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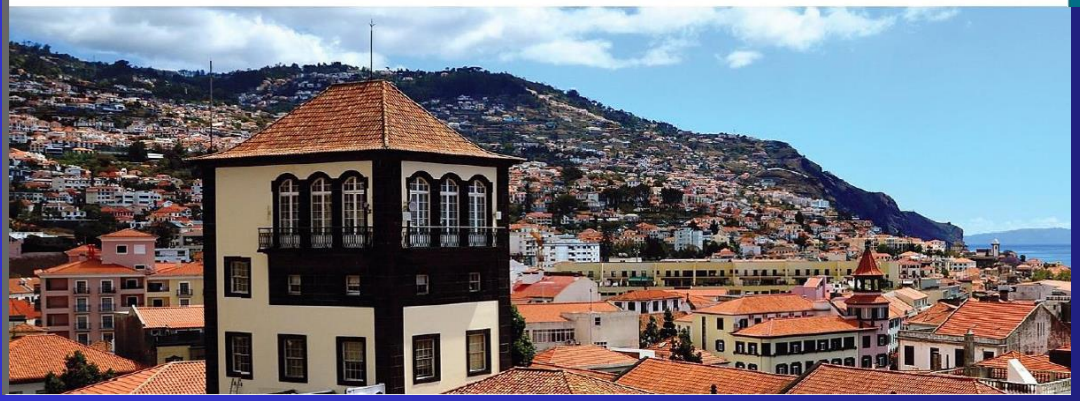

CONSERVATION OF SANDSTONE MONUMENTS: A NEW APPROACH IN CONSOLIDATION TREATMENTS

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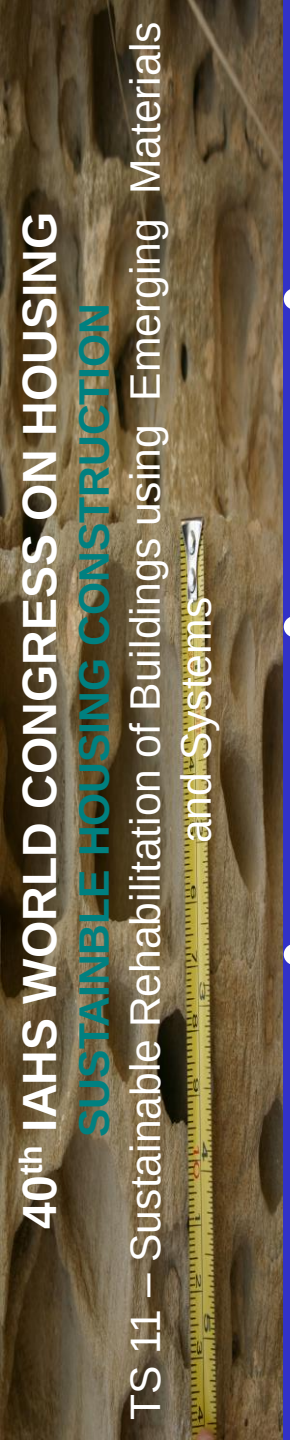

INTRODUCTION

- Scientific conservation plays a major role in a sustainable cultural heritage preservation.
- Suitable conservation actions optimize the environmental value of the cultural resources in a long-term point of view
- Suitable conservation actions have an important contribution to the creation of a sustainable habitat.

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INTRODUCTION

STONE DEGRADATION PATTERNS ON BUILT HERITA OF ATOUGUIA DA BALEIA VILLAGE

- **Sandstones use is common in traditional buildings in west region of Portugal, namely Peniche.**
- **Alveolization or honeycomb weathering is the worst pattern of stone degradation in the medieval St. Leonard's church.**
- **Consolidation action could be required.**

CONSOLIDATION TREATMENTS

- **Silanes (MTMOS and TEOS) are the most used on sandstones from the late 19th century to the beginning of the 21st century.**
- **Better consolidation effect on sandstones than on other stones and its commercial availability.**

