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ORIGINAL ARTICLE

Drying induced moisture losses from mortar to the environment. Part I: experimental research

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Abstract Moisture conditions in the pore structure of hardening cementitious materials are known to have determinant influence on the onset and continuance of hydration reactions. Moisture loss from regions near exposed surfaces may jeopardize the quality of concrete cover in terms of both mechanical and durability issues. In addition, drying shrinkage, a phenomenon directly related to a moisture loss to the environment, is known to be responsible for several surface cracks that impair durability performance and pose aesthetical problems. Furthermore, evaporative cooling that occurs in concrete surfaces in the first minutes just after formwork removal may cause thermal cracking. For the above mentioned reasons, it is important to assess the mechanisms of moisture losses from cement-based materials to the environment, in order to rationally establish curing criteria. This paper describes an experimental campaign conducted with the purpose of better understanding the effect of various environmental conditions on the referred moisture interactions, accounting for influences such as the environmental temperature, the relative humidity (RH), the wind speed and direction, as well as the duration of curing. Numerical simulations with comparisons against test data, as well as some sensitivity analyses, are relegated to the companion paper that follows in this issue.

Résumé *Les conditions d'humidité présentes dans la microstructure des matériaux cimentaires au jeune age ont une influence déterminante sur la prise et la continuation des réactions l'hydratation. La perte d'humidité près des surfaces exposées du béton peut compromettre certaines propriétés mécaniques et la durabilité du béton en surface. Aussi, le retrait de séchage—un phénomène directement lié aux pertes d'humidité dans le béton—peut causer la fissuration du béton, ce qui risque d'affecter sa durabilité et son esthétique. De plus, après le décoffrage, le refroidissement par évaporation peut provoquer une certaine fissuration thermique à la surface du béton. Pour ces raisons, il est important d'évaluer les mécanismes d'échange d'humidité entre les matériaux cimentaires et l'environnement extérieur afin d'établir de façon rationnelle des critères de cure humide.*

Cet article décrit une campagne expérimentale réalisée dans le but de mieux comprendre les effets de diverses conditions environnementales sur les

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interactions d'humidité en considérant l'influence de plusieurs variables telles que la température ambiante, l'humidité relative, la vitesse et la direction du vent, ainsi que la durée de cure humide du béton.

La comparaison de simulations numériques avec les résultats expérimentaux ainsi que plusieurs analyses de sensibilité sont présentées dans un deuxième article publié dans ce numéro (partie 2).

Keywords Cement · Moisture · Evaporation · Evaporative cooling · Experimental campaign

1 Introduction

1.1 Overview

Moisture movements inside hardening and hardened concrete have important consequences in many fields. In hardening concrete, water shortage due to self-desiccation leads to a deceleration and minimizes the extent of the hydration reactions of cement. On the other hand, near the surface of hardening concrete water shortage due to evaporation onto the atmosphere may be responsible for abrupt drops of the hydration reaction rate, leading to very coarse pore structures, with negative consequences in what concerns to durability and strength of the concrete cover. The referred water shortage in cementitious materials also causes volumetric changes known as shrinkage, which are usually classified as autogenous shrinkage when the water is consumed by self-desiccation or as drying shrinkage when water is removed by evaporation from the material. Accordingly, none of these two shrinkage mechanisms causes uniform shrinkage strains at a cross-sectional level, and thus, even if no external mechanical restraint exists, self-equilibrated stresses will arise that may reach the tensile strength of the material and cause cracking, with detrimental effects to the aesthetics and durability of structural elements.

Therefore, a good knowledge of how moisture is removed from the pore structure of the paste is a quite relevant issue. In this paper an experimental campaign carried out to better understand the effects of environmental conditions on moisture loss from freshly cast mortar specimens is described in Sect. 2, and the results are discussed in Sect. 3. Influences of the following environmental conditions are analyzed: temperature, relative humidity (RH), air velocity and duration of moist curing (in this paper curing is referred to as the maintenance of moisture conditions that promote the hydration of cement). Previous research in the field of experimental observation of moisture interactions between concrete and the environment can be found in Selih et al. [1, 2].

Another relevant issue concerned with moisture exchanges in cementitious materials is the so-called ''evaporative cooling'': to initiate evaporation water has to overcome a barrier (the latent heat of vaporization), related to the energy that must be supplied to the evaporating molecules to accomplish the phase change from liquid to vapour. When this energy is supplied by the mortar/concrete, and water starts a sudden evaporation—for instance upon formwork removal—a temperature drop is engendered in the cover, which corresponds to the evaporative cooling phenomenon, reported for concrete by Kovler [3]. The corresponding volumetric contraction near the surface induces tensile stresses in this region, whose magnitude is important in correspondence to a possible thermal cracking, thus the importance of studying this phenomenon. In this paper an experimental trial on evaporative cooling is presented, whilst its numerical simulation is discussed on the companion paper that follows.

