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COMPATIBILITY ASSESSMENT OF EXTERIOR FINISH COATS FOR INSULATED WALLS

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INTRODUCTION

New approaches are emerging in contemporary wall construction as a result of improved understanding of building materials and their behaviour. Not so long ago, the accepted practice was to create impermeable exterior walls by using moisture-proof and vapour-proof layers in their sectional compositions. However, any failure, such as tiny cracks in any one of these impermeable layers, causes accumulation of entrapped moisture which could not escape by evaporation from the wall surface (Hughes, 1986; Massari and Massari, 1993; Richardson, 2001). This results in a decrease in the lifetime of building materials, visible defects on wall surfaces, such as discoloration, cracking, scaling and flaking on finish coats, and unhealthy interiors (Bochen et al., 2005). The concept of the "breathing wall", therefore, gained importance in the last few decades and external wall compositions, allowing the passage of water vapour back and forth through it, were started to be constructed.

Along with this, energy efficient buildings and improvement of construction technology in this regard became a current issue in contemporary buildings. In addition to installing more efficient fuel-burning equipment, the use of both thermal insulation layers and lightweight porous masonry blocks and/or panels for its walls proper, should be incorporated within the compositions of the building envelope. However, due to their high water absorption characteristics, light-weight porous masonry needs to be protected from rainwater by means of watertight protective coatings and/or by water repellents (Andolsun et al. 2006; Kuş, 2004). For these reasons, the exterior finishing systems consisting of under- and finish-coats, having low water permeability but high water vapour permeability properties are necessary.

The matter which has not yet been foreseen, even overlooked, for multi-layer constructions is "compatibility with neighbouring materials". The compatibility of finishing/complementing layers with the porous masonry,

in fact, has vital importance for contributing to the long-term durability and thermal performance of masonry wall structures. However, the basic performance and compatibility properties of those layers, such as water vapour permeability, water impermeability, thermal resistance, dilatation, modulus of elasticity characteristics, are as yet not well known. Comprehensive studies are, therefore, needed to derive this information so that the performance expected of such systems in providing healthy interiors can be improved.

Materials are considered to be compatible with each other if they have similar characteristics in terms of some physical, mechanical and compositional properties (Sasse and Snethlage, 1997; Fassina et al., 2002; Andolsun et al., 2005, 2006; Karoglou et al., 2007). The two important parameters of compatibility are water vapour permeability and modulus of elasticity (*MoE*):–

- What is required of the finish coat is to permit water vapour transmission while resisting droplet penetration from rain or surface wash; in other words, being essentially watertight (Kuş, 2004; Harderup, 1996; Cerny, et al., 1996). It is also necessary to ensure continuity in this vapour transmission property throughout all the layers making up the wall section in order to avoid interstitial condensation.
- The compatibility assessment of a layer with its neighbouring layers in terms of *MoE* is still under discussion. The *MoE* is defined as the ratio of stress to strain and indicates the deformation ability of a material under external forces (Timoshenko, 1970). According to studies discussing this subject, the *MoE* of coating layers should not exceed that of the underlying masonry (Caner, 2003; Fabbri and Grossi, 2000; Kovler and Frostig, 1998; Sasse and Sneathlage, 1997). This means that, any compatible layer should be expected to have *MoE* not higher than that of the base material which is in contact so as to prevent mechanical damage in any of the weaker intermediate layer(s). If not so done, failures–especially in the form of tiny cracks–are liable to develop on the fine coat and/or on sub-layers, which is often followed by flaking and scaling.

Here, a number of proprietary exterior finish coats produced in Turkey were examined in order to determine their compatibility for insulated masonry walls with an emphasis on their water vapour permeability and modulus of elasticity characteristics (Örs, 2006) (**1**). It was expected to reveal not only their individual material properties, but also to develop awareness in architects, builders and manufacturers about the significance of compatibility in attaining an integrated building envelope.

MATERIALS AND METHOD

Each finishing/coating system is basically composed of at least two layers; namely, "undercoat" and "finish coat". Primer is used under synthetic emulsion- or polymer-based finish coats in order to promote adhesion with cement-based undercoats (Williams and Williams, 1994; Kaleterasit, 2012). In cases where a colorless final coat is used, the surface also receives a coating of paint. The cement-based undercoats, complementing exterior finishing system, are obligatory sub-layers for the application of finish coats.

1. The research is derived from a part of the M.S. thesis of Kerime Örs, completed in the Graduate Program of Building Science, Department of Architecture, Faculty of Architecture, METU.

Sample Code	Description
FC1SB	Synthetic emulsion-based elastic finish coat with silicone additives
FC2SB	Synthetic emulsion-based elastic finish coat with silicone additives
FC3SB	Synthetic emulsion-based finish coat
FC4SB	Synthetic emulsion-based finish coat
FC5CB	Cement-based finish coat
FC6APB	Acrylic polymer-based elastic finish coat containing silicone additives
FC7ACB	Acrylic copolymer-based finish coat with silicone additives
FC8ACB	Acrylic copolymer-based finish coat
Pa1ACB	Acrylic copolymer-based exterior paint
$UC1CB_R$	Cement-based rough plaster
$UC2CB_F$	Cement-based fine plaster
$UC3CB_{Ti}$	Cement-based thermal insulation plaster
Pr1SB	Synthetic emulsion-based primer
Ti1XPS	Extruded polystyrene type of thermal insulation board
Ti2EPS	Expanded polystyrene type of thermal insulation board
Ti3RW	Rockwool type of thermal insulation board

Table 1. List of samples subjected to laboratory analyses. Descriptions are from the manufacturer (Kaleterasit, 2012).

Four types of synthetic emulsion-based finish coats, *FC1SB*, *FC2SB*, *FC3SB* and *FC4SB*; one type of cement-based finish coat, *FC5CB*; one type of acrylic polymer-based elastic finish coat, *FC6APB*; and two types of acrylic co-polymer-based finish coats, *FC7ACB* and *FC8ACB* were examined. All finish coats were self-coloured, except the finish coat *FC5CB*. A number of undercoats were also examined. These were cement-based rough plaster, $UC1CB_R$; cement-based fine plaster, $UC2CB_F$ and thermal insulation plaster, $UC3CB_T$, together with one synthetic emulsion-based primer, *Pr1SB*. Complementing materials considered were thermal insulation, as extruded polystyrene board, *Ti1XPS*; expanded polystyrene board, *Ti2EPS*; and mineral wool board, *Ti3RW*, and surface coating as acrylic copolymer-based exterior paint, *Pa1ACB*. Descriptions of the materials examined are given in **Table 1**. In practice, the cement-based undercoat $UC3CB_T$, is directly applied on thermal insulation board, together with a reinforcing mesh in order to provide a sub-surface for the finish coat and to improve adherence between layers (Williams and Williams, 1994). The tests on this sample were conducted without its reinforcing mesh.

