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SURFACE WATERPROOF PROTECTION OF CONCRETE STRUCTURES

Jan Ślusarek
Civil Engineering Faculty, Silesian University of Technology, Gliwice, Poland.

ABSTRACT

Building materials should have such properties that buildings, in which they are used, would have desirable utility properties. The ability of building materials to fulfil required functions for certain duration of time, under action of definite factors, is called durability. The requirements for necessary durability of structure are fulfilled when all tasks: performance, strength and stability are fulfilled, during the whole life-time without substantial reduction of its utility and excessive unforeseen costs of maintenance. The significant issue is to protect properly concrete structures against the damaging effect of dampness. An essential condition for correct operating is to effectively protect the construction. The defective protection against water in an object generates destructive processes, which significantly reduce its permanence. It causes the necessity of carry out expensive repairs, in order to determine the predicted period of using the object. The protection of the concrete construction against the harmful activity of dampness is a major economical and technical problem. The general characteristic of protection against water preceded the review of selected, modern (1991÷2005) surface protections of concrete structures. Analysis of selected, modern waterproof protections brought to notice some characteristic inclinations in material solutions. The modifications of "classical" materials' structure, both mineral and bituminous, became common. Modern waterproof protections are the composites built of – modified by various kinds of polymers – "classical" materials. These composites demonstrate very high resistance to water action, as well as for different outer influences. As a rule they demonstrate the elasticity and resistance to impacts and also very good adhesion to the concrete.

Key words: durability, maintenance, damaging effect of dampness, surface protection of concrete structures, waterproof, resistant to impacts, adhesion to the concrete.

INTRODUCTION

Building materials should have such properties that buildings, in which they are used, would have desirable utility properties. The ability of building materials to fulfil required functions for certain duration of time under action of definite factors is called durability. Requirements for necessary durability of structure are fulfilled when all tasks: performance, strength and stability are fulfilled, during the whole life-time without substantial reduction of its utility and excessive unforeseen costs of maintenance.

The significant issue is to protect properly concrete structures against the damaging effect of dampness. For correct operating, an essential condition is to effectively protect the construction. The defective protection against water in an object generates destructive processes, which significantly reduce its permanence. It causes the necessity of carry out expensive repairs, in order to determine the predicted period of using the object. The protection of the concrete construction against the harmful action of dampness is a major economical and technical problem. The general characteristic of protection against water preceded the review of selected, modern (1991 ÷ 2005) superficial protections of concrete structures.

GENERAL CHARACTERISTIC OF WATER PROTECTIONS

An efficient protection of building constructions against harmful action of water is an essential condition of the proper exploitation of these constructions. A defective waterproof protection of a building generates destructive processes that considerably decrease its durability. It causes the necessity of building repairing.

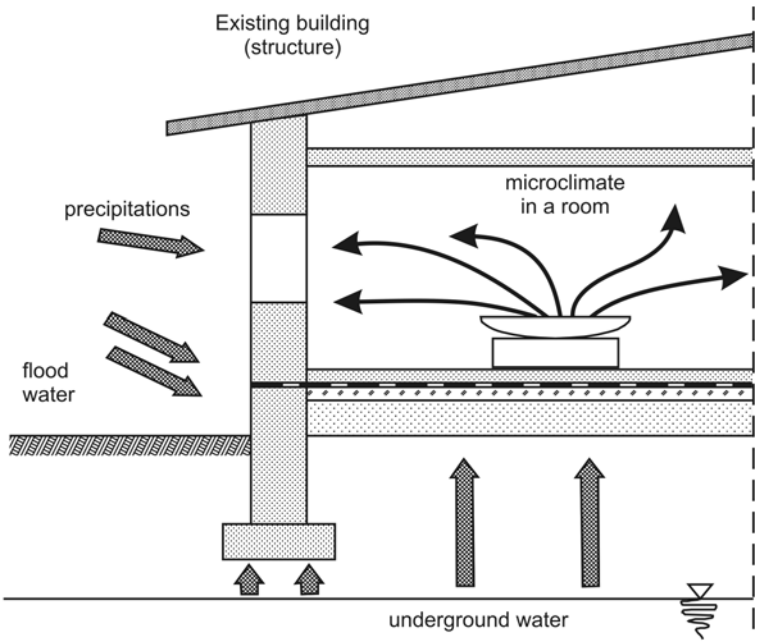
Sources of dampness of structures

The dampness of a structure may be caused by water coming from many different sources. The basic sources of dampening of materials and building elements are [1]:

- technological water,
- ground water,
- rainfalls,
- sorption dampness,
- condensation of water vapour on the surface of or inside the element,
- flooding water.

Sorption dampness and condensation of water vapour on the surface of and inside the building elements are connected both with the external climate and the microclimate of the room. The sources of dampness of building materials and elements are presented schematically on the Fig. 1.

