Cement- cork mortars for thermal bridges correction. Comparison with cement-EPS mortars performance
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ABSTRACT

The aim of this paper is to demonstrate the advantage of cork-mortars for renderings when compared to EPS-mortars, from a thermal characteristics point of view, namely in steady and unsteady conditions. It was intended to develop specific rendering mortars able to be applied in thermal bridges to reduce condensation effects and heat transfer in buildings envelopes. The impact of this solution is significant, especially in building typologies as framed reinforced concrete structures. Cement mortars and cement-EPS mortars are used as a reference as their properties are easily recognized compared to cement-cork mortars, which are made with by-products from the cork industry. Several studies were made concerning fresh and hardened state behaviour of mortars, namely: rheological and mechanical properties, microstructure evolution with time and thermal behaviour. For a cement based mortar, different cork dosages (from 0% to 80%) were tested (as sand replacement by mass). Microstructural analyses show that the mechanical properties of cement-cork blends are not only controlled by cork's low density, but also by interaction of cork extractives with the cement hydration process. Thermal conductivity presents a linear decrease for an increasing cork dosage in mortars. Concerning the effect on thermal delay, cork-mortars seem to behave better than EPS-mortars.

KEYWORDS

Cement mortar; cork granulate by-product; EPS beads; rheology; thermal behaviour; mechanical properties; microstructure

1. Introduction

Portugal is the major producer of cork (bark of *Quercus suber L.)* and the major manufacturer of cork products. Cork is a natural product obtained from removing (each 9 years) the outer bark of the cork tree and has been studied and reported for their extraordinary and remarkable mechanical and physical properties [1-9].
It is intended to demonstrate in this paper the advantage of cork-mortars for renderings when compared to EPS-mortars, from a thermal characteristics point of view, namely in steady and unsteady conditions.
Thus, this paper deals with the coupled effect of cork granulate (and EPS beads) on rheological, mechanical, microstructure and thermal behaviour of cement based mortars, proportioned with a polycarboxylate-based high range water reducer (HRWR). The main challenge consists in developing a rendering mortar, able to be applied for thermal bridges correction in recent buildings, with the maximum cork (or EPS) dosage as possible, while minimizing mortar thermal conductivity and cost changes.
This subject is actual and important issue as in western Mediterranean climate these thermal bridges produce not only heat losses but frequently also condensation effects. Cement mortars and cement-EPS mortars are used as a reference as their properties are easily recognized compared to cement-cork mortars.
While the EPS beads are industrially produced, cork is a natural product and the cork granulate is a by-product from the industry; therefore its use has environmental advantages. It is produced from scrap of cutting and trimming operations; some granules are subsequently used in the production of agglomerated products but others are rejected. Hence, its cost is considerably lower compared with that of virgin cork. Thus, the goal of this work is also to transform this cork by-product into a highly value composite product.

The real value is also dependent on the mechanical performance of this product. Thus the mixture between cork and cement, particularly the evolution of its microstructure, is an important topic which needs to be developed and studied concerning the time effect.

2. Literature review - Cork and EPS properties

Cork is a cellular material and its unique properties seem to arise from the combination of aligned, prismatic closed cells and their structural arrangement (Figure 1 (a) and (b)). Cork shows nonlinear elasticity and compressibility without fracture, which provides an effective dissipation energy mechanism. In addition to the mechanical properties, other attractive features involve remarkable thermal and acoustic insulation properties, together with low permeability to liquid [7,9].

Figure 1 show the anisotropy of cork's cellular structure, which implies that its properties will also be anisotropic. Cork cells are closed and hollow, containing in their interior a gas, presumably similar to air, that plays an important role in their properties.

Cork from *Quercus suber L*. has peculiar properties such as high elasticity and low permeability; these results came, at least partially, from its specific chemical composition (and more especially from that of suberin) [10–12].

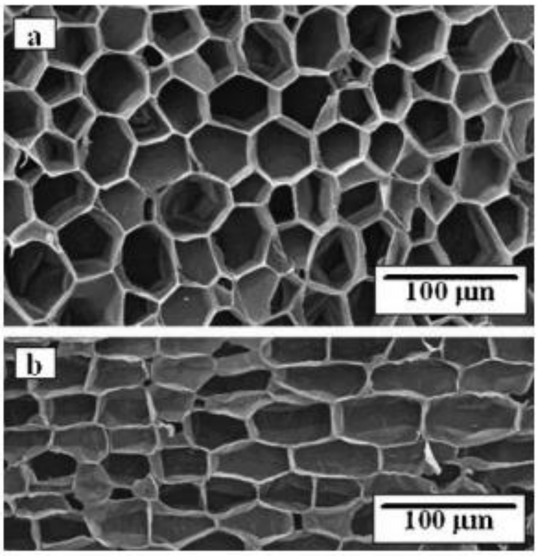

Figure 1: SEM image of natural cork cellular structure (after boiling): (a) radial section and (b) tangential section [13].

The cellular structure of cork wall consists of a thin, lignin rich middle lamella (internal primary wall), a thick secondary wall made up from alternating suberin and wax lamella and a thin tertiary wall of polysaccharides (Figure 2). Some studies suggest that the secondary wall is lignified and therefore may not consist exclusively of suberin and waxes. Besides that, in these cell wall components, suberin is the most abundant with approximately 40%, while lignin corresponds to 22%, polysaccharides to 18% and extractables to 15% [13].

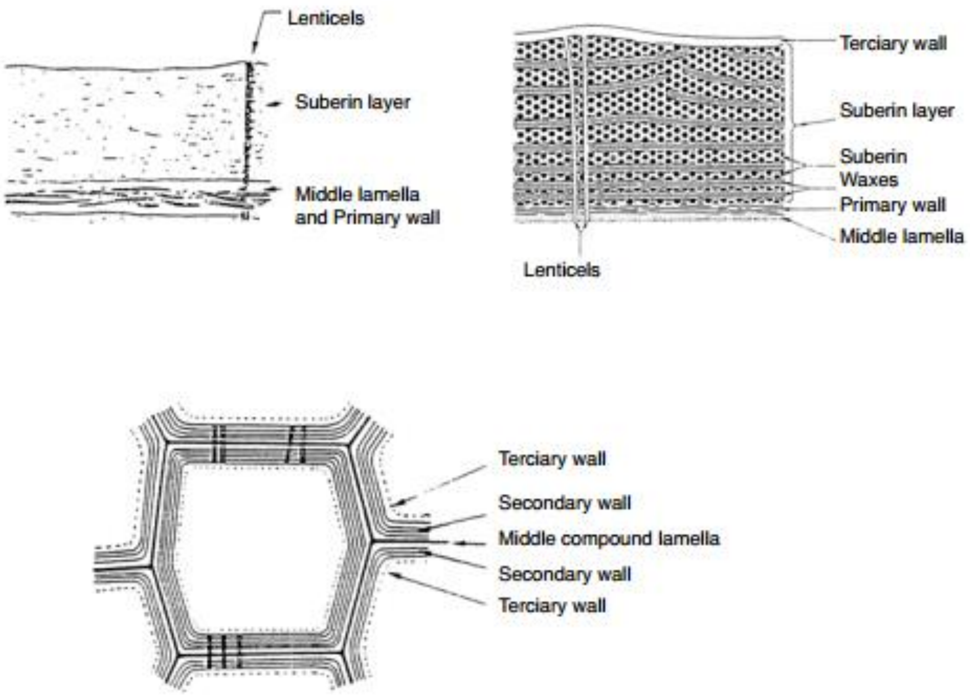

Figure 2: Microscopic structure of cork oak cell wall [14].

Table 1 summarises the compositions reported in the literature.

Table 1: Differences in results of quantitative analysis of cork chemical composition [13].

Component (%)	Virgin cork		Reproduction cork (amadia)					
	Caldas	Pereira	Gil	Caldas	Pereira	Paramesw	Holloway	Carvalho
Suberin	45	45	42	48	33.5	33	37	50
Lignin	27	21	21.5	29	26	13	14.8	19
Polysaccharides (cellulose and hemicellulose)	12	13	16	12	25	6	15.8	13
Extractables	10	19	13	8.5	13	24		15
Ash	5	1.2		2.1	2.5	...		3
Others	...	0.8		...	...	6	...	...

Besides the principal macromolecular constituents (suberin and lignin), other components, such as polysaccharides, present at lower concentrations exert an important influence on the chemical and physical properties of cork. These constituents are compounds with low molecular weight, mainly polysaccharides, waxes and tannins (Table 2).

Table 2: Low molecular weight components of cork [13].

Component (%)	Pereira		Gil and Moiteiro	Natividade
	Virgin	Amadia		
Polysaccharides	11-16	25-30	12-20	22
Waxes	17-20	13-14	3.5-7.9	2
Tannins			6-7	1

As it was mentioned before, suberin is responsible for cork's compressibility and elasticity while lignin is responsible for the structure of the cell walls. The polysaccharides provide structural rigidity to the cork cell, preventing the cells from collapse. Polysaccharides that are present in cork are cellulose (homopolymer) and hemicellulose (heteropolymer) [13,15,16]. Waxes repel water and contribute to cork's low permeability while tannins are responsible for colour and protection/preservation of the material.
Cork is comprised of both structural components, of an extensive and complex polymeric form, and also non-structural components. The latter are categorized by extractive and non-extractive. The extractive components are divided into wax-like, which influences the permeability of cork, and phenolic compounds, which in turn seem to play a protective role against attacks of biological organisms [17].
An estimated 75% of harvested cork is discarded as waste from the production of high quality punched bottle stoppers. Some of this waste is ground into small granules of which the relatively larger granules are made into panel-like products for thermal and acoustic insulation and anti vibratic construction – or other – purposes. However, a large portion of the waste (20–25% by weight) remains under-utilized because the granules have nonconforming density or are of very small dimensions or both [18].