The continuity of water vapour transmission throughout the layers was examined for two types of single leaf-exterior wall section, one externally-, the other internally- insulated. The materials specified for the wall sections, including their order and respective thicknesses were determined according to the standard, TS 825 (2008). The wall section proper was assumed to consist of 19cm-thick hollow clay tile or 20cm-thick autoclaved aerated concrete (AAC) masonry units with 5 cm-thick thermal insulation board under the external finishing system. Three different exterior finishing compositions were produced for each wall section according to application instructions described by the manufacturer (Kaleterasit, 2012). These wall sections are given in **Figure 1** and **Figure 2**, where the externally- and internally-insulated wall sections, together with the alpha-numeric designations used for each layer are individually described.

Samples for the laboratory analyses were prepared according to the standards TS EN 1015-19 (2000), TS EN 1015-2 (2000), ASTM E96-92 (1992), ASTM D 2845-90 (1990), TS 7847 (1990), DIN 52615 (1987) and to the

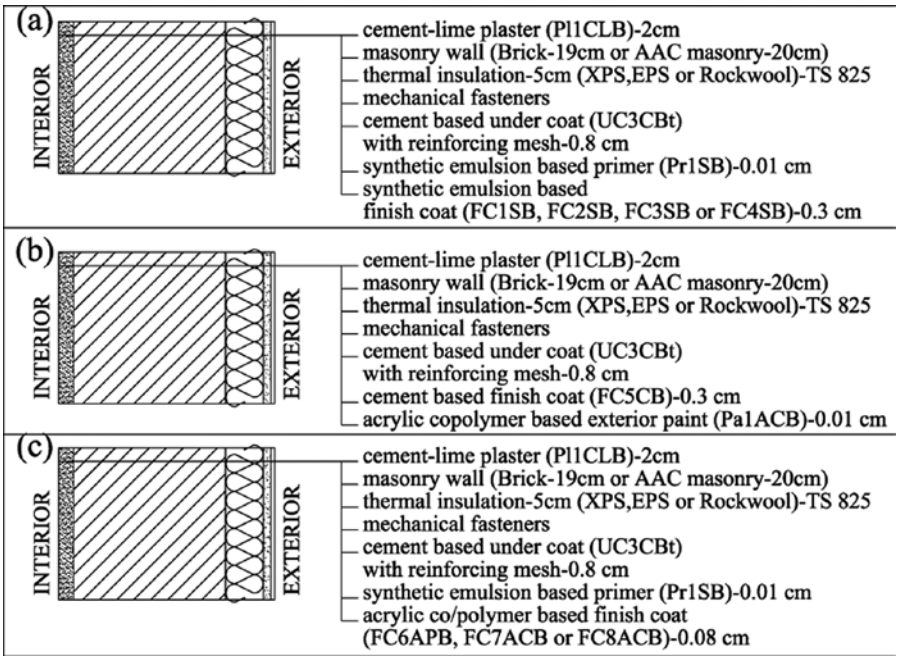

Figure 1. Externally insulated single leaf wall plastered with three different finishing composition: (a) synthetic emulsion-based exterior finish coat (FC1SB, FC2SB, FC3SB or FC4SB); (b) cement-based exterior finish coat (FC5CB); (c) acrylic polymer-based exterior finish coat (FC6APB, FC7ACB or FC8ACB).

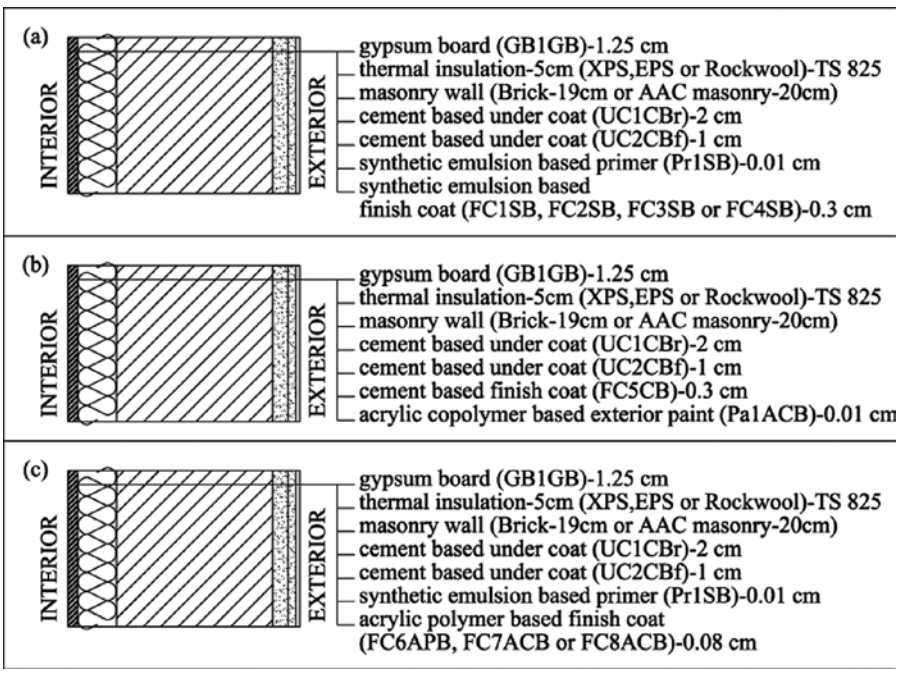

Figure 2. Internally insulated single leaf wall plastered with three different finishing composition: (a) synthetic emulsion-based exterior finish coat (FC1SB, FC2SB, FC3SB or FC4SB); (b) cement-based exterior finish coat (FC5CB); (c) acrylic polymer-based exterior finish coat (FC6APB, FC7ACB or FC8ACB).

instructions of the manufacturer (Kaleterasit, 2012). The analyses on the physical and physicomechanical properties were described in detail under the following subheadings

Analyses of Physical Properties

Some physical properties of the samples were determined in terms of bulk density (ρ), porosity ($\varnothing$) and water absorption capacity (θ_{max}), according to the RILEM standards (1980) and instructions given by Teutonico (1986). An emphasis was given to water vapour permeability properties of all samples in respect to their water vapour transmission rate (R_T), permeance, equivalent air layer thickness of water vapour diffusion (SD), permeability

(*1/SD*) and water vapour diffusion resistance index (μ). These properties were examined according to the standards, TS EN 1015-19 (2000), TS prEN ISO 7783-2 (1999), TS 825 (2008), ASTM E96-92 (1992), TS 7847 (1990), DIN 52615 (1987) and RILEM (1980). The permeability analyses were done for all finish coats individually while some of them were also analyzed together with its primer or paint layer to better understand the interaction of primer or paint to the permeability properties of finish coats.

