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INFLUENCE OF DURABILITY OF WATERPROOFING SOLUTIONS TERRACES PROTECTING AGAINST WATER AND MOISTURE

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ABSTRACT

The article analyses the changes in the durability of waterproofing of terraces, with particular emphasis on the properties of waterproofing materials as a result of utility factors. It was analysed the influence of tensile properties of the above-mentioned materials on their resistance against fatigue resulting from movements of the substrates caused by temperature changes on the surface of the terraces coverings. The adopted range of horizontal plate movements was from 0 to 2 mm at variable temperatures: –15°C and +70°C. The durability of waterproofing sheets, such as reinforced bitumen sheets and PVC sheets and rubber sheets, as well as coating products was assessed. Thermal deformations of the substrate plates occurring within the terrace covering are most effectively transferred by flexibility sheets with a high relative elongation value, that is: bitumen sheets with polyester reinforcement, PVC sheets and EPDM sheets. The correlation between the mechanical properties of the coatings and their resistance to fatigue cannot be determined but the most favourable properties are shown by two-component (polymer-cement) liquid applied water impermeable products reinforced on the entire surface or reinforced with special tapes over the thermal expansion joints of the substrate plates.

Key words: waterproofing of terraces, durability of waterproofing, resistance to fatigue

INTRODUCTION

In the Polish climate conditions, all destructive processes in building structures occur in the presence of water and moisture with a simultaneous influence of variable temperatures with numerous transitions through 0°C. Ensuring adequate protection of the building structures against the abovementioned impacts contributes significantly to the durability of building structures and the comfort of using their rooms, indirectly impacting the life and health of their users (Francke, 2005a; Runkiewicz & Sieczkowski, 2018). Factors affecting the durability of waterproofing layers in buildings are presented graphically in Figure 1.

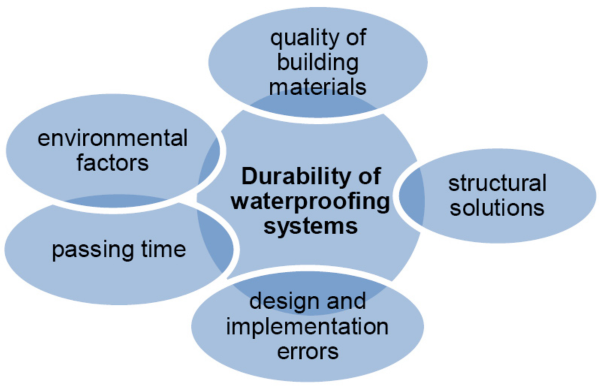

Fig. 1. Factors affecting the durability of waterproofing solutions

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Taking account the results of laboratory tests made in Building Research Institute and conclusions presented by other authors in the available technical literature that's possible to determine typical groups of faults that can potentially occur in the waterproofing layers, combined with the applied material type and the severity of the environmental impact. To avoid these problems, the main attention has to be paid to:

- determination of the optimum performance of waterproofing materials that would guarantee the longest possible use due to exposure to selected application considerations characteristic of the operating conditions;
- determination of the optimum methods of embedding the abovementioned materials into structures to ensure failure-free operation as long as possible, including the methods of improving the works' execution; in the authors' opinion, such supplementation was necessary from the point of view of the waterproofing layers' durability, since even the best materials intended for their execution will not ensure the expected tightness if they are not correctly embedded in the structure and the water-proofing membranes are not appropriately closed.

As presented before, durable protection of a building against storm water, water accumulated in the ground and moisture requires a provision of two key components:

- materials whose properties are adequate to transfer the service loads in the building structure;
- correct embedding of the abovementioned materials.

The evaluation of the waterproofing materials' durability and the evaluation of the waterproofing protection made of such materials, should be carried out depending on the location of waterproofing layer, i.e.: waterproofing of the underground parts of buildings; roofing; waterproofing of terraces and balconies.

As mentioned before, one of the elements influencing the durability of waterproofing is the use of materials which can transfer the service loads prevailing in the facility. This article analyses the working conditions of waterproofing's on terraces and balconies, because this issue is very important from the functional point of view, due to the numerous problems reported in these areas by the users of the building objects. While terraces can be treated as a covering over the rooms below, i.e. requiring effective waterproofing, balconies are only roofing and, in accordance with applicable regulations, do not require a waterproofing layer.

