 (1980) and EN 12370, replacing sodium sulphate solutions by sodium chloride solutions.

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

- **The variation of mass loss ratio is lower on treated specimens with R than on treated specimens with TG, ranging between a mean value of 3% after 70 salt cycles on R to 3% - 15% after 60 salt cycles on TG. The variation of mass loss ratio is even lower on R than on non-treated specimens (mean value of 8%).**

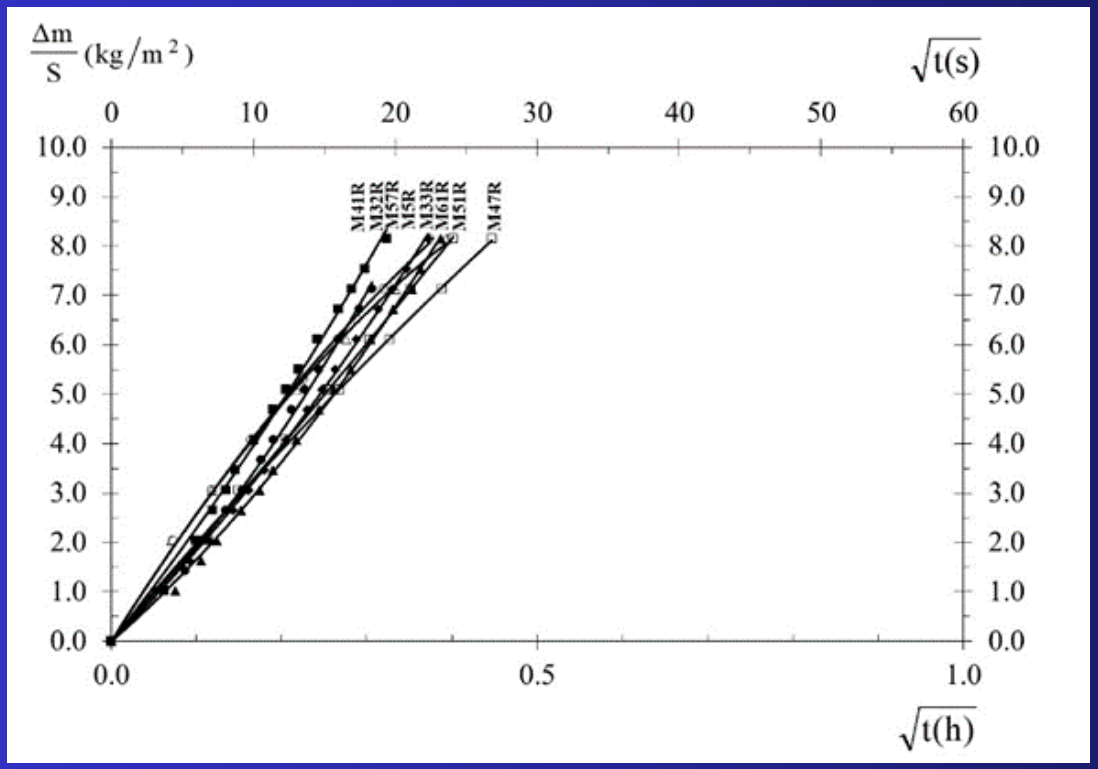
- **TG treated specimens had an average UCS reduction of circa 75% after 60 cycles of accelerated salt crystallization, in comparison with sandstone specimens treated with R that had a minor reduction of about 18% at 70th cycle. Non treated specimens decreased the mean compressive strength values of about 56%.**

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (k)

Salt crystallization-dissolution ageing tests on R (70 cycles)



(RILEM V.1a, b, V.2 (1980) and EN 12370)

