ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 9, No. 3. 2003

The Compatibility of Finishing Layer and Substrate of External Surface of Buildings Walls in Environment of Variable Humidity and Temperature

R. Miniotaitė*

Institute of Architecture and Construction, Kaunas University of Technology, Tunelio 60, LT-3035 Kaunas, Lithuania

Received 10 September 2002; accepted 24 April 2003

External surface of building walls is continuously effected by the natural climate phenomena of variable intensity and the factors occurring due to the anthropogenic activity. The heat and mass exchange between outside air and walls is the most distinct in a relatively thin (1 - 3 cm) surface layer. The activity of physical processes, substantial variations of temperature and moisture and the effects of various origins are particularly distinct in the above layer. Durability of the surfaces depends on the prevailing climate effects and on a complex of physical and mechanical values of the materials used. The complex and partial methods have been worked out for application at investigation of destruction processes. Partial methods have been applied in the cases of investigation of the physical and mechanical characteristics, which are necessary to be evaluated before direct weather durability test in the climatic chamber along the program of simulated effects. It is established that the paint under consideration should be grouped according to their nature and character of macrostructure and ground layer to be covered by paint according to their capillary structure and moisture deformations.

Keywords: paints, physical and mechanical properties, interaction of materials, investigation method, durability.

1. INTRODUCTION

Physical and mechanical properties of construction substrate and finishing layer can supplement one another or, on the contrary, stimulate destruction [1 – 7].

In [8 – 12] much information is given on the paint and coatings, physical and chemical nature of paints, structure formation, results of investigations of physical and mechanical values. However, the data of complex investigations of the surfaces already finished are insufficient. Usually the physical and mechanical values of individual components – the coating and the wall being painted – are known. However, the knowledge about the resulting of the whole complex of properties of a new derivative – the surface layer – is insufficient.

The differences of moisture and temperature cause deformations of coating and substrate, which may cause internal stress in the coating and shift in the joint, that can be increased by the pressure of vapour migration to outside [13]. The resistance to shift can be defined by mutual adhesion of materials, which is not yet well enough investigated. On the other hand, vapour migration flow outside and moistening of external layers show contrary effects [14 – 18, 20]. The above phenomenon creates a certain collision between the necessity to thicken paints against rain penetration and, vice versa, to thin the thickness of paints, so that they do not accumulate vapour between the layers, but evaporate freely. So, the material beyond the vapour barrier does not undergo delamination.

The investigation of the external layer of walls and durability of different paints is carried out in the present paper.

2. MATERIALS AND INVESTIGATION METHODS

In [7, 14 – 17, 20 – 27] we find some data on the physical and mechanical properties of materials intended for finishing, which predetermine the durability of such materials. However, these data are often insufficient and fragmentary. Therefore, the partial comparative investigations have been carried out.

In order to properly investigate the durability of paints, it is necessary to compose a methodical chain - the scheme of stage-by-stage (intermediate) and chamber-type consecutive investigations (Fig. 1).

The methods of generalised complex investigations were made up on the basis of the results of investigations carried out according to the stage-by-stage methods.

It was found that the provided specific physical and mechanical properties of the paints may change in the new combination of “paint - substrate”. The adequate and comparative results of durability were obtained by the classification of coatings in three groups according to their structural nature: 1) paints formed out of aqueous polymeric dispersions; 2) silicate paints; 3) paints formed out of polyacrylates and silicone solutions in organic solvents, or silicone dispersions.

In the case of bi-laminar system “paint film - wall painted” we encounter with water (rain) flow rate from outside towards the wall and water vapour flow rate from the wall to outside. The optimum selection of the paint is necessary for the wall to be painted. The water vapour is accumulated in the wall, when disturbed from escaping through a very dense (vapour - tight) film might cause blebs or tear off the whole film or its parts.

