

## **THE DEGREE OF CAPILLARY ABSORPTION REDUCTION AS A PARAMETER TO CLASSIFY THE EFFECTIVENESS OF SECONDARY HORIZONTAL WATERPROOFING**

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### **Abstract**

The dampness of the ground floors in buildings is generally a consequence of capillary rise of groundwater caused by the absence, damage or technical deterioration of the horizontal waterproofing of the masonry. Capillary absorption and damp transport are determined by the wetting properties of water relative to the material, as well as the structure and distribution of pores in the material. Chemical (injection) methods of secondary horizontal waterproofing are based on the technology of introducing injection liquid into the masonry section, which forms a lock which relies on the mechanism of capillary lumen constriction, hydrophilization, capillary sealing or a combined effect. A vital outcome of secondary horizontal waterproofing in a wall using the injection method is not only limited absorption but also its changed dynamics. The research paper describes the procedure leading to determining a criterion that allows to classify injection agents in terms of their impact on inhibiting capillary transport of damp in construction partitions.

**Keywords:** absorption, capillary rise, dampness, effectiveness, injection, waterproofing

### **1. INTRODUCTION**

The role of water as part of the porous building material destruction was recognized as far back as antiquity [1], [2], and its presence in antique masonry structures is one of the most important issues impacting architectural heritage [3]. The adverse impacts of damp in buildings can also be considered a phenomenon that is experienced in a majority of these structures [4], as well as other buildings erected prior to 1920, the damage of which is a consequence of the absence, damage or technical wear of waterproofing [5], [6], although it is unfortunately also encountered in relatively new buildings, where waterproofings have been implemented incorrectly (or not at all) [7]. Dampness affecting structures leads to their increased corrosion – it is estimated that 50-60% of corrosion cases is specifically associated with excessive moisture [6]. The destructive impact of damp is manifested in the lower parts

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of buildings as frost damage, salt efflorescence and lichen growth. Less visible effects include a deterioration of material mechanical properties, reduced thermal insulation properties (leading to increased thermal energy demand) and worse sanitary conditions in the premises [5], [8].

One of the most commonly recurring threats to buildings with no adequate waterproofing is the capillary rise of groundwater in masonry walls [3]. Although there are numerous methods of preventing or mitigating this phenomenon, there is not a single method that could be successfully applied in every situation [3]. Methods involving the so-called "secondary horizontal waterproofing" in the walls of newly erected buildings are the most similar to the solutions aimed at counteracting capillary transport of damp. In the case of mechanical methods, an insulating material is inserted into an existing wall, which enables forming a water-impermeable, permanent layer in the masonry section, thus inhibiting its capillary transport. On the other hand, chemical (injection) methods are based on the technology of introducing injection liquid into the masonry section, which forms a lock based on the mechanism of capillary lumen constriction, hydrophilization, capillary sealing or a combined effect. The execution effectiveness of secondary horizontal waterproofing is not only difficult to unequivocally assess but it is, in fact, an area of the construction domain which has experienced probably the greatest accumulation of conflicting opinions or even misunderstanding of ongoing phenomena [9]. Because the success of operations aimed at executing secondary horizontal waterproofing depends not only on the parameters of the injection agent itself, but also on the parameters of the partition and the work method ('correctness'), comparing individual agents and selecting them for specific conditions of a given application should be based on the results of test conducted under pre-defined conditions.

Although the chemical injection method against capillary damp rise in masonry walls has been known and successfully applied for more than six decades [10], [11], and developing a domestic procedure for approving the application of methods and measures related in the field of broadly understood building drainage was postulated already in early 1990s [12], it has still not been summarized in the form of an international standard or, at least, an assessment method that would be considered an international standard.

The most popular methods for assessing the effectiveness of injection agents applied to execute secondary horizontal waterproofing in walls include the method of the Building Research Institute (ITB) [13] and the one described in the method statement of the Scientific and Technical Association for Building Conservation and Historic Preservation (WTA) No. 4-10-15/D [14]. In the case of these two above methods, as well as other numerous described in source literature, injection effectiveness is equated to the progress of drying of the partition above the executed membrane. An alternative is the application of the  $w_{24}$  wall capillary absorption coefficient in the injection zone, as a parameter that enables classifying the absorptivity of building materials [15], [16]. The research paper describes the procedure leading to determining a criterion based on the aforementioned coefficient that allows to classify injection agents in terms of their impact on inhibiting capillary transport of damp in construction partitions.

