Moisture transport in coated plaster

§E.L.J. Goossens, *W.H. van der Spoel, §E.L.J. Bancken

§ Eindhoven University of Technology, Department of Architecture, Building and Planning, Group Building Physics, Eindhoven, The Netherlands
* Delft University of Technology, Department of Civil Engineering and Geosciences, Section Building Engineering, Delft, The Netherlands

In the framework of the research project: 'Water balance of water-borne paint systems on plaster substrates in relation to fungal growth', a study is carried out to moisture transport mechanisms in coated gypsum plaster. In this contribution, the set-up of the study is described. Besides a description of the experiments to investigate the moisture transport properties of the plaster, coating and coated plaster, attention is given to the effect of slight alterations of the paint formulation on the moisture transport characteristics of the final paint.

Key words: **wall paint; gypsum plaster; moisture transport; fungi; moulds.**

1 Introduction

Fungi (or moulds) significantly lower the quality of the indoor environment. Besides potential implications to human health, fungi also cause musty smells and deface interior finishes. Fungal growth in buildings is frequently seen on finishing materials in places with a periodically high indoor relative humidity like bathrooms and kitchens. It is common practice in Dutch buildings to use gypsum-based plasters, coated with a water-borne wall paint. Such a finish has the ability of moisture storage and consequently may prolong high surface humidity conditions that favour fungal growth.

Of all factors influencing fungal growth in the indoor environment, the availability of water (at the material surface) is the only one that can be reasonably controlled. For this reason, the water transport properties of water-borne coatings largely determine the susceptibility to fungal growth. Part of the study therefore focuses on the effect of slight modifications in the type and concentration of paint constituents (binder, pigments, fillers, surfactants and additives) on the water transport characteristics of the final paint. Because of pending strict legislation, these paint formulations do not contain film-biocides. As the resistance to fungal growth can not be considered without regard to the substrate to which the paint is applied, the water transport properties of the porous substrate are studied as well.

A first research path is the experimental determination of the relevant transport properties of the substrate and the coating separately. This data will be used in a moisture transport model to predict the moisture behaviour of painted plaster. Although models exist for moisture transport in

HERON, Vol. 46, No. 3 (2001) ISSN 0046-7316

porous materials and wall paints separately, a model describing moisture transport (vapour as well as liquid) in the composition of wall paint applied to a porous substrate has yet to be developed and tested. The model development and comparison of model results with experimental data is also part of the work. The aim is to have a validated model available that may be used to optimise the fungal resistance of painted plaster in dependence of their material characteristics.

Finally, the fungal resistance of the formulated paints will be tested under controlled laboratory conditions and transient moisture loads. These fungal-resistance tests are being developed and tested by Van der Wel within the framework of the same research project. In this paper, the attention is limited to the experiments that have been designed to determine the moisture transport coefficients of plaster, free paint films and painted plaster and to possible adaptations of the water-borne paint formulation and their influence on the water transport characteristics.

2 Experimental programme

2.1 Materials and methods

Free paint films

A water-borne reference paint was formulated based on an aqueous dispersion of acrylic polymers. The paint is comparable to commercially available wall paints, but contains a minimum amount of components and has no film-biocides. Inorganic titanium dioxide (TiO2) pigments are used in such amounts that canals in the film are avoided. The measured properties of - to be developed - formulations will be compared to the measured properties of this reference paint.

Traditional water-vapour permeability and sorption experiments are performed on free paint films to obtain the corresponding moisture transport coefficients. To prepare free films, wet paint is applied on siliconised paper attached to a smooth substrate. The siliconised paper allows an easy release after formation of the film. A drawback of the method concerns one-sided drying and possible relaxation after release from the paper which both may affect the moisture transport properties. Therefore, the comparison with properties of films that are formed on a porous substrate might be complicated. However, more advanced methods for producing free films are not available.

The water-vapour permeability is determined using the well-known cup method. In this method, the paint films (diameter 5cm) are sealed on top of a glass cup containing a saturated salt solution that provides a constant relative humidity (RH) below the film. The cups are placed in a conditioned chamber that provides a constant but different RH above the film. The vapour pressure difference over the film causes water transport into (or out of) the sealed cup. The gain or loss of water is measured gravimetrically. Since the permeability depends on the (average) vapour pressures, these measurements are performed at a range of vapour pressure differences to obtain the relationship between the two quantities. The measurements of the sorption isotherm are made gravimetrically as well. Because of hysteresis, both the absorption and desorption curves are considered.