Fig. 1. The sources of dampness of building materials and elements

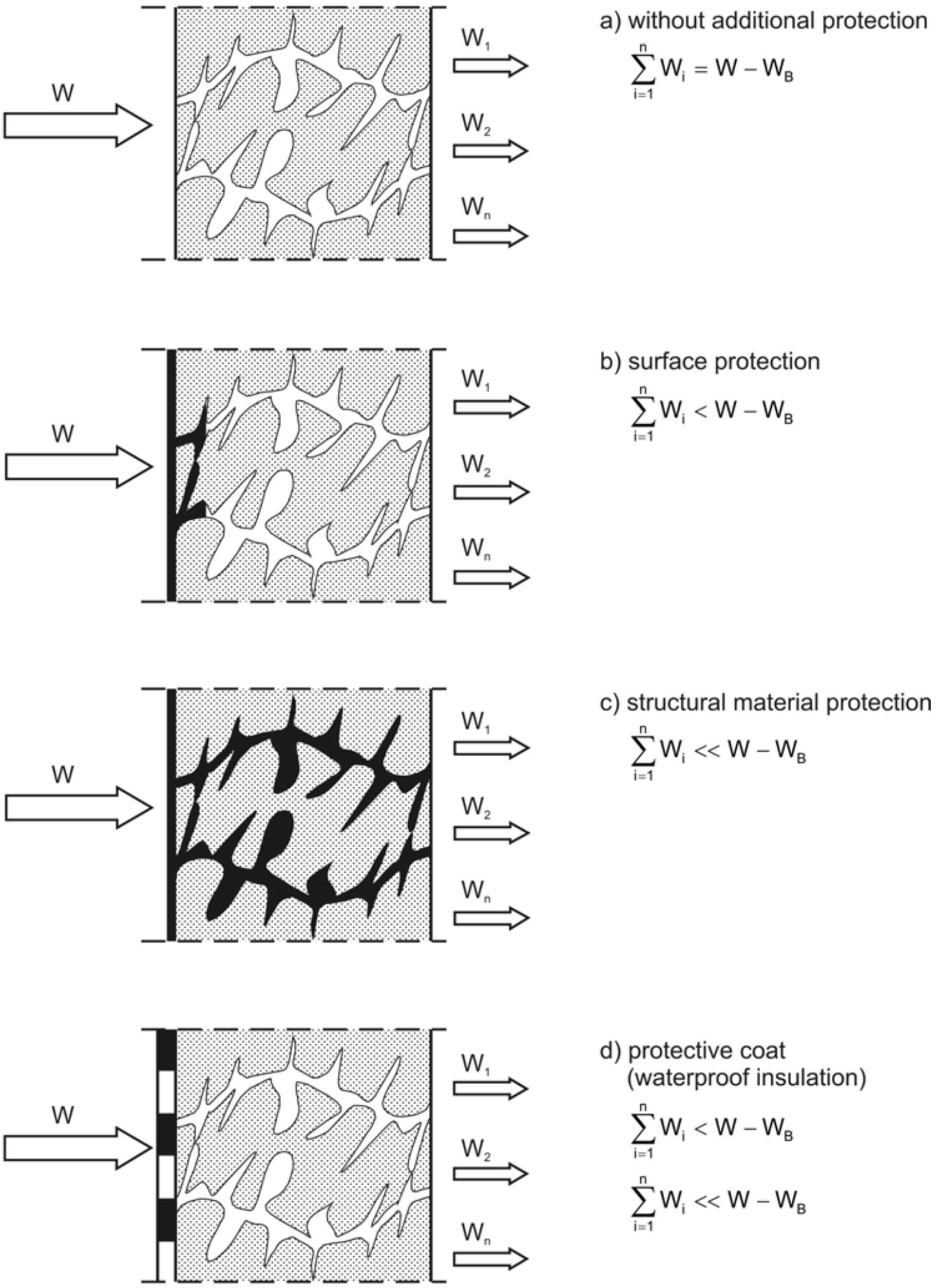


Essence of protection

The concrete structures submitted to the damp and water activity may be protected in different ways. The following waterproof protections are usually used [2,3]: surface protection, structural-material protection, protecting covers. The essence of waterproof protections is shown schematically on Fig. 2.

Concrete resistance against flow of damp (W_B – see Fig. 2) is the important property but not sufficient for suitable protection of concrete structure against thermal-moisture (compare: Chapter 2.4 and 2.5). It is necessary to use the additional solutions. Often one must to apply the surface protection (see Fig. 2b), structural-material protection (see Fig. 2c) and protective coats (see Fig. 2d). In the paper has been undertaken a trial to describe protective coats only. The methods of surface and material-structural protection are the subject of separate studies, for example [3,17].

Fig. 2. Essence of waterproof protections for concrete structures: W – the density of inflowing stream of moisture (water), W_B – the resistance of concrete against flow of moisture (water), $\sum_{i=1}^{n} W_i$ – the density of outflowing stream of moisture (water).



Types and assignation of waterproof insulations

This is possible to find in the bibliography the various classifications and divisions of waterproof insulations, depending on their assignation, place of integration, type of used materials, etc. In accordance with mandatory in civil engineering technical conditions [13] it is possible to distinguish vapour barriers, damp-proof insulations, and waterproof insulation.

Vapour barriers protect the space dividing elements against penetration through them steam. They should be made of materials with low permeability for steam. Damp-proof insulations protect building structures or their parts against water that does not exert hydrostatic pressure, but the waterproof barriers protect building structures or their parts against water that exerts hydrostatic pressure, including pressure and artesian water [13]. In the bibliography is possible to find the following division of anti-moisture and waterproof insulations [15]: the light type, medium type and heavy type.

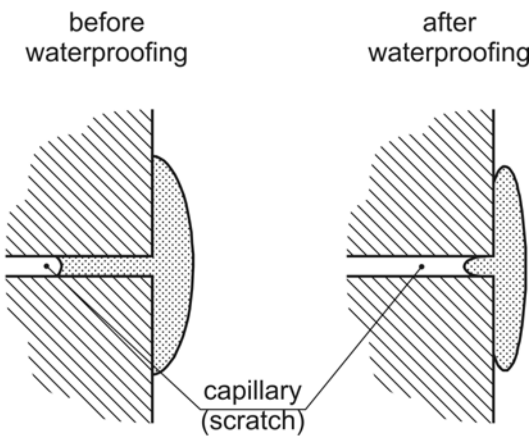
The insulations of light type are used for protection of buildings against penetration of moisture in side direction. Light insulations should not be used for protection of buildings against direct rain water (roof coverings), filtering towards horizontal baffles (terraces, culverts, underground reservoirs, etc.) or against pressure water [15].

The insulations of medium type: are used for protection of buildings against direct rain, capillary water or filtering towards a horizontal or vertical baffle. Insulation of such type may not be used for protection of buildings against pressure water. The exception is the case where water pressure is temporary or total water-tightness is not required [15].

The insulations of heavy type are used for protection of building structures against pressure water [15]. In order to connect commonly used divisions of waterproof insulations were taken, basing on detailed analysis some additional criteria. Their essence is presented on the Fig. 12.

The waterproofing coat is a special type of water-proof protection. It allows for passing steam. Such coat protects against penetration of moisture in liquid phase into concrete. The essence of waterproofing is presented on the Fig. 13. All types of vapour permeable membranes used for discharge of condensate from inside of a baffle (for example: from warm deck roof) could be included to this group.

Fig. 3. The essence of waterproofing of concrete surface [3,18,20]



Taking into consideration the criteria presented on the Fig. 2, the guidelines from [13] and the essence of waterproofing (see Fig. 3) it is proposed to use division of water-proof insulations presented in Table 1.

Table 1. The division of waterproof insulations [18,20]

Item	Water-proof insulations		Water pressure **p**	Diffusion resistance*) $\mathbf{r_{min}}$
	Sort of insulation	Type of insulation	[MPa]	$m^2 \cdot h \cdot hPa \cdot g^{-1}$
1.	Waterproofing- permeable for vapours	protection against penetration of moisture in liquid phase inside concrete	0.000	< 10
2.	Vapour retarder	-	0.000	10
3.	Anti -	Light	0.000	30
4.	- moisture	Medium	max. 0.002	40
5.	Water-proof	Heavy	> 0.002	60

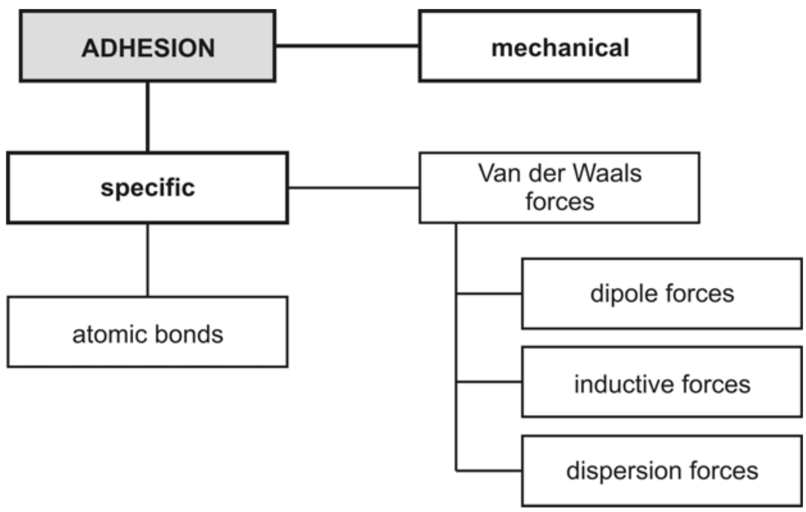
p – hydrostatic pressure exerted on water-proof insulation
r_{min} – minimum diffusion resistance of water-proof insulation
*) – criterion of diffusion resistance does not concern mineral coats