## 2. CAPILLARY RISE

The tendency of a liquid to rise in very low-diameter pores, i.e., in pores with a radius from  $10^{-7}$  to  $10^{-4}$  m (from 100 nm to 0.1 mm) – also called capillary (from the Latin *capillus*) pores – is also known as a capillary rise or capillary pull-up phenomenon [17]–[19], and is caused by a physical phenomenon called surface tension.

Water is characterized by one of the highest surface tension values. Greater values are exhibited only by liquid metal fluids. Due to the action of surface tension, water can behave in various ways – a spherical shape of a freely descending droplet good and poor wetting of solid surfaces, sinking

(depression) or rising (pulling-up) of water in a narrow tube, as well as the formation of a meniscus on water surfaces edges can be observed (Fig. 1) [20].

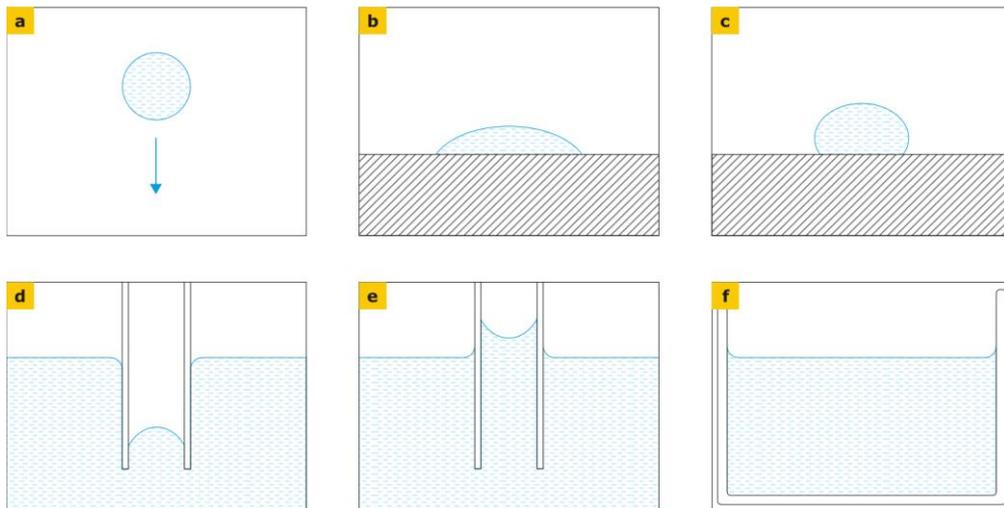


Fig. 1. Most frequently observed water surface tension effects (Fig.: [20])

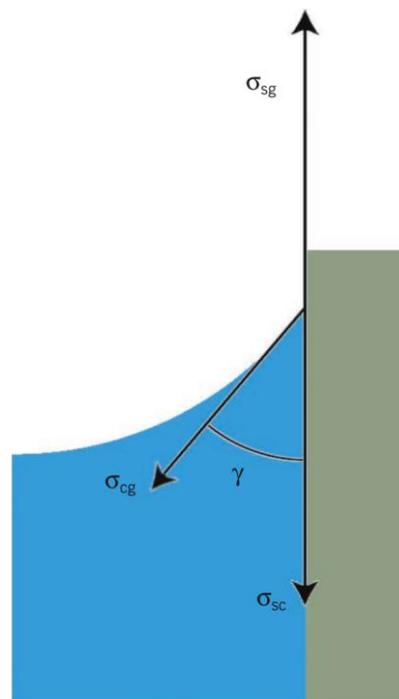


Fig. 2. Force equilibrium leading to the formation of a wetting angle  $\gamma$  (Fig.: [19])

Apart from the structure and distribution of pores in a material, capillary transport of damp is determined by the wetting properties of the liquid relative to the material or (in other words) material properties relative to the water penetrating the capillaries. Surface tension forces lead to water (contacting a solid) forming a so-called "wettability angle", which is the angle between the surface of

the solid and the tangent to the liquid surface routed at the point of contact – on the boundary of the three phases (Fig. 2).

The occurrence of a wetting angle is the outcome of force equilibrium at the liquid-solid point of contact [19]. If the surface tension (or, more precisely, the energy required for unit area to form on each of the phase boundaries) at the solid/gas, solid/liquid and solid/gas phase interface is denoted as  $\sigma_{sg}$ ,  $\sigma_{sc}$  and  $\sigma_{cg}$ , respectively, the forces will remain in equilibrium if the following condition is satisfied:

$$\sigma_{sg} = \sigma_{sc} + \sigma_{cg} \cos \gamma \quad (2.1)$$

which leads to:

$$\cos \gamma = \frac{\sigma_{sg} - \sigma_{sc}}{\sigma_{cg}} \quad (2.2)$$

After taking into account the fact that liquid adhesion operation relative to the solid body (per unit of mutual contact) is expressed by the formula:

$$W_{ad} = \sigma_{sg} + \sigma_{cg} - \sigma_{sc} \quad (2.3)$$

The equation above can be expressed as follows:

$$\cos \gamma = \frac{W_{ad}}{\sigma_{cg}} - 1 \quad (2.4)$$

where:

$\gamma$  [°] – material water wetting angle,

$W_{ad}$  [J] – operation,

$\sigma_{cg}$  [N/m] – surface tension.