Since several hundreds of combinations are formed while plenty of surfaces are coated with various paints, the silicate brick was chosen for investigation. The choice was

---

[*] Corresponding author. Tel.: +370-37-300481; fax: +370-37-300454.
E-mail address: *rutaminiot@centras.lt* (R. Miniotaitė)

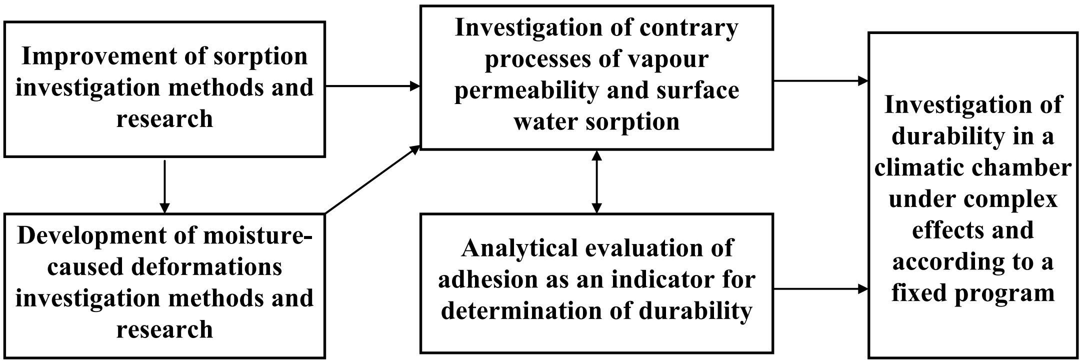

Fig. 1. Principal scheme of complex research methods

predetermined by the advantages of the silicate brick surface and its homogeneous capillary structure in order to have the results less scattered. The moisture diffusion processes in the silicate brick are comparatively even [15, 17, 18, 19].

The brick was coated using paints of different origin (total 26 compositions). Analyses of compositions of the paints indicate that vapour permeability depends on the paint used, polarity of film-makers, and bonding agents used.

Water vapour permeability coefficient was determined in 20 °C environment according to requirements of the EN ISO 12572:2001 [28]. It was determined by preparation of 3 specimens of 100 mm diameter and 25 mm thickness of the materials without paint and 3 specimens with surfaces already painted. The painted specimens were fixed on a cup, paint facing down (cup method).

Water vapour resistance Z_p, [m^2·h·Pa/mg] is in reverse proportion to vapour permeability δ_p, [mg/(m·h·Pa)]:

$$Z_p = \frac{d_x}{\delta_p}, \tag{1}$$

where d_x is the thickness of samples of bricks, in meters.

The specimens used for determination of vapour permeability were as well used for determination of surface water sorption coefficient by DIN 52 617 [29].

The specimens paint facing down were soaked in a water bath keeping 20 °C temperature.

Water sorption coefficient w, [kg/(m^2·h$^{0.5}$)] is calculated:

$$w = \frac{m}{\sqrt{t}}, \tag{2}$$

where m is a mass of absorbed water related to 1 square meter of sample, in kg/m^2; t – duration of soaking, in hours.

The basic conditions and means used for climatic tests were as follows:

a) in the warm part of the chamber room temperature is automatically maintained at $t = (18 \pm 2)$ °C and RH $\phi = (50 - 70)$ %;

b) an automatic climatic regime was maintained in the cold part of the chamber:

– room temperature during 15 hours freezing down to $t = -(15 \pm 5)$ °C;

– the temperature of a protective finished layer of the wall $\theta_v = (15 \div 20)$ °C during 8 hours reheating;

– UV light lamp was used at the last hour of heating;

– in the cold part of the chamber, enclosure-flushing equipment has been installed. During one hour water-flushing operation, the finish of the wall must get covered by a uniform water film (flushing intensity 1 l/m^2 min, temperature $t = (7 \div 12)$ °C, water pressure in the flushing tube – 0.15 MPa);

– air circulation at the velocity of $v = 2 \div 4$ m/s was maintained by a ventilating device installed in the cold part of the chamber.

3. RESULTS AND ANALYSIS

Physical properties of the surface layer (0.025 m) of silicate bricks coated with aqueous polymeric disperse paints are compared in Fig. 2 and Fig. 3 [26].

Aqueous disperse paints are distributed according to the water sorption coefficient in two subgroups: a) *A*1 (EA-1-1), *A*2 (Dufa), *A*3 (Herbol), *A*4 (Akmena) [$w > 0.60$ kg/(m^2·h$^{0.5}$)] (Fig. 2); b) *A*5 (Renovierfarbe), *A*6 (EA-1-2), *A*7 (Hansa Nobel), *A*8 (EA1), *A*9 (EA-1-3) [$w \leq 0.10$ kg/(m^2·h$^{0.5}$)] (Fig. 3). As can be seen the increase of vapour resistance less than twice, decreases the water sorption coefficient more than 30 times. The water sorption coefficients of neighbouring paints (*A*4 and *A*5) in separate subgroups vary in 6 times.