The μ-value is a measure for the vapour tightness of a material. It indicates how many times greater the resistance to moisture transmission of a material layer is, compared to a static layer of air of the same thickness at the same temperature (Helms, 2006; TS 7847, 1990; DIN 52615, 1987). The μ value is a unitless parameter and used to compare the materials regardless of their layer thicknesses. Since the μ value of the static air layer is given as "1.0" in the standards, the μ value of materials should be greater than "1.0". The S_D value is the thickness of the static air layer in meters which has the equivalent vapour resistance of material having the thickness "*D*" (Helms, 2006; TS prEN ISO 7783-2, 1999; TSE 7847, 1990; DIN 52615, 1987). The *SD* value of material is calculated by multiplying its μ value with its layer thickness "*D*". Here, the layer thickness has vital importance to define the breathing capability for a material. For instance, a coating material having high resistance to water vapour permeation (high μ value) may act as highly vapour permeable layer (low *SD* value) when it is applied as a very thin layer (Esen et al., 2004; Akyazı, 1998; Akkuzugil, 1997).

According to the classification given in the standard TS prEN ISO 7783-2 (1999), R_T values above 6.0g/m²h or *SD* values below 0.14 m indicate high water vapour permeability of a material while the R_T values below 0.6g/m²h or *SD* values above 1.4 m indicate low water vapour permeability of a material. The ranges for the medium vapour permeability were given as 0.60g/m²h – 6.00g/m²h for the R_T values and 0.14m – 1.4m for the *SD* values. The total *SD* of a wall section was calculated by taking the sum of the individual *SD* value of each component/layer forming the overall section (TS 825, 2008, TS prEN ISO 7783-2, 1999).

For the analyses of physical properties, all samples were poured into 3mm-thick circular plastic moulds. Two sets were prepared for each finish coat (**Figure 3**): the first was the finish coat sample prepared individually, while the second was the finish coat prepared together with primer or with the paint layer. The paint was applied on the finish coat surface with a 10cm-wide roller. Primer and paint layers were also examined individually. Samples of synthetic emulsion-based primer (*Pr1SB*) were applied directly on filter paper by means of the same paint roller and samples of acrylic copolymer-based paint was prepared similar to the finish coats by pouring them into the 3mm-thick plastic molds. Due to their very thin application of 0.8mm, two sets of samples were prepared for each acrylic polymer-based finish coat by brushing them onto two different backing materials, one on filter paper (TS prEN ISO 7783-2, 1999) and the other on primer (**Figure 3**). Cement-based rough plaster $UC1CB_R$ was composed of 750g sand (0.3mm grade), 250g cement and 6g proprietary mortar and was mixed with 110mL of distilled water. Cement-based fine plaster $UC2CB_F$ was composed of 750g fine-grained sand, 250g cement and 6g proprietary mortar, and was mixed with 200mL of distilled water. Each of these mixtures was poured into 3.5x3.5x3.5cm wood moulds. For the cement-based thermal insulation undercoat $UC3CB_T$, being in powder form, the mixture was prepared by weight, with five parts powder to one part distilled water and was poured

Figure 3. The samples: synthetic emulsion-based finish coats with and without primer (at the top left); acrylic polymer-based finish coat applied on primer (at the top right); cement-based finish coat, incorporating a coat of paint (at the bottom).

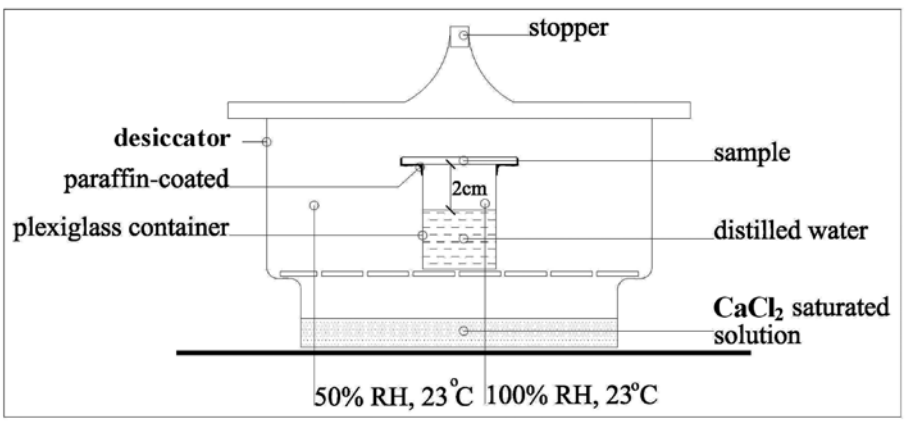

Figure 4. The experimental set-up used for the analysis of water vapour permeability properties.

into 3mm-thick circular plastic moulds. The set of all finish and undercoat samples were kept under constant conditions of 20°C ±2°C and 50% ±5 % RH for 28 days during their hardening (TS EN 1015-19, 2000; TS 7847, 1990; DIN 52615, 1987). Samples of polystyrene- and mineral wool-based thermal insulation materials, *Ti1XPS*, *Ti2EPS* and *Ti3RW*, were cut from standard boards.

The principle for the analyses of water vapour permeability properties was to determine the amount of water vapour passing through the material per unit time under conditions of constant humidity and temperature on both sides of the specimen. The experimental set-up used for the analyses was shown in **Figure 4**.

Analyses of Physicomechanical Properties

The physicomechanical properties of the samples were examined in terms of ultrasonic pulse velocity and dynamic modulus of elasticity. The

modulus of elasticity of material was determined indirectly by means of equations described in ASTM D 2845-90 (1990) and RILEM (1980), using its ultrasonic pulse velocity (*UPV*) and density. The *UPV* values were measured in the direct transmission mode (cross direction) by using a portable PUNDIT Plus CNS Farnell Instrument with 220 kHz transducers.

For the analyses of physicomechanical properties, the ultrasonic pulse velocity (UPV) measurements were taken for all finish and undercoats, except the finish coats *FC4SB*, *FC6APB*, *FC7ACB* and *FC8ACB*. A certain thickness was required for accurate *UPV* measurements (ASTM D 2845-90, 1990), which was difficult to obtain for the contemporary finish coats. The application thicknesses recommended for finish coats vary in the range of 0.8mm-3.0mm. For some of them, it was not possible to produce thicker samples even to a thickness of 5mm due to the wide cracks occurred during their hardening. This may be attributed to their high shrinkage behaviour. The *UPV* measurements were, therefore, taken only from samples in the form of cylinders having diameters of 4 cm and heights of 2.2cm, in which no visible cracks had occurred during their hardening.

RESULTS AND DISCUSSION

The results were interpreted to reveal "the physical properties of the contemporary coatings" and to discuss "the effect of primer and paint on the vapour permeability of finish coats, the continuity of water vapour permeability along the insulated wall section" and "the compatibility of finish coats in terms of their modulus of elasticity values". The interpretations and discussions are presented below under dedicated headings.