Therefore, the  $\gamma$  angle value is the measure of wettability:

- when the adhesion forces prevail over cohesion forces, a liquid droplet spreads over the substrate surface ( $1 < W_{ad}/\sigma_{cg} < 2 \rightarrow 0 < \gamma < \pi/2$ ) – wetting liquid, hydrophilic material,
- cohesion forces prevail ( $0 < W_{ad}/\sigma_{cg} < 1 \rightarrow \pi/2 < \gamma < \pi$ ) – not wetting liquid, hydrophobic material.

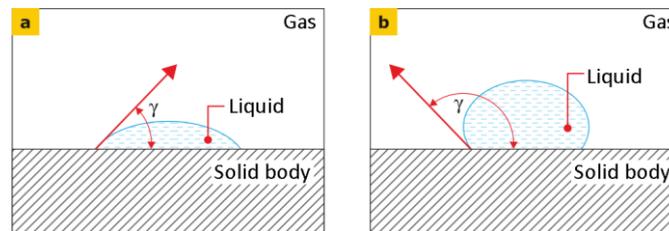


Fig. 3. Contact between a water droplet and a solid body surface: a) wetting, b) no wetting (Fig.: [20])

In the capillaries of a body with good wettability, the liquid surface forms a concave meniscus – it rises a little upon contact with a solid – although experimental evidence has indicated that spontaneous infiltration had not been achieved in many cases, even when the wettability angle is lower than 90° [21]. Whereas in the case of bodies with insufficient wettability a convex meniscus is formed – the liquid sinks.

It is extremely difficult to develop a model that describes capillary transport of damp in porous materials, primarily due to the complexity of pore geometry – the system is made up of pores in various shapes (cylindrical, wedge-shaped, fissure-shaped, spherical) and different system of connections (open, sack and closed pores). Also the capillaries form discontinuous systems with complex shapes [17]. An

approximate analysis of the phenomenon can be executed, while applying a simplified capillary body model in the form of a bundle of parallel low-diameter capillaries, based on the Young and Laplace equation (also called the basic capillarity equation) [22]:

$$\Delta p = \sigma \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \quad (2.5)$$

where:

$\Delta p$  [Pa] – pressure differential on both meniscus sides,

$\sigma$  [N/m] – surface tension,

$R_1, R_2$  [m] – meniscus curvature radius.

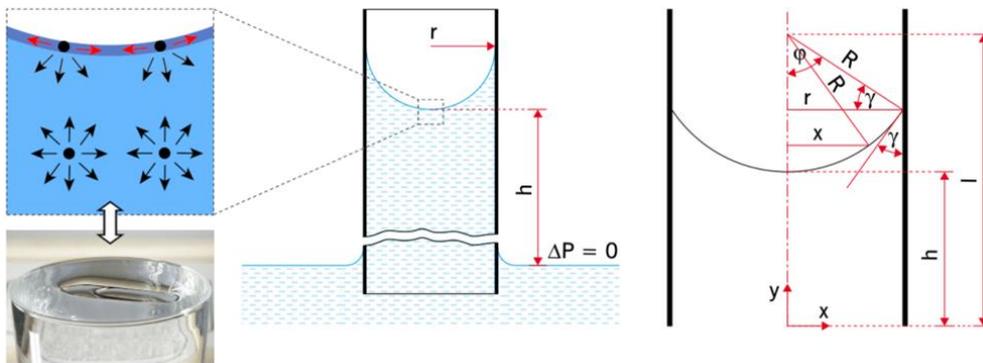


Fig. 4. Liquid rise in a fixed-radius capillary (Fig. by the author, based on [1])

For a rotationally symmetric capillary ( $R_1 = R_2 = R$ ) and taking into account that water does not perfectly wet the material (therefore, the wetting angle between the meniscus edge and the capillary wall  $\gamma > 0$ ), the equation will take the form:

$$\Delta p = \frac{2\sigma \cos \gamma}{r} \quad (2.6)$$

In the case of a capillary with the  $r$  radius, inclined to vertical, liquid is moved under the pressure differential  $\Delta p$  balanced by the gravitational force component, friction-related pressure drop resulting from the Hagen-Poiseuille law, and the force of inertia [18], [23]:

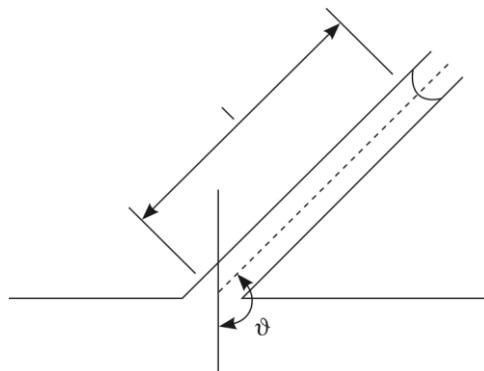


Fig. 5. Water rise from free liquid surface through an inclined capillary

Due to the low flow rate, the force of inertia is small enough to be discarded. The notation of the force equilibrium will then take the following form:

$$\Delta p = \frac{2\sigma \cos \gamma}{r} + g\rho l \cos \vartheta - \frac{8\eta l}{r^2} \frac{dl}{dt} = 0 \quad (2.7)$$

which enables deriving the capillary motion speed formula:

$$v = \frac{dl}{dt} = \frac{r^2}{8\eta l} \left( \frac{2\sigma \cos \gamma}{r} + g\rho l \cos \vartheta \right) \quad (2.8)$$

where:

$v$  [m/s] – capillary rise speed,

$l$  [m] – water movement route in a capillary,

$t$  [s] – rise time,

$r$  [m] – capillary internal angle,

$\eta$  [Pa·s] – liquid dynamic viscosity,

$\sigma$  [N/m] – surface tension,

$\gamma$  [°] – material water wetting angle,

$g$  [m/s<sup>2</sup>] – acceleration of gravity,

$\rho$  [kg/m<sup>3</sup>] – fluid density,

$\vartheta$  [°] – capillary inclination angle.

For a horizontal motion  $\cos \vartheta = 0$ , and then the capillary motion speed becomes equal to

$$v = \frac{dl}{d\tau} = \frac{\sigma r \cos \gamma}{4\eta l} \quad (2.9)$$

hence, it can be seen, that increasing route  $l$  entails a decrease in the capillary motion speed, and induces a relationship:

$$l \frac{dl}{dt} = \frac{\sigma r \cos \gamma}{4\eta} \quad (2.10)$$

which, after integration for initial conditions ( $t=0, h=0$ ), provides a Washburn equation [21], [24], [25]:

$$l^2 = \frac{\sigma r \cos \gamma}{2\eta} \cdot t \quad (2.11)$$

The several following simplifications are applied to the Washburn equations. These include [21], [25]:

- steady-state laminar flow,
- no slip – zero liquid speed at the solid/liquid phase interface,
- no external pressure applied, and
- negligible gravitational differences.

In turn, transforming the equation provides an equation that describes liquid flow duration according to capillary motion:

$$t = \frac{2l^2\eta}{\sigma r \cos \gamma} \quad (2.12)$$

On the other hand, if the transport is in the vertical direction,  $\cos \vartheta = -1$ , capillary rise speed expressed by formula 27 becomes equal to:

$$v = \frac{dl}{dt} = \frac{r^2}{8\eta l} \left( \frac{2\sigma \cos \gamma}{r} - g\rho l \right) \quad (2.13)$$

it follows from the above that the speed becomes equal to zero for a specific water column height in the capillary. Hence, the maximum capillary rise height is determined as per the Jurin law [26]:

$$h = l_{max} = \frac{2\sigma}{g\rho r} \cdot \cos \gamma \quad (2.14)$$

The formulae above express two fundamental laws that describe capillary transport of damp. These indicate that the capillary rise speed is higher in materials with *thick* capillaries, than in materials with thin capillary vessels. In turn, the rise height in materials with thin capillaries is much greater. For a very low or very high capillary radius, the rise speed and maximum height are reduced to zero (in other words, there is no capillary transport). In reality, although capillary and porous materials are of much more complex structure than described by the model of identical parallel capillary bundle [27], the absorption speed disappears in the case of capillaries with a radius below 0,1  $\mu\text{m}$ . On the other hand, the maximum possible rise height drops to zero in the case of capillaries with a radius above 100  $\mu\text{m}$ .