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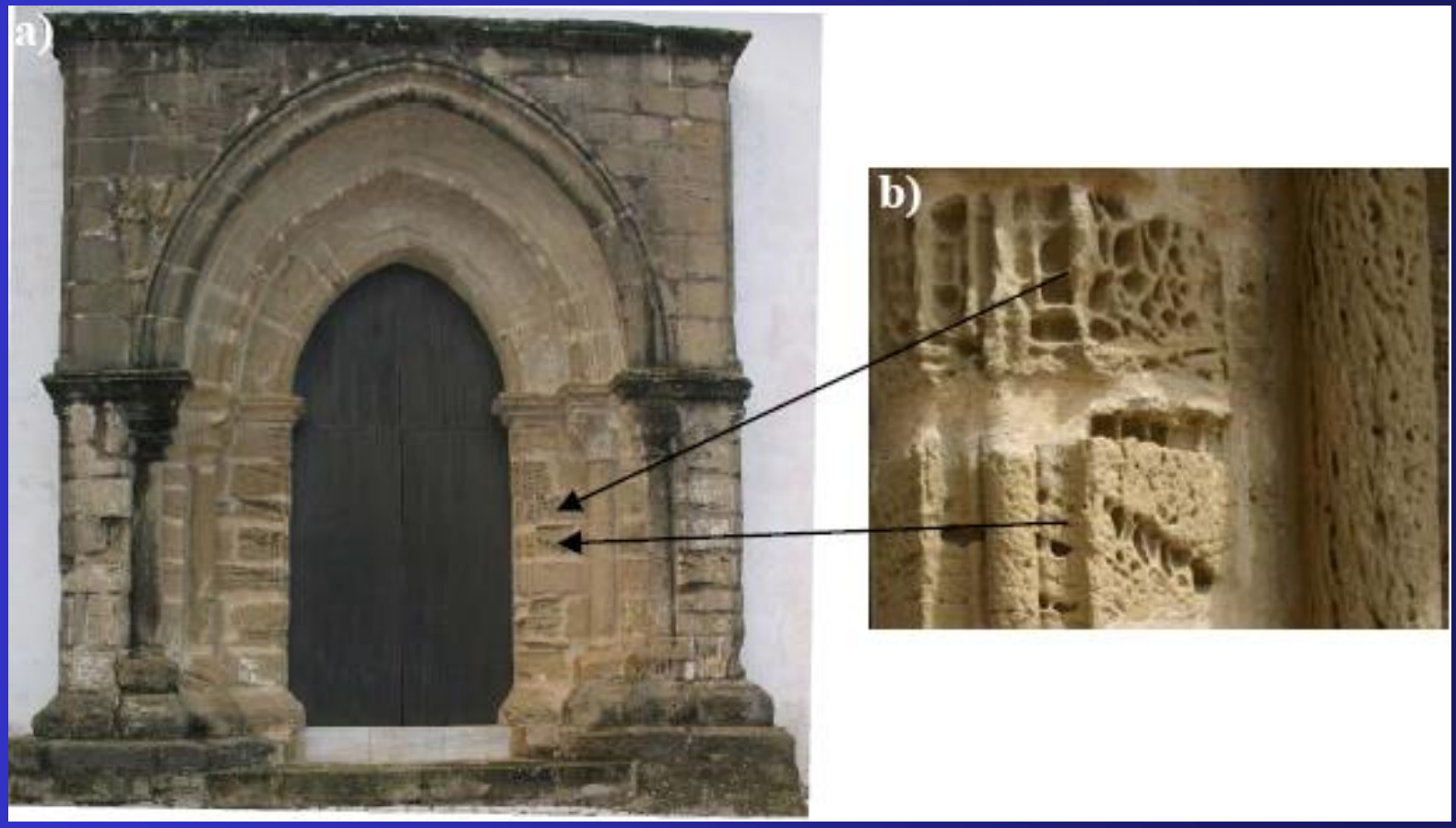
INTRODUCTION



St. Leonard's Medieval Church

INTRODUCTION

The traditional application methods of the consolidating products on stone surfaces are the following:

. Brushing and spraying (suitable polyethylene cover).