Fig. 2 shows that surface water absorption in the case of the paints of subgroup "a" is high - these are relatively "rain permeable" paints: $w = (0.81 \div 0.60)$ kg/(m^2·h$^{0.5}$). Their vapour resistance $Z_p = (0.47 \div 0.62)$ m^2·h·Pa/mg [$\delta_p = (0.053 \div 0.041)$ mg/(m·h·Pa)].

Surface water absorption in the case of paints of subgroup "b" is low – these are rather "tight" paints $w = (0.024 \div 0.10)$ kg/(m^2·h$^{0.5}$) (Fig. 3).

Their vapour resistance $Z_p = (0.65 \div 0.84)$ m^2·h·Pa/mg [$\delta_p = (0.038 \div 0.030)$ mg/(m·h·Pa)] is on the average 35 % higher than those of subgroup "a".

As was foreseen before investigations of paints on the durability the theoretical attitude (low vapour resistance - low rain penetration - "good"; high vapour resistance - high rain penetration - "bad") can be insufficient evaluate paints durability.

Therefore, during investigation the changes in the surface layer showing decrease in adhesion between paint and silicate brick, were fixed. After the investigations in the climate chamber were finished and the results were

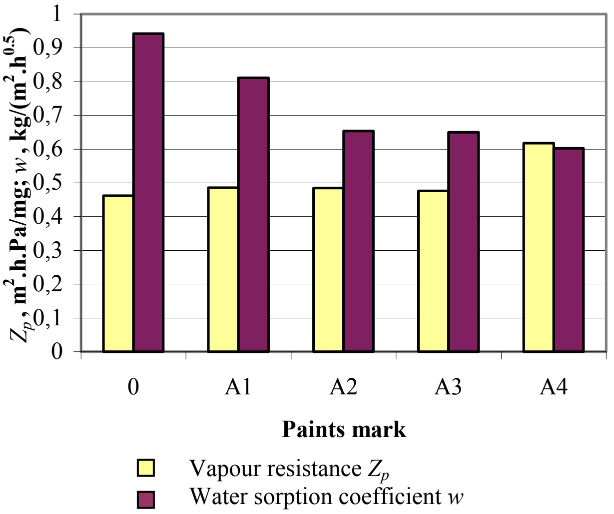

Fig. 2. Comparison of variation in the water sorption coefficient and in the vapour resistance of the aqueous polymeric disperse paints (subgroup "a") applied on silicate bricks. Notes: paints mark 0 - non-painted silicate brick

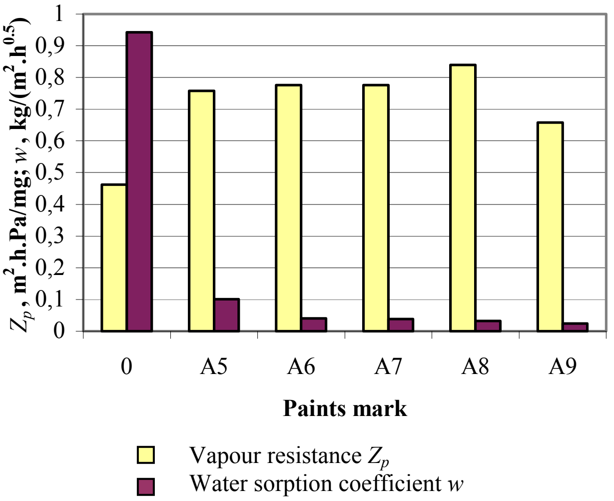

Fig. 3. Comparison of variation in the water sorption coefficient and in the vapour resistance of the aqueous polymeric disperse paints (subgroup "b") applied on silicate bricks

calculated, the reliability of theoretical statement was verified.

The value of resistance to complex effects was compared with the resistance of non-painted silicate bricks surface in the modelled cycles.

The tests carried out in the chamber indicated that the paints of identical vapour resistance could be compared even though the nature of deterioration and ageing as well as protective significance of such paints for the painted surface were different. The mechanism of such differences is explained taking into account additionally the complex effects of the moisture-caused deformations of the substrate and physical and mechanical values of the paints [6, 7].

Paint - substrate adhesion is explained by interaction between polar and ionic groups of the bonding agent of paint and functional groups of substrate surface.