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

PHYSICAL BEHAVIOUR (k) ON R AFTER 70 CYCLES OF SALT AGEING

Typology M

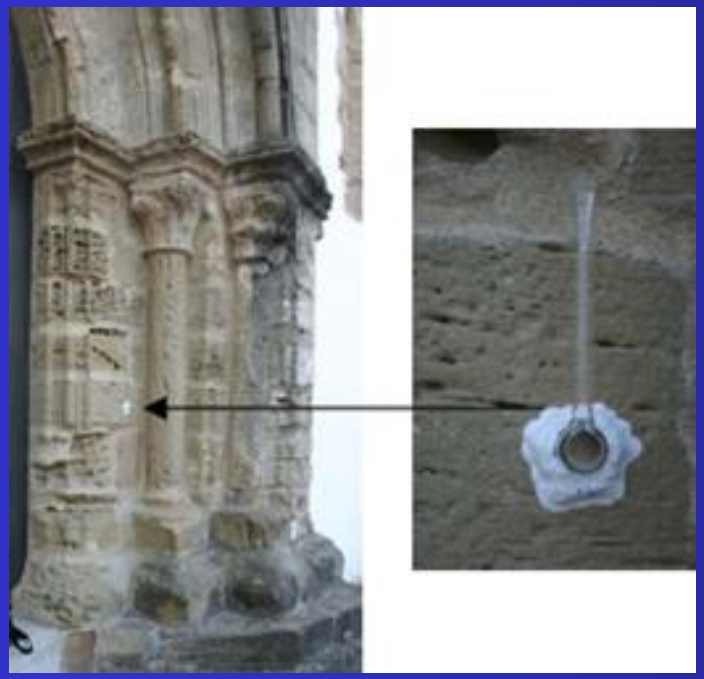
Consolidating product	Water absorption coefficient, k ($kg/m^2/\sqrt{h}$)
R	22.0± 2.1 (2.7)

Increment of mean value of k about 5%

EXPERIMENTAL RESULTS

- Better performance of R in comparison to TG treatments assessed by means of durability and harmfulness tests (Ludovico-Marques 2008, 2014, 2016).

- Then, R was applied by Karsten pipe method on a selected sandstone block of C variety at right side of south portal below the vault.