Physical Properties of Coatings

The bulk density, porosity and water absorption capacity values of finish and undercoats were summarized in **Figure 5**. The bulk density of the finish coats was found to vary in a wide range of 1.11 ±0.03g/cm^3 and 1.94 ±0.07g/cm^3. In this range, cement-based finish coats were found to have the highest density, the lowest porosity and the lowest water absorption capacity with the mean values of 1.94 ±0.07g/cm^3, 25.5±2.1% and 13.2±1.5%,

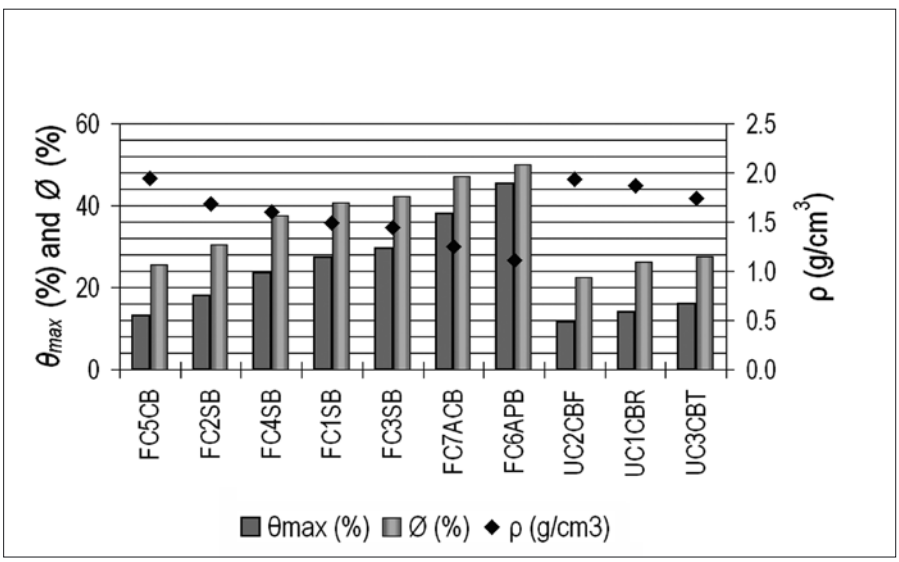

Figure 5. The bulk density (ρ), porosity (Ø) and water absorption capacity by weight (θmax) values of the finish- and under-coats.

Samples	*D* mm	R_T g/hm²	Permeance g/Pasm²	Perm	*SD* m	1/ *SD* m^{-1}	μ a.u.
FC1SB	3.0	7.4±0.3	$1.75\pm0.07\times10^{-6}$	30.61±1.27	0.092±0.005	10.9±0.6	30.6±1.5
Pr1SB+FC1SB	0.1+3.0	6.7±0.6	$1.59\pm0.1\times10^{-6}$	27.81±2.61	0.104±0.012	9.7±1.1	N.A.
FC2SB1	3.0	5.9±0.2	$1.41\pm0.05\times10^{-6}$	24.64±0.96	0.119±0.005	8.4±0.4	39.6±1.8
Pr1SB+FC2SB	0.1+3.0	4.2±0.1	$9.88\pm0.2\times10^{-7}$	17.28±0.37	0.178±0.004	5.6±0.1	N.A.
FC3SB1	3.0	8.8±0.6	$2.09\pm0.1\times10^{-6}$	36.63±2.54	0.074±0.007	13.6±1.2	24.5±2.2
Pr1SB+FC3SB	0.1+3.0	8.3±0.1	$1.98\pm0.02\times10^{-6}$	34.62±0.40	0.079±0.001	12.7±0.2	N.A.
FC4SB	3.0	7.0±0.2	$1.65\pm0.05\times10^{-6}$	28.93±0.87	0.098±0.004	10.2±0.4	32.7±1.2
Pr1SB+FC4SB	0.1+3.0	4.5±0.2	$1.06\pm0.04\times10^{-6}$	18.61±0.64	0.164±0.006	6.1±0.2	N.A.
FC5CB	3.0	8.8±0.8	$2.09\pm0.2\times10^{-6}$	36.62±3.21	0.074±0.008	13.6±1.5	24.6±2.7
Pa1ACB+FC5CB	0.1+3.0	5.3±0.5	$1.25\pm0.1\times10^{-6}$	21.81±2.22	0.138±0.016	7.3±0.9	N.A.
FC6APB	0.8	11.3±0.6	$2.69\pm0.1\times10^{-6}$	47.05±2.44	0.053±0.004	19.0±1.4	65.9±4.7
Pr1SB+FC6APB	0.1+0.8	5.7±0.2	$1.36\pm0.05\times10^{-6}$	23.79±0.86	0.124±0.005	8.1±0.3	N.A.
FC7ACB-	0.8	7.8±1.4	$1.85\pm0.3\times10^{-6}$	32.36±5.90	0.088±0.022	11.3±2.6	110.3±27.4
Pr1SB+FC7ACB	0.1+0.8	6.0±0.1	$1.44\pm0.02\times10^{-6}$	25.12±0.32	0.116±0.002	8.6±0.1	N.A.
FC8ACB-	0.8	14.8±1.0	$3.52\pm0.2\times10^{-6}$	61.56±4.03	0.036±0.004	28.1±2.9	44.5±4.4
Pr1SB+FC8ACB	0.1+0.8	10.6±0.3	$2.53\pm0.07\times10^{-6}$	44.20±1.14	0.057±0.002	17.5±0.6	N.A.
UC1CBR	20	1.5±0.2	$3.45\pm0.5\times10^{-7}$	6.04±0.84	0.552±0.074	2.2±0.3	27.6±3.7
UC2CBF	10.0	3.5±0.3	$8.33\pm0.7\times10^{-7}$	14.58±1.27	0.215±0.021	3.0±0.4	21.5±2.1
UC3CBT	8.0	2.3±0.4	$5.55\pm0.9\times10^{-7}$	9.72±1.62	0.341±0.069	2.9±0.5	42.6±8.6
Pr1SB	0.1	30.6±1.0	$7.26\pm0.2\times10^{-6}$	127.0±3.97	0.007±0.001	144.7±19	69.1±8.3
Ti1XPS	50.0	0.1±<0.01	$2.84\pm0.05\times10^{-8}$	0.50±0.01	6.858±0.111	0.1±<0.1	137.2±2.2
Ti2EPS	50.0	0.3±0.02	$7.15\pm0.4\times10^{-8}$	1.25±0.07	2.714±0.152	0.4±<0.1	54.3±3.0
Ti3RW	50.0	4.5±0.2	$1.06\pm0.04\times10^{-6}$	18.56±0.69	0.164±0.007	6.1±0.3	3.3±0.1
Pa1ACB	0.1	30.6±0.7	$7.27\pm0.2\times10^{-6}$	127.3±2.79	0.007±0.001	146.2±13	68.4±5.9
Ma1BM(*)	190.0	0.9	2.01×10^{-7}	3.52	0.950	1.1	5.0
Ma2AAC(*)	200.0	0.9	2.19×10^{-7}	3.84	0.870	1.1	4.4
Pl1CLB(*)	20.0	2.6	6.10×10^{-7}	10.67	0.300	3.3	15.0
GB1GB(*)	12.5	10.1	2.37×10^{-6}	41.40	0.065	16.0	5.0

Table 2. The results on water vapour permeability properties for the samples.

N.A.: not available; refers to values that could not be calculated, especially for samples comprised of more than one layer.