. Capillarity (cotton poultice on the stone surface).

. Immersion and immersion under vacuum (removed single blocks or elements of stone art).

Karsten pipe based method of application is a variation of RILEM's water absorption under low pressure test procedure.

$V=4cm^3$

$P=0.098\rho$

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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]**

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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 25ºC After application: dry residue of 34% after evaporation of solvents at 20ºC 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 20ºC and 60% of RH).

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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 3% of mass content in variety C.

. Drying at 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 1% of mass content.

. R was applied by Karsten pipe method on sandstone block at right side of south portal below the vault and was absorbed an amount of 2.5 g, i. e. 1.1 kg/m^2 per application.

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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 C was obtained by mercury intrusion porosimetry. Microporosity settled as the percentage of pores radii lower than 7,5 μm (Pellerin, 1980), is 85-95% in variety C.
- Drying tests were carried out on top face of sandstone cubic samples of variety C before and after treatments, following the Recommendations of NORMAL 29/88 (1991) and RILEM (1980) at laboratory environment of 20 ± 2 º C and 55 ± 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.

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EXPERIMENTAL PROGRAMME

PROCEDURES FOR MECHANICAL TESTS

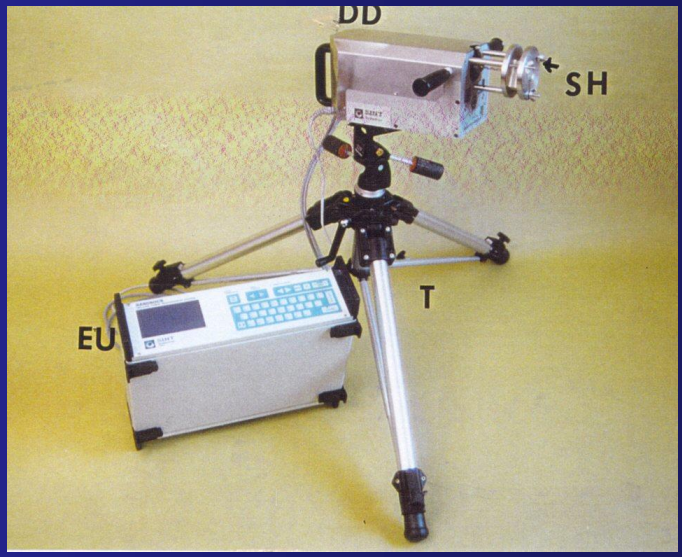
The Drilling Resistance Test Measurement System (DRTMS):

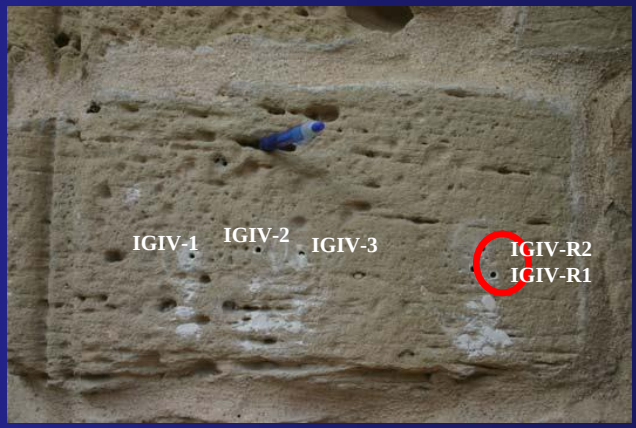
Portable micro drilling device with a load cell on a drill bit.

Diaber tungsten drill bits used with 5mm in diameter and a triangular tip allow a maximum drill hole depth up to 25 mm.

Drilling parameters adopted: 200 rpm of speed rotation and 20 mm/min of advancing rate

The tests were performed on a block of South façade of St. Leonardo's church in the right side below the vault, before and after consolidation treatments.