As cork bottle stopper production (natural corks) is only able to use until, at most, 25% of the raw material, new applications were sought. Cork granules are produced as by-products and waste by the cork processing industries that make 'bottle stoppers' as a main product. These granules are of low density and could be used as lightweight aggregates for making concrete and mortars with thermal – and acoustic - insulation properties and higher deformability. Cork composites are part of the current cork derivatives and are one of the most promising fields of cork technology evolution. They have been studied for cement composites, with environmental and technical advantages.
Karade et al. [18] studied the compatibility of cork granules with cement for the manufacture of lightweight cementitious composites. Several grades of cork granules, varying in terms of size and density, were investigated and the effects of extractives, particle size and density of the cork granules were studied. The results indicate that these parameters affect cement hydration in a complex way. At lower contents of cork (10% by weight of cement), only the extractives have an influence on hydration behaviour. At higher cork contents (20% and 30%) particle size and density also affect the compatibility, due to the change in the surface area of the cork. The hydration test results showed that large size (2–3 mm) and medium size (≈ 1mm) cork granules are compatible with cement and can be added up to 30% by weight of the binder. However, when using fine size granules, the use of a set-accelerator or a pre-treatment of the granules may be required.
Nóvoa et al. [19] studied the mechanical behaviour of a cork modified polymer mortar with different resin/sand (i.e., binder/fine aggregate) weight ratios. The mechanical performance of the cork-modified polymer mortar was evaluated by flexural and compressive tests performed at room temperature. In this research, a linear decrease in properties was observed as function of cork volume content (from 0% to 45% of the total aggregate volume). However, as cork content rises throughout each test series, material becomes more ductile, particularly in compression, and shows less brittle failure. It was also shown that, comparatively with conventional cement materials, elasticity modulus of cork-modified polymer mortars is quite low, but flexural/compressive strength ratio is remarkably high.

Taking advance of the low density and high gas content of cork's cellular structure in the low thermal conductivity, Panesar et al. [20] studied the impact of cork used as sand replacement or stone replacement on the plastic, mechanical, transport, microstructural and thermal properties of mortar and concrete. Mix design variables include the percentage of cork, cork size and the cork blend. All mortar mixtures were prepared as 1:2 mortars (i.e. 1 part of cement to 2 parts of sand by mass) with a water-to-binder (w/b) ratio of 0.40. The mortar and concrete mix variables examined included the percentage of cork as sand replacement (0%, 10% and 20%, by weight). Panesar et al. [20] concluded that the thermal conductivity of concrete–cork composites decreases, as the concrete density decreases. A 46% greater thermal resistance was measured for concrete-cork composites containing 20% of cork in comparison to the reference concrete without cork. The thermal conductivity is controlled by the percentage of cork used, which is attributed to the direct relationship observed between cork density and the concrete–cork composite density. No direct correlation between cork size and cork gradation on the thermal conductivity was identified.

Cork has a limited range of variation in properties, owing to its defined morphology and structure - with only minor variations, as described above. Therefore, it could not be possible to obtain the vast range of properties possible with, for example, expanded polystyrene (EPS), polyurethane (PU) or polyethylene (PE) foams, industrially produced. Thus, it is of interest to compare the properties of cork with those of other natural and synthetic foams.
EPS is a thermoplastic polymer, rigid and tough, closed-cell foam, consisting essentially of 98% of air. It is usually white and made of pre-expanded polystyrene beads, presenting remarkable thermal insulation properties. EPS beads are a type of artificial ultra-lightweight non-absorbent aggregate [21]. At a first glance one could conclude that natural cork has a poor mechanical behaviour when compared with other types of core materials, such as synthetic foams as it is the case of EPS, that can be produced with different levels of density. However, for some specific

applications, cork can compete with these materials. In fact, its low thermal conductivity combined with a reasonable compressive strength make it an excellent material for thermal insulation purposes, as well as for applications in which compressive loads are present (Figure 3). Compared to synthetic foams, its acoustic properties are also significant.

The best materials in terms of thermal conductivity versus compressive strength fall in the bottom right corner of Figure 3, where can be noticed that cork performs similarly to synthetic rigid polymer foams [13].

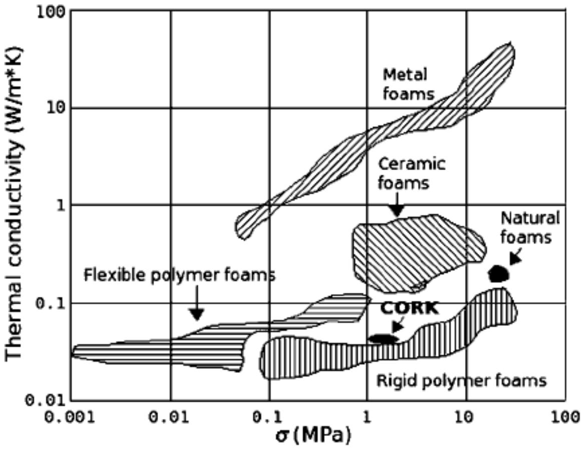

Figure 3: Materials selection chart comparing thermal conductivity with compressive strength [13].

EPS was used as aggregate in ordinary mortar or concrete by several authors [22–25]. Madandoust et al. [26] studied the fresh properties of structural self-compacted lightweight concrete (SCLC) containing EPS assessed by means of slump flow, T50, V-funnel and L-box tests. Fifteen mixes including different water/binder (w/b) ratios, nano-SiO_2 contents and EPS percentages (10%, 15%, 22.5% and 30% by volume) were designed. The use of EPS decreased the high range water reducer demand, while higher slump flow was achieved. The compressive strength test results also revealed that the use of the EPS aggregates remarkably decreased the compressive strength of SCLC.
Miled et al. [27] studied the particle size effect on EPS lightweight concrete. To emphasize the EPS bead size influence on EPS concrete compressive strength, three sizes of EPS beads were used: 1 mm, 2.5 mm and 6.3 mm beads. It was shown that the compressive strength of EPS lightweight concrete increases significantly with a decrease in EPS bead size, for the same concrete (macro) porosity (ranging from 10% to 50%).

3. Requirements for rendering mortar design

The reduction of energy consumption in the buildings sector is an important measure to help reduce energy dependency. For this purpose, the thermal behaviour of buildings envelope needs to be improved and appropriate energy performance requirements for technical building systems should be established. High thermal resistance should be achieved for opaque and transparent building elements, and approaches based on other thermal performance parameters, such as the thermal inertia or the thermal delay, need to be developed.

A thermal bridge is a building element area or interface where a significant change in the thermal resistance occurs compared to that of the envelope. It occurs due to the presence of different materials, with distinct thermal conductivities - as in the case of a structural concrete pillar adjacent to a brick masonry wall -, as well as to changes in the geometry of the fabric - as in the case of the junction between roofs, floors, ceilings and walls [28].

Several studies have been investigating into the impact of thermal bridges on the energy performance of a building or in occupant's health due to condensation effects. As example, Theodosiou and Papadopoulos [29] studied typical three-storey apartment building with an open ground-floor space and a flat roof; the façades are composed by two brick layers with interposed insulation (5 cm expanded polystyrene). The study shows that the correction of the thermal bridges, mainly carried out by the installation of a 3 cm layer of extruded polystyrene on the outer surface of the concrete beams and pillars, can reduce the building annual heating load of about 30%; on the contrary, their effect on the cooling load is negligible. In the context of renovating houses, Roberts [30] discusses the relationship between air quality and air humidity, commenting that when old draughty windows are replaced by new sealed types of windows the moisture content of the interior air increases. This becomes critical once surface temperatures drop so low, such as around thermal bridges, where relative humidity rises locally to 80% or more, producing condensation and associated dampness. These condensation effects also may occur in beams or pillars and prevalence of symptoms of sick building syndrome (SBS) may arise.

In [31] it is presented a study were it is analysed if and how Member States from European Union deal with thermal bridges in their calculation procedures. It is shown that all countries in Northern and Central Europe are dealing with the problem as far as new constructions are concerned. This is not the case for renovation projects. The problem of thermal bridges, appearing for example at the junction between two separately insulated elements, or between a vertical and a horizontal element, is not always dealt with properly.

Thus, the analysis of the thermal bridges' impact should be made and the development of improved insulation, low cost easy to apply, rendering mortars is necessary.

The main challenge presented in this paper consists in developing a rendering mortar with lower thermal conductivity, able to reduce condensations effects, with the maximum cork or EPS dosage as possible, while minimizing cost changes compared to EPS mortars. Thus, it was necessary to define the requirements for this mortar design.

The qualitative requirements for the developed mortars are the following:

- present the highest percentage of cork/EPS as possible.
- have an open time higher than 30 minutes;
- present good workability for rendering mortars application;
- have appropriate compressive and tensile strength properties;
- present lower thermal conductivity, higher thermal delay and provide good thermal resistance when applied as a layer on a wall external surface.

This high performance cementitious mortar was developed using partial replacement of sand by waste cork (or EPS), in the presence of a high range water reducer (HRWR). Thus, the current investigation also compares the effect of various replacement levels of waste cork (and EPS) on the properties of cement mortars, namely in its microstructure evolution with time.

4. Material characteristics

For the mortars formulation a cement, a type of sand, a water reducer, a cork granulate and EPS beads were used and its characteristics are presented.

- Cement: CEM II B-L 32,5 N produced in Portugal by Secil with the characteristics presented in Table 3 and 4.
- Sand: siliceous sand with grain size 0/1 (Figure 4).
- High range water reducer: modified polycarboxylates (PCE) (Table 5).
- Cork granulates: with grain size 0.5/2, supplyed by Fabricor-Indústria, Preparação e Transformação de Cortiça, SA (Figure 4 and Table 6).
- EPS beads: 2 mm beads were used (Table 6).

Table 3: Chemical and physical characteristics of CEM II B-L 32,5 N provided by the manufacturer.