1.2 Drying of porous media

Due to the nature of their internal structure, cement-based materials are classified as porous media. The range of pore diameters existing in concrete, mortar or cement pastes is quite wide, and spans from radiuses as small as 10^{-9} m (gel pores) up to 10^{-2} m (air voids). These pores may be more or less interconnected, leading to a multitude of possible moisture paths.

The mechanism of drying of porous materials is usually described as occurring in three main phases [4–6] depicted in Fig. 1, where schematic plots of the rate of evaporation and of the total weight loss of an initially saturated body may be observed. During an initial period (stage I) enough water exists on the surface of the porous body (meaning that either a film of water exists on the surface, or surface pores are saturated enough to produce a similar effect), and so the drying rate is mainly controlled by the surrounding environment (radiation, wind, air temperature and

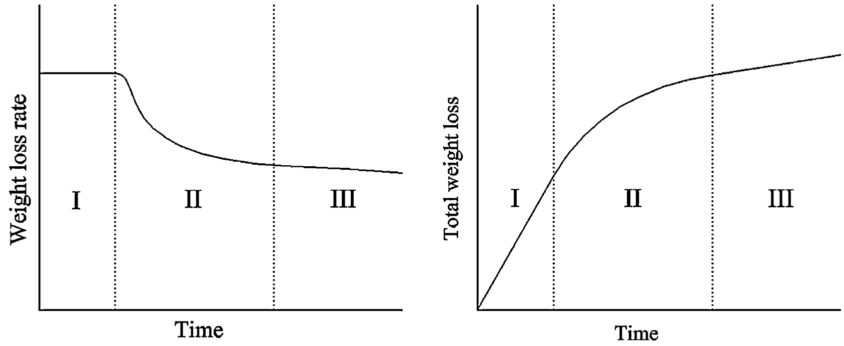

Fig. 1 Weight losses along drying

humidity, etc.), rather than by the moisture profile inside the solid. Therefore, during this environmentally controlled evaporation stage the drying rate is constant—similarly to what occurs on a free water surface—as the moisture transport inside the material is faster than the mass transfer out of the body due to evaporation. Note that in the case of freshly cast cementitious materials, the mechanism of bleeding helps the prolongation of stage I.

As drying proceeds (stage II), the rate at which water is supplied to the body surface due to capillarity becomes less than the rate at which the liquid evaporates, and so the water film that initially existed on the that surface starts to become largely disrupted. As a consequence, the global drying rate decreases during this phase.

Finally (stage III), a residual drying phase occurs, which may persist as a near steady-state condition for long periods of time. This stage starts when the body surface has become so desiccated that further conduction of liquid water to the surface is limited to the few small-sized pores that remain totally or partially saturated, in equilibrium with the surrounding environment [6]. Water transmission across the desiccated surface occurs primarily due to the slow process of vapour diffusion, and accordingly this stage of evaporation is said to be diffusion controlled.

In cement hydration research it is generally accepted that when RH inside the pore structure of partially hydrated cement drops to bellow 80% further hydration is almost negligible [7–10], and for practical purposes it could be considered that such reaction ceases. The experimental research of Patel et al. [8] goes further, and suggests that only for RH values very near 100% (over about 97%) the hydration reactions could be guaranteed to proceed with rates of the same order of magnitude as under completely saturated conditions. Accordingly, it is reasonable to assume that as soon as the pores located near the surface become non-saturated (i.e., the RH drops bellow ~100%) cement hydration reactions of such zone are jeopardized. One possible indirect way to identify this situation is by monitoring the stages of drying: as soon as stage I reaches the end, and stage II begins, it is plausible to consider that hydration of surface areas becomes compromised. Therefore, based on this transition in the drying process it is possible to estimate the time lapse between the end of curing procedures (if they exist) and the onset of hindering of the hydration reactions near the body surface.

2 Experimental program

As stated on Sect. 1.1, an experimental campaign was undertaken to assess the many influences that affect the moisture removal from mortar specimens, having in mind the considerations related to drying of porous media referred in Sect. 1.2.

For all the experiments in this research, mortar specimens cast with ordinary Portland cement were used. Two water/cement (w/c) ratios were studied: w/c = 0.35 (mixes named as 'H') and w/c = 0.55 (named as 'N'), with the compositions reproduced in Table 1. The water content in sand was measured immediately before casting, and the proportions of the mortar mixes components were adjusted in order to assure that the final w/c ratios were 35% and 55%, respectively for the 'H' and 'N' compositions. The general idea of most of the experiments was to study the effect of exposing mortar specimens to different environmental situations (in terms of temperature, RH, wind speed or even age of exposure) on the loss

Table 1 Composition of the used mortars

	Water (Kg/m^3)	Cement (Kg/m^3)	Sand (Kg/m^3)
w/c = 55 − N	311	565	1315
w/c = 35 − H	257	734	1315

of water out of those porous media. For the assurance of environmental conditions in terms of temperature and RH, controlled environment chambers were used. For the experiments to simulate the influence of wind a wooden wind tunnel and a fan were used. For ages of exposure greater than 0 days initial sealing of specimens was undertaken. At the end of this section experiments regarding evaporative cooling are also presented, reporting the measured temperature drops that occurred in mortar specimens immediately after exposure.