Gypsum plaster + coating
A common Dutch machine-made gypsum[1] plaster, of which the moisture transport properties already have been investigated by Adan (1994) and Pel (1995), is chosen as standard substrate for the experiments.

As for free paint films, similar permeability and sorption experiments are carried out to determine the hygroscopic moisture transport coefficients of the coated plaster in comparison to the pure gypsum plaster.

Paint formulation
The formulation of paint is determined by the type, size and/or concentration of its constituents in the wet state. Binder, pigments, fillers, surfactants and additives control the characteristics of the final paint. With regard to the water transport properties, the most important considerations that will be taken into account when modifying the reference formulation are listed below.

- Capillary channels may be formed in a latex paint due to a lack of coalescing agent, insufficient deformation of the binder droplets, poor inter-diffusion between the latex particles during film formation and/or incomplete covering of the water-soluble constituents by the hydrophobic binder. As liquid water transport may occur in capillary channels, the porous substrate of a painted finish may easily absorb water if condensation takes place on an 'open' paint layer. Although it has to be verified by model calculations, it is speculated that due to this effect capillary channels lower the fungal resistance of the paint.

- The influence of surfactants depends on their final location in the dry film. If the surfactants remain on the surface of the latex particle during coalescence, they might block inter-diffusion between the latex particles, which leads to reduced film properties. Alternatively, autohesion to the paint / air or paint / substrate interface may result in water retention at these interfaces and a lower drying rate (Bradford and Vanderhoff, 1966). Secondly, dissolution in the latex-particle has a plasticizing effect resulting in a lower water-vapour permeability. Quite the reverse, crystallisation inside the film due to incompatibility with the polymer phase may cause macroscopic inhomogeneities and increase the water-vapour permeability (Roulstone et al., 1992). Furthermore, high surfactant concentrations can lead to open films due to flocculating particles during water evaporation.

- The amount of pigments and fillers relative to the amount of binder is usually expressed as the pigment volume concentration (PVC). When all pigments are just completely wetted by the binder, the PVC equals the so-called Critical PVC (CPVC) that is considered a transition point for many coating properties (Van der Wel, 1999). Beyond the CPVC a dramatic change in the geometry of the mixture occurs due to the formation of voids (air spaces). The onset of porosity in a pigmented film leads to a tremendous increase in the water permeability.

- Complete dispersion, no flocculation and proper binding between pigment and resin are required for a low permeability. Pigment agglomeration, caused by incomplete dispersion or flocculation, might result in a larger empty volume, facilitating water retention and transfer.

- The type of binder plays an important role. Alkyd emulsions show a different film formation mechanism compared to an acrylic dispersion. De Meijer (1999) showed that alkyd emulsions formulated for and applied on wood substrates have better moisture barrier properties compared to acrylic dispersions. It is expected that wall paints based on alkyd emulsions are characterised by a lower permeability as well.

- Finally, weathering has a significant influence on moisture transport properties. Because of their (slight) solubility in water, additives will evaporate and leach out of the coating. Consequently, the actual coating performance may vary in time because the hygroscopicity decreases and the empty volume in the film increases. Coating free space may also result from degradation of binder and additives.

2.2 *Experiments*

Moisture permeability and sorption isotherm

As many parameters determine the properties of the final paint, hundreds of formulated paint films have to be characterised to be able to draw conclusions on the (combined) effect of the formulation adaptations on the vapour permeability and sorption isotherm. Moreover, repeated measurements are planned to obtain some insight in degradation processes. To handle this large number of identical measurements, an experimental set-up has been constructed to weigh 96 samples semi-continuously using a pick-and-place unit. The complete set-up is placed in a conditioned and pressure-controlled room to obtain a constant relative humidity, temperature and absolute pressure.

Dynamical vapour transport

A clear distinction exists between the static conditions in the measurements described above and practise. The indoor climate in kitchens and bathrooms is characterised by transient moisture conditions due to short-lasting vapour-producing activities such as cooking and taking a shower. To determine the diffusivity of water vapour under isothermal dynamical moisture loads in plain as well as coated gypsum plaster, laboratory experiments in which in-situ conditions are approached or simulated have been developed. Air with a time-dependent relative humidity is blown by a ventilator over the top of a cylindrical sample, sealed at bottom and sidewall to assure one-dimensional transport. The mass of the sample and relative humidity imposed on top of the sample are recorded as a function of time. An analytical solution of the vapour transport equation, using sorption-isotherm data, is fitted to the recorded data to obtain the moisture diffusivity in the hygroscopic range.