General requirements in scope of water-proof insulations

Concrete base adherence

The adherence of waterproof coat to concrete base depends on many factors and in principle is the result of attractive forces acting at the contact of these two media. The above forces are named as adhesion [12,16]. There are two principal theories concerning adhesion [16]: the theory of mechanical adhesion and theory of specific adhesion. Mechanical adhesion consists in penetration of glues to pores and inequalities of glued surfaces and arising after hardening strong bonding with a base. Detail tests showed that in gluing processes the most important is not mechanical but specific adhesion, related to polar structure of molecules. Van der Waals forces and atomic bond forces are of great importance in that specific process [16]. The adhesion diagram is presented on the Fig. 4.

Fig. 4. The diagram of adhesion at contact of concrete and waterproof coat [16]



Van der Waals forces are the forces of mutual attraction of molecules and in general are considerably weaker than atomic (valence) bonds forces. It is often necessary to activate bonded surfaces. Activation of molecules may be achieved for example by melting, dissolution or coating with polar substances (bonded layers). In such cases the molecules obtain additional degree of freedom enabling their quick bonding with molecules of another body. One of specific adhesion conditions is the ability of moistening contact surfaces by glue. Only in such case atoms and molecules may bring closer, enabling entire use of attractive forces. Wet ability may be improved (for example) owing to reduction of surface tension of glue. In such case the wetting angle θ is reduced (see: Section II, p. 4).

Moisture content in concrete base

The moisture content in concrete base is very important for effectiveness of waterproof insulation. Adverse impact of water content in concrete base on waterproof protections durability is especially great if moisture may occur on from a side without insulation. Therefore in elements endangered for dampness influence from both sides are to be used as suitable insulations. Such cases may occur in particular in roof baffles, so called solid flat roofs. In these cases one should aim at minimisation of steam accumulation effects. It is necessary to use effective vapour barriers and in extreme cases to use roof structures with suitable ventilation.
Lack of proper ventilation in such structures causes delamination of waterproof insulation (blisters) as effect of high steam pressure.
In accordance with requirements [13] moisture content of concrete base should be as follows:

- < 8 % (by weight) – for roof coverings of building paper,
- < 6 % (by weight) – for water proof insulations of terraces,
- ≤ 3 % (by weight) – for bituminous, resin coats.

If mineral coats are used, concrete bases require wetting with water.

Supporting solutions

One of principal condition of effective protection of building structures against adverse impact of water may be the liquidation of moisture source. Of course the elimination of such sources is not always possible.

The satisfactory results may be achieved by lowering water table of underground waters. It is possible by use of perimeter draining system. But decisions concerning use of such solutions are to be taken up after detailed analysis of water-ground conditions.

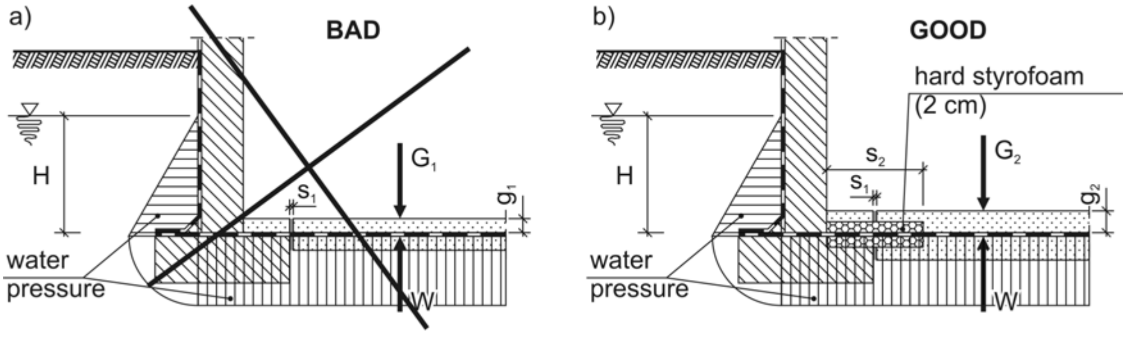
In the case of variable underground water level is necessary to take into consideration one more important problem related to hydrostatic pressure, exerted at the level of water-proof membrane of medium type. Such membranes subject to buoyant forces action and are endangered by 'cutter' type damages. Therefore, the thickness of floor layers should be selected in such way that their weight will reduce the effects of buoyant forces action. Additional, advantageous solution is enabling deformations of waterproof coat near dilatations. The essence of effectiveness of recommended solutions is presented on Fig. 5.

The example of calculations for Fig. 5:

Data:
$h = 0.2$ m; $\rho_{bp} = 21.0$ kN·m^{-3} (specific density of floor's concrete);
$s_1 = 0.02$ m; $g_1 = 0.05$ m;
$G_1 = 1.05$ kN·m^{-2}; $W = 2.0$ kN·m^{-2} (buoyancy); $W > G_1$
membrane limit deformation – 10 %,
membrane safe deformation (for point a) $u_{gr}^{a} = s_1 \cdot 10\% = 0.002$ m

Searched:
$G_2 \geq W$; $s_2 >> s_1$ (for example $s_2 = 10 \cdot s_1$)
$g_2 \geq \frac{W}{\rho_{bp}} = \frac{2.0}{21.0} = 0.095$ m; $U_{gr}^{b} = 10 \cdot s_1 \cdot 10\,\% = 0.02$ m

Fig. 5. Protection of water-proof membrane of medium type in dilatation [18,20]



Proper construction of a building near dilatations that subject to considerable movements gives very advantageous results. Apparent enlargement of dilatation's width to the value s_2 (Fig. 5b) allows for considerable enlargement of absolute deformation of water-proof insulation. The increase of floor's thickness up to value g_2 (Fig. 5b) allows for balancing buoyant force, therefore this joint will not subject so intensive movements as in case a) on Fig. 5.

The limitation of moisture inflow to the structure is possible also for moisture from inside rooms. In this case the effective draining and air conditioning installations should be used.

Properly functioning draining installations allow for removal of excessive water outside the construction. Proper profiles of inclinations in concrete base (floor) and suitable quantity of floor drains according to volume of drainage basin may considerably limit the amount of water filtering inside the structure.