For most of the tests in this paper, two specimens were cast per situation. In addition, and to compare the evaporation from a water surface with the ones from the mortar specimens, containers with water samples were also tested for all the analyzed environmental conditions.

2.1 Effects of temperature and relative humidity

Three combinations of temperature (T) and RH conditions were considered for the two mortar compositions: (i) T = 20°C and RH = 60%; (ii) T = 35°C and RH = 30%; (iii) T = 60°C and RH = 60%. The specimens were cast at a temperature of 20°C into a cylindrical container with an internal diameter of 5 cm and a height of 5 cm. After casting, no curing measures (that is, sealing, submersion or cover) were adopted, and the specimens were subjected immediately to the environmental conditions (i–iii). Weightings in a high precision weight scale (with a resolution of 0.001 g) were conducted for all specimens within regular intervals, selected in accordance to the observed gradients of weight losses.

2.2 Effect of wind

To investigate the effect of wind on evaporation from mortar surfaces, tests under three distinct wind speeds were conducted. The size of the mortar specimens for these experiments was 7.3 × 5.1 × 3.0 cm prisms (approximately paralelipipedal), and drying was only allowed by the top surface, with dimensions 7.3 × 5.1 cm (see photo in Fig. 2). Casting, curing

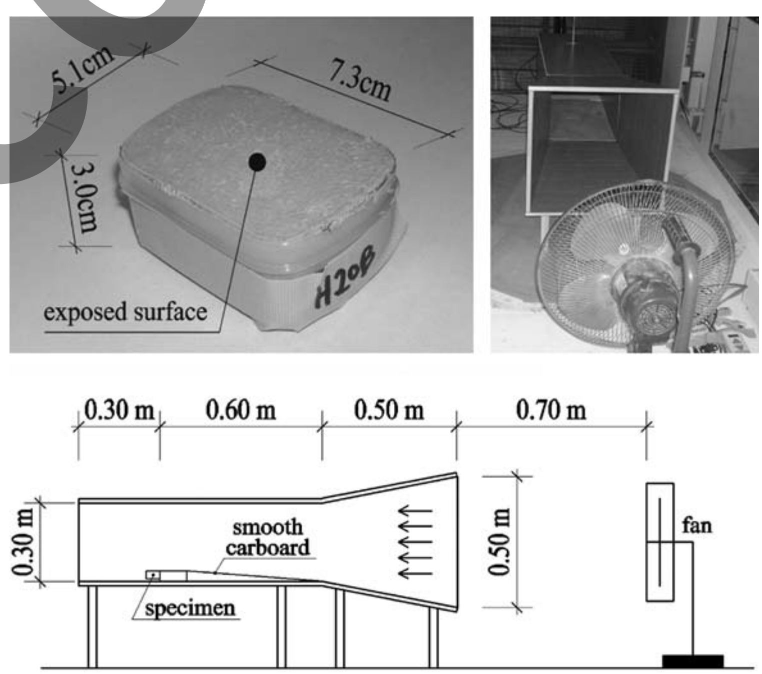

Fig. 2 Photo of the prismatic specimen (upper left); photo and scheme of the hand-made wind tunnel

and weight measurement procedures were the same as mentioned in paragraph 2.1. The tests were carried out in a controlled environment with $T = 20°C$ and a RH = 60%.

For wind testing, an ordinary fan combined with a hand-made wind tunnel (based on the one formerly mentioned by Sun and Marrero [11]) were used, according to the setup and geometry depicted in Fig. 2. Three different wind speeds (v) inside the wind tunnel were tested: v = 1.8, 3.3 and 4.2 m/s. These wind speeds were measured with a hot wire anemometer placed 130 mm above the exposed surface of the specimens.

Since only a single wind tunnel was available, the three wind speed situations were not tested simultaneously. Therefore, as the experiments were started immediately after casting, three mortar batches (mixed at different dates) were necessary. Simultaneously with the evaporation tests under each wind speed, control specimens not subjected to forced wind were also measured. With this strategy the repeatability of both the experimental conditions and the mortar casting/mixing operations was checked.