Characteristics		**CEM II/B-L 32,5N**
Setting time (min)	start	128
	end	164
Expansibility (mm)		0.5
7 Days	Flexural strength (MPa)	5.80
	Compression strength (MPa)	31.10
28 Days	Flexural strength (MPa)	7.30

Compression strength (MPa)	40.10
LOI (%)	13.60
Insoluble residue (%)	1.60
SiO_2 (%)	14.44
Al_2O_3 (%)	3.37
Fe_2O_3 (%)	2.50
CaO (%)	61.27
MgO (%)	0.96
Chloride content (%)	0.04
SO_3 (%)	2.35
Free lime (%)	0.91

Table 4: Density and fineness using Blaine permeameter of CEM II B-L 32,5 N provided by the manufacturer.

Sample	Density (kg/m^3)	Fineness (Blaine) (m^2/kg)
CEM II B-L 32,5 N	3000	452

Table 5: Technical and physical data provided by the manufacturer for the HRWR.

Technical data	**Aqueous solution of modified polycarboxylate**
Form	Aqueous solution of modified polycarboxylate
Density (kg/dm^3)	1.07 ± 0.02
pH-value	5.5 ± 1.0
Chloride content (%)	≤0.1
Solid content (%)	26.5 ± 1.3

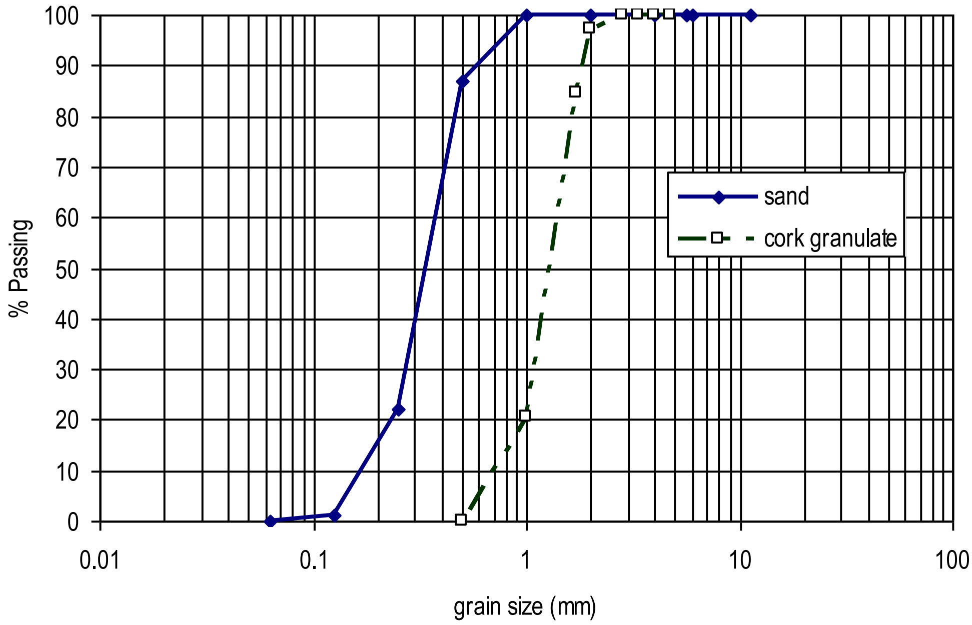

Figure 4: Grain size distribution for sand and cork aggregate type used in the cement based mortar.

Table 6: Loose bulk density of sand, cork granulates and EPS beads used in mortar preparation.

Loose bulk density(kg/m³)	Sand	Cork granulate	EPS beads
	1590.0	112.4	16.7

5. Mixing and testing procedures

5.1 Mixing procedures

Before preparing the mortars, the dry cement, the sand (with or without cork or EPS) was hand mixed with a trowel to avoid the formation of granules. The mixer blade had a helicoidal shape, with a diameter (10 mm), slightly smaller than the cup diameter (11 mm) in order to allow all the mortar to be mixed. The gap at the bottom, between the blade and the cup, was 4 mm. Ordinary tap water was used for the preparation of the mortars. The water was allowed to flow freely until a stable water temperature was reached.
The mixing procedure was controlled to ensure that the method of mixing is representative and robust, i.e., uncontrollable variations in materials and procedures must not have a major effect. Thus, several mixing procedures were tested and the adopted mixing procedure was the following: the whole binder and sand (with or without cork or EPS) where added to 90% of the water and mixed during 3 minutes. 1 minute after the beginning of the mix the HRWR is added. The remaining water is added 3 minutes after. Once all materials had been added, the mixture was mixed for 2 min at 2100 rpm.

The mortar mix proportions, namely the percentage of cork as sand replacement by mass (in mortar volume) and the percentage of EPS also as sand replacement, are summarized in Table 7 and 8. Six cork and EPS percentages were used: 10%, 20%, 40%, 50%, 70% and 80%. Those mortars were compared to a reference composition mortar (CB). All mortar mixtures were prepared as 1:3 mortars (i.e. 1 part of cement to 3 parts of aggregate (sand + cork) by mass).

Table 7: Use of cork in mortar mix design.

Cement-cork mortars	Identification	Percentage replacement (%)
CB HRWR 0,3% w/b=0,6	CB	0
CC 10% HRWR 0,3% w/b=0,6	CC10	10
CC 20% HRWR 0,3% w/b=0,6	CC20	20
CC 40% HRWR 0,3% w/b=0,6	CC40	40
CC 40% HRWR 1% w/b=0,6	CC40*	40
CC 50% HRWR 1% w/b=0,6	CC50	50
CC 50% HRWR 2% w/b=0,6	CC50*	50
CC 70% HRWR 2% w/b=0,6	CC70	70
CC 70% HRWR 2% w/b=0,7	CC70*	70
CC 70% HRWR 3% w/b=0,7	CC70**	70
CC 80% HRWR 2% w/b=0,7	CC80	80
CC 80% HRWR 2% w/b=0,75	CC80*	80

Table 8: Use of EPS in mortar mix design.

Cement-EPS mortars	Identification	Percentage replacement (%)

CB HRWR 0,3% w/b=0,6	CB	0
CE 10% HRWR 0,3% w/b=0,6	CE10	10
CE 20% HRWR 0,3% w/b=0,6	CE20	20
CE 40% HRWR 0,3% w/b=0,6	CE40	40
CE 50% HRWR 0,3% w/b=0,6	CE50	50
CE 70% HRWR 0,3% w/b=0,6	CE70	70
CE 70% HRWR 1% w/b=0,6	CE70*	70
CE 80% HRWR 1% w/b=0,6	CE80	80

Notation: CB – reference mortar, CC – cement-cork mortar CE – cement-EPS mortar, X% - percentage of cork or EPS, HRWR Y% – percentage of modified polycarboxylate, w/b=Z – water/binder ratio, * - change in HRWR percentage or w/b ratio for the same percentage of cork/EPS, ** - change of the other parameter (HRWR percentage or w/b ratio) for the same percentage of cork.

5.2 Flow table test and rheological characterization

As these mortars were designed to present good workability for rendering application; therefore, an optimization of the flow properties of the mortar was necessary. By using rheology to optimize the flow properties, one is able to focus on each constituent of the mortar composition.

The flow table test is used to determine the “workability” of fresh mortar and the measurements were done following the description in ASTM C230 [32]. The spread was measured for all the mortar compositions, for different resting times. After that, an attempt to estimate the yield stress was made since the spread seems to be a more relevant parameter for estimating the material yield stress [33, 34].
Since the rheological properties of mortars are extremely dependent on paste behaviour, some paste mortars' were studied using a Bohlin Gemini HRnano rotational rheometer, in a plate/plate geometry (ϕ = 40 mm), with a gap of 0.5mm. The samples were subjected to a pre-shearing stage during 30 s at $\dot{\gamma}$ = 300 s^{-1}, 8 minutes after binder was placed in water. After 30 s at rest, a step up test of shear rate was applied including a linear 10-min upwards from 0 to 300 s-1, 60 s at maximum shear rate and an analogous step-down from 300 s-1 to rest (Figure 5). The time step adopted was the necessary to obtain the steady state behaviour for each shear rate applied. For each step, the duration to reach the equilibrium state was 10 s, which was revealed to be long enough to obtain steady state, but was also as short as possible to limit segregation (and of course also hydration). For the reference paste mortar, different temperatures were applied: 5, 10, 15, 20, 25, 30, 35, 40 and 45 ºC; for each temperature a new mortar sample was used in all the tests. The procedure enabled the determination of the flocculation area, which is related to the mortar workability loss before hydration.

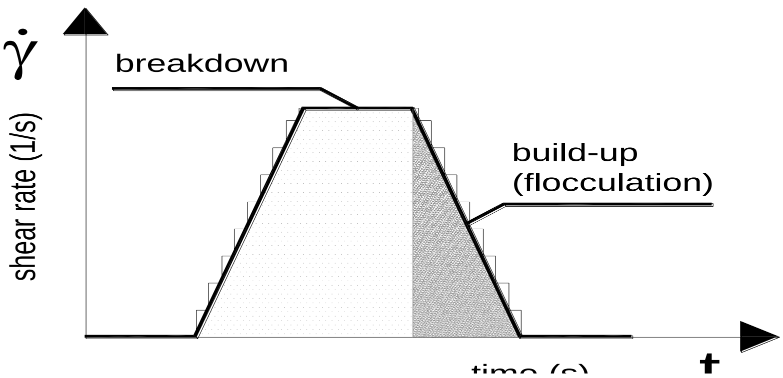

Figure 5: Rheological procedure for mortar properties determination.

To describe the mortar rheological behaviour of cement-based mortar it was chosen to adopt the Sisko model and the modified Bingham eq. (1) [35], since it suits better in this shear-thinning behaviour:

$$\tau = \tau_0 + \eta_p \times \dot{\gamma} + c \times \dot{\gamma}^2 \qquad (1)$$

where τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate, τ_0 is the yield stress (Pa), η_p is the plastic viscosity (Pa.s) and *c* is a constant.