Proper microclimate in internal rooms may also advantageously influence the limitation of moisture quantity filtering into the concrete structure. In the case of rooms where steam is produced in great amount the above problem is of particular importance. The removal of excess steam, keeping suitable temperature and humidity in rooms should be controlled by properly selected air conditioning system. Owing to such activities it is possible to limit steam condensation on internal surfaces of concrete baffles.

THE REVIEW OF SELECTED MODERN WATERPROOF PROTECTIONS

The analysis of modern waterproof protections used in concrete constructions was carried out on the basis of the available original materials and publications in magazines [4]. The review of the protection was made with the proper classification (Fig. 6).

Seamless coats

Seamless coats are the layers of protective materials adhering protected concrete surface. They are applied on concrete surface with use of paint or plaster techniques.

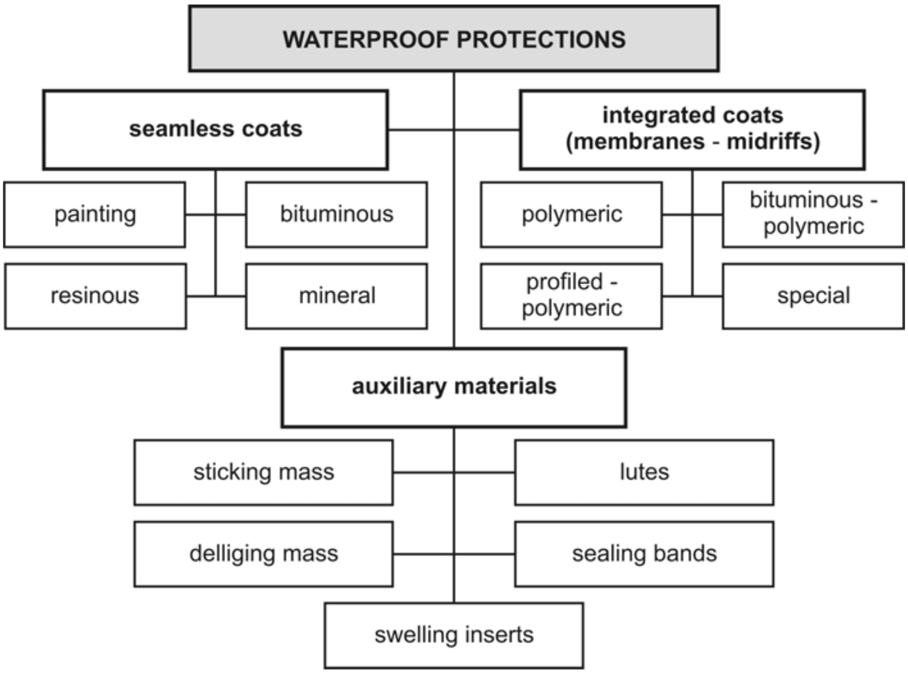
Painting coats

Painting coats are the layers of liquid, fluidised or powdered, applied on properly prepared concrete base, with use of paint techniques [3,17]. Thickness of painting coats should not exceed 1 mm and their adherence to concrete of C16/20 class may not be lower than 0.5 MPa [17]. Below the selected painting coats - both domestic and foreign – are presented. Various types of paints are being used. Most frequently ones are silicone, acrylic and epoxy paints.

Silicone paints are produced on the base of silicone resin [10]. Silicone-organic resins (silicones) with various grade of polarization may be applied on concrete as thin films, not causing significant reduction of capillaries' cross-section [3,10]. Thanks to such property good permeability for steam and other gases is obtained. Relatively high permeability for steam enables drying even wet concrete baffle. Paint may be applied on concrete bases in air-dry state but also on wet bases. Before painting the concrete base may be grounded with use of silicone impregnate. The thickness of protective coats on concrete may not be lower than 0.18 mm. Before applying successive layers one should wait 24 hours [10]. Silicone paints have properties waterproofing concrete surfaces. Therefore they protect against penetration of moisture in liquid phase into a concrete structure. The diffusion resistance for a coat 0.18 mm thick is: $r = 0.12$ [$m^2 \cdot h \cdot hPa \cdot g^{-1}$].

Acrylic paints do not contain solvents. They protect against carbonatization and wetting. They are permeable for vapours and may be used as anti-moisture insulation of light type and as protective paint for protection of concrete surfaces [25]. Acrylic coats may be formed as single-component material using acrylic resin containing organic solvents. Such coats are used for protection of concrete structures subject to atmospheric conditions (for example: bridges, viaducts, buildings' facades, external sides of jackets of cooling towers, chimneys) [25].

Fig. 6. A proposal of classification of waterproof protection



Epoxy coats may be used as a set of possible for elastification, bi-component coating materials on the basis of epoxy resin, containing organic solvents. Epoxy coats Icosit 2406 may be used for execution of protective coats on internal sides of jackets of cooling, ventilators towers and other structures endangered by water and condensate [25]. The concrete base should be in air-dry condition.

Bituminous coats

Bituminous coats are the layers of bituminous materials (asphalt or tar) in form of binders, emulsions and masses, cold or hot applied on suitably prepared base [17]. Thickness of these coats is of 0.2 – 6 mm depending on the method of modification and their adherence to concrete of C 16/20 class should not be lower than 0.5 MPa. Depending on requirements bituminous coats may be modified using micro – reinforcement, addition of polymer or filling materials.

Reinforced bituminous coats are called 'laminates' [3,17]. Bituminous coats should be protected against mechanical damages. The following components are in use: asphalt - polymer binders hot applied, asphalt-polymer binders cold applied, asphalt emulsions, emulsion bituminous coats and bituminous hydro-insulation masses.

Asphalt-polymer binder hot applied belongs to the group of asphalts modified by SBS and SIS rubber [1]. In natural conditions this binder is elastic-plastic body of black colour. Warmed to temperature 170 ÷ 180°C is a uniform liquid mass. It may be easily distributed on concrete base. It may be used as damp-proof insulation of light type. Thickness of protective coat in most cases varies from 0.7 to 2.0 mm.

Asphalt-polymer binder cold applied belongs to the group of asphalts modified by SBS (styrene – butadiene – styrene) and SIS (styrene – isoprene – styrene) rubber with addition of organic solvent. It is thick uniform black liquid, containing fungicides [22]. Other version of this binder is sticky liquid of brown-silver colour. After applying occurs evaporation of solvent and next insulation reflective coat with long-term silver colour [22]. Before applying this binder it is necessary to ground concrete base with use of priming solution. Thickness of protective layer in most cases varies from 0.7 to 2.0 mm. Properties of cold applied asphalt-polymer binders are similar to properties of hot applied asphalt-polymer binders.

Asphalt emulsion mass is asphalt thixothropic mass dilute in water, modified with use of latex, cold applied [8]. Applied mass within one hour after applying is not hardened and not resistant for water action. Vulcanisation process may be checked by observation of colour change – from brown into black.