2.3 Effect of age of sealing removal

In this set of tests, the specimens, with the same prismatic geometry described in Sect. 2.2, were sealed immediately after casting and maintained that way until the following ages: 1, 3 and 7 days. Upon sealing removal, which exposed solely the top 7.3 × 5.1 cm specimen surface, some water drops that remained were removed with the aid of a moist cloth. All tests were conducted with the 'N' mortar composition, under an environment with $T = 20°C$ and RH = 60%. In terms of wind speed, three conditions were considered: v = 0, 1.8 and 4.2 m/s. The number of tested specimens per environmental situation is summarized in Table 2. For the v = 4.2 m/s case one specimen out of each pair was placed with the exposed surface vertically, facing the wind stream, in order to investigate the effect of the wind incidence direction on the water loss from the specimen.

Table 2 Number of specimens per environmental situation

	No wind	1.8 m/s wind	4.2 m/s wind
1 day removal	3	2	2*
3 days removal	2	2	2*
7 days removal	1	–	–

* One of the specimens with the evaporating surface in vertical direction, facing upstream

2.4 Effect of evaporative cooling

Using prismatic specimens with the same geometry adopted in Sect. 2.2 and 2.3, and a mortar composition 'N', two specimens were cast with two embedded thermocouples, one 0.5 cm below the exposed surface, and the other at a depth of 2.0 cm. Moreover, two additional specimens were cast to monitor the rates of evaporation via weight measurements. All specimens were cast in a $T = 20°C$ environment and immediately sealed; afterwards they were placed in a controlled environment chamber at $T = 36.4°C$ and RH = 30%. The choice of a high temperature and low humidity environment was related to the purpose of obtaining a high, yet feasible surface temperature variation due to evaporative cooling. After 1 day of sealed curing, measurement of temperatures started, and the sealing was removed from the top surface of the specimens.

3 Discussion of experimental results

The discussion of the obtained results is presented in the same order and topic sub-division as adopted in Sect. 2.

3.1 Effects of temperature and relative humidity

Measurements performed for the experiments described in Sect. 2.1 are depicted in Figs. 3–5 for environments (i–iii). From these figures it becomes clear that good coherence was obtained in measurements made for the specimens within each pair. Also, the evaporation rate is very similar for water and mortar specimens during the initial period (stage I of evaporation) for the three environmental conditions. This indicates that during this period the mortar surface is able to remain saturated (or in almost saturated conditions) long enough to keep evaporation environmentally controlled. The end of this phase is reached due to shortage of water on the drying surface, as a consequence of the mechanism explained in Sect. 1.2, as well as due to consumption in the cement hydration reactions. Besides, the

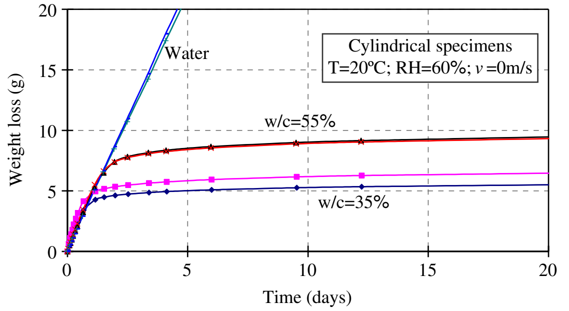

Fig. 3 Weight losses for environment with T = 20°C, RH = 60%

increasingly denser pore structure of cement increases the difficulty for the water to migrate from the core to the evaporating surface of the specimen. Bleeding may also influence the transition from the environmentally controlled phase to the diffusion controlled one, as it engenders a supply of water to the surface, maintaining it wet for longer times. In the cases reported in this paper, the observed bleeding was small or even negligible, and thus it can be considered to have had a minor contribution to the observed results.

Regarding the evaporation rates in the water specimens, some interesting remarks can be made by recalling the water evaporation formulas from Menzel [12]:

$$q_s = E\,(e_s - e) \tag{1}$$

$$E = 2.188 \times 10^{-8} + 1.859 \times 10^{-8} V \tag{2}$$

where q_s is the water vapour flux from the evaporating surface [kg m^{-2} s^{-1}], E is the moisture emissivity coefficient [kg m^2 s^{-1} Pa^{-1}], e is the vapour pressure