Since the fact that the spread value on flow table test is more related to yield stress than to plastic viscosity [36, 37], an attempt was made to use the correlation between the measured spread radius and the yield stress, allowing for the measurement of the yield stress of a given cement-cork and cement-EPS mortar without the use of a rheometer.

5.3 Bulk density of fresh and hardened mortar

This test was performed according to EN 1015-6: 1998 and EN 1015-10:1999 [38, 39]. For each type of mortar a sample of 3 specimens was used at the fresh state. Mortars specimens were prepared with 40x40x160 mm. At the hardened state the 3 specimens were previously subjected to a curing period of 28 days at 20ºC and relative humidity (RH) equal to 95 $\pm$ 5 %.

5.4 Mechanical strength and open porosity

Together with the previous tests, mortar strength determination was made. In order to determine mechanical characteristics of the formulated mortar, a testing campaign was undertaken and all 3 specimens of each mortar composition were submitted to flexural and compressive strength tests following standard EN 1015-11 [40]. In order to understand the previous results, the mortars open porosity was measured by vacuum and hydrostatic weighting based on EN 1936:2008 [41].

5.5 Water absorption due to capillary action of hardened mortar

This test was performed based on EN 1015-18: 2002 [42]. For each type of mortar a sample of 3 specimens (semi-prisms) previously subjected to a curing period of 28 days and laterally waterproofed was used.

5.6 Mercury intrusion porosimetry

Mercury intrusion porosimetry (MIP) was conducted on mortar samples using a Micromeritics' AutoPore IV 9500 Series mercury intrusion porosimeter. The experimental recommendations adopted were the ones used and suggested by Rato [43]. The test was conducted in accordance with ASTM D4404 - 10 [44] in order to determine the pore size distribution, and open porosity by mercury intrusion.

The pressure required to intrude mercury into the sample's pores is inversely proportional to the size of the pores. The instrument has a pressure capacity of 206 MPa (30 ksi) and is capable of penetrating pores as small as 7 nm in diameter.

In hydraulic based mortars such as cement, pore structure is a major component of the microstructure that affects water permeability, strength and durability [45]. Thus, for the optimal mortars composition obtained according to the previous procedures, the pore size distribution of the hardened mortars and its changes due to time evolution were studied at age of 30 days and 150 days.

5.7 Thermal conductivity

Thermal conductivity of the mortars was evaluated with a portable Isomet equipment with a circular contact probe (0-2 W/(m.K) range) at lab conditions of 23ºC and 55% RH. The probe have 6 cm diameter; although the specimens

that were used only had 4 cm thickness, but values are comparable among the mortars because all the specimens have the same size.
Heat flow through an object follows the model in eq. (2), where q is the heat flux (W), A is the area perpendicular to the heat flow (m^2), λ is the thermal conductivity of the section (W/mK), Δ t is the temperature drop across the object (K) and L is the thickness of the object (m). If the test is running with a constant energy input, then eq. (2) can be used.

$$q = \lambda A \frac{\Delta t}{L} \qquad (2)$$

5.8 Thermal behaviour in unsteady state

The unsteady behaviour of mortars was tested using an innovative experimental procedure.
In order to understand what was the mortars´ behaviour in terms of unsteady state, a transient heat flow rate was imposed at all the surfaces of a prismatic mortar using preheating in a climatic chamber at (35±2) ºC. Before running any test, the specimens were conditioned in that climatic chamber, in a controlled environment with a set-point temperature of (35±2) ºC and (50±5) % RH, until constant mass was reached.

The tests were carried out in a controlled laboratory environment at 18ºC. After conditioned at 35ºC, each tested mortars was placed inside an EPS box with 20x20x15cm. Inside each box a temperature and RH sensor was placed, enabling monitoring hygrothermal variation each 5 minutes. During the test, the temperature of the mortar starts to decrease with time. For each mortar composition (CB, CC70 and CE80) three samples were tested during 2 hours and the data were recorded until mortar temperature reached lab temperature.

Measurements of temperature variation with time, as a function of tested mortar mass, were calculated. The goal was to detect the behaviour of each mortar when subjected to thermal variations that simulate what happen in summer conditions (18ºC-35ºC). Results are presented as temperature variation, taking into account the weight of each tested mortars.

6. Results and discussion

6.1 Flow table test and rheological characterization

The consistence considered adequate for cement-based rendering mortars is, according to EN 1015-3:1999 [46], 175 mm ± 10 mm, used as target in terms of water and HRWR quantity for each mortar. It was considered to correspond to workable rendering mortars. Based on this target value, some adjustments were adopted, namely in CC40, CC50, CC70 (* and **), CC80, CE70 and CE70*, in terms of w/b ratio and/or HRWR percentage (Table 9 and 10). The results are presented in Figure 6 and 7.

Table 9: Cement-cork mortars with modified compositions.

Cement-cork mortars	Identification
CC 40% HRWR 0,3% w/b=0,6	CC40
CC 40% HRWR 1% w/b=0,6	CC40*
CC 50% HRWR 1% w/b=0,6	CC50
CC 50% HRWR 2% w/b=0,6	CC50*
CC 70% HRWR 2% w/b=0,6	CC70
CC 70% HRWR 2% w/b=0,7	CC70*
CC 70% HRWR 3% w/b=0,7	CC70**
CC 80% HRWR 2% w/b=0,7	CC80
CC 80% HRWR 2% w/b=0,75	CC80*

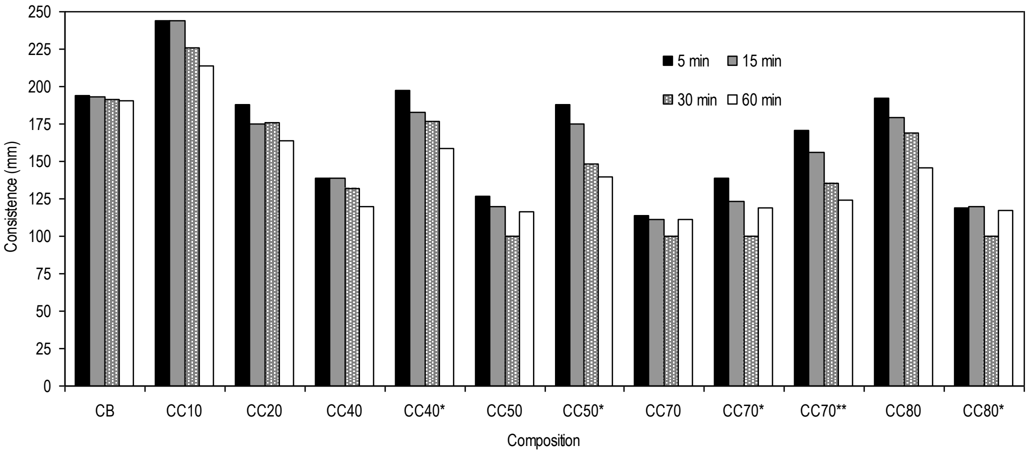

Figure 6: Consistency values obtained for the reference mortar (CB) and for the mortars with cork granulate (CC) (from 10% to 80%). The results are presented for 5, 15, 30 and 60 minutes of resting time (after mortar preparation).

Table 10: Cement-EPS mortars with modified compositions.

Cement-EPS mortars	Identification
CE 70% HRWR 0,3% w/b=0,6	CE70
CE 70% HRWR 1% w/b=0,6	CE70*

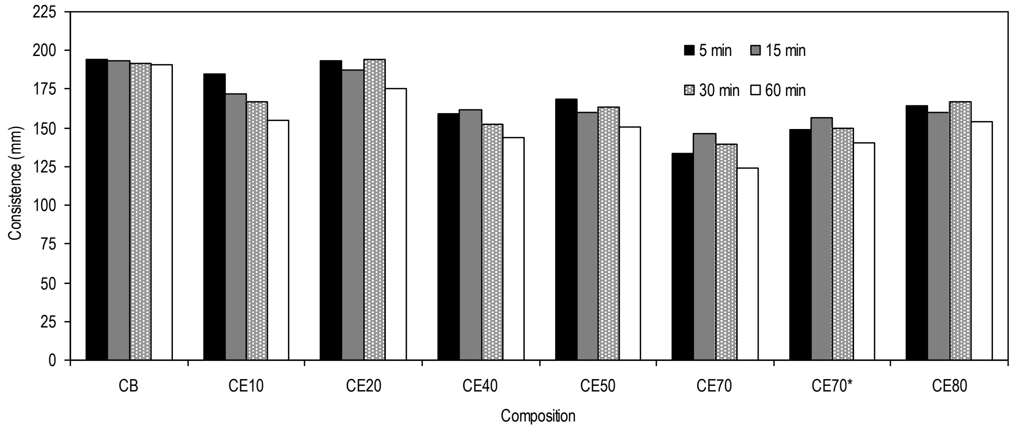

Figure 7: Consistency values obtained for the reference mortar (CB) and for the mortars with EPS beads (CE) (from 10% to 80%). The results are presented for 5, 15, 30 and 60 minutes of resting time (after mortar preparation).

According to the previous results, it is possible to get good performance up to 80% of cork in cement based mortars volume (CC80) if HRWR is well dosed (until 3% by cement mass).
The higher water absorption capacity of cork granulates compared to the sand leads to a higher w/b demand with the increasing cork dosage in mortar composition. In order to minimize w/b ratio maintaining appropriate consistency, more HRWR was used.

In order to optimize the workability of the mortar with 70% of cork, it was decided to test the effect of HWRW= 2% (w/b=0.6 and 0.7) and HWRW= 3% (w/b= 0.7). In fact, CC70** presents the best consistency for 5 minutes of resting time. However, the increase of resting time leads to a decrease of workability, especially in the first 30 minutes.