(*) For the samples of Ma1BM, Ma2AAC, Pl1CLB and GB1GB, the calculations were based on μ-value data taken from the literature (Andolsun et al., 2006; TS 825, 2008).

respectively. The cement-based undercoats were also observed to have similar physical properties with the cement-based finish coats. The synthetic emulsion-based finish coats had lower density, higher porosity and higher water absorption capacity than the cement-based ones, with the mean values of 1.55 $\pm$0.11g/cm^3, 37.7$\pm$5.2% and 24.6$\pm$5%, respectively. The polymer-based ones, on the other hand, were observed to have the lowest density, the highest porosity and the highest water absorption capacity, with the mean values of 1.18 $\pm$0.10g/cm^3, 48.7$\pm$2.1% and 41.7$\pm$5.1%, respectively. Due to their high porosities, all coatings except cement-based ones were found to have high water absorption capacities varying in the

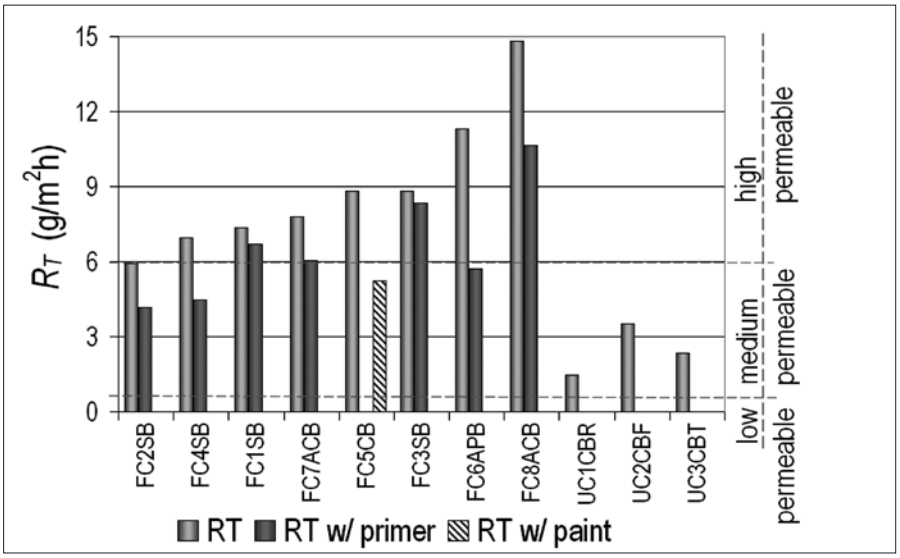

Figure 6. The RT values of finish coats and undercoats individually and the total RT values of the coats together with primer or paint layer, showing their permeability rating as low, medium or high.

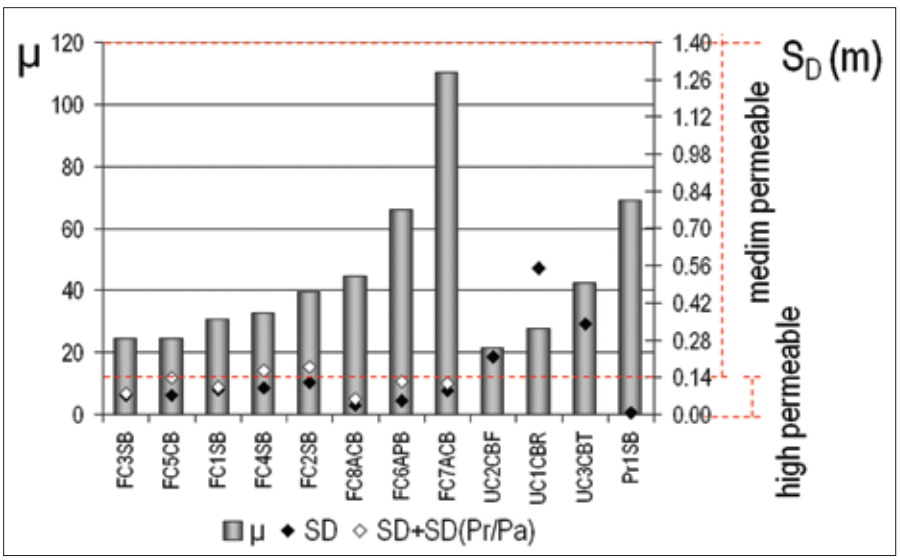

Figure 7. The μ and SD values of the finish coats, undercoats and primer, individually, and the total SD values of the coats together with primer or paint, showing their permeability rating as low, medium or high.

range of 18.1±1.5% and 45.3±2.5%, while lower water absorption capacities were desirable.

The water vapour permeability characteristics for each coating layer, individually and together with the paint/primer layer, were summarized in **Table 2**, **Figure 6** and **Figure 7.** According to the results:

- All finish coats examined were found to behave as high vapour permeable layers due to their application in thin layers while having high resistance to water vapour permeation (μ). The permeance and perm values were also found to be high, representing their high vapour permeability characteristics.
- Among all samples, the *FC8ACB*, *FC6APB* and *FC7ACB* polymer-based ones were found to have the highest μ values. Being in the range of 44.5±4.4 to 110.3±27.4, these were considerably above the range of 15 to 35 given in the literature for similar finish coats (Pfeifer *et al.*, 2001). On the other hand, these coats were determined to possess high water vapour permeability according to their *SD* values (in the range of

0.036±0.004m – 0.088±0.022m), and to their R_T values (in the range of 7.8±1.4 g/hm^2 – 14.8±1.0 g/hm^2). The high permeability of these coats was attributed to their application in very thin layers of 0.8mm.

- The synthetic-emulsion based finish coats *FC3SB*, *FC1SB*, *FC4SB* and *FC2SB* were found to be of high permeability due to their *SD* values in the range of 0.074±0.007 to 0.119±0.005m, while having μ values in the range of 24.5±2.2 to 39.6±1.8.
- Though it is a cement-based finish coat, the *SD* value of *FC5CB* was found to be 0.074±0.008m, which exhibited higher water vapour permeability than some synthetic emulsion- and polymer-based finish coats.
- Cement-based undercoats *UC2CB*$_F$, *UC1CB*$_R$ and *UC3CB*$_T$, on the other hand, were found to be medium water vapour permeable due to their *SD* values being in the range of 0.215±0.021m to 0.552±0.074m. Their μ values, in the range of 21.5±2.1 and 42.6±8.6, were similar to the μ values of synthetic emulsion- and cement-based finish coats.
- When the μ and *SD* values of contemporary coats, especially the cement-based undercoats complementing the exterior finishing system, were compared with the historic lime, mud and gypsum plasters, which are well-known with their own high breathing properties (Caner et al., 2006; Esen et al., 2004; Caner, 2003; Akkuzugil, 1997; Akyazı, 1998), the contemporary ones definitely seemed to have lower breathing capabilities than the historic ones.

The Effect of Primer or Paint on the Permeability of the Finish Coat

The effect of primer or paint on the permeability of finish coats was assessed by a comparison of individual R_T and *SD* values for each primer, paint and finish coat with the total R_T and *SD* values for each finish coat, either applied on primer or treated with paint (**Table 2** and **Figure 6 and Figure 7**).