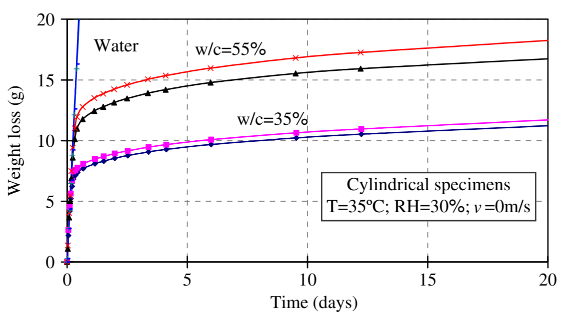

Fig. 4 Weight losses for environment with T = 35°C, RH = 30%

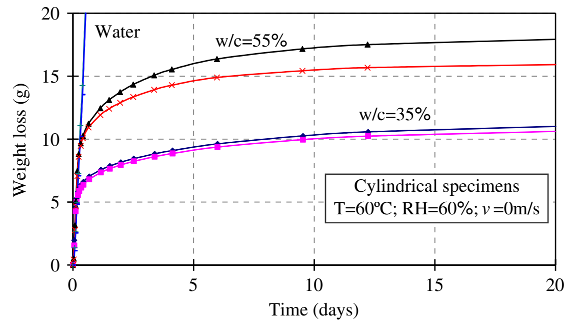

Fig. 5 Weight losses for environment with T = 60°C, RH = 60%

of the surrounding environment [Pa], e_s is the vapour pressure of the surface (saturated conditions) [Pa] and V is the air velocity measured 0.50 m above the evaporating surface [m/s]. Analyzing Eq. 1 two contributions may be individualized: the moisture emissivity coefficient that is dependent on the wind speed, and the vapour pressure differential between the liquid and the environment. The saturated vapour pressure is temperature dependent, and it may be computed by the use of the Clausius Clapeyron equation:

$$e_s = p_0\, e^{-\frac{H_{vap}}{R}\left(\frac{1}{T_s} - \frac{1}{T_0}\right)} \tag{3}$$

where p_0 is the reference pressure (1.01 × 10^5 Pa), T_0 is the reference temperature (373 K), R is the universal gas constant (8.314 J/mol K) and H_{vap} is the evaporation heat of water at the reference temperature (40.7 × 10^3 J/mol). The vapour pressure of the environment may be obtained by direct measurement, or by multiplying the RH by the saturated vapour pressure.

In Table 3 a summary of the main experimental observations for the three selected environmental conditions and respective numerical calculations performed with Eqs. 1–2 is presented.

It can be observed that the rates of weight loss for environments (ii) and (iii) are much higher than the one measured in situation (i), which can be explained by the very large difference that can be found in the magnitudes of the vapour pressure differences (henceforward referred to as 'driving potential'). Justification of the differences in the evaporation rate for situations (ii) and (iii) is not so straightforward: in fact, taking solely the driving potential into account

Table 3 Evaporation from cylindrical shaped water specimens

Environment	T (°C)	RH (%)	Measured rate of weigh loss (g/day)	$e - e_s$ (Pa)	E (kg/m^2/s/Pa)	Estimated v (m/s)
(i)	20	60	4.4	936.3	2.79×10^{-8}	0.33
(ii)	35	30	39.1	3933.1	5.85×10^{-8}	1.97
(iii)	60	60	36.9	7967.3	2.73×10^{-8}	0.29

the expectable evaporation rate for situation (iii) should be greater than for (ii), according to column 5 of Table 3. A crucial aspect that should be kept in mind in this comparative study is the following: the chamber adopted for the environmental condition (ii) had more ventilation requirements than the one used to create the environmental conditions (iii). Therefore, combination of the moisture emissivity coefficient with the driving potential may have led to a higher rate of evaporation for situation (ii). Computing the emissivity coefficient from Eq. 1 and applying Eq. 2 allowed the estimation of wind speeds for the three environments as shown in the last column of Table 3.

In the three studied environments the transition from an environmentally controlled evaporation to a diffusion controlled one occurs later for the 'N' composition than for the 'H' one, and the intermediate period seems to last longer for the 'N' composition, as it can be seen in Figs. 3–5. This is probably due to a combination of factors: lower amount of water available in the 'H' composition; higher cement content in the 'H' composition that increases self-consumption of water; faster build-up of a denser pore structure for the 'H' composition. In what concerns to the total weight losses at 20 days, they were higher for situations (ii) and (iii) than for (i). The reason for this is that in situations (ii) and (iii) much higher quantities of water were removed by the environment before the mortar pore structure had the time to become so dense as to hinder migration of water towards the evaporating surface.

3.2 Effect of wind

Results of the experimental campaign to evaluate influence of wind on the evaporation from freshly cast mortar specimens are depicted in Figs. 6–9, which report the weight losses from the prismatic specimens as a function of time for each wind speed. Once again, good coherence was found on the results within each pair of specimens. Also, consistency of results between the various tests conducted for the stagnant air situation confirms the good repeatability of the adopted experimental procedures.