### 3. CAPILLARY ABSORPTION COEFFICIENT

When porous, wettable building materials come into contact with water, capillary pressure generated in the menisci draws it into the pores. Water flow resistance increases along with growing rise height. Therefore, water penetration depth  $h$  increases more slowly over time, which has been confirmed by calculations based on the Washburn equation, as well as numerous experiments [20]. The penetration depth increases with the square root of time:

$$h = w'_w \cdot \sqrt{t} \quad (3.1)$$

The root prefix is referred to as the capillary water absorption coefficient  $w_w$ . Many experiments on building materials have confirmed the theoretically predicted parabolic time law related to water penetrating absorbent building materials. The following research method describing capillary absorptivity of building material surfaces is based on the above.

A studied building material specimen is immersed several-millimetre-deep into a water bath, with the reference surface facing downwards. Regular observation of the building material specimen enables determining the water penetration depth over time. If the penetration depth is plotted as a function of immersion time on the graph, the expected parabola is obtained. However, it is more expedient to calculate the penetration depth as a function of time root – in such a case, a straight line is obtained on the graph.

The same rule applies to the value that can be determined much easier and more accurately than penetration depth, namely, the mass of water absorbed by a unit area as a function of time; therefore, it is preferred for characterizing capillary absorption of water by building materials [20], [28]. By analogy to the equation above, the water absorption coefficient is defined by the following relationship [20], [29], [30]:

$$m_s = A_w \cdot \sqrt{t} \quad (3.2)$$

where:

$A_w$  [ $\text{kg}/\text{m}^2 \cdot \text{s}^{0.5}$ ] – water absorption coefficient,

$m_s$  [kg] – mass of damp absorbed from the water interface surface, divided by the area of this surface,

$t$  [s] – time.

Water absorption coefficient related to a specific time  $t$ , expressed in seconds, is written as  $A_{wt}$ . However, an alternative definition with reference to time expressed in hours is widely applied – in this case, the capillary absorption coefficient is denoted as  $w_w$  (and as  $w_{wt}$  in relation to a specific time) [30]. The traditional absorption coefficient measuring method involves bringing one surface of the tested specimen in contact with the water table, and then recording the rate of the non-stationary process occurring therein [31], [32]. In this case, determining the coefficient is reduced to measuring the mass of water absorbed by the specimen over a unit of time – in a general case, it is calculated from the formula [20], [33], [34]:

$$w_w = \frac{\Delta m}{A \cdot \sqrt{t}} = \frac{m_t - m_i}{A \cdot \sqrt{t}} \quad (3.3)$$

where:

$w_w$  [ $\text{kg}/\text{m}^2 \cdot \text{s}^{0.5}$ ] – water absorption coefficient,  
 $\Delta m$  [kg] – mass increment after soaking over time  $t$ ,  
 $m_t$  [kg] – specimen mass after time  $t$ ,  
 $m_i$  [kg] – specimen initial mass,  
 $A$  [ $\text{m}^2$ ] – face area,  
 $t$  [s] – soaking time.

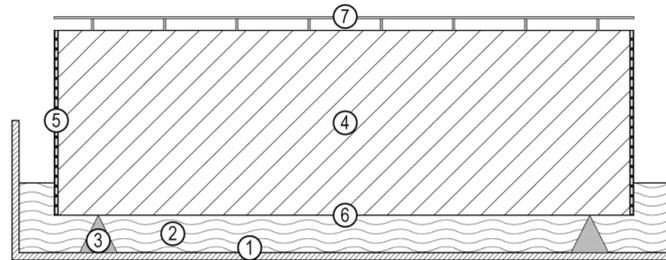


Fig. 6. Diagram of a building material capillary absorption determination test bench; so-called *absorptivity test* (Fig.: [20])

- 1) water vessel, 2) water, 3) point support, 4) tested specimen, 5) side surface sealing,  
 6) water contact surface, 7) loading grid

Pursuant to the EN ISO 15148 [30] standard, the mass absorbed by water  $\Delta m_t$ , per unit area is calculated as the difference between the mass after immersion in water and initial mass:

$$\Delta m_t = \frac{m_t - m_i}{A} \quad (3.4)$$

Its graph is plotted as a function of the square root of time  $\sqrt{t}$ . There are two possible forms of this graph. Usually, after the initial stabilization phase, water absorption as a function of time root, determined through repeated weighing, can take the form of a straight line – such a line should be extended to intersect the vertical zero-time axis at point  $\Delta m'_0$ . Pursuant to the EN 15148 [30] standard, the water absorption coefficient is calculated from the formula:

$$w_w = \frac{\Delta m'_{tf} - \Delta m'_0}{\sqrt{t_f}} \quad (3.5)$$

where:

$w_w$  [ $\text{kg}/\text{m}^2 \cdot \text{s}^{0.5}$ ] – water absorption coefficient,

$\Delta m'_{tf}$  [kg/m<sup>2</sup>] –  $\Delta m$  value read from the straight line for time  $t_f$ ,  
 $\Delta m'_0$  [kg/m<sup>2</sup>] –  $\Delta m$  value read from the straight line for time  $t=0$ ,  
 $t_f$  [h] – study duration (usually one day).