Fresh coat may be protected with use of mineral topping. After drying this coat may be protected by reflective coat made of aluminium foil [6]. The coats reinforced by polypropylene textile are also in use. This mass, after vulcanisation, shows among others [6]:

- impact strength,
- adherence to concrete – minimum of 0.7 MPa,
- permeability for vapours – steam permeability coefficient $\delta = 6.3 \cdot 10^{-5}$ [g·m·h·hPa]; number of diffusion resistance $\mu = 1110$,
- tensile strength of a coat reinforced with polypropylene textile – minimum of 1.2 MPa,
- relative ultimate elongation of the coat reinforced with polypropylene textile – minimum of 92%,
- density of emulsion – about 1.0 $g \cdot cm^{-3}$,
- theoretical consumption at single applying – 0.8 ÷ 1.1 $kg \cdot m^{-2}$.

Thickness of protective coat is in general of 0.7 ÷ 4 mm, depending on requirements and possible modification (reinforcing textile, topping). Diffusion resistance of protective coats with thickness as above is accordingly of 11.1 ÷ 63.5 $m^2 \cdot h \cdot hPa \cdot g^{-1}$.

Emulsion bituminous coat is the coat without solvents, with single component. It is elastic, made on basis of rubber bituminous emulsion in the form of a paste [25]. It is characterised by properties similar to properties of asphalt emulsion mass. Thickness of protective coat is in general of 0.7 ÷ 4 mm depending on requirements and possible modification (reinforcing textile, topping). Diffusion resistance of protective coats with thickness as above is accordingly of 11.7 ÷ 66.7 $m^2 \cdot h \cdot hPa \cdot g^{-1}$.

Bituminous hydro-insulation mass may be used as single-component or double component material. It has similar properties as materials such as bituminous membranes [5].

Single-component materials are sensitive to low temperatures and high relative humidity of air that in great extension of hardening time. Double-component material is sealing bituminous mass with addition of plastic. It shows thixothropic properties. After hardening it is elastic.

Bituminous masses are applied by use of metal long float on previously grounded base. As priming agent the single-component mass diluted with water (1: 10) is being used.

Thickness of insulation layer is of 4÷6 mm (consumption of materials of 4 ÷ 6 $l \cdot m^{-2}$). It depends on water pressure and maximum thickness and ensures resistance for water hydrostatic pressure up to 0.7 MPa. Ready insulation coats should be protected against possible damages by use of (for example) foamed polystyrene plates of minimum thickness of 2 cm [15].

Resin coats

Resin coats are made of liquid resin products or resin composites. Resin coats may be applied by use of the paint or plaster techniques. Thickness of such coats is of 1 ÷ 6 mm, depending on the method of modification and their adherence to C16/20 class concrete should not be lower than 1 MPa [17]. In the dependence on the requirements the resin coats may be modified using micro-reinforcement or filling materials. There is possible to use as reinforcements the mats and textiles made of glass fibre (also other fibres, for example polypropylene, may be used) or cut glass fibres (dispersed micro-reinforcement) [17]. Reinforced resin coats are called laminates [3,17]. Resin coats should be protected against mechanical damages. The following components are being used: water emulsions of acrylic co-polymers [25], water emulsions of acrylic resin [5], coats on base of epoxy and polyurethane resins [25], coats on base of epoxy resins [25] and coats on base of polyurethane elastomers [9].

Water dispersion of acrylic co-polymers makes the protective system consisting of intermediary priming layer and coating layer [25]. Intermediary layer is a coat 0.5 ÷ 1.0 mm thick in form of water thixotropic dispersion. This plastic-elastic layer allows for obtaining decorative texture. The coating layer 0.2 ÷ 0.3 mm thick is made of water and colour dispersion. It is elastic and hardens when exposed to light. Total thickness of protective coat is usually of 1 ÷ 1.5 mm. But the use of total system is not always justified. Protective coat of total thickness of 1 ÷ 1.5 mm is characterised by diffusion resistance of 33.7 ÷ 50.5 [$m^2 \cdot h \cdot hPa \cdot g^{-1}$]. It means that protective coat 1.2 mm thick meets requirements for damp-proof insulation of medium type [25].

Water acrylic dispersion hardens under influence of ultra-violet radiation. Protective coat is elastic and shows good adherence to base (minimum of 1.0 MPa) and permeability of vapours (permeability coefficient for steam $\delta = 7.7 \cdot 10^{-5}$ g·m·h·hPa); diffusion resistance number μ =909). This system may be used as single-component with coat thickness of 0.4 ÷ 3 mm, depending on the requirements. Diffusion resistance for coat 3 mm thick is r ≅ 40 [$m^2 \cdot h \cdot hPa \cdot g^{-1}$]. It means that such coat should function as damp-proof insulation of medium type [5].

Resin coat on the base of epoxy and polyurethane resins.

It makes chemically hardened, without solvents, bi-component binder with high chemical and mechanical resistance. After mixing with hot dried quartz sand with graining of 0.4 ÷ 0.7 mm, it forms elastic coat. It has high abrasion resistance [25]. Thickness of insulation-pavement coat is to be set out individually depending on pavement load. For pavement assigned for pedestrian traffic minimum coat thickness is of 2 mm and for roads assigned for heavy vehicles of 10 mm. Using of the pavements thicker than 15 mm is not recommended [25]. Concrete base should be primed using colourless, bi-component epoxy resin, without solvents in amount of 0.3 ÷ 1.6 $kg \cdot m^{-2}$ [25].

Coat on the base of epoxy resin makes bi-component binders. By mixing a binder and quartz sand with graining of 0.1 ÷ 1.3 mm it is possible to make waterproof coats with high mechanical and chemical resistance [25]. Preparation of protective layer of 1 mm thick requires about 1.9 $kg \cdot m^{-2}$ of mortar (binder + sand). Concrete base should have suitable strength (concrete of class minimum C20/25).
Resin coats have high tensile strength at bending (25 ÷ 30 MPa), high compression strength (50 MPa) and long-term resistance for water, sea water, wastewater, salts, oils, etc. [25]. These coats are hard and ductile, with high abrasion resistance and impact strength. They may function as water-proof insulation. They are used also as binding layers between old and new concrete. Thickness of resin coats – waterproof insulations is usually of 1 ÷ 3 mm.

Coats on the base of polyurethane elastomers are produced using special machines and applied using most frequently spraying method. Two liquid components warmed to temperature of 40 ÷ 60°C are mixed in strictly determined proportion and next applied layer by layer on concrete surface. This surface should be dry, without dust, grease and oil. It is recommended to apply suitable ground coat on base of epoxy or polyurethane resins. Polyurethane elastomeric coats have properties such as [9]:

- good adherence to concrete,
- tensile strength – minimum of 6 MPa,
- relative ultimate elongation: from 80 ÷ 400% depending on version,
- coat flexibility.
- The protective coats of thickness of 2 ÷ 3 mm are in most common use. They function as damp-proof insulation of medium type.

Mineral coats

Mineral coats are made of mineral composites. They should be applied by use of paint or plaster techniques. Mineral coats should have suitable thickness depending on required properties. The adherence of mineral coats to concrete base should be at least 2 MPa.