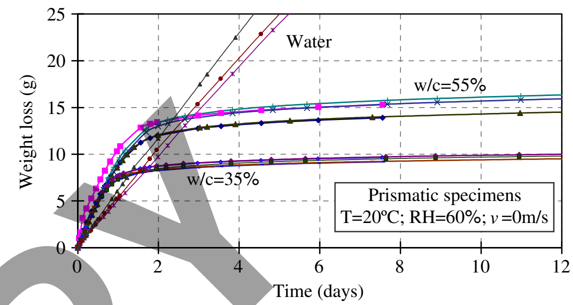

Fig. 6 Weight losses for wind with v = 0 m/s

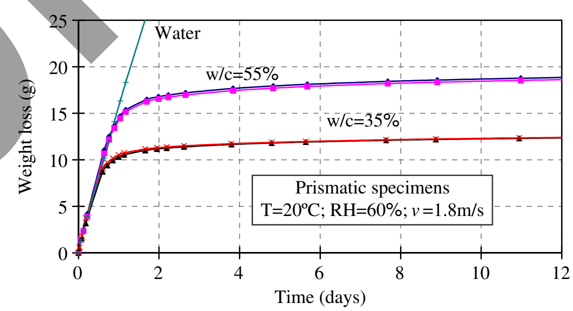

Fig. 7 Weight losses for wind with v = 1.8 m/s

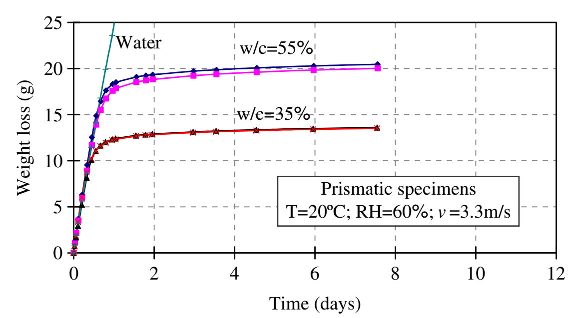

Fig. 8 Weight losses for wind with v = 3.3 m/s

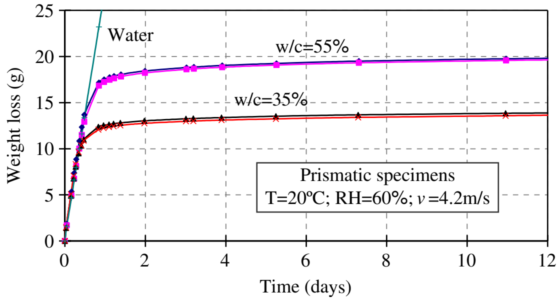

Fig. 9 Weight losses for wind with v = 4.2 m/s

For all experiments under forced wind the initial rate of evaporation from water samples matched the rate of evaporation from mortar specimens during the environmentally controlled phase. In the case of the stagnant air tests (Fig. 6) this match was not so good, unlike it happened in the set of experiments described in Sect. 2.1 for the same environment (yet cylindrical specimens—see Fig. 3). No explanation for faster evaporation when cement is present could be found in the bibliographic review that was made for this research. Having ruled out the possible effect of temperature rise due to heat of hydration (once measured temperature rises were very low and cannot account by themselves for the observed differences), the most plausible cause for the observed tendency may rely on a possible acceleration of evaporation rates due to the chemical reactions of cement that occur at early stages.

As expected, the initial evaporation rates increased with the wind speed in a quite consistent manner when compared to the predictable tendencies of Eq. 2. Yet, in what concerns the overall trend of the moisture loss curves it is evident that there are more important differences when the stagnant air situation (Fig. 6) is compared to the forced wind situations (Figs. 7–9), than between the forced wind situations themselves. This can be confirmed by comparing the total weight loss at the age of 8 days for w/c = 0.55: 15 g for v = 0 m/s; 18.4 g for v = 1.8 m/s; 20 g for v = 3.3 m/s and 19.6 g for v = 4.2 m/s. The unexpected slightly larger total moisture loss for the 3.3 m/s wind speed than for v = 4.2 m/s leads to the conclusion that at this level of wind velocities the real differences in the overall moisture losses are small enough to be overcome by inevitable inaccuracies in the experimental campaign.

The tendency for earlier transition to diffusion controlled evaporation in the 'H' mortar when compared to the 'N' mortar is also confirmed in Figs. 6–9. Furthermore, such transition occurs sooner for increasing wind speeds.

Assuming completion of stage I of drying when evaporation from mortar specimens starts to deviate from what is observed in water samples, duration of this phase as a function of the wind speed is plotted in Fig. 10 for the two mortar mixes under study. It is interesting to observe that the duration of such stage is shortened as the wind speed increases, and that the ratio between the length of stage I for mortars 'N' and 'H' is always about 1.6, which is also the quotient between their w/c ratios. This points to the duration of the drying phase I to be linearly dependent on the available water in the mix.