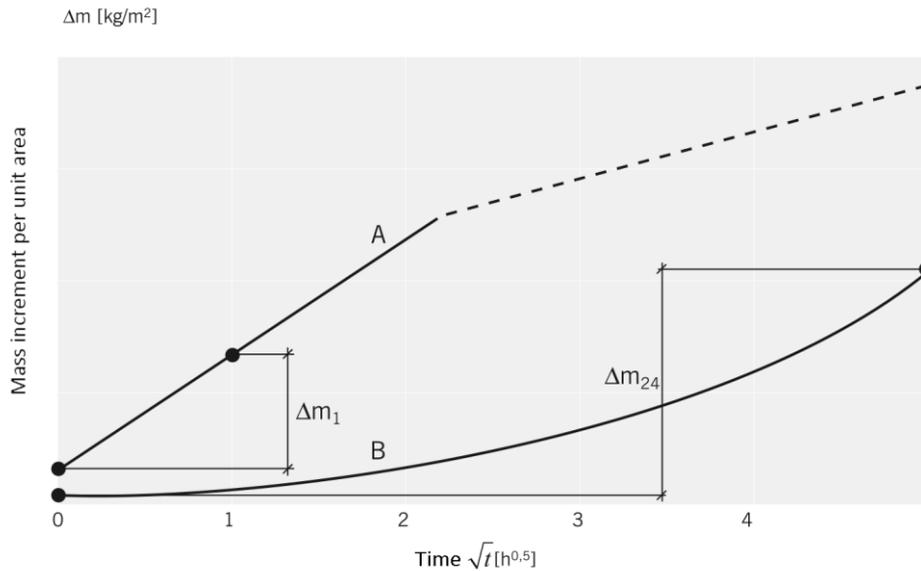


Fig. 7. Typical waveform of water absorption as a function of time root (Fig.: [20])

In turn, the EN 15801 [35] (for porous, non-organic materials), EN 772-11 [33] (in the case of masonry elements made of natural stone), and EN 1015-18 [36] (in the case of mortars other than intended for renovation) standards define the absorption coefficient as inclination of the  $\Delta m_t(\sqrt{t})$  curve (calculated through linear regression) over the initial section of the graph.

Mass gain resulting from capillary damp rise can also have a different waveform. If the obtained graph is in the form of a straight line with a sudden decrease in the inclination angle, it means that (in the case of a homogeneous specimen) water in its liquid phase appeared on the upper surface of the specimen. The flattening of the curve is related to the redistribution of water from thick pores to finer pores and the slower rate of absorption [20] – moisture content reached by the material during the first, more rapid capillary rise period (initial absorption [37]) is defined as the material capillary capacity [38], [39]. Reaching capillary capacity enables calculating the absorption coefficient value upon adopting the  $t_f$  value lower than one day [30].

It is possible in the case of certain building materials, e.g., products with added plastics or hydrophobic products, for the graph of unit mass increment as a function of time root not to be a straight line, but a certain curve [20]. In such a case, the  $\Delta m_t$  value after 24 hours should become the  $\Delta m_{24}$  value, and the absorption coefficient should be calculated from the formula [30]. If water appears on the upper surface of the specimen before the 24 hours elapse, the water absorption coefficient is not calculated (but the water appearance time should be recorded) [30].

Capillary absorptivity of building materials is classified based on the water absorption coefficient after 24 h after immersion.

$$w_{24} = \frac{\Delta m_{24}}{\sqrt{24h}} \quad (3.6)$$

where:

$w_{24}$  [ $\text{kg}/\text{m}^2 \cdot \text{s}^{0.5}$ ] – water absorption coefficient after 24 h,

$\Delta m_{24}$  [ $\text{kg}/\text{m}^2$ ] – mass increment per face unit area, after 24 h.

as per the division set out in Table:

Table 1 Building material division based on the capillary absorption coefficient [20], [28]