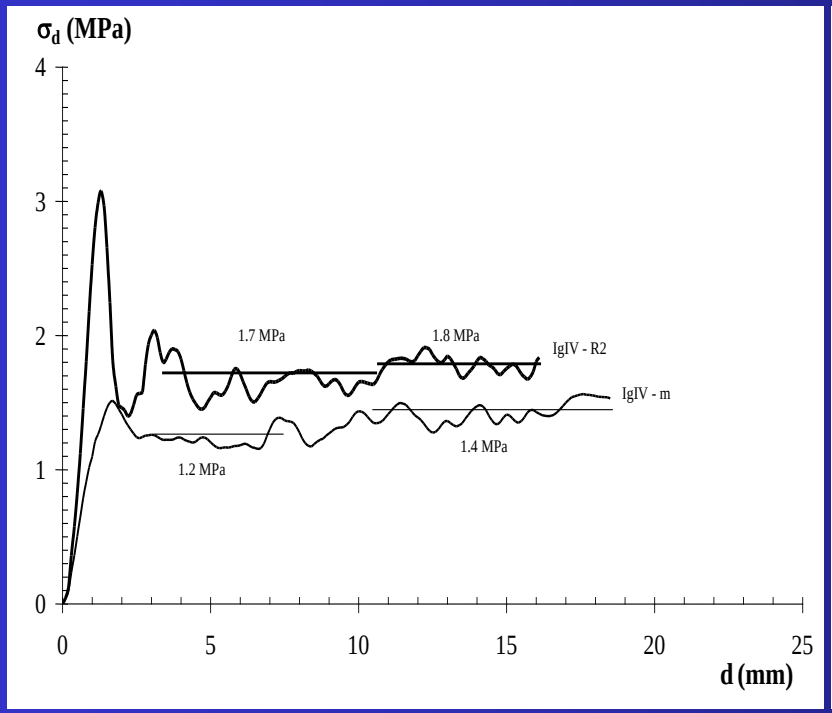


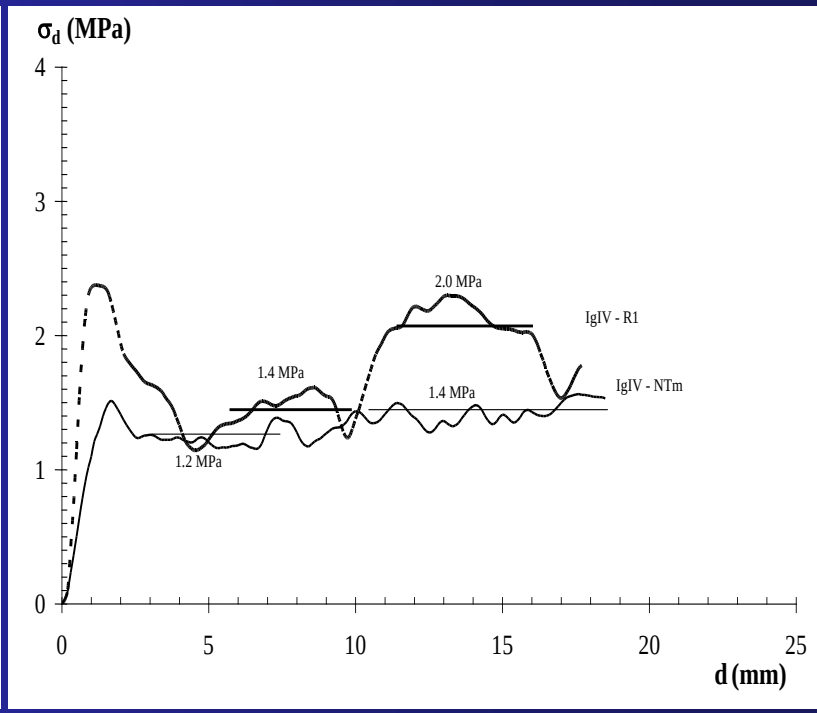
Easiness for applying stone consolidation treatments on its smooth surface, but more difficulty to apply than a block of M variety due to the lower value of porosity.

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

EXPERIMENTAL RESULTS

MECHANICAL BEHAVIOUR (Drilling Strength)





Mean values increased from 1.2 – 1.4 MPa on C sandstone to 1.7 – 2.0 MPa on R applications (up to 40%).
Drilling depths reached up to 20 mm.
Impregnation thickness higher than 15 mm.

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

WEATHERING AFTER 14 YEARS OF TREATMENT

- **Visual inspection**

assessment by Karsten tube & water absorption under low pressure coefficient

Before treatment

14 years after treatment

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

WEATHERING AFTER 14 YEARS OF TREATMENT

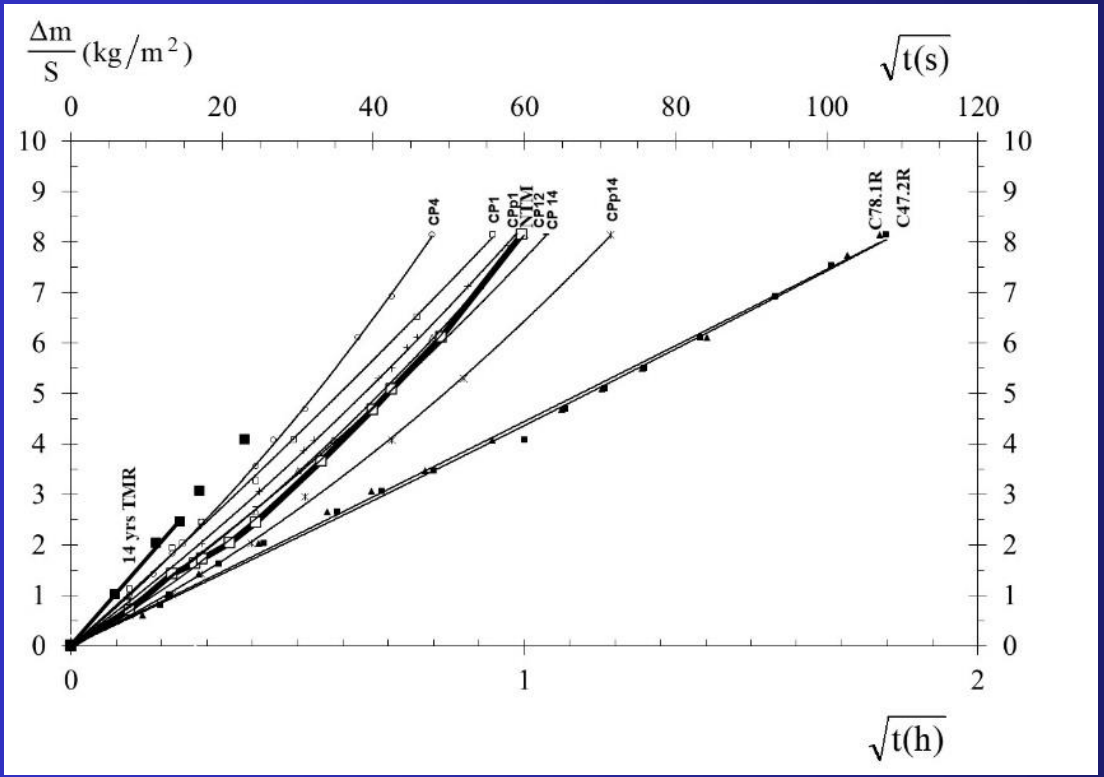
Coefficient of absorption of the area of non-treated block (NTM) is a value of 6 kg/m^2/√h, i.e. between mean values of 7.9 kg/m^2/√h on non-treated specimens and 4.5 kg/m2/√h on R, being closer of R value than non-treated specimens value.