The workability decrease observed with an increasing cork dosage occurs due to the reduction on cement paste as long as cork amount is increasing. The same trend is not detected in cement-EPS mortar, probably due to the fact that cement paste content is almost the same for all mortar compositions. This comes from the fact that cork granulates and EPS beads have completely distinct densities.
On the other hand, the water absorption capacity of cork granulate is much higher than EPS beads. Cork granulates retains a larger amount of water in the initial instants, increasing its weight by about 400% (according to our lab

tests), but releases part of the water 1 hour after being in contact with it, with no benefits on mortar workability. In most of mortar compositions with EPS beads there is a workability increase especially between 5 and 15 minutes. EPS beads are composed by 90% of air and present a non-absorbent nature but when in contact with water, beads retain part of it without absorbing the water. After a certain time, this water is released by beads and absorbed by mortars which increase workability [47]. Probably this phenomenon occurs due to the fact of EPS beads release its retaining water faster than cork, enabling a recovering of mortar workability.

Concerning mortars with EPS, consistency values are near the established range up to 20% of EPS as sand replacement. For values higher than 20% in volume (CE20) the consistency values are always lower than 175mm but, when compared to the results of the cement-cork mortars, the results also show that using EPS decreases the HRWR demand, which is in agreement with Madandoust et al. [26].

Regarding the influence of resting time in mortar workability, it does not change as fast as in mortars with cork. It was also detected that for some mortar compositions there is a slightly increase of workability between 15 and 30 minutes of resting time. Thus, it means that the water retention capacity of cork is higher than for EPS beads.

Taking into account the spread measured for all the mortar compositions, as said before, an attempt to estimate the yield stress was made since the spread seems to be a more relevant parameter for estimating the material yield stress. In fact, there are several methods allowing for the prediction of the yield stress τ_0 of a given mortar or concrete without the use of a rheometer [37, 48, 49, 50]. According to ASTM mini cone for cement paste [48, 49] τ_0 can be determined by (eq. 3):

$$\tau_0 = \frac{225\rho g V^2}{128\pi^2 R^5} \qquad (3)$$

with ρ the density of the tested cement paste, V the tested volume and R the spread radius.

Since mortar rheological behaviour is mainly dependent on cement paste rheology, a cement based paste (with w/b=0.70 and HRWR=1%) was tested at different temperatures (from 5 ºC to 45 ºC) and its flocculation area was calculated (Figure 8).

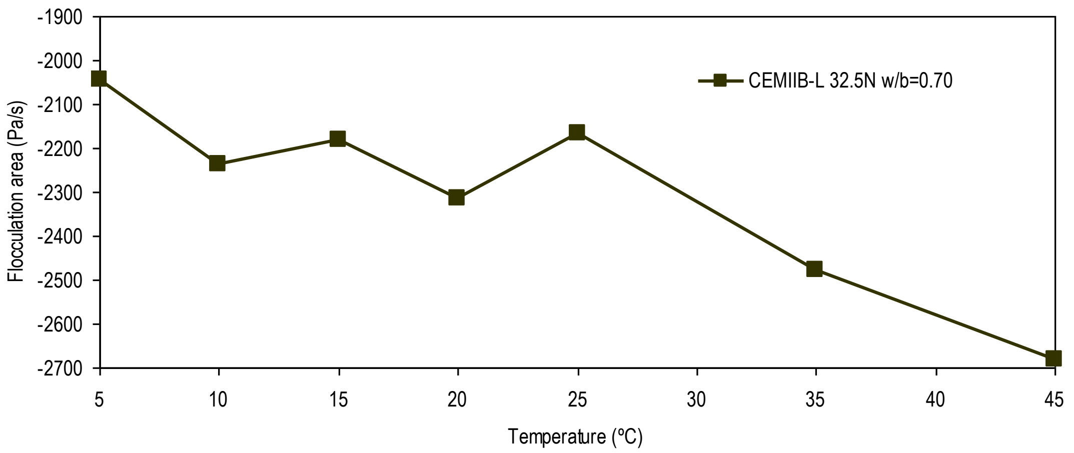

Figure 8: Flocculation area of CEMII 32.5N w/b=0.7 and HRWR=1%.

Like in the measurement of thixotropy in a loop test, the flocculation and de-flocculation areas also have the dimension of energy related to the volume of the sample sheared. The methodology used is developed in [51].
According to the previous results of paste flocculation area, it seems that there is a paste threshold temperature (T_{limit}) that separates a domain where the flocculation area is almost constant, which contrasts to another where the flocculation area starts to significantly increase. Probably, this means that in the first region (T<25 ºC) thixotropic effects are almost isolated from the irreversible effects (due to hydration). The same does not happen in the second region, where a temperature increase leads to faster hydration reactions. It is expected that this behaviour could be found in mortar in the sense that paste limitations induce similar or worst mortar behaviour.

For the steady state analysis in cement paste, the Sisko model was adopted. The modified Bingham equation (1) was chosen for yield stress and plastic viscosity determination (Table 11).

Table 11: Yield stress and plastic viscosity values of CEMII 32.5N cement paste, w/b=0.7 and HRWR=1%.

Temperature (ºC)	τ_0 (Pa)	η_p (Pa.s)
5	0.11	0.07
10	0.26	0.08
15	0.45	0.08
20	0.58	0.08
25	0.74	0.08
35	0.98	0.08
45	0.46	0.10

According to eq. 3 and taking into account all spread values for the cement-cork and cement-EPS mortars, the relation between yield value in mortars and spread diameter is presented in Figure 9. A comparison between those values and the ones presented in Table 11 shows the huge scale difference.

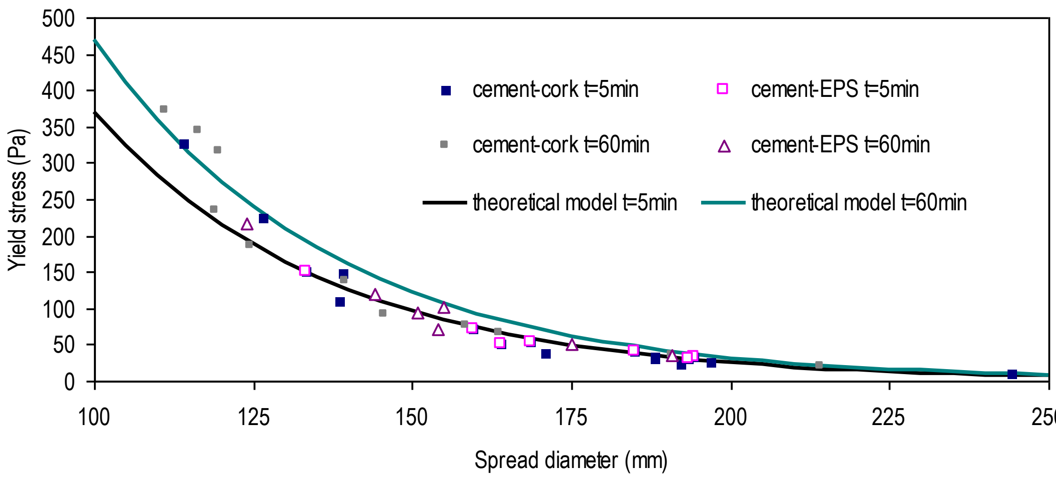

Figure 9: Relation between yield stress and spread diameter calculated with eq. 3 for the cement mortars with cork granulate and EPS beads (from 10% to 80%) (for a resting time of 5 and 60 min). Theoretical models proposed for a resting time of 5 min and 60 min.

For a resting time of 5 minutes after mortars preparation, the previous figures shows that yield stress values range from 10 Pa to 300 Pa for cement-cork mortars and from 30 Pa to 150 Pa for cement-EPS mortars.

Taking as an assumption that a typical mortar present an hardened density of 1800 kg/m^3 and that the spread diameter is the adequate for cement based rendering mortars (175 ± 10 mm), the use of eq. 3 demonstrate that the yield stress value is 50Pa. In fact, it is known that a mortar presents a self-levelling behaviour for a yield stress value smaller than 50 Pa, which is in agreement with the obtained results.

In order to find a simple relation between spread and yield stress, a theoretical model is proposed (see theoretical model curve for a resting time of 5 min in Figure 9), together with the following equation for a resting time of 5 minutes (eq. 4).

$$\tau_0 = 5500 e^{-0.054R} \qquad (4)$$

where R is the spread radius in mm.

According to this expression the mortar density variation is a less relevant parameter, at least for this type of materials, which simplify equation 3.
Taking into account the time effect, the mortar yield stress tends to increase (see theoretical model curve for a resting time of 60 min in Figure 9). Equation 5 is now proposed.

$$\tau_0 = 7000e^{-0.054R} \qquad (5)$$

A comparison between eq. 4 and 5 shows that the results change with time and yield stress expressively increases if spread diameter is less than 175 mm, which means that a mortar with these types of aggregates should present this value as the minimum spread if more open time is needed.

Flatt et al.[50] also studied this correlation between yield stress and spread diameter for cement pastes and they have shown that the yield stress obtained from a calibrated Viskomat and the yield stress obtained from a spread measurement show quantitative agreement. This is in fact a useful result for industrial laboratories that extensively use both methods.

6.2 Mechanical strength and porosity

Results of flexural and compressive strength at 28 days are presented in Tables 12 and 13 together with the coefficient of variation (COV) (the ratio of the standard deviation to the mean value). Figures 10 and 11 present the non dimensional strength values (which are a result between the divisions of each strength value by the reference values - CB) for different incorporation ratios of cork or EPS.

Table 12: Flexural and compressive strength of hardened mortar with cork granulate for the different incorporation ratios studied at 28 days of age.