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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 C.**

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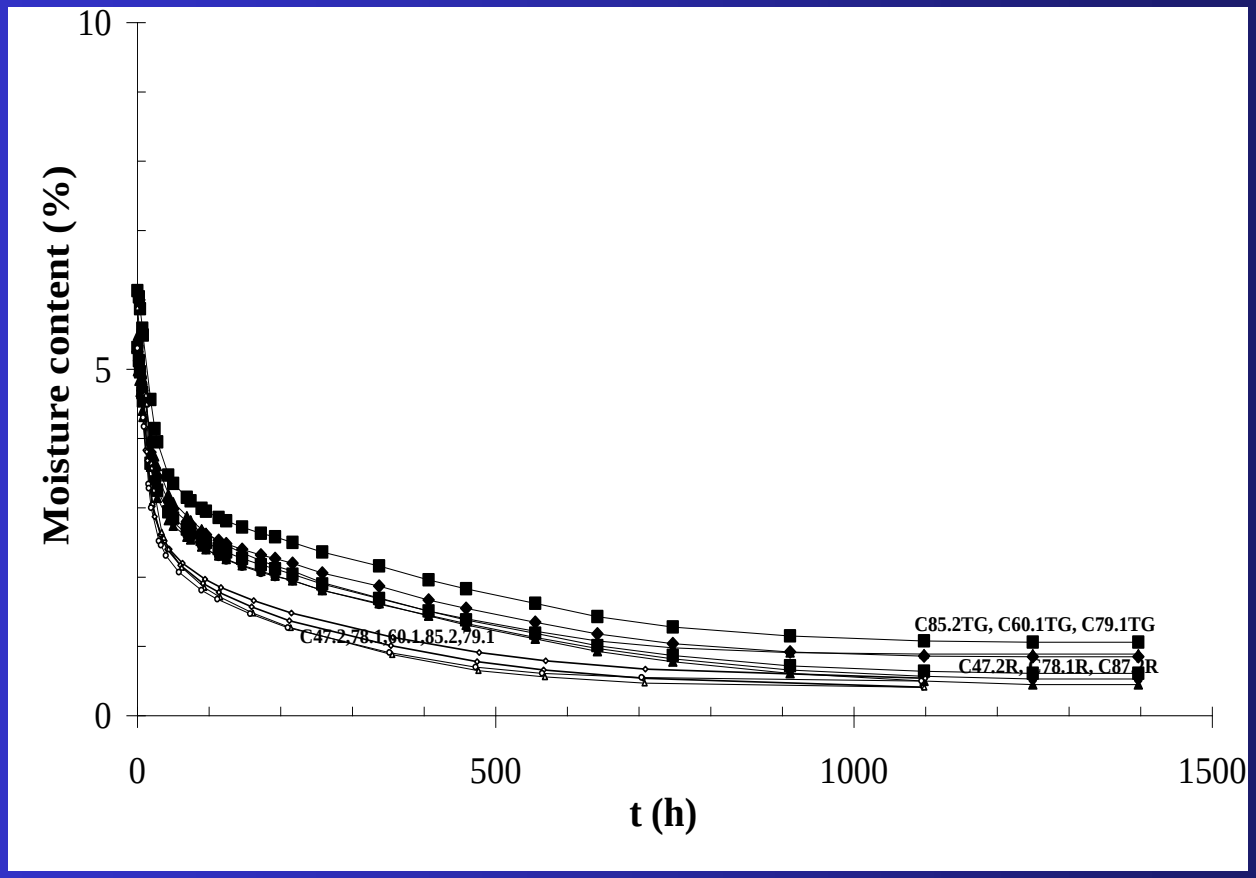
ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (DI)



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ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (DI)

Consolid product	Specimens (cubes)	Drying Index (DI)	Drying Index Average ± SD (CV %)
TG	C85.2	0.29	0.29 ± 0.01 (3.45)
	C79.1	0.29	
	C60.1	0.28	
R	C47.2	0.25	0.25 ± 0.01 (4.00)
	C78.1	0.24	
	C87.2	0.25	