The synthetic-emulsion based primer *Pr1SB* had a very high μ value of 69.1±8.3 when compared to the finish coats and undercoats, except for the polymer-based finish coat FC7ACB, having μ value of 110.3±27.4. It was found, however, to be much more vapour-permeable than all coats with the *SD* value of 0.007±0.001m, due to its application in a very thin layer of 0.1mm (**Table 2** and **Figure 7**). On the other hand, except for the finish coats *FC1SB* and *FC3SB1*, the results of the total R_T and *SD* values of finish coats applied on primer, showed an increase greater than expected. These results indicated that the water vapour permeability of finish coats decreased in varying amounts when primer was applied (**Figure 6** and **7**). For instance, the application of a primer layer produced an increase of 0.063m in the *SD* values of synthetic finish coats, *FC4SB* and *FC2SB*, which thus rendered them medium permeable layers. The highest increase in the *SD* value was observed for the polymer-based *FC6APB*, with an increase of 0.071m (ten times the *SD* value of primer), while still falling in the high permeable range. The same primer, however, seemed to affect slightly the *SD* values of copolymer-based finish coats *FC7ACB* and *FC8ACB*, with an average increase of 0.025m. It was thought that the decrease in vapour permeability by differing amounts when finish coats were applied direct on primer might be due to an interaction between primers and finish coats having different material compositions.

The *SD* value of the acrylic co-polymer-based exterior paint, *Pa1ACB*, was found to be 0.007±0.001m, showing that it individually had high water vapour permeability despite its high μ value of 68.4±5.9 (**Table 2**). Similar to the effect of the primer, when the cement-based finish coat, *FC5CB*, had received a coat of *Pa1ACB* paint, the increase in the total *SD* value rendered the finishing layer medium permeable. This could have been due to the fact that the paint had filled the pores of finish coat to a certain depth and had slowed down the vapour flow.

In summary, with the application of primer or paint, *FC2SB*, *FC4SB*, *FC5CB* became medium permeable while the others still remained high permeable. The use of a primer or paint layer appeared to somewhat inhibit the breathing capability of certain finish coats. The reasons underlying this particular phenomenon need investigation by further studies.

Continuity of Water Vapour Permeability throughout Wall Section

For walls to be considered "breathing", the water vapour transmission of each layer should be continuous throughout their section and remain within certain ranges. In other words, it is necessary to eliminate any interruption of water vapour passage so as to ensure the drying of moisture within the wall section from its exposed surfaces. The wall section compositions were examined in this regard. The data were used to analyse each layer making up the wall section in terms of its *SD* values and then breathing capability of the overall wall section by calculating its total *SD* value (**Table 3, 4**) The graphs were produced present the increase in total *SD* value of the wall by adding up the individual *SD* values of each layer as a function of layer thickness (**Figure 8 and 9**). The slope of linear increase belonging to a layer presented its individual μ value. Any change on the slope throughout the wall section exhibited the change in resistance to water vapour permeation. A sharp increase in *SD* value meant an interruption of water vapour passage between the layers.

The acrylic copolymer-based *FC8ACB* and *FC7ACB*, and the synthetic emulsion-based *FC3SB* and *FC1SB* finish coats that had received primer

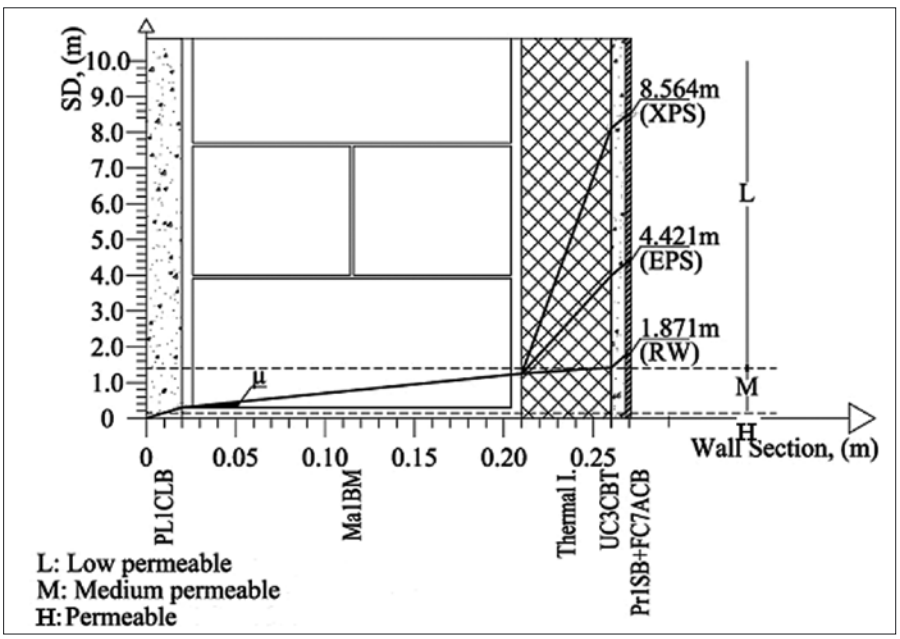

Figure 8. The graph showing the increase in total SD value throughout the wall section as a function of layer thickness for the walls externally insulated with RW, EPS or XPS, and externally plastered with FC7ACB. The slope of each line presents the individual μ value of each layer.

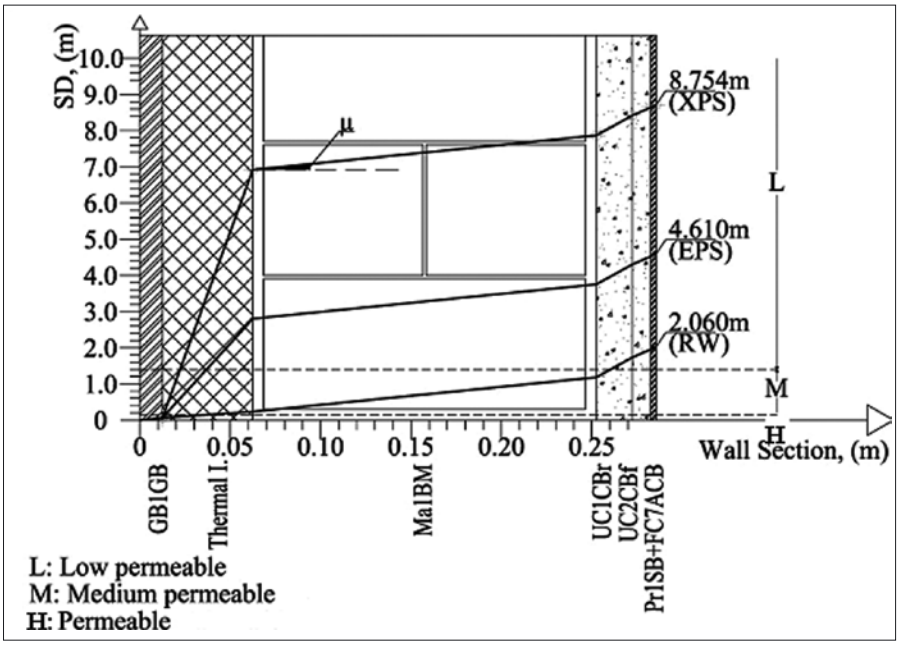

Figure 9. The graph showing the increase in total SD value throughout the wall section as a function of layer thickness for the walls internally insulated with RW, EPS or XPS, and externally plastered with FC7ACB. The slope of each line presents the individual μ value of each layer.

were found to have good breathing properties (**Table 2**- **3**). External walls composed of those layers therefore seemed to be more desirable for ensuring the evaporation of any entrapped water and/or water vapour within the finishing system.