Mortars with cork granulate	Flexural strength (MPa)	COV (%) - Flexural strength	Compressive strength (MPa)	COV (%) - Compressive strength
CB	5.2	7.8	24.4	2.5
CC10	4.1	1.4	15.4	13.0
CC20	4.0	6.2	16.1	8.1
CC40	2.9	6.0	10.0	2.1
CC40*	3.6	4.8	14.8	6.7
CC50	2.9	15.2	6.0	9.5
CC50*	2.7	4.8	9.2	4.1
CC70	2.5	3.0	6.4	1.5
CC70*	1.8	7.4	4.4	37.6
CC70**	1.8	12.4	4.5	16.6
CC80	1.8	8.7	5.0	6.7
CC80*	1.7	3.2	3.9	44.0

Table 13: Flexural and compressive strength of hardened mortar with EPS beads for the different incorporation ratios studied at 28 days of age.

Mortars with EPS beads	Flexural strength (MPa)	COV (%) - Flexural strength	Compressive strength (MPa)	COV (%) - Compressive strength
CB	5.2	7.8	24.4	2.5
CE10	4.1	13.3	20.9	6.4
CE20	4.1	7.9	19.2	4.1
CE40	3.4	7.6	15.1	8.1
CE50	3.2	12.0	14.0	1.4
CE70	3.0	5.6	10.3	2.7
CE80	2.7	16.4	10.7	5.6

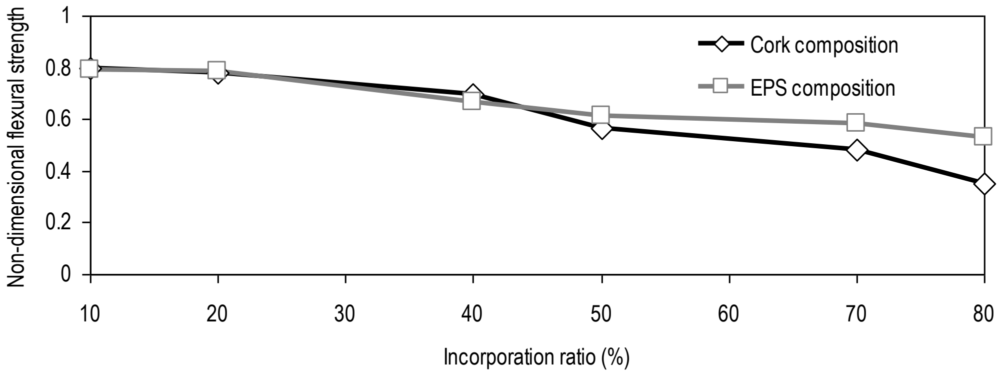

Figure 10: Non-dimensional values for flexural strength (at 28 days) for mortars with cork granulate and EPS beads (from 10% to 80%).

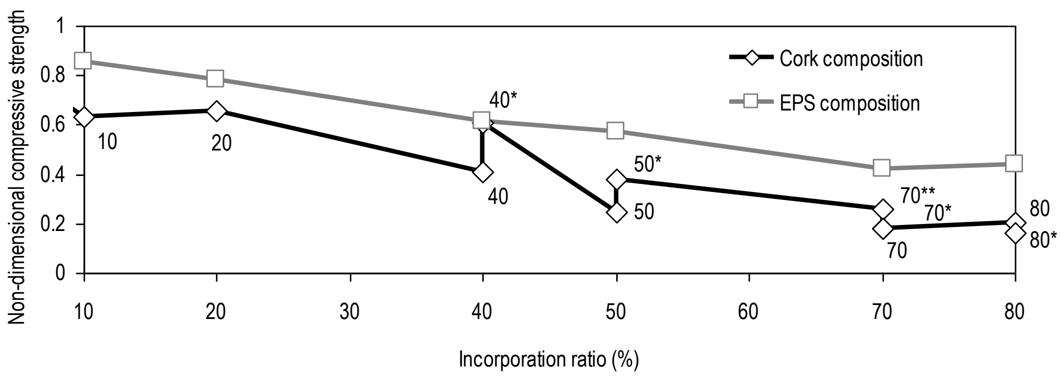

Figure 11: Non-dimensional values for compressive strength (at 28 days) for mortars with cork granulate and EPS beads (from 10% to 80%).

Table 12 and Figure 10 show that the addition of cork granulates originates mortars with substantially lower flexural and compressive strength. However, those values are still very good for rendering mortars [52, 53]. These results may be explained by a highest w/b ratio (as compared to the reference mortar) and an increase of cork dosage (with much lower mechanical resistance) as sand replacement.

Figure 10 shows that the decrease in flexural strength is almost linear for an increasing of cork or EPS dosage. It is also observed that the decrease is substantial for mortars with cork granulate. EPS bulk density is smaller than for cork which means that the mass of sand available is higher in EPS-cement mortars than in cork-cement mortars, explaining the higher compressive strength presented in EPS compositions (Figure 11). According to this figure, there is a linear decrease of compressive strength for an increasing dosage of EPS. For mortars with cork granulate the strength decrease is more expressive and more HRWR is needed to improve strength. Above 50% of cork as sand replacement there are no main differences in compressive strength of mortars and the value is just 20% of the compressive strength of a conventional mortar.

As said before, in order to understand the previous results, the mortars' open porosity was measured. Those values are presented in Figure 12.

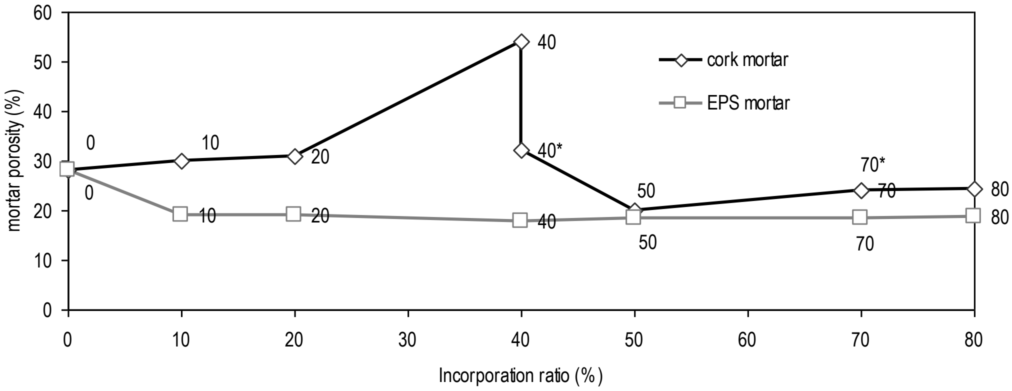

Figure 12: Mortar open porosity at the age of 28 days for cork dosage and EPS dosage (from 0% to 80%).

It can be observed that cement-cork mortar porosity does not change too much (it ranges between 20% and 30%) for the incorporation ratio tested, except for 40% where more HRWR dosage was necessary. More stable porosity can be found for EPS, with a decrease of 10% between the reference mortar and all the mortars with EPS replacing sand (from 30% to 20%).

This behaviour indicates that cork granulates do not decrease the mortar porosity, at least for the HRWR dosages adopted, which could also explain the mechanical strength evolution especially according to Figure 11 – excluding the porosity of mortar CC40, the cement-cork mortar evolution of Figures 11 and 12 are in total agreement. In fact, the cork increase does not imply the decrease of mortar´ compressive strength from an incorporation ratio higher than 40%, probably due to a correct selection of w/b and HRWR dosage.

The compressive strength of the mortars were also tested at 150 days for CB, CC50*, CC70*, CC70** and CE40, CE50 and CE80. The results are presented in Table 14.

Table 14: Compressive strength of hardened mortar with cork granulates or EPS beads for the different incorporation ratios studied (28 days and 150 days).

Mortars with cork granulate or EPS beads	Compressive strength at 28d (MPa)	COV (%) - Compressive strength 28d	Compressive strength at 150d (MPa)	COV (%) - Compressive strength 150d	Increase rate (%)
CB	24.4	2.5	34.0	11.3	39.0
CC50*	9.2	4.1	10.7	13.1	16.1
CC70**	4.5	16.6	6.1	15.1	36.1
CE40	15.1	8.1	18.5	11.0	22.6
CE50	14.0	1.4	15.7	3.5	12.3
CE80	10.7	5.6	12.6	7.4	17.8

According to the previous results, the compressive strength increase with age is higher for the reference mortar and if more cork is added to mortar composition. The same trend does not occur for mortar with EPS beads.

In fact, if the incorporation ratio of cork is 70%, the compressive strength increases 36% from 28 d to 150 d. In order to understand the previous behaviour, mercury intrusion porosimetry (MIP) was conducted on mortar samples.

6.3 Mercury intrusion porosimetry

Figure 13 presents the results of this test on mortars with 30 days and 150 days.

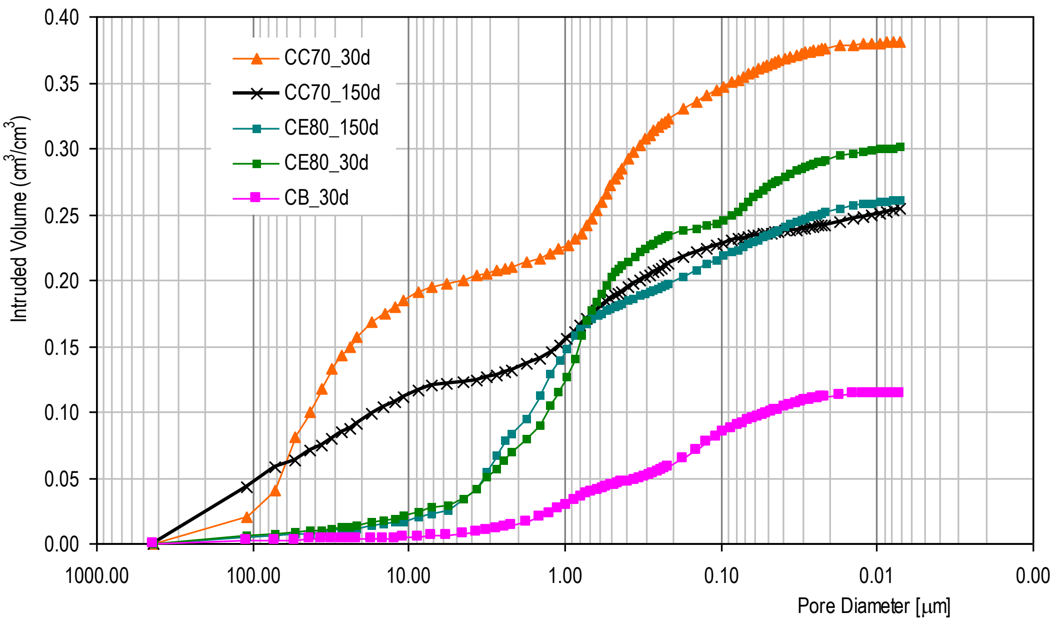

Figure 13: Effect of age (30 days and 150 days) on pore size distribution of mortars with cork granulate or EPS beads.