Summing up, terraces are building partitions which have to fulfil important tasks in the field of basic requirements and protection of the building and its interior against (Ślusarek & Orlik-Kożdroń, 2010):

- atmospheric precipitation;
- cooling down as a result of a large temperature difference during the cold parts of the year and resulting from a direct exposure to wind;
- overheating due to high outside temperature and solar radiation in the warm parts of the year (Błażejczyk et al., 2018).

In the case of balconies of the above-mentioned the tasks are limited to protection against penetration of rainwater into the walls and the structural balcony plates. In the case of terraces and balconies, it is, therefore, necessary to ensure the durability of the waterproofing layer working in extremely difficult load conditions. When using the term "working of the waterproofing layer in extremely difficult load conditions", one should consider the fact that materials with different thermal expansion coefficient cooperate within the terrace / balcony covering, what requires ensuring their safe cooperation in changing thermal and humidity conditions (Wetzel, Herwegh, Zurbriggen & Winnefeld, 2012a; Wetzel, Zurbriggen, Herwegh, Greminger & Kaufmann, 2012b). The temperatures acting on the waterproofing layers of terraces and balconies vary depending on the location of the building, climate variability, including the impact of solar radiation energy throughout the year, as well as the colour of the surface layers (Wojewódka & Wilk, 2007). Extreme temperatures ranging from –15°C to +70°C are assumed to be used to evaluate the performance of waterproofing layers in Poland. In European conditions, deviations from the above-mentioned assumptions are confirmed. According to Zurbrigenand and Herwegh (2015), in the northern Alps, for the purposes of examining balcony surfaces, the minimum daily temperatures in winter at 0°C and the maximum average temperatures in summer at 18°C were determined, with average monthly winter rainfall of 65 mm, and up to 150 mm in the summer period. The abovementioned temperatures in the summer evoke the temperatures 45–50°C on the surface layer made of dark ceramic tiles on sunny days, which is reflected in the heating mechanism of the balcony / / terrace. Considering the above, it should not be surprising that the maximum test temperature for the assessment of the work of waterproofing layers of terraces and balconies is + 70°C, in the case of extreme outside air temperatures of +30°C, especially since the moisture accumulated inside the tiles and joints as a result of precipitation may cause an increase in thermal conductivity (Ślusarek, 2006; Ślusarek & Orlik-Kożdroń, 2010).

In such working conditions, before choosing the right waterproofing material, it is important, inter alia, to assess its tensile properties corresponding to the ability to transfer tensile stresses arising within the terrace covering during the operation of the object at changing temperatures. Research work was carried out at the Building Research Institute to compare these two parameters in laboratory conditions.

MATERIAL AND METHODS

Waterproofing materials

The basic waterproofing materials used in the waterproofing layers of terraces are bitumen sheets with reinforcement and PVC sheets and rubber sheets as well as coating products applied in a liquid form on the substrates, creating waterproofing coatings after drying. Unfortunately, in the case of the above-mentioned groups of materials, the standards do not specify requirements for mechanical properties. In the case of flexible products, these requirements are described in product standards as:

- MLV – manufacturer's limiting value, which should be achieved in the tests (maximum or minimum, depending on the test type);
- MDV – manufacturer's declared value, including specified tolerance.

A lack of requirements for the majority of essential characteristics enables positive assessment of the products by manufacturers, based on these standards, and consequently launching the products whose properties often do not guarantee failure-free transfer of loads which the particular structure is exposed to. Customers, including designers and contractors of building works, who receive product authorisation documents issued by manufacturers and who have no specific requirements for the particular product group, do not suspect that the products do not guarantee the required durability (life) in specific application conditions. In order to limit the technical chaos resulting from such provisions in the European standards introduced into the collection of national standards, the authors extended the scope of research, what resulted in dividing the previously mentioned key groups of waterproofing products into subgroups (Francke, 2020, 2021, 2022). Then, the recommended values were determined for their essential characteristics, guaranteeing optimum durability of the products in their application conditions. It was done for each subgroup. Sample effects of the work are summarised in Tables 1 and 2 for only one essential property selected from several dozen of tested and proposed values. Based on one property, it can be concluded how significant the presented research was and how vital its outcomes are for ensuring the durability of the implemented waterproofing membranes. Only one essential characteristic, i.e. tensile mechanical properties for reinforced bitumen sheets, plastic sheets and rubber sheets, for which there are no recommended values in the European standards, reveals that the differences in the products under the same product group can be considerable.