Mineral coats are cement materials modified by polymers or other additives. The coats thickness is usually of 1 ÷ 5 mm. The following coats are used: waterproof mineral plaster [25], single-component elastic sealing micro-mortar [7,26], bi-component elastic sealing micro-mortar [7,26], elastic water-proof coat [27], mineral water-proof coat [4].

Waterproof mineral plaster is single-component sealing putty on base of cement modified by micro-silicate. It does not contain polymers. It is rigid thin-layer sealing of surface. This plaster has the following properties [25]:

- density of fresh mortar – 210 $g \cdot cm^{-3}$,
- compression strength after 28 days – 50 ÷ 60 MPa,
- tensile strength at bending after 28 days – 8 ÷ 10 MPa,
- modulus of elasticity – approx. of 27 GPa,
- adherence to concrete base after 28 days – 2÷3 MPa,
- permeability for vapours – permeability coefficient of steam – $\delta = 140 \cdot 10^{-5}$ g·m·h·hPa, diffusion resistance number $\mu \cong 50$,
- diffusion resistance for a coat 1 mm thick – r = 0, 71 [$m^2 \cdot h \cdot hPa \cdot g^{-1}$].

Waterproof mineral plaster is used as waterproof insulation of drinking water reservoirs, pools, structures loaded by water [25]. At protection of internal surfaces of reservoirs coat thickness may not be lesser than 2 mm. While protecting reservoirs and other structures against underground water may not be lesser than [25]:

- 1.5 mm for wet ground,
- 2.0 mm at hydrostatic pressure p_{max} = 0,01 MPa,
- 3.0 mm at hydrostatic pressure p_{max} = 0,02 MPa.
- Prior to applying plaster concrete surface is to be intensively watered. Maximum thickness of coat applied in single cycle is of 2.5 mm.

Cement-epoxy mortar is ternary material. Two components make make-up liquid and third component is specially selected mixture of cement of micro-fillers. Protecting coat made of such mortar is rigid. Below are shown properties of mortar [25]:

- compression strength after 28 days – approx. of 40 MPa,
- tensile strength at bending after 28 days – approx. of 9 MPa,
- elasticity modulus – approx. of 12.6 GPa,
- adherence to concrete base after 28 days – 2.5 ÷ 3.5 MPa,
- permeability for vapours – permeability coefficient for steam: $\delta = 8.2 \cdot 10^{-5}$ g·m·h·hPa; diffusion resistance number: $\mu \cong 850$.

Protective coat 1 mm thick may be damp-proof insulation of medium type. The coat becomes water-proof at thickness of 2 mm. Before applying plaster concrete surface is to be intensively watered. Maximum coat thickness applied in one cycle is of 0.5 ÷ 3 mm, locally of 5 mm.

Single-component elastic sealing micro-mortar is cement material modified by polymers and additives [7,26]. Sealing coat is waterproof, resistant against atmospheric impact and ageing. It may be applied on horizontal and vertical surfaces. It is used as waterproof insulation. Diffusion resistance for a coat 1 mm thick is r = 12.2 [$m^2 \cdot h \cdot hPa \cdot g^{-1}$]. The consumption of micro-mortar is the following [7,26]:

- approx. of 3 $kg \cdot m^{-2}$ – for damp-proof insulation,
- approx. of 4.2 $kg \cdot m^{-2}$ – for waterproof insulation at hydrostatic pressure: p_{max} = 0.05 MPa.

Bi-component elastic sealing micro-mortar is cement material modified by polymers and additives. Sealing coat is water-proof, resistant for atmospheric conditions and ageing. It may be applied on horizontal and vertical surfaces and is used as waterproof insulation. Consumption of micro-mortar is [26]:

- approx. of 3.6 $kg \cdot m^{-2}$ – for damp-proof insulation,
- approx. of 4.5 $kg \cdot m^{-2}$ – for waterproof insulation at hydrostatic pressure: p_{max} = 0.05 MPa.

Elastic waterproof coat is made of cement material modified by polymers. This coat is resistant for salt and is permeable for vapours. It is allowed to use in contact with drinking water. It ensures waterproof insulation [27]:

- pools and water reservoirs,
- structures deepened in ground,
- hydro-engineering structures (tunnels, irrigation channels, dams and baffles),
- floors in garages and car parks (including floors subject to water pressure).

Mineral waterproof coat is the ready, dry preparation on the base of bridge cement 42.5 modified by sealing agent and fine washed sand [4]. Sealing agent is a powder of yellow colour consisted of the mixture of some mineral, non-toxic components penetrating pores of wet concrete and reacting with minerals in cement. In this way arise gels sealing capillaries in concrete to depth of 30 ÷ 50 mm from its surface [4].
Deep sealing of concrete structure increases water-tightness of concrete by approx. of 0.5 MPa. Also freeze-resistance is improved and this coat is permeable for vapours. The coat is applied on wet base by use of paint technique in three layers. The total thickness of the coat is of 1.5 mm [4].

Integrated coats

Amongst integrated covers one may single out: roof polymer-bituminous membranes (thermowelding, glued to the foundation, self-sticking), roof polymer membranes (mechanically fastened, glued to the foundation, used in ballast roofs), thermowelded hydroisolating membranes, system of bentonite isolation against water, India rubber membrane EPDM, profiled membranes HDPE, stratified membranes P-S-P, isolation-drainage membranes, Fig. 7–11.

Fig. 7. The scheme of a structure of a multilayer waterproof membrane [30]

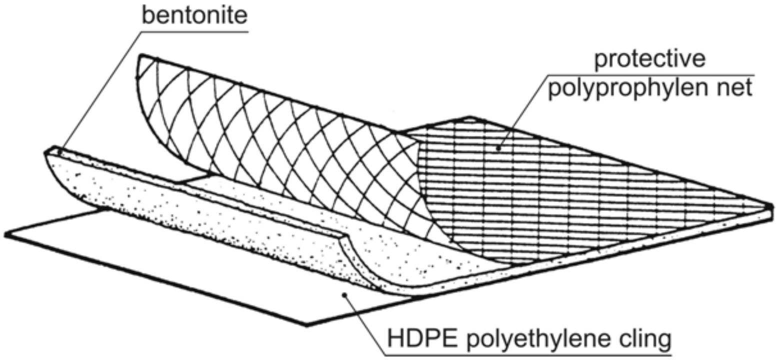


Fig. 8. The scheme of mechanical fastening of EPDM membrane [28]

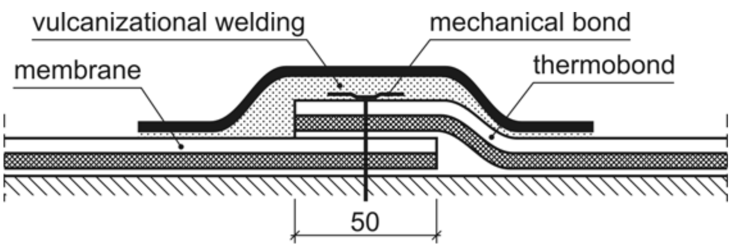


Fig. 9. The scheme of gluing fastening of EPDM membrane [28]