At an age of 30 days, the microstructure of the reference mixture, CB, and two of the mortar mixtures with best behaviour (CC70 and CE80) were examined using MIP to assess the impact of cork and EPS dosage on the pore size distribution. Increasing cork granulate dosage as sand replacement yields a coarser pore structure, as shown by the pore size distributions plotted in Figure 13.

In terms of the effect of age on mortars´ microstructure, the results presented in Figure 13 shows that there is an impressive decrease of coarser pore structure from 30 to 150 days for the mortar with cork. The same trend was not confirmed in the mortar with EPS dosage, where age seems not to affect pore size distribution.

These results may explain the mechanical behaviour of these mortars with age and are in agreement with Karade et al. [18]. In fact, the mechanical properties of cement-cork blends are not only controlled by the cork's low density, but also the interaction of cork extractives with the cement hydration process. Those extractives can inhibit the hydration process and slow down the microstructure evolution of the mortar paste.

Panesar [20] tested the influence of cork gradation on microstructure in cement based mortars. Those mixes are presented in Table 15 and the MIP results are presented in Figure 14.

Table 15: Use of cork in mortar mix design (based on [20]).

Material	Mix	Identification	Cork Size (mm)	Percentage as sand replacement (%)
Mortar	M1	Control	None	0
	M2	10%C (0.5-1)	(0.5-1)	10
	M3	10%C (2-3)	(2-3)	10
	M4	10%C (3-5)	(3-5)	10
	M5	5%C (0.5-1)+5%C (2-3)	(0.5-1) + (2-3)	5+5
	M6	5%C (0.5-1)+5%C (3-5)	(0.5-1) + (3-5)	5+5
	M7	5%C (2-3)+5%C (3-5)	(2-3) + (3-5)	5+5
	M8	20%C (0.5-1)	(0.5-1)	20
	M9	10%C (0.5-1)+ 10%C (2-3)	(0.5-1) + (2-3)	10+10
	M10	10%C (0.5-1)+ 10%C (3-5)	(0.5-1) + (3-5)	10+10

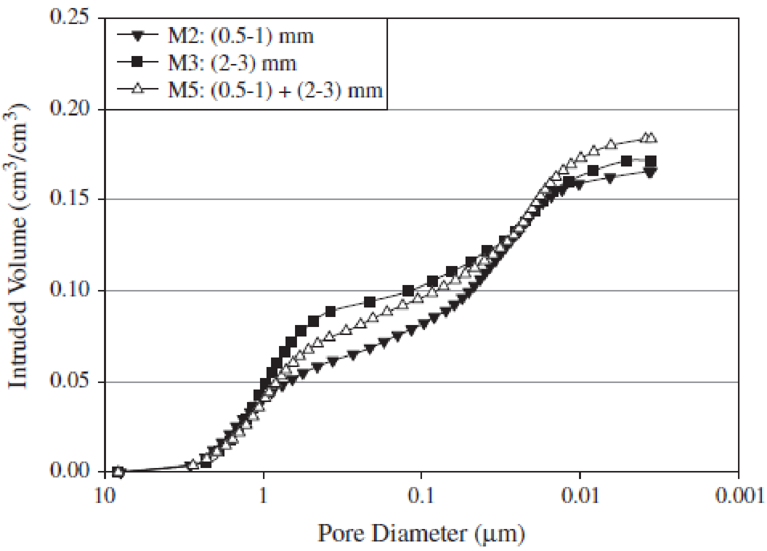

Figure 14: Pore size distribution influenced by cork size and gradation (based on [20]).

Panesar [20] concluded that the percentage of cork used as sand or stone replacement has a more significant effect on the mechanical, microstructure and thermal resistance properties of concrete–cork composites than cork size or cork gradation, which is also in agreement with results of the present paper.

6.4 Thermal conductivity

The thermal conductivity (λ) measurements for all the mortar mix designs with cork granulate and EPS beads are presented in Figure 15.

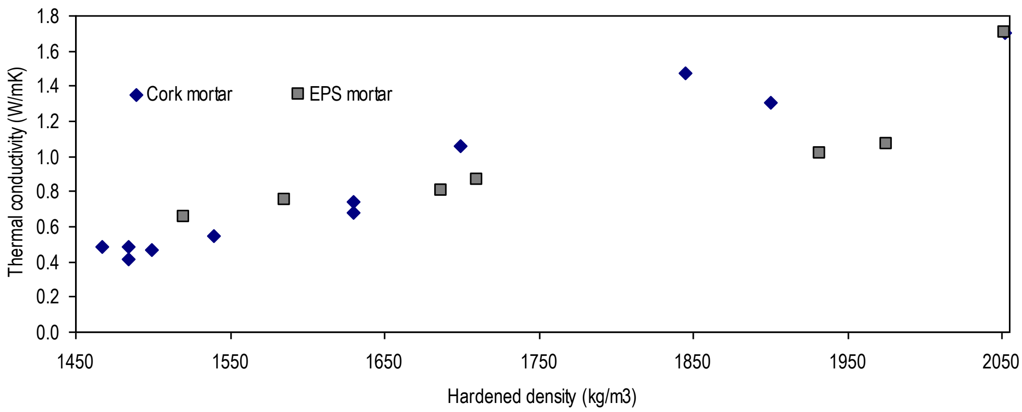

Figure 15: Relationship between mortars hardened density and thermal conductivity at 28 days.

For the mortars with cork granulate, an increasing cork dosage (which is related to a decreasing hardened density) leads to a linear decrease of thermal conductivity and this decrease is higher than for mortars containing EPS.

In fact, for the mortars with EPS beads, an increase of EPS dosage does not contribute to the decrease of thermal conductivity as fast as in the case of cork granulates. There is not a linear relation between λ and cement-EPS mortar hardened density. An impressive decrease of λ is detected between 0-10% of sand replacement (mortars with hardened density between 2050 to 1950 kg/m^3) but for higher replacements by EPS (20%-80%) the decrease is much smaller.

6.5 Thermal behaviour in unsteady state

The unsteady behaviour of CB, CC 70 and CE 80 mortars was tested using an innovative experimental procedure described in 4.8. Figure 16 presents the temperature variation per kg of mortar against time for CB, CC70 and CE80. Figure 17 presents the non dimensional temperature variation values (taking as reference CB values) for CB, CC 70 and CE 80.

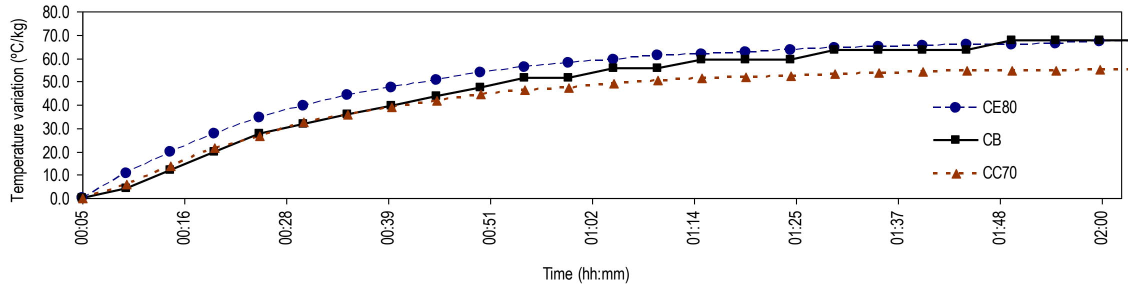

Figure 16: Temperature variation per kg of mortar against time for CB, CC70 and CE80.

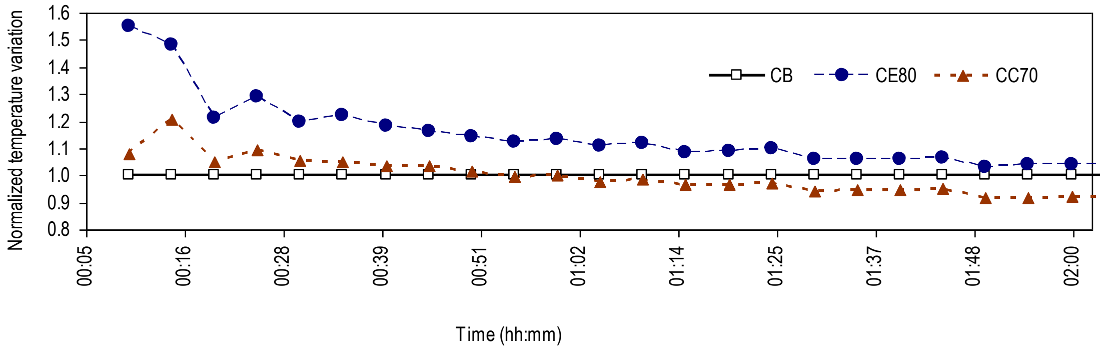

Figure 17: Normalized temperature variation against time for CC70 and CE80.