Typical groups of products used in waterproofing layers of terraces were used in the research:

- bitumen sheet for waterproofing (asphalt-polymer-based sheet with reinforcement: woven glass and polyester non-woven fabric) and plastic and rubber sheets (PVC – 1.2 mm thick and EPDM sheet – 1.7 mm thick); the analysis does not include bitumen sheets with reinforcement, which, due to their mechanical properties, should not be used in waterproofing of terraces, i.e. with non-woven glass reinforcement and bitumen sheets with aluminium tape;

Table 1. Recommended values for the tensile properties for bitumen sheets with different reinforcements (Francke, 2004, 2005b, 2011)

Tensile properties	Bitumen sheets with reinforcements made of				
	polyester	glass fabric	polyester-glass mixture	glass veil and/or glass non-woven fabric	construction card board
Maximum tensile force [N]:					
longitudinal	≥ 800	≥ 900	≥ 600	≥ 300	–
transverse	≥ 600	≥ 900	≥ 500	≥ 200	–
mean of two directions	–	–	–	–	≥ 315
Elongation at maximum tensile force [%]:					
longitudinal	> 40	> 2	> 2	≥ 2	–
transverse	> 40	> 2	> 2	≥ 2	–
mean of two directions	–	–	–	–	> 2

Table 2. Recommended values for the tensile properties for PVC and rubber sheets (Francke, 2004, 2005, 2011)

Tensile properties	Non-reinforced membranes	Reinforced or laminated membranes		
		with polymer fibre reinforcement	with glass fibre reinforcement	with mixed reinforcement
For plastic sheets				
Maximum longitudinal and transverse tensile stress [N·mm^{-2}]	≥ 15	–	–	–
Elongation at maximum longitudinal and transverse tensile force [%]	≥ 250	–	–	–
Maximum longitudinal and transverse tensile force [N/50 mm]	–	woven ≥ 800 non-woven ≥ 650	≥ 500	≥ 500
Elongation at the maximum longitudinal and transverse tensile force [%]	–	woven ≥ 15 non-woven ≥ 40	≥ 2	≥ 40
For rubber sheets				
Maximum longitudinal and transverse tensile stress [N·mm^{-2}]	≥ 6	–	–	–
Elongation at maximum longitudinal and transverse tensile force [%]	≥ 300	–	–	–
Maximum longitudinal and transverse tensile force [N/50 mm]	–	≥ 400	≥ 250	≥ 400
Elongation at the maximum longitudinal and transverse tensile force [%]	–	woven ≥ 15 non- woven ≥ 40	≥ 2	≥ 40

– coating products, applied in a liquid form on the substrates, creating waterproofing coatings after drying, respectively from the following materials:
  - two-component (polymer-cement ones), both in the version reinforced on the entire surface and in the version reinforced with plastic tapes only over the thermal expansion joints of the substrate plates,
  - one-component (cement-based) materials, also in the version reinforced over the entire surface as well as in the version reinforced with plastic tapes only over the thermal expansion joints of the substrate plates,

- one-component polymer materials, also in the version reinforced version over the entire surface as well as in the version reinforced with plastic tapes only over the thermal expansion joints of the substrate plates.

The coatings were reinforced with internal carries due to their low tensile stress resistance, often too low to carry working loads occurring in terrace and balcony coverings.

Mechanical properties of the above-mentioned materials are presented in the Tables 3 and 4. Additionally, Table 5 presents the method of strengthening the waterproofing coatings in the tests of resistance to fatigue (Francke, 2011, 2022).