Surface condensation

A device will be developed to simulate surface condensation. In this set-up, air with an elevated temperature and RH is led over the top of a sample that is conditioned at a temperature below the saturation point of the air. The mass of the sample, which is a measure of the mass of water absorbed, is monitored continuously. As the transport process involves combined heat and moisture transfer as well as phase transitions, these experiments engage a much more complicated transport problem than in the previous experiments. The data will be compared with results of model calculations.

Paint deformation
Most moisture transport models assume an inert medium. The swelling of paint, as a result of water permeation and absorption, might however have a large impact. As an indication, a 30% swelling of latex-based paint films has been observed when immersed in water (RH = 100%) (Gans, 1972). The dimensional change of the paint film as caused by sorption or desorption of water vapour is determined using so-called Electronic Speckle Pattern Interferometry (ESPI)[2]. Preliminary results show that the reference paint hardly swells ($\approx$ 0.2%) in the relative humidity range between 0% and 60%. Measurements above RH = 60% are in preparation.

3 Moisture transport model

Model calculations will be carried out using the programme Delphin, which is based on the mathematical description of combined heat and moisture transport in materials given by Grunewald (1997). Delphin can handle most transport processes but might not be suited to model moisture transport in the paint layer if it contains pinholes. In that case, condensed water on the paint surface may be immediately capillary absorbed by the porous substrate. Results of preliminary experiments of (iso-thermal) liquid water absorption by painted plaster samples indicate this behaviour. In this situation, the macroscopic transport equations implemented in Delphin do actually not apply to the paint layer. It is however anticipated that effective transport coefficients can still be devised. Besides, Delphin can not model hysteresis in the sorption isotherm and/or capillary pressure curve. To which extent hysteresis affects the moisture balance in painted gypsum plaster is not known yet. If hysteresis turns out to be important, a more elaborate model will be required.

4 Conclusions

The surface relative humidity of indoor finishes is the key-factor controlling the risk of fungal growth. Measures to reduce this risk should therefore aim at improving the moisture transport properties of the finish such that a low surface humidity prevails. Knowledge of the transport processes in the finish is required to set guidelines for these properties.

Water transport in the finish is governed by the transport properties of its constituents: the porous substrate and the paint layer. The relevant transport coefficients of the substrate and paint can be obtained from laboratory measurements. The question however remains whether water transport in the substrate-paint configuration can be described based on the properties of the substrate and paint separately. It is speculated that an intermediate layer between the gypsum and applied coating, originating from penetration of wet paint during first stages of film formation, may have a large influence on the moisture transport.

An integral approach is required for understanding the processes governing the growth of fungi on indoor finishes, taking into consideration the transient indoor conditions, the properties of the wall paint, porous substrate and building envelope. Laboratory experiments under well-known and controlled conditions is a prerequisite to obtain this insight. Although part of this knowledge is still to be acquired, it appears that a prime potential for lowering the risk of fungal growth on indoor porous finishes concerns the modification of the formulation of water-borne wall paints aimed at reducing the water sorption and water permeability of the final paint.

Acknowledgement

We acknowledge G.N.M. Kloosterman, Akzo Nobel Coatings BV, Groot Ammers (NL), for formulating the reference water-borne wall paint; and H.L.M. Wijen and S.L. Overdijk, Department of Constructional Design, Faculty of Architecture, Building and Planning, Eindhoven University of Technology (NL), for their support with ESPI.

References

Adan O.C.G. (1994) On the fungal defacement of interior finishes, Ph.D. Thesis, Eindhoven University of Technology (NL).

Bradford E.B. and J.W. Vanderhoff (1966) Morphological Changes in Latex Films, J. Macromol. Chem., 1, 335.

De Meijer, M. (1999) Interactions between wood and coatings with low organic solvent content, Ph.D. Thesis, Wageningen University (NL).

Gans D.M. (1972) Water soak expansion of free paint films, J. Paint Technol., 44 (572), 97-100.

Grunewald J. (1997) Diffusiver und konvektiver Stoff- und Energietransport in kapillarporösen Baustoffen, Dissertation, Technischen Universität Dresden (D).

Pel L. (1995) Moisture transport in porous building materials, Ph.D. Thesis, Eindhoven University of Technology (NL).

Roulstone B.J., Wilkinson M.C. and J. Hearn (1992) Studies on polymer latex films, Polym. Int., 27 43-50.

Van der Wel G.K. and O.C.G. Adan (1999) Moisture in organic coatings – a review, Prog. Org. Coat., 37 1-14.

Noten

[1] Knauf MP75SL, Knauf, Germany.

[2] GOM International AG, Germany.