The previous mortars were subjected to thermal variations that simulate what happen in summer conditions (18ºC-35ºC). For the same initial temperature conditions, Figure 16 shows that CC70 mortars tend to present less temperature variation than CB or CE80, meaning that at the unsteady state, mortars with cork promote the reduction of heat transfer through the system, which is probably related to a higher thermal delay. In fact, [54] shows that the heat transfer through a system incorporating natural cork exhibits higher thermal delay than the extruded polystyrene (XPS), which prove the relevance of this study.

Figure 17 also proves the difference between a mortar with cork or with EPS. A normalized value less than one corresponds to less thermal variation with time when compared to a reference cement mortar (CB). Thus, it means that the thermal delay promoted by EPS mortars can not achieve the one promoted by cork mortars.

6.6 Water absorption due to capillary action of hardened mortar

Together with the previous tests, capillary action was tested. The results of capillary water absorption coefficient are presented in Figure 18.

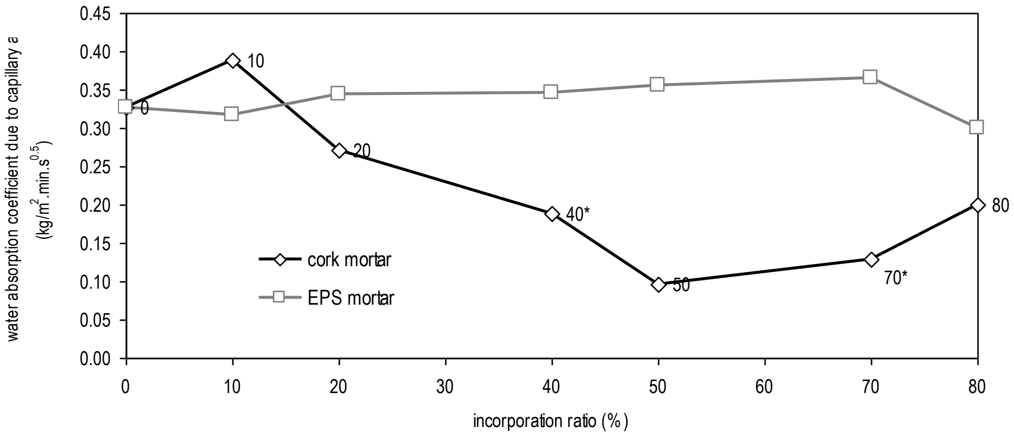

Figure 18: Water absorption coefficient due to capillary action of hardened mortar for the different incorporation ratios studied.

Taking into account only the best (the lower) water capillary absorption coefficient for each incorporation ratio of cork tested (Figure 18), it is detected a linear decrease until 50% of cork dosage as a replacement of sand (except for a replacement of 10% by cork). Between 50% and 70% the values are almost constant and are much lower than the ones presented when the sand is replaced by EPS. Concerning these mortars with EPS beads, the water absorption coefficient is almost the same and seems not to depend on the incorporation ratio used.

Those results can be explained by the existence of higher dimension voids within the hardened mortars due to the cork addition, thus maybe providing thicker capillary vessels and a smaller water flux within the mortar. Therefore, this property shows a clear improvement as cork granulates are added until at least the maximum ratio tested (80%).

In fact, the workability decrease observed in mortars with an increasing cork dosage occurs due to the reduction on cement paste as long as cork amount is increasing. The same trend is not detected in cement-EPS mortars, probably due to the fact that the amount of cement paste is almost the same for all mortars compositions, which leads to similar workability behaviour even if EPS dosage change.

On the other hand, the cement paste is the responsible for the existence of micro-pores in mortar microstructure, which enable the increasing of capillarity water absorption coefficient and explains the substantial decrease detected in cement-cork mortars.

In a cement paste, it is suggested that capillary pores larger than 10 nm influence mostly the strength and permeability, while gel pores smaller than 10 nm influence the drying shrinkage and creep [55]. The capillary pores can further be divided into large (>50 nm) and medium (50–10 nm) capillary pores. The same assumption was used for the studies presented in this paper.

Figure 19 shows the volume of pores in the three size categories for samples cured for 30 days and 150 days. This information was determined using mercury intrusion porosimetry.

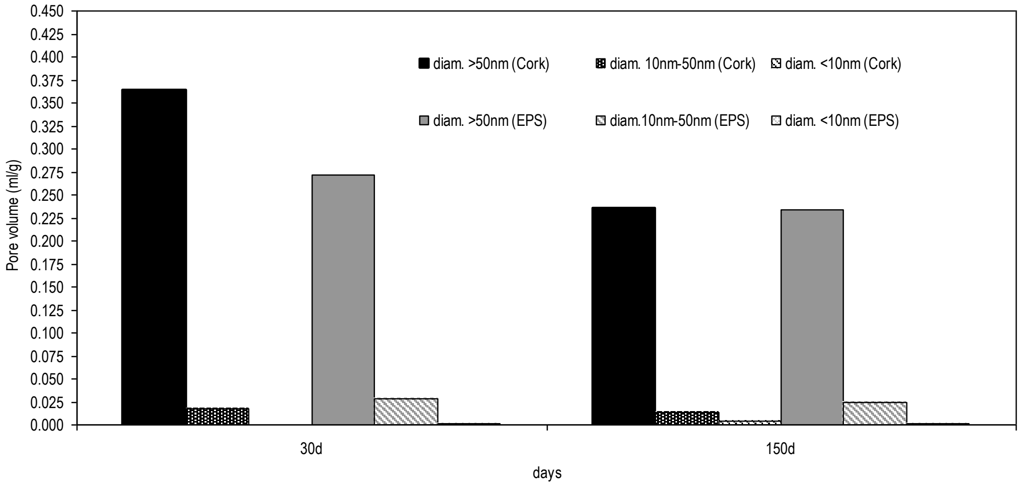

Figure 19: Volume of pores in the three size categories for samples cured for 30 days and 150 days, for mortars with cork granulate (CC70*) or EPS beads (CE80).

It can be observed that the higher size category of pores diameter is much higher for the cork compositions than for the mortar with EPS, which is in agreement with the previous results of water capillary absorption coefficient.

Besides that, there is a reduction of the higher size category of pores diameter in CC70* from 30 to 150 days, which represents a successful outcome since strength will be improved (as it was previously confirmed) and permeability reduced. This decreased permeability to liquid of cork compositions is also in agreement with [7,9]. Comparing the pores smaller than 10 nm to the total pore volume it does not seems to have an expressive relevance.

7. Conclusions

The aim of the present work is to demonstrate the advantage of cork-mortars for renderings when compared to EPS-mortars, from a thermal characteristics point of view, namely in steady and unsteady conditions. Besides that, cork is a natural product and cork granulates are a by-product from the industry and its use has environmental advantages.

The reduction of energy consumption in the buildings sector is an important measure to help reduce energy dependency. For this purpose, the thermal behaviour of buildings envelope needs to be improved and appropriate energy performance requirements for technical building systems should be established. Thus, it was intended to develop improved insulation materials, such as specific rendering mortars, able to reduce condensation effects and minimize heat transfer in thermal bridges, since its impact is significant especially in western Mediterranean climate.

Cement mortars and cement-EPS mortars are used as a reference as their properties are easily recognized compared to cement-cork mortars. In order to optimize composition, several studies were made concerning fresh and hardened state behaviour of mortars taking into account several properties, namely: rheological, mechanical, microstructure evolution with time and thermal behaviour.

- Concerning the fresh state behaviour of mortars:

The workability decrease observed with an increasing cork dosage in a cement based mortar is more expressive than for cement-EPS mortars, mainly due to the higher water absorption capacity of cork granulates in comparison with EPS beads. In mortar compositions with EPS beads there is a workability increase especially between 5 and 15 minutes due to the water released by beads, with benefits on mortar workability.

Through the use of a sophisticated rheological analysis, an impressive workability loss was detected if cement paste temperature increased beyond 25 ºC. It is expected that this behaviour could be found in mortars in the sense that paste limitations induce similar or worst mortars behaviour.

A simple theoretical model is proposed for the relation between yield stress and spread diameter for a resting time of 5 min and 60 min. A comparison between those models shows that the results change with time and yield stress expressively increase if spread diameter is less than 175 mm, which means that a mortar with these types of lightweight aggregates should present this value as the minimum spread if more open time is needed.

- Concerning the hardened state behaviour of mortars:

Mechanical strength tends to decrease if more cork/EPS dosage is used. There is a linear decrease of compressive strength for an increasing dosage of EPS. For mortars with cork granulate the strength decrease is more expressive and more HRWR is needed to maintain strength. Probably, an effort to use other type of cork granulates treatment should be planned if the target is to optimize mortar strength, although this is not a crucial factor for rendering mortars.

A microstructural analysis induces that the mechanical properties of cement-cork blends are not only controlled by cork's low density, but also by interaction of cork extractives with the cement hydration process. Concerning the time effect, there is a reduction of the higher size category of pores diameter from 30 to 150 days, which represents a remarkable result since strength will be improved (as it was previously confirmed) and water permeability will decrease, which is an advantage from a rendering mortar durability point of view. The same trend was not confirmed for the mortar with EPS dosage, where age seems not to affect pore size distribution.

For the mortars with EPS beads, an increase of EPS dosage does not contribute to the decrease of thermal conductivity as fast as in the case of cork granulates. Cork granulate can decrease the conductivity of conventional cement mortar in 75%, while EPS can only contribute to a decrease of 60%.

Concerning the unsteady state analysis, cork mortars show less thermal variation with time when compared to a reference cement mortar. Thus, it means that the thermal delay promoted by cork is higher than the one promoted by EPS.

The obtained results highlight some advantages of cork-cement (and of EPS-cement) mortars, showing that the improvement of rendering mortars for thermal bridges corrections with aggregates such as cork (or EPS) are a possibility that should be further explored. Eliminating or at least reducing thermal bridges with insulation mortars can contribute for the interior air quality, for a higher comfort with lower energetic costs and for an increased durability of the external envelope building elements. For that purpose, the sustainability of use of cork by-products must by particularly emphasized.

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