Durability of the aqueous polymeric disperse paints is described (considering two basic physical properties) in Fig. 4 and Fig. 5.

In the all cases the vapour resistance increase was influenced by using the acrylic bonding agent in appropriate proportions. However, the increase of vapour resistance is permissible and does not reduce durability of a properly selected composition of the paint. In the case of subgroup "a" permissible water sorption coefficient $w < 0.65$ kg/(m^2·h$^{0.5}$) and the highest value of vapour resistance $Z_p < 0.62$ m^2·h·Pa/mg [$\delta_p > 0.041$ mg/(m·h·Pa)] are suitable with respect to durability. In the case of subgroup "b" all physical parameters are high enough. The reason of undurability of two paints *A6* and *A9* is distinguished: the amount of bonding agent was insufficient. The interaction between paint and silicate brick was low.

The deterioration of silicate bricks in climatic chamber was compared with the natural 15 years duration observation.

Durability of paints in the case of insufficiently stabilized compositions of the aqueous polymeric dispersions is $C < 80$ cycles irrespective of the values of the water sorption and vapour permeability coefficients. Destruction of the above compositions is expressed in the fast wrinkling of the film, mould formation, loss in the adhesion (small blebs) and washing off after 50 – 80 cycles.

150 accelerated cycles in the climatic chamber correspond to 12 years at an average natural ageing.

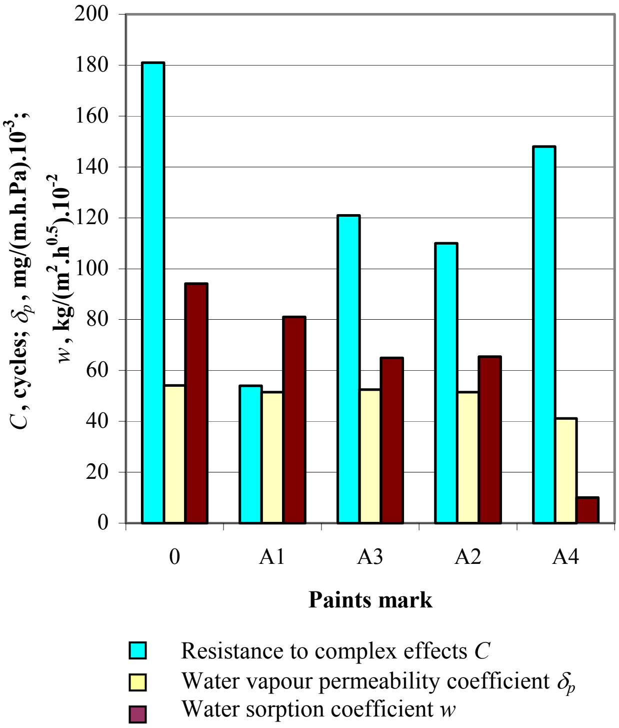

Fig. 4. Resistance to climate effects of aqueous polymeric disperse paints (subgroup "a") on silicate brick walls considering water sorption coefficient and vapour permeability

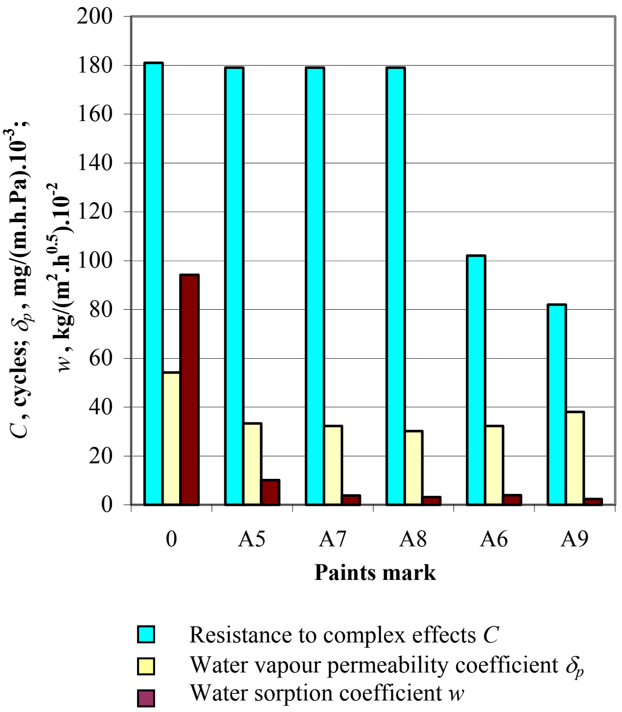

Fig. 5. Resistance to climate effects of aqueous polymeric disperse paints (subgroup "b") on silicate brick walls considering water sorption coefficient and vapour permeability

The resistance of the non-painted silicate bricks surface was found to be about 180 cycles. Following the effect of 170 – 180 cycles, hydrosilicate crystalline structure of the silicate bricks surface thin layer (0.05 – 0.2 mm) underwent deterioration. Ground sand particles together with hydrosilicate deterioration products, dirt and other adhered aerosol inclusions crumbled off or were washed away comparatively easily.