3.3 Effect of age of sealing removal

Regarding the experimental campaign focused on the influence of the age of sealing removal, Figs. 11–13 report the monitored weight loss evolutions, taking also into account the relevant wind speeds. From these figures it is noticed that water losses are reduced as the age of sealing removal increases. This tendency can be confirmed by comparing the average water losses 9 days after sealing removal and for v = 0 m/s: for a removal age of 1 day the water loss is about 8.2 g (Fig. 11), for 3 days it reaches 6.3 g (Fig. 12) and for 7 days it becomes about 5.1 g (Fig. 13). Also, transition to diffusion controlled evaporation seems to occur sooner for later sealing removal—see Fig. 14. These trends are most probably due to the fact that upon later sealing removal a denser pore structure exists, and less water is likely to be available after cement hydration.

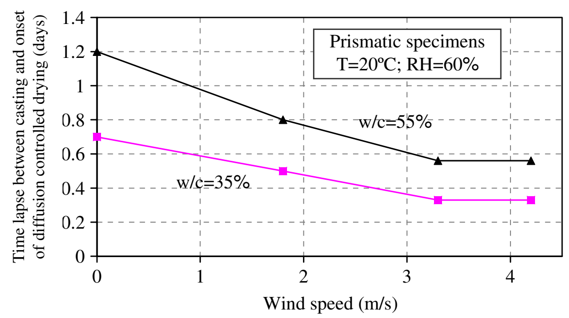

Fig. 10 Transition to diffusion controlled drying as a function of wind speed

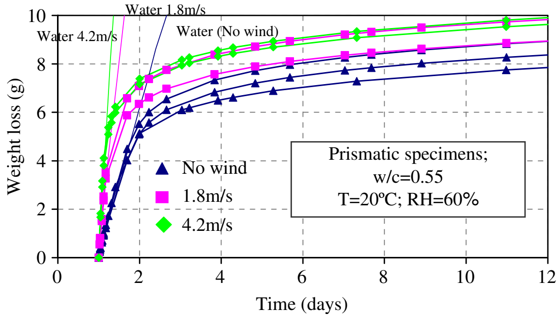

Fig. 11 Weight losses for sealing removal at 1 day of age (w/c = 0.55)

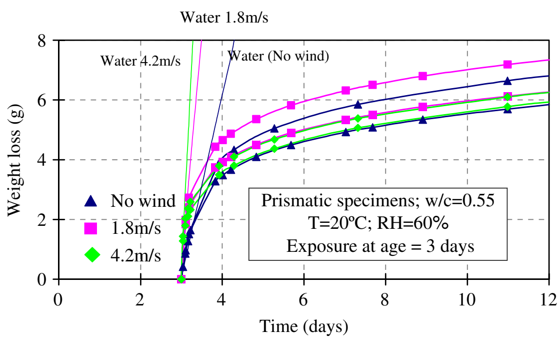

Fig. 12 Weight losses for sealing removal at 3 days of age (w/c = 0.55)

All mortar specimens appear to exhibit the same trend as that of the companion water samples in what concerns the rate of evaporation immediately after sealing removal (see Figs. 11–13).

For sealing removals occurring not before the age of 1 day the effect of wind speed on the evaporation seems to be much smaller than what happened in the case of exposure right after casting. This is a

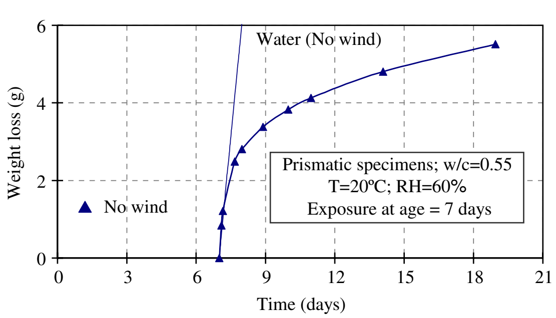

Fig. 13 Weight losses for sealing removal at 7 days of age (w/c = 0.55)

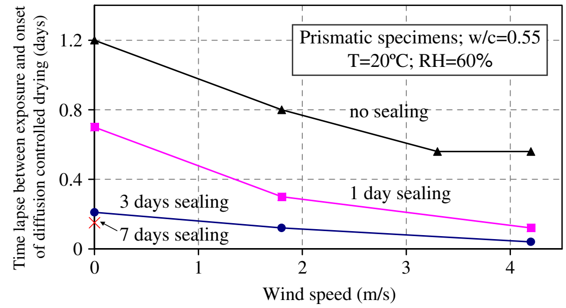

Fig. 14 Transition to diffusion controlled drying as a function of wind speed (w/c = 0.55)

consequence of the already mentioned anticipation of onset of the diffusion controlled evaporation that takes place when specimens are initially sealed: from then on, the wind speed has no effect on the evaporation rate. So, the small differences in the weight losses under different wind speeds are mostly due to the evaporation that occurred during stage I, rather than during the diffusion controlled phase.