Classification	Capillary absorption coefficient [ $\text{kg}/\text{m}^2 \cdot \text{h}^{0.5}$ ]
highly absorbent material	$w > 2$
reduced-absorptivity material	$0.5 < w \leq 2$
waterproof material	$0.001 < w \leq 0.5$
watertight material	$w \leq 0.001$

#### 4. ASSESSMENT OF INJECTION AGENT EFFECTIVENESS

In the case of a vast majority of methods assessing the effectiveness of injection agents and/or technologies, the adopted assessment criteria include drying progress in the masonry zone above a completed membrane or the change of partition in the injection zone. While proofing effectiveness (similarly to standard waterproofing materials) in the case of such mechanical methods is determined primarily by the properties of the material itself (and these should be tested), the specificity of the secondary horizontal insulation execution injection method makes it virtually impossible to assess a given preparation and/or its application separately from the construction partition parameters. The previously employed effectiveness testing methods, the result of which is supposed to constitute a criterion for the selection of an injection agent, cannot directly translate to obtaining the same or very similar outcomes in the case of specific construction structures. This is because they do not take into account other factors, which are impossible to assume for all encountered applications (e.g., the degree of damp penetration or wall salinity level) [13]. However, they enable comparing individual injection agents available on the market and indicate certain advantages or limitations thereof. In most cases however, there is no unambiguous criterion (such as, e.g., strength class for concrete and mortar types or the thermal conductivity coefficient  $\lambda$  for thermal insulation materials) that would enable classifying injection agents in terms of not their properties as such, but rather their impact on inhibiting capillary damp transport in construction partitions. Therefore, it seems justified to introduce such a criterion.

Studying the effectiveness of injection agents for secondary horizontal waterproofing in existing [40] walls enables demonstrating that the  $w_{24}$  capillary absorption coefficient – which is the value often applied to evaluate the effectiveness of injection operations – does not allow to fully characterize the process of capillary water absorption in a partition with an injection membrane. The results of conducted tests provided a finding that the application of structural horizontal waterproofing in walls does not only limit absorption but also changes its dynamics. Whereas, none of the applied methods for calculating the capillary absorption coefficient 24 takes this fact into account. Therefore, it is reasonable to introduce a new value – synoptic capillary absorption coefficient (after 24 h from immersion)  $S_{w,24}$ .

The value of the synoptic capillary absorption coefficient corresponds to the integral of the graph showing the mass increment per unit area as a function of time root (area under the graph) within integration limits from the intersection between the primary straight line with the abscissa axis  $\sqrt{t_0}$  to point  $\sqrt{t_{24}} = \sqrt{t_0} + \sqrt{24h}$  (Fig. 8).

Calculating the synoptic capillary absorption coefficient requires:

- determining the intersection of the primary straight line (corresponding to the initial absorption) with the abscissa axis  $\sqrt{t_0}$  together with uncertainty  $u(\sqrt{t_0})$ ,

- determining the so-called ‘critical point’ (if any), i.e., an intersection between the primary and secondary curves, and the corresponding  $\sqrt{t_{pk}}$  and  $\Delta m_{pk}$  values (together with uncertainties),
- determining the  $\sqrt{t_{24'}} = \sqrt{t_0} + \sqrt{24}h$  value and the corresponding  $\Delta m_{24'}$  (together with uncertainties),
- calculating the value of the synoptic capillary absorption coefficient as per the formula:

$$s_{w,24'} = \frac{\sqrt{24} \cdot \Delta m_{pk} + \Delta m_{24'}(\sqrt{t_{24'}} - \sqrt{t_{pk}})}{2} \quad (4.1)$$

where:

$s_{w,24'}$  [kg·h<sup>0.5</sup>/m<sup>2</sup>] – synoptic capillary absorption coefficient,

$\Delta m_{pk}$  [kg/m<sup>2</sup>] – capillary capacity,

$\Delta m_{24'}$  [kg/m<sup>2</sup>] –  $\Delta m$  value read from the straight line for time  $t_{24'}$ ,

$t_{pk}$  [h] – time the sample reaches capillary capacity.