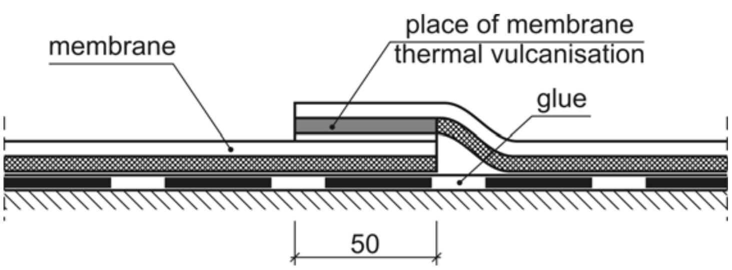


Fig. 10. The scheme of isolation against water made of profiled membrane [31]: 1 - drainage pipe; 2 - foundation of thin concrete; 3,4 - surface layers; 5 - concrete resistance wall; 6 - profiled membrane; 7 - filter fibre point - stuck to the membrane; 8 - fastening profile; 9 - pressure water; 10 - permeating water.

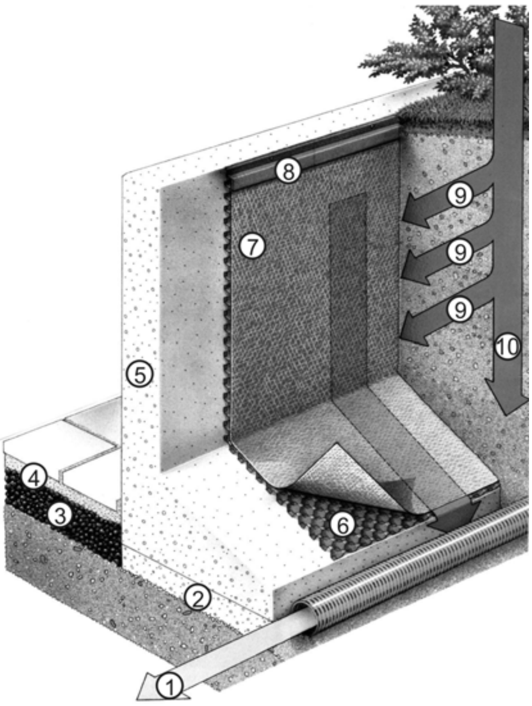
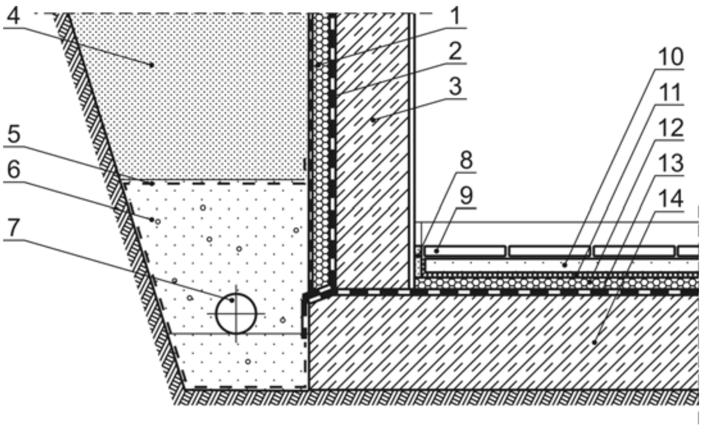


Fig. 11. The example of application of isolation-drainaging membranes [34]: 1 - isolation-drainaging membrane; 2 - proper isolation against water; 3 - reinforced concrete slab; 4 - fill-up ground; 5 - geofibre; 6 - gravel; 7 - drainage pipe; 8 - pedestal beading; 9 - floor finish; 10 - concrete foundation; 11 - protective layer; 12 - thermal isolation; 13 - isolation against water; 14 - reinforced concrete slab.



Roof bituminous-polymer membranes

Modern roof coverings are mainly materials laid in single-layer, but also in multi-layers systems. In order to improve durability and quality, polymers modify the bitumens used for production of such membranes. Most frequently is used butadiene-styrene rubber SBS (elastomers) and atactic polypropylene APP (thermoplastic material) [9,22]. SBS is elastomer, material keeping constant and durable during utilization. SBS maintain sticky/elastic properties in lowered temperature and is resistant for atmospheric conditions [9].
The following roof bituminous-polymer membranes may be used:

- thermowelded membranes [9,28],
- membranes glued to the base [9,28],
- self-adhesive membranes [8].

Roof bituminous-polymer membranes meet requirements of damp-proof insulation of medium type.

Polymer roof membrane on PCV base

Roof membranes are material produced on base of high-molecular polymers (PVC) reinforced by polyester textile. Membranes may be used as layer protecting against water on horizontal surfaces and with complex shapes. Membranes may be particularly used in the following systems [1,25]:

- anchored mechanically,
- ballast roofs,
- glued roofs.

Membranes are to be joined by hot welding in temperature not lower than 50°C.
In general membranes are available in following thickness: 1,2 mm; 1.5 mm; 1.8 mm. Top surfaces of membranes are brighter comparing with bottom surface. Roof membranes are characterised by the following properties:

- resistance to solar radiation,
- resistance to mechanical impacts,
- resistance to biological corrosion,
- ultimate elongation – minimum 15 %,
- permeability for vapours – permeability coefficient for steam: $\delta = 0.39 \cdot 10^{-5}$ g·m·h·hPa; diffusion resistance number: $\mu \cong 18.000$.

Diffusion resistance of a roof membrane of G type depends on coat thickness and is:

- $r \cong 308$ [m2·h·hPa·g^{-1}] for coat of thickness of 1.2 mm,
- $r \cong 385$ [m2·h·hPa·g^{-1}] for coat of thickness of 1.5 mm,
- $r \cong 462$ [m2·h·hPa·g^{-1}] for coat of thickness of 1.8 mm.

Therefore roof membranes meet requirements for water-proof insulation. However, they are not resistant to influence of bitumens and organic solvents. They react with plastics (for example polystyrene, polyurethane foam). In the case of materials harmful for membranes occurrence, a separating layer is to be used.

Thermowelded waterproofing membrane on PVC base

The membrane is smooth, laminated sealing one, without reinforcement on the base of multi-molecular polymers (PVC). It is assigned first of all for execution of waterproofing insulation in tunnel and underground constructions.

The membrane consists of two joined layers. Top layer (yellow) is 0.6 mm thick. Bottom layer (dark grey) is 1.4 mm thick. This membrane has the following properties [25]:

- tensile strength – minimum 15 MPa (in both directions),
- ultimate elongation – approx. of 300 % (in both directions),
- resistance to penetration of roots,
- resistance to mechanical impacts,
- resistance to micro organisms.

This membrane meets requirements of waterproofing insulation [25].