Variety	Specimens (cubes)	Drying Index (DI)	Drying Index Average ± SD (CV %)
C	C60.1	0.18	0.20 ± 0.07 (35.00)* 0.17 ± 0.01 (5.88)
	C85.2	0.15	
	C79.1	0.16	
	C78.1	0.18	
	C47.2	0.18	
	C87.2	0.35*	

Significant increase

71% on TG

47% on R

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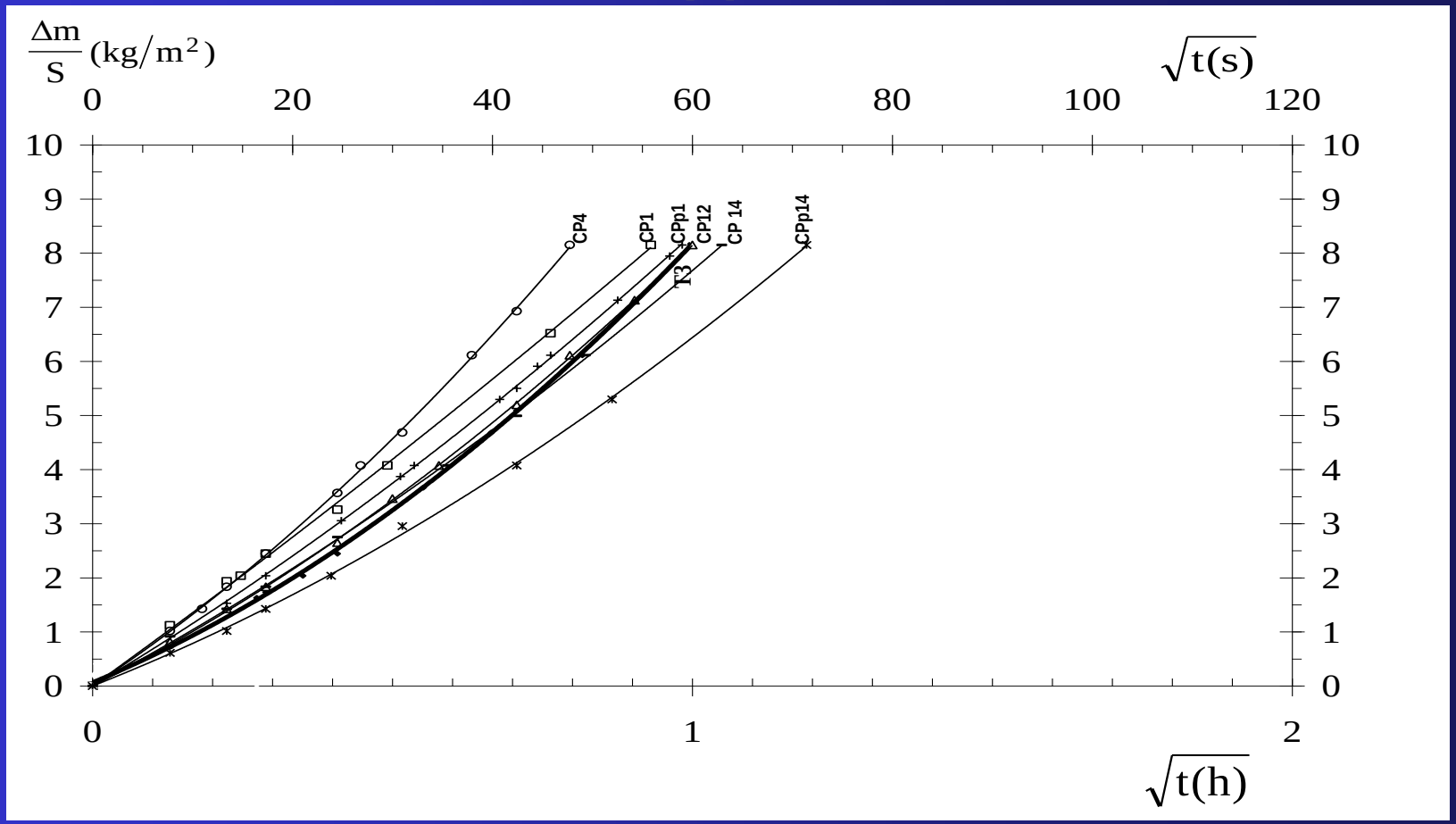
ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (k)



ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (k)

VVariety	SSpecimens	WWater absorption coefficient, k (kg/m²/√h)	Water absorption coefficient, k (kg/m²/√h) Average ± SD (CV %)
C	CP1	8.3	7.6 ± 1.3 (17.1)* 7.9 ± 0.9 (11.4)
	CP1p	7.4	
	CP4	8.7	
	CP4p	8.8	
	CP12	8.7	
	CP12p	6.8	
	CP14	5.3*	
	CP14p	6.7	
	T3	6.0	-

Close values of coefficient of absorption k on monument block to those obtained on C variety sandstone' specimens.

Physical match between the block stone and the C variety (average value of porosity of 12.7%).

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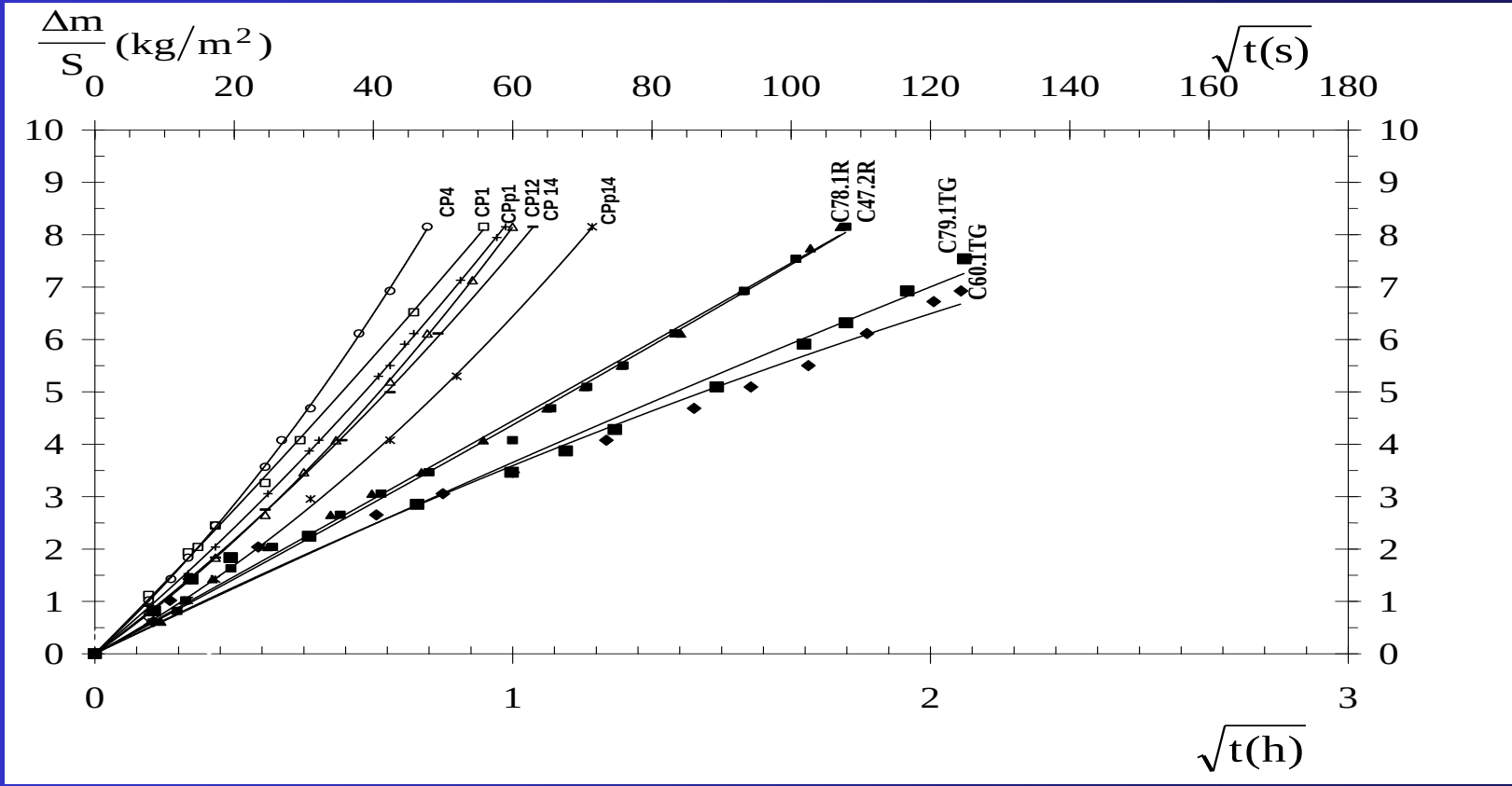
ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