By analysing the results of grouped paints it was found that peculiar nature of vapour permeability and water sorption was typical of each group; spreading of the paint destruction is different. The nature of paint destruction depends on the moisture-caused deformation of the substrate on the different level.

3. CONCLUSIONS

1. Investigation on the durability of the building walls external surfaces paints by modelled complex effects in a climatic chamber is purposive only after intermediate investigations and measurements of the substrate physical and mechanical properties predetermining durability, sorption-desorption and moisture-caused deformations. The effect of the above mentioned properties upon durability should be evaluated.
2. Proper determination of paint durability is possible only in the case of simultaneous investigation of the wall surface layer.
3. Influence of moisture deformations upon destruction of coatings depends on the porosity of materials of the surface being coated and on the origin and macrostructure of the coating.
4. Moisture-caused deformations increase the number of blisters of aqueous polymeric disperse paints and paints formed out of polyacrylates and silicone solutions in organic solvents.
5. The nature and signs of deterioration and ageing of paints of the separate groups develop in a different way.
6. The intensity of surface destruction is unproportional to the number of testing cycles. The increase of the number of modelled cycles accelerates destruction processes.
7. Durability of the paints formed out of aqueous polymeric dispersions as well as the subgroups of paints is distributed (not so distinctly due to some decrease in water vapour permeability) in the direction of fast decrease of water sorption coefficient.
8. Durable coatings should be considered to be thoses which have withstood from 150 to 180 modelled complex cycles of climate effects. The coatings of acceptable (permissible) durability are those withstanding 110 – 150 cycles. Non-durable are the coatings withstanding less than 100 – 110 cycles - their aesthetic depreciation usually starts following 30 – 50 testing cycles. The coatings of acceptable durability depreciation of which starts after 80 – 100 cycles are not recommended either.

REFERENCES

1. **Lentinen, T.** Capillary Moisture Transfer in Combined Porous Building Materials *Proceedings of the Symposium on Building Physics in the Nordic Countries*, *Finland*, 1996: pp. 483 – 490.
2. **Carmeliet, J., Roels, S.** Moisture Transfer and Durability of Open Porous Media *Proceedings of the 4th Symposium on Building Physics in the Nordic Countries*, *Finland*, 2 1996: pp. 587 – 594.
3. **Store, M.** Water Vapour Permeability and Sorption Curves of Painted Substrates Materials *Proceedings of the Symposium on Building Physics in the Nordic Countries*, Finland, 1996: pp. 691 – 698.
4. **Miniotaite, R.** Moisture-Caused Deformations of Construction Materials *Proceedings of the Symposium on Building Physics in the Nordic Countries, Gothenborg, Sweden*, 1999: pp. 581 – 588.
5. **Miniotaite, R.** Determination Method for Weather Durability of Finish Layers in External Walls of Buildings *Proceedings of the Conference on the Subject of Construction and Architecture*, *Kaunas University of Technology, Institute of Architecture and Construction, Kaunas, Lithuania,* 1996: pp. 140 – 145 (in Lithuanian).
6. **Miniotaite, R.** Compatibility of Finishing Layer and External Surface of Buildings' Walls from the Standpoint of Durability *Doctoral Dissertation*, Lithuania, 1999: 180 p.
7. **Miniotaite, R.** The Durability of Finishing Layer External Surface of Buildings' Walls *Monograph*, Lithuania, 2001: 175 p.
8. **Puterman, M.** Surface Deterioration of Building Paints Exposed to Natural and Accelerated Weathering *Proc. of the 7 Int. Conf. Durability of Building Materials and Components (Sjöström C., editor)* 1 1996: pp. 658 – 666.