As R value of coefficient of absorption corresponds to higher water repellency characteristics, than non-treated specimens value, a closer value to the former means less similarity to the hydric properties of the stone-substrate.

Larger differences of these properties could jeopardize the durability of the treatment for being responsible for more severe damages than the slight weathering evolution of C sandstone block.

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

WEATHERING AFTER 14 YEARS OF TREATMENT



In TMR the water absorption coefficient increases from 6 to 10.7 kg/m^2/√h. The latter value is higher than the recorded range of 6 to 9 kg/m2/√h obtained in sandstone specimens and in the monument.

DISCUSSION

Butlin et al (1995) presented detailed records of the application of the alkoxyalkysilane Brethane on sandstones building stones of 6 sites and treated buildings, mostly castles and abbeys. Its effectiveness was lower after 8 to 16 years regarding decay almost in all sites and the water absorption has increased.

Wheeler (2005) reported that the levels of decay of the treated zones with the alkoxyalkysilane Brethane generally took 4-8 up to more than 15 years to reach the same extent of non-treated zones.

The reduction of water absorption values to the corresponding values before ageing of treatments took between around 10 years to almost 21 years.

WEATHERING AFTER 14 YEARS OF TREATMENT

DISCUSSION

Wheeler (2005) stated an important finding: a stone could be preserved when water repellence is not due to the increment of water absorption.

The consolidated area of the selected block of St. Leonard's church is still well-preserved, as visible in Figure, in spite of the higher value of water absorption.

Conclusions

- An experimental programme was carried out on sandstones of C and M varieties of St. Leonard's church of in order to select the ethyl silicate application with better performance. Minor harmful characteristics and a better durability assessed by salt crystallization artificial ageing tests were obtained on R applications.

- A sandstone block of C variety was selected on the monument to apply the treatment and monitoring the weathering evolution through visual inspection and assessment of coefficient of water absorption under low pressure.

- A recent visual survey revealed a better surface, regarding visible degradation patterns after 14 years of the treatment occurrence.

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro

Conclusions

- The consolidated zone of the treated block reveals a higher value of the coefficient of water absorption under low pressure after 14 years than the non-treated zone in the beginning of the study. This result agrees with the data reported by several authors about the performance of sandstones circa 5-10 to 20 years after Brethane applications.

- The treated zone of the selected block of the monument is well-preserved in spite of the significant increment of the value of water absorption under low pressure.

MONITORING DEGRADATION PATTERNS OF SANDSTONE MONUMENTS AFTER CONSOLIDATION TREATMENTS

Thank You
for
Your Patience!

IPS Instituto Politécnico de Setúbal
Escola Superior de Tecnologia do Barreiro