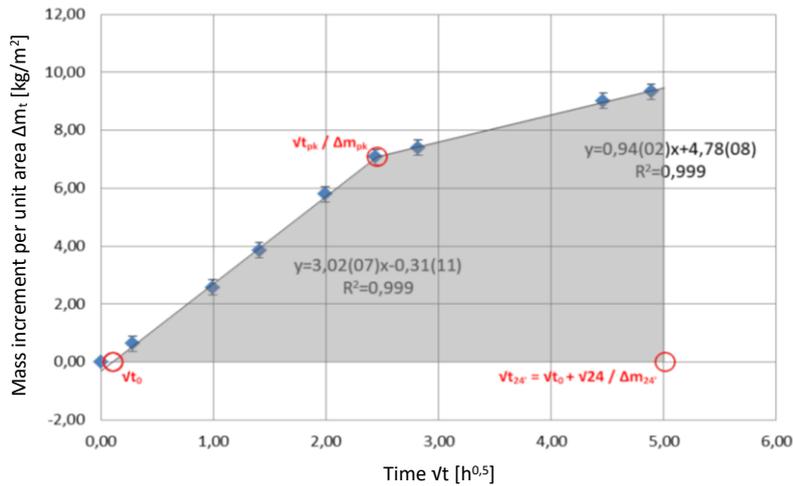


Fig. 8. Capillary absorption graph for a reference masonry wall subject to injection

The effectiveness of injection agents against capillary rise of damp in a masonry wall can be assessed using two reference values, i.e.:

- mean synoptic capillary absorption coefficient of specimens not subject to injection  $s_{w24',(0)}$ , as the 'baseline' value, and
- mean synoptic capillary absorption coefficient of specimens with mineral coating waterproofing  $s_{w24',(1)}$ , as a 'reference' value

and an introduction of a new value, which is the degree of reduction in capillary absorption  $R_a$ .

If the  $(s_{w,24(0)} - s_{w,24(1)})$  value is assumed as a point of reference, the degree of reduction in capillary absorption for a specific injection agent would be expressed by the formula:

$$R_a = \frac{s_{w24'(0)} - s_{w24'(i)}}{s_{w24'(0)} - s_{w24'(1)}} \quad (4.2)$$

where:

$R_a$  [-] – degree of reduction in capillary absorption dynamics,

$s_{w,24'}$  [kg·h<sup>0.5</sup>/m<sup>2</sup>] – mean value of capillary absorption dynamics coefficients of samples subject to injection (i), not subject to injection (0) and containing a coating seal (1).

Assessing the certainty of obtained results requires the application of expanded measurement uncertainty (i.e., a measure of certainty that enables inferring compliance of a result with other result), calculated through determining a product of the expansion coefficient and composite standard uncertainty pursuant to the principles of the measurement data evaluation methodology of the ISO the International Organization for Measurement [41].

## 5. SUMMARY AND CONCLUSIONS

It is proposed to introduce the degree of reduction in capillary absorption  $R_a$ , as a parameter that allows to classify injection agents in terms of their effectiveness. Since both reference specimens and specimens subject to injection are studied under the same conditions (taking into account both test wall parameters and external conditions), the degree of reduction in capillary absorption dynamics can constitute a clear criterion for the classification of injection agents in terms of their impact on inhibiting capillary rise of damp in construction partitions. In doing so, it should take into account specific boundary conditions (wetting degree, or wetness and salinity) – e.g., the  $R_a^{95}$  symbol would mean a capillary absorption reduction degree for a degree of wetness  $S = 95\%$ . However, it should be noted that when the capillary absorption reduction degree were to be applied on a broader scale to classify (and/or certify) injection preparation, this would require determining an optimal amount of employed specimens. As demonstrated by the results of conducted tests, the convergence of results obtained in the case of individual specimens may – depending on the applied injection agent and its application method – differ significantly.

The size of specimens employed to determine the capillary absorption reduction degree also requires analysis, which is an advantage on the one hand (enabling, among others, to reduce test costs), while implying certain limitations on the other. Because, while in the case of reference masonry walls with a mineral mortar waterproofing layer, one can be sure that first-stage absorption is the same as in a wall without horizontal waterproofing, small specimens subject to injection may experience a situation wherein water will be in direct contact with the impregnated material during testing.

It also seems reasonable to extend the entire testing process. For the capillary absorption reduction coefficient to take the change of masonry wall parameters into account as far as possible, after it undergoes horizontal waterproofing, the test duration should be twice as long as the mean  $\sqrt{tpk}$  value determined for the aforementioned reference specimens, which means that water absorption within these specimens would be uninterrupted during the first period (equal to half the duration of the entire test) in layers below waterproofing, with water redistribution in material pores in this zone throughout the subsequent period.

In addition, research should be conducted under stabilized (defined) thermal and humidity conditions, since (as indicated by Karagiannis et al. [39]) the water absorption coefficient increases with temperature.

The capillary absorption reduction degree could constitute a standard test necessary in the course of work in relation to marketing and use of injection preparations on the European market. However, this would require subjecting it to the European system for marketing of construction products (with CE marking). However, it would first be necessary to analyse whether this is economically viable.

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