PHYSICAL BEHAVIOUR (k)



Reduction of coefficient of absorption k
27% on TG and 43% on R (linear part of curves).
68% on TG after

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ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

MECHANICAL BEHAVIOUR (UCS)

Variety	Specimens (cubes)	σ_c (MPa)	σ_c (MPa) Average ± SD (CV %)
C	C18.1	51.2	57.5 ± 4.9 (8.5)
	C24.1	61.7	
	C60.2	53.5	
	C79.2	59.1	
	C87.1	61.9	
TG	C21	76.5	72.2 ± 5.5 (7.6)
	C22	68.6	
	C23	66.5	
	C47.1	77.3	
R	C19.2	60.5	63.2 ± 2.9 (4.6)
	C21.2	66.3	
	C20	68.2	

26% on TG

10% on R

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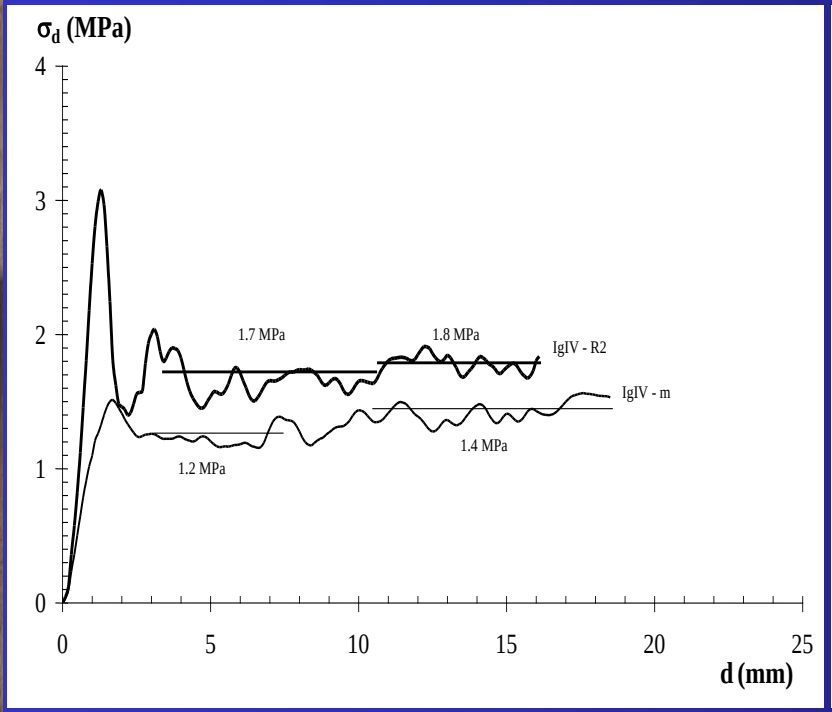
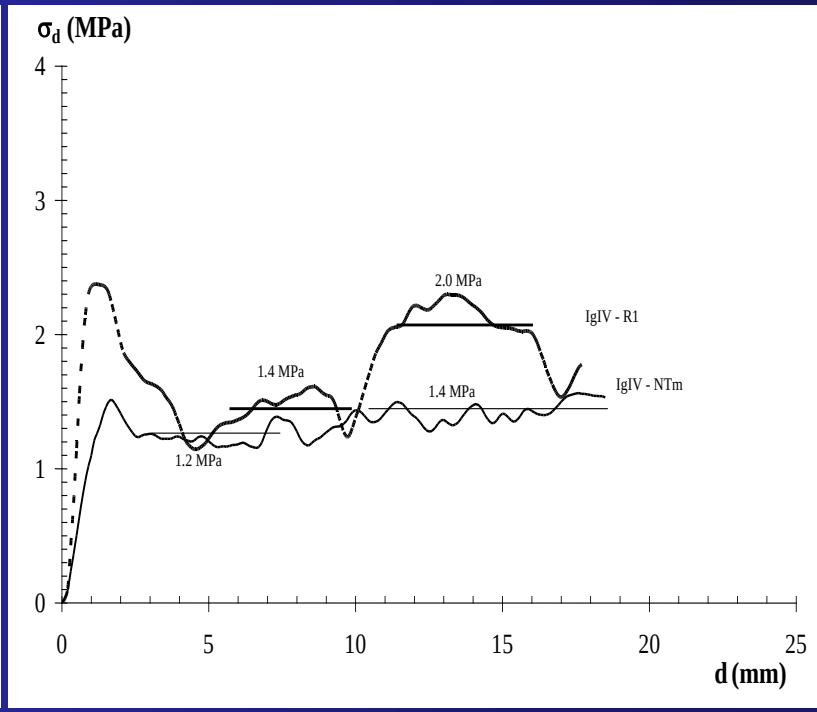
ANALYSIS OF RESULTS OF EXPERIMENTAL PROGRAMME