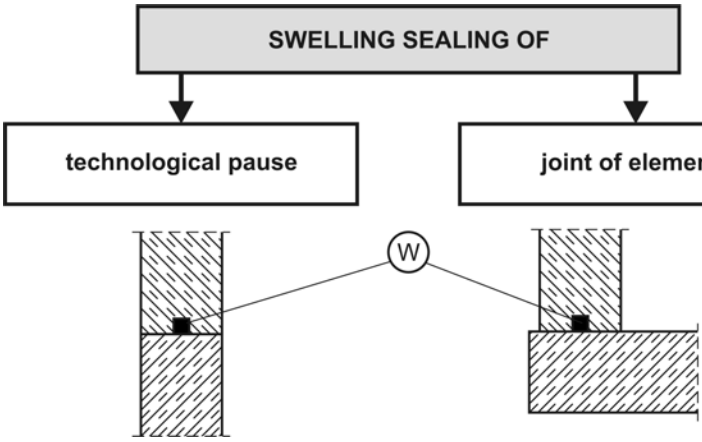
Laminar membranes P-S-P

Laminar membranes P-S-P are made of hard foamed polystyrene plates covered from both sides by asphalt building paper. They form the integrated system of thermal and waterproofing insulation. A core of thermal insulation may be of any thickness, depending on needs. Entire waterproofing insulation requires additional coats of building paper [33].

Auxiliary materials

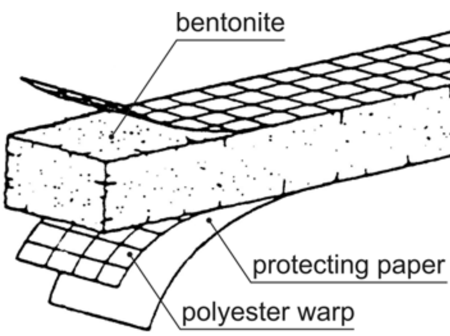
The following auxiliary materials play an important role in waterproof protection: sticking masses, flexible drenching masses, self-sticking bands, flexible bands made of foliated PVC, epoxide-polyurethane lutes, elastomer lutes, bulging sealing materials [27,30].

Fig. 12. The scheme of an application of sealing inserts (W) [27]



Sealing materials are resistant to water pressure (even to 46 meters water column). They are made on the basis of special sealing rubber which enlarges while absorbing water [27] and sealing bands (SUPERSTOP) made of expansive materials, produced on the basis of granulated soda bentonites [30].

Fig. 13. The scheme of the structure of sealing bands [30]



Adhesive masses

Adhesive masses form the group of products of new generation, on the base of asphalts modified by thermoplastic rubber. These masses are flexible, with very good adherence to concrete. They are assigned mainly for sticking protective layers of asphalt building paper to asphalt-polymer insulation. They also may be used on bridges for execution of laminates [22].

Elastic pourable sealant

Elastic pourable sealant belongs to group of products on the base of asphalts, modified by thermoplastic rubbers. At room temperature it is adhesive-elastic solid body of black colour. After heating to 170 ÷ 180 ° C and mixing, it is uniform thick liquid, easy for distribution and filling gaps up to 5 mm wide. After cooling this mass becomes solid body again, maintaining original properties [22].

Self-adhesive tapes

Such tapes are asphalt-polymer products. They may be formed exclusively of insulation-adhesive mass or may consist of carriers (textile, foil, unwoven) coated by this mass form one side or from both sides [6]. Tapes without carriers may be 20 ÷ 70 mm wide and 1 ÷ 5 mm thick. Coated tapes are 100 ÷ 500 mm wide and 1.7 ÷ 3.5 mm thick. They have good adherence to concrete, good flexibility and tensile strength [22].

Elastic tapes of laminated PVC

Elastic tapes are made of PVC, laminated by polymers (polyester, synthetic rubber) [7,26]. They are used for sealing dilatation gaps. They are joined by welding with hot air. Tapes may be 240 mm, 400 mm, 500 mm wide. To the base may be glued using adhesive mass [7,26].

Epoxy-polyurethane putty

This putty is bi-component, self-spilling material consisted of mixture of epoxy resins and polyurethanes. It is assigned for protection of dilatation gaps subject to great dynamic loads. Dilatation gaps should be designed in such way, that maximum change of gaps in concrete would be of 10 % [35]. Depth of putty lying depends on dilatation's width. Depth of putty at gap's width of 6 ÷ 12 mm should be at least 5 mm for gap 12 ÷ 20 mm wide; 12 mm for gap 12 ÷ 20 mm wide and for gaps > 20 mm depth of putty should be at least 15 mm, but not greater than 20 mm [35].

Elastomer building putty

Elastomer building putty is single-component putty made on base of selected polymers ensuring high elasticity and resistance to weather conditions. It has good adherence to concrete. It is used for protection of dilatation gaps, in particular in concrete structures [35].

Putty may be used in gaps 6 ÷ 40 mm wide at putty depth of 6 ÷ 20 mm (accordingly). Putty surface is to be formed immediately after applying. Final parameters are achieved within 10 ÷ 28 days depending on width and climate conditions.

The optimal conditions for putty occur if width/thickness ratio is of 2:1 [35].

CONCLUSIONS

Durability is the most important property of the structure. The requirements for necessary durability of structure are fulfilled when all tasks: performance, strength and stability are satisfied, during the whole lifetime without substantial reduction of its utility and excessive unforeseen costs of exploitation.

Concrete structures are often exposed on influence of environmental impacts. The significant issue is to protect properly concrete structures against the damaging effect of dampness. For correct operating, an essential condition is to effectively protect the structure. The defective protection against water in an object generates destructive processes, which significantly reduce its permanence. It causes the necessity of carrying out the expensive repairs, in order to determine the predicted period of using the object. The protection of the concrete structure against the harmful action of dampness is a major economical and technical problem.

In the article author presents the idea of waterproof protection of concrete structures. The sources of dampness of structures, essence of protection, types and general requirements in scope of waterproof insulations are shown. On the basis of proper analysis, the general characteristic of protection against water preceded the review of selected, modern (1991 ÷ 2005) surface protections of concrete structures and the author's proposal of classification of waterproof protection are presented as well.

Analysis of selected, modern waterproof protections brought to notice some characteristic inclinations in material solutions. The modifications of "classical" materials" structure, both, mineral and bituminous became common. Modern waterproof protections are the composites built of "classical" materials (but modified by various kinds of polymers). These composites demonstrate very high resistance to water action, as well as to various outer influences. As a rule they demonstrate the elasticity and resistance to impacts and also very good adhesion to the concrete.

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32. Materials from Onduline company.
33. Materials from Widawa company.
34. Materials from DOW company.
35. Materials from Fosroc company.

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Jan Ślusarek
Civil Engineering Faculty
Silesian University of Technology
Akademicka 5, 44-100 Gliwice, Poland
tel. (+ 48) 601 43 06 71
E-mail: Jan.Slusarek@polsl.pl
jkslusarek@wp.eu