On the other hand, the use of high-vapour-permeable finish coats alone was not enough to render breathing walls. The continuity of water vapour transmission through the wall section was found to be somewhat disturbed due to medium- and/or low-permeable layers such as cement-based undercoats and thermal insulation layers (**Tables 3-4 and Figures 7-8**). The results were briefly explained below:–

- The *SD* and R_T values showed that the cement-based undercoats as used on both internally and externally insulated walls were medium

SD-Internal finish, m		*SD*-Masonry, m		*SD*-Thermal insulation, m		*SD*-Undercoat, m		*SD*-Finish coats (w/ primer or paint), m		Total *SD*-Minimum, m
Pl1CLB	0.300	Ma1BM	0.950	Ti1XPS	6.858	UC3CBt	0.341	Pr1SB+FC1SB	0.104	1.779
								Pr1SB+FC2SB	0.178	1.853
								Pr1SB+FC3SB	0.079	1.754
				Ti2EPS	2.714			Pr1SB+FC4SB	0.164	1.839
		Ma2AAC	0.870					Pa1ACB+FC5CB	0.138	1.813
				Ti3RW	0.164			Pr1SB+FC6APB	0.124	1.799
								Pr1SB+FC7ACB	0.116	1.791
								Pr1SB+FC8ACB	0.057	1.732
Total SD-Minimum		(Pl1CLB + Ma2AAC + Ti3RW + UC3CBt + Pr1SB +FC8ACB)								1.732
Total SD-Maximum		(Pl1CLB + Ma1BM + Ti1XPS + UC3CBt + Pr1SB +FC2SB)								8.627

Table 3. The individual *SD* values of each layer forming an externally insulated wall section. The total *SD* value of the wall section is the sum of individual layer values. The wall composition with the highest permeability is shown by grey shading, which yields a total *SD* value of 1.74m in average.

SD-Internal finish, m		*SD*-Thermal insulation, m		*SD*-Masonry, m		*SD*-Undercoat, m		*SD*-Undercoat, m		*SD*-Finish coats (w/ primer or paint), m		Total *SD*-Minimum, m
GB1GB	0.063	Ti1XPS	6.858	Ma1BM	0.950	UC1CBr	0.552	UC2CBf	0.215	Pr1SB+FC1SB	0.104	1.968
										Pr1SB+FC2SB	0.178	2.042
										Pr1SB+FC3SB	0.079	1.943
		Ti2EPS	2.714	Ma2AAC	0.870					Pr1SB+FC4SB	0.164	2.028
										Pa1ACB+FC5CB	0.138	2.002
		Ti3RW	0.164							Pr1SB+FC6APB	0.124	1.988
										Pr1SB+FC7ACB	0.116	1.980
										Pr1SB+FC8ACB	0.057	1.921
Total SD-Minimum				(Pl1CLB+Ti3RW+ Ma2AAC+UC1CBr+UC2CBf+Pr1SB+FC8ACB)								1.921
Total SD-Maximum				(Pl1CLB+Ti1XPS+Ma1BM+UC1CBr+UC2CBf+Pr1SB+FC2SB)								8.816

Table 4. The individual *SD* values of each layer forming an internally insulated wall section. The total *SD* value of the wall section is the sum of individual layer values. The wall composition with the highest permeability is shown by grey shading, which yields a total *SD* value of 1.93m in average.

permeable, disturbing the water vapour transmission along the wall section. Due to its higher vapour permeability, the undercoat $UC3CB_T$, as used on externally-insulated walls, seemed to be more advantageous than the other two, $UC1CB_R$ and $UC2CB_F$, as used on internally-insulated walls (**Table 3-4).**

- The thermal insulation materials, especially the polystyrene-based ones at thicknesses of 5 cm, were observed to significantly hinder the passage of water vapour through the wall section. The polystyrene-based types, *XPS* and *EPS*, were found to be low-permeable, with *SD* values of 6.858±0.11m and 2.714±0.152m, respectively; while the mineral wool type, rockwool (*RW)*, was found to be medium-permeable, with an *SD* value of 0.164±0.007m. The *XPS* and *EPS* also had higher μ values of 137.2±2.2 and 54.3±3.0, respectively, while the *RW* had a noticeably lower μ value of 3.3±0.1.
- The externally- and internally-insulated walls seemed to become low permeable particularly due to low breathing characteristics of these insulation layers. As shown in **Table 3-4**, the total *SD* values of externally-insulated and internally-insulated walls were calculated to be in the range of 1.732m to 8.627m and in the range of 1.921m to 8.816m, respectively.

In the context of energy conservation, the incorporation of thermal insulation in the building envelope is obligatory for all new construction (TS 825, 2008). Taking into consideration this fact, among these three types of insulation, the mineral-based one seemed to be more advantageous than the polystyrene-based ones in yielding walls that breathe.

Compatibility of finish coats in terms of modulus of elasticity

The physicomechanical properties of the finish coats and undercoats in terms of their *UPV* measurements and *MoE* values were summarized in **Figure 10**. The finish and undercoats exhibited similar *MoE* values with a mean of 1.60±0.25 GPa, except the finish coat *FC2SB* with the highest *MoE* value of 2.89±0.78 GPa and the undercoat $UC3CB_T$ with the lowest *MoE*

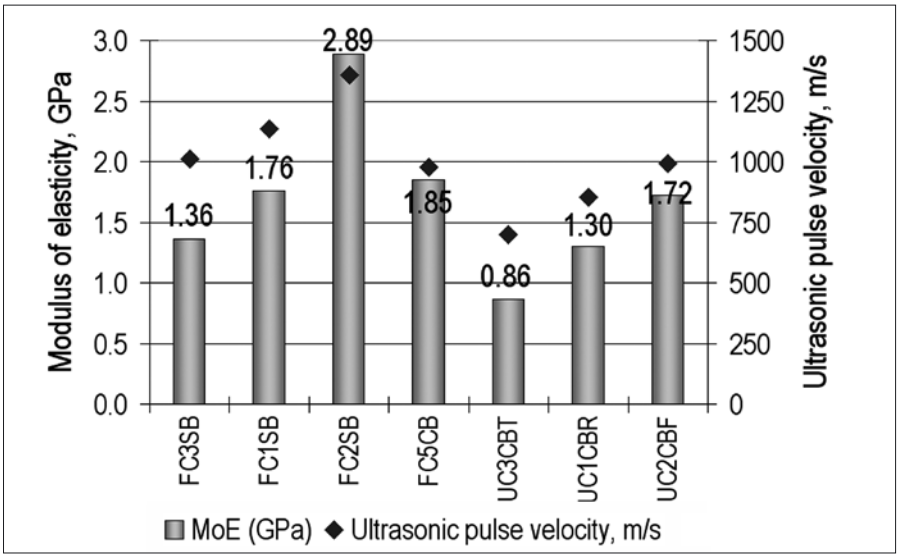

Figure 10. The UPV and MoE values for finish coats and undercoats

value of 0.86±0.12 GPa. As the undercoat $UC3CB_T$ was applied together with reinforcing mesh, its strength was expected to be higher.