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.

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CONCLUSIONS

A Karsten pipe using total head to allow full absorption of consolidating products on sandstone façades was used in conservation treatments.

Two ethyl silicates (TG and R) were selected and applied on sandstone specimens. The experimental study of physical and mechanical behaviour revealed slight harmful characteristics of the applications on C variety of sandstones and a good consolidation effect.

The comparison between immersion based procedure of applications and Karsten pipe's method on stone monuments indicate the potential viability of this new approach to obtain a good consolidation effect when difficult conditions of absorption occurs.

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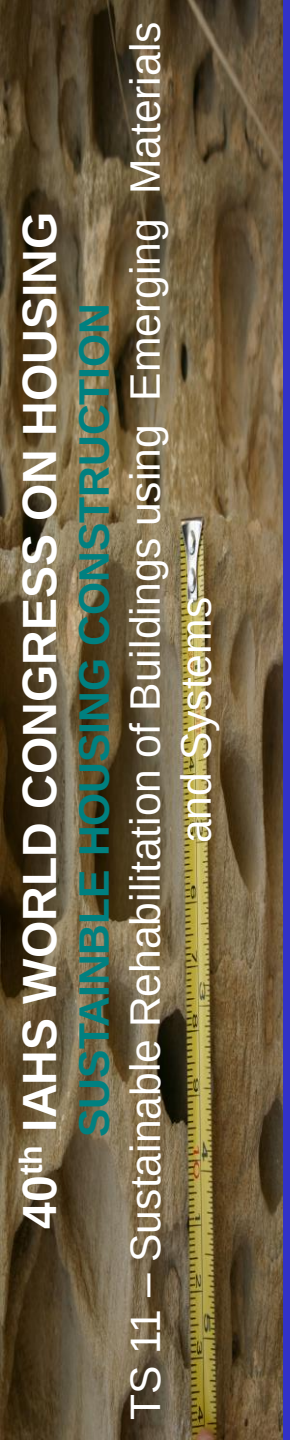

THANK YOU

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