According to Figs. 11 and 12 it is also possible to observe that the two pairs of specimens that were placed in different relative positions to the wind direction for v = 4.2 m/s exhibited almost the same weight losses during the whole duration of the experiment. This result points to a possible independence of the water loss from cementitious materials with respect to the wind direction, as a consequence of the predominance of the diffusion controlled water loss mechanism in the partially hydrated paste.

3.4 Effect of evaporative cooling

The experimental results for the tests concerning the evaporative cooling are depicted in Figs. 15 and 16, which reproduce the global weight loss and the temperature evolutions in the specimens. The rate of evaporation from the mortar specimens matches the one from the water sample in the moments just after sealing was removed during 0.025 days (35 min)—as it can be confirmed in Fig. 15. The temperature near the surface (see Fig. 16) suffered a sudden drop from 37°C at the moment of sealing removal to 28.7°C about 35 min later (coinciding with the moment at which the rate of evaporation from mortar started to exhibit a different behaviour from that of the water sample—see Fig. 15). The mortar temperature

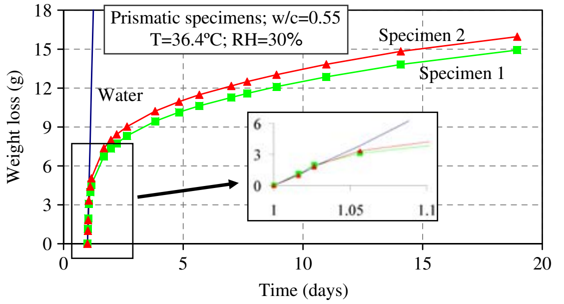

Fig. 15 Weight losses: evaporative cooling tests (w/c = 0.55)

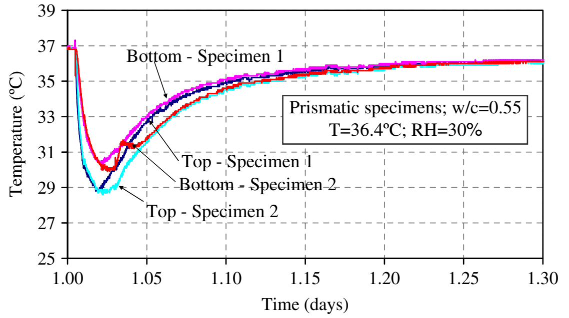

Fig. 16 Measured temperatures: evaporative cooling tests (w/c = 0.55)

reached equilibrium with the environmental one about 8 h later. According to Fig. 16 temperatures within the specimens are rather homogenous, even though the amplitude of the measured temperature drop is larger in the thermocouples located nearer the surface.

The results obtained in this experiment suggest that the temperature drop lasts until evaporation from the surface ceases to be completely environmentally controlled. Nevertheless, more testing should be done with different specimen geometries, and different environmental conditions, in order to confirm this statement. The observed temperature development confirms that formwork removal should be carefully planed in construction sites, as the volumetric changes associated with this kind of thermal shock may induce cracks due to hindered deformation.

4 Conclusions

Moisture loss from mortar specimens and its sensitivity to several environmental and curing conditions were investigated, as well as the evaporative cooling phenomenon.

Experiments on the combined effect of environmental temperature and RH were conducted, revealing the quantitative influence of these parameters on the moisture loss from mortar specimens, with and without curing measures.

Similitude of evaporation from a water pan and from a saturated mortar specimen during the first stage of drying, reported in past researches [12–14], was also confirmed in this research.

Transition from the environmentally to the diffusion controlled evaporation stages in cementitious materials has been identified as a possible criterion to establish the instant when the surface hydration starts to be hindered due to water shortage. For mortar specimens exposed to drying immediately after casting the duration of the environmentally controlled evaporation is strongly dependent on wind conditions: the higher the wind speed, the sooner the transition to diffusion controlled evaporation takes place. Yet, if curing measures are undertaken, such as sealing until specified ages, the pore structure at the time of exposure becomes denser and more water is already consumed in the hydration reactions, which reduces the influence of wind speed on the mentioned transition. From then on the water loss from the specimens becomes diffusion controlled, and the governing phenomenon is the vapour pressure gradient between the interior of the specimen and the environment. So, after adequate curing, moisture loss and the inherent drying shrinkage can be considered independent of the wind speed. Also, based on the consideration that after adequate curing the water loss from the specimens is diffusion controlled, and bearing in mind the identical results obtained for specimens with exposed surfaces parallel and perpendicular to the wind stream, it was concluded that moisture loss at this stage is not only independent of wind speed, but also of wind direction.

The evaporative cooling phenomenon from cementitious materials was experimentally confirmed in this research, and the ~8°C temperature drop observed near the surface of the studied specimen just after sealing removal was important enough to justify further investigation on this topic, object of very few studies up to now, but that may be the cause for thermal cracking upon formwork removal in hot and dry environments.

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