In order to better interpret the *MoE* values of the finish coats examined in this study, the data were compared with the ones found in literature. Those finish coats were found to have considerably lower *MoE* values than the calcium sulphate-based unmodified, latex-modified and polymer-impregnated plasters studied by Çolak (2006). When compared to other proprietary cement-based plasters with additives specifically produced for AAC masonry (Andolsun *et al.*, 2006), the coats examined in this study exhibited lower *MoE* values than the former, being in the range of 2.00GPa to 3.90GPa.

On the other hand, when compared with the mechanical properties of historical mortars and plasters, it was seen that these coatings exhibited *MoE* values similar to some historical lime mortars, being in the range of 1.07GPa to 2.69GPa (Tunçoku and Caner-Saltık, 2006), and to some historical lime plasters, being in the range of 1.50GPa-3.30GPa (Caner, 2003) and 1.04GPa-2.91GPa (Esen et al., 2004). As these compositions were reported to still be in good order even after exposure to weathering for centuries, there seemed to be no overt reason not to assume their *MoE* values to be viable yardsticks. From this point of view, the finish coats examined in this study appeared to have low but enough strength to properly do their job in terms of their *MoE* values.

The compatibility of those coats with underlying masonry was discussed by checking whether or not elasticity of layers exceeds that of backing masonry towards exterior finishing layers. The results showed that:–

- Except *FC2SB*, the *MoE* values of synthetic emulsion- and cement-based coating layers, varying in the range of 1.30±0.13 GPa and 1.85±0.37 GPa, were less than the *MoE* value of load-bearing AAC units, which was determined as 2.1 GPa by Andolsun et al. (2006). The similar *MoE* values of the layers forming the wall section and the gradual decrease of these values from the AAC towards the exterior seemed to establish a viable composition in terms of *MoE* values.

- For *FC2SB* when applied to AAC masonry, there seemed to be a likelihood of early failure, such as cracking and flaking, resulting from its higher *MoE* value.

CONCLUSION

The compatibility properties of contemporary finish coats and their complementary sub-layers forming the overall exterior finishing system were discussed with an emphasis on water vapour permeability and modulus of elasticity. It was pointed out that not only the properties of each material, individually, are important, but also, their suitability with their neighbouring materials forming a part of an overall structure, is essential. It was concluded that:-

- The material properties of the synthetic emulsion-, cement- and polymer-based finish and undercoats seemed to vary in accordance with their material composition. In this regard, cement-based finish and undercoats were found to have the highest bulk density with the lowest porosity. The synthetic finish coats had higher bulk density and lower porosity than the polymer-based ones.
- All finish coats examined were found to behave as high vapour permeable layers due to their application in thin layers while having high resistance to water vapour permeation (μ). These properties are desirable for breathing finish coats. In order to achieve this, careful workmanship is necessary during their application since special care should be given to the coat thickness.
- The use of a primer or paint layer appeared to decrease the breathing capability of finish coats in various amounts. The material properties of any primer and paint layers should, therefore, be improved for their proper combination with finish coats.
- The cement-based undercoats and thermal insulation layers, especially the polystyrene types, seemed to be unsuitable for the construction of breathing exterior walls due to their less vapour permeability properties.
- The synthetic emulsion- and cement-based finish coats and their complementary cement-based undercoats seemed to have low but sufficient physicomechanical strength for their proper functioning. These coats, except the synthetic emulsion-based finish coat *FC2SB*, were thought to be compatible with each other and with AAC masonry in terms of their *MoE* values.

The analysis of the multi-layer constructions by producing the charts showing the increase in total SD value throughout the wall section versus layer thicknesses were found to be useful to locate the interfaces interrupting the vapour flow along the wall section.

It should be brought to the attention of future researchers that difficulties were experienced in the preparation of samples in proper thicknesses for the examination of *MoE* values of finish coats, especially for the polymer-based ones. Owing to this fact, it is necessary to improve the standard test methods in terms of sample preparation and/or determination of the modulus of elasticity for the layers applied in very thin layers.

Some other measureable parameters of compatibility, such as thermal and moisture dilatation properties, water impermeability, as well as the

relationship between the resistance to water vapour permeation and water impermeability for multi-layer finishing systems should also be examined by further studies.

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Anahtar Sözcükler: dış cephe kaplamaları; uyumluluk özellikleri; su buharı geçirimliliği; esneklik modülü; nefes alan duvarlar; ısı yalıtımlı dış duvarlar.

YALITIMLI DIŞ DUVARLARDA KULLANILAN DIŞ CEPHE KAPLAMALARININ UYUMLULUK ÖZELLİKLERİNİN DEĞERLENDİRİLMESİ

Yalıtımlı dış duvarlarda kullanılan sentetik emülsiyon, polimer ve çimento esaslı koruyucu dış cephe kaplamaları ve bunları tamamlayan alt katmanların oluşturduğu dış cephe bitirme sistemleri, su buharı geçirimliliği ve esneklik modülü açısından incelenmiştir. Astar, boya ve ısı yalıtım katmanları gibi yalıtımlı dış duvar kesitini tamamlayan diğer katmanların da su buharı geçirimlilikleri incelenmiştir. Yapı bileşenlerini oluşturan malzemelerin tek başlarına özellikleri önemli olmakla birlikte, ilişkide oldukları diğer komşu malzemelerle de uyumlu

olmaları önemlidir. İncelenen tüm cephe kaplamalarının yüksek su buharı geçirimliliğine sahip oldukları anlaşılmıştır. Gerçekte su buharı geçirimliliğine direnç indeksi (μ) yüksek olan bu kaplamalar, çok ince tabakalar halinde uygulandıklarından dolayı, yüksek su buharı geçirimli hale gelmişlerdir. Astar veya boya katmanı, cephe kaplama malzemelerinin nefes alma özelliklerini değişen seviyelerde azaltmaktadır. Polistiren ısı yalıtım malzemeleri ile çimento esaslı kaba ve ince sıvalar, duvar kesiti içerisindeki su buharı akışını önemli ölçüde kesen, yani duvarların nefes almasına engel olan katmanlardır. Sentetik emülsiyon ve çimento esaslı cephe kaplamalarının ve bunlarla birlikte kullanılan çimento esaslı sıvaların düşük ama yeterli bir dayanıma sahip oldukları görülmüştür.

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