9. **Boxall, J., Smith, G. A.** Maintenance Painting of Exterior Timber *JOCCA* 71 (12) 1988: 419 p.
10. **Bradford, E. B., Vanbderhoff, J. W.** Additional Studies of Morphological Changes in Latex Films *Journal of Macromolecular Science / B Physics* 6 (4) 1972: pp. 671 – 694.
11. **Sandin, K.** Some Facts about Hydrophobic Facade Impregnation *Proceedings of the 4th Symposium on Building Physics in the Nordic Countries*, *Finland* 2 1996: pp. 515 – 521.
12. **Hale, D. K.** The Physical Properties of Composite Materials (review) *Materials Science* 11 1976: pp. 2105 – 2141.
13. **Kalanta, S.**, **Grigusevičius, A., Krutinis, A.** Formulations of Deformable Foundation Contact Problems *Civil Engineering and Management,* Vilnius VIII (1) 2002: pp. 49 – 53.
14. **Carmeliet, J., Roels, S.** Determination of the Isothermal Moisture Transport Properties of Porous Building Materials *J. of Therm. Env. & Bldg. Sci.* 24 2001: pp. 183 – 210.
15. **Freitas, V. P., Abrantes, V., Crausse, P.** Moisture Migration in Building Walls – Analysis of the Interface Phenomena *Building and Environment* 31 (2) 1996: pp. 99 – 108.
16. **Hedenblad, G.** Moisture Permeability of Some Porous Materials *Proceedings of the 3rd Symposium on Building Physics in the Nordic Countries*, *Copenhagen* 2 1993: (Saxhof, B., editor), pp. 697 – 702.
17. **Brocken, H. J. P., Spiekman, M. E., Pel, L., Kopinga, K., Larbi, J. A.** Water Extraction out of Mortar during Brick Laying: A NMR Study *Materials and Structures* 31 (5) 1998: pp. 49 – 57.
18. **Ccrny, R., Drchalova, J., Hoskova, S., Toman, J.** Inverse Problems of Moisture Transport in Porous Materials *Proceedings of the Second ECCOMAS Conf. on Numerical Methods in Engineering* 1996: pp. 664 – 670.
19. **Descamps, F.** Continuum and Discrete Modelling of Isothermal Water and Air Transfer in Porous Media. Thesis K. U. Leuven, 1997: 35 p.
20. **Semerak, P., Cerny, R.** A Capacitance Method for Measuring Moisture Content of Building Materials *Stavebni obzor* 6 1996: pp. 102 – 103 (in Czech).
21. **Bednar, T., Dreyer, J.** Moisture Transport in Masonry. Influence of Different Historic and Modern Renders on the Moisture Performance of Walls under Rain Load *Proceedings of 5th Symposium on Building Physics in the Nordic Countries*, *Gothenburg, Sweden* 2 1999: pp. 529 – 536.
22. **Maciulaitis, R.** Frost Resistance and Durability of Ceramic Façade Products. Vilnius, Technika, 1997: 308 p. (in Russian).
23. **Maciulaitis, R.** Frost Resistance and Long Service life of Ceramic Façade Products. Part 5 *Brick Tile Ind. Int.* 7 1997: pp. 427 – 434; 9 1997: pp. 594 – 601.
24. **Bruning, H.** Frost Resistance of Masonry Bricks *Brick Tile Ind. Int.* 10 1987: pp. 502 – 503.
25. **Ritchie, T., Davison, J. I.** Moisture Content and Freeze-Thaw Cycles of Masonry Materials *J. Mater.* 13 (3) 1968: pp. 658 – 671.
26. **Miniotaite, R.** Compatibility of Finishing Layer and External Surface of Buildings' Walls from the Standpoint of Durability *Summary of the Thesis for a Doctor's Degree, Kaunas, Lithuania* 1999: 47 p. (in Lithuanian).
27. **Noghabai, K.** Environmental Effects on bond in Reinforced Concrete Structures *Proceedings of the 7 Int. Conf. Durability of Building Materials and Components* (Sjöström, C., editor) 1 1996: pp. 605 – 614.
28. EN ISO 12572:2001. Building Materials. Hydrothermal Performance of Building Materials and Products. Determination of Water Vapour Transmission Properties.
29. DIN 52 617. Determination of the Water Absorption Coefficient of Building Materials, 1987.

Paper presented at the XI International Baltic Conference
"Materials Engineering & Tribology - 2002",
November 14 - 15, 2002, Kaunas, Lithuania