Table 3. Mechanical properties of flexible sheets

Set	Product type	Maximum tensile force [N/50 mm] / / Coefficient of variation [%]	Elongation at maximum tensile force [%] / / Coefficient of variation [%]
1	bitumen sheet with woven glass reinforcement	1 492 / 5	5.1 / 5.2
2	polymer modified bitumen sheet with polyester non-woven fabric reinforcement	1 034 / 2	44.9 / 5.3
3	PVC sheet thickness of 1.2 mm	1 283 / 6	22.5 / 4.1
4	EPDM sheet thickness of 1.7 mm	520 / 2	519.8 / 4.3

Table 4. Mechanical properties of coverings

Set	Product type	Maximum tensile stress [MPa] / / Coefficient of variation [%]	Elongation at maximum tensile stress [%] / / Coefficient of variation [%]
1	covering of two-component (polymer--cement) waterproofing material	0.96 / 2.10	112.0 / 5.6
2		1.33 / 5.78	19.6 / 10.5
3		1.20 / 2.65	17.8 / 6.6
4		1.22 / 2.04	29.0 / 7.2
5		2.29 / 10.59	28.0 / 20.2
6		0.68 / 6.45	21.4 / 6.3
7		1.15 / 2.42	40.7 / 8.9
8		1.22 / 2.04	29.0 / 7.23
9		1.04 / 6.11	65.8 / 2.02
10		1.47 / 11.50	125.6 / 17.6
11		1.23 / 2.69	42.4 / 7.1
12		1.12 / 5.30	37.4 / 18.0
13		1.40 / 9.78	17.2 / 23.4
14		0.98 / 5.08	26.6 / 18.8
15		0.83 / 8.88	169.0 / 5.16

Table 4. cont.

16	covering of one-component (cement based) waterproofing material	3.67 / 4.20	15.0 / 14.0
17		1.88 / 2.77	18.4 / 2.66
18		3.66 / 4.20	44.8 / 18.4
19		3.22 / 6.48	30.0 / 18.0
20		2.50 / 9.76	12.2 / 17.5
21	covering of one-component (polymer) waterproofing material	0.45 / 5.07	220.0 / 6.2
22		2.80 / 3.06	14.4 / 19.9
23		0.43 / 13.64	20.0 / 9.5
24		2.59 / 3.80	132.6 / 9.1
25		1.99 / 7.39	127.4 / 9.0

Table 5. Types of covering tests kits used in fatigue tests (Francke, 2011, 2022)

Set	Type of tests kits
1–7 (marked *w* in Figs 4–6)	covering made of two-component (polymer-cement) material, with the reinforcement on the whole entire surface
8–15 (marked *t* in Figs 4–6)	covering made of two-component (polymer-cement) material, with the plastic tape only over the thermal expansion joint
16–17 (marked *w* in Figs 4–6)	covering made of one-component (cement based) material with the reinforcement on the whole entire surface
18–20 (marked *t* in Figs 4–6)	covering made of one-component (cement based) material, with the plastic tape only over the thermal expansion joint
21–22 (marked *w* Figs 4–6)	covering made of one-component (polymer) liquid material, with the reinforcement on the whole entire surface
23–25 (marked *t* in Figs 4–6)	covering made of one-component (polymer) liquid material, with the plastic tape only over the thermal expansion joint

Determination of tensile properties

The tensile properties of flexible products were tested in accordance with PN-EN 12311-1:2001 (standard for bitumen sheets with reinforcement) (Polski Komitet Normalizacyjny [PKN], 2001) or PN-EN 12311-2:2013-07 (standard for plastic and rubber sheets) (PKN, 2013). The test was performed on test specimens with dimensions 50 × 200 mm with applied tensile speed of 100 $mm \cdot min^{-1}$.

In the case of coating products, the tensile properties were tested in accordance with the PN-EN ISO 527-1:2020-01 (PKN, 2020) and PN-EN ISO 527-3:2019-01 (PKN, 2019) on test samples of type 5, i.e. with applied tensile speed of 100 $mm \cdot min^{-1}$. As a rule, the study of the tensile properties was performed for the coating without the reinforcement in order to characterize the product itself and not the strength of the reinforcement.

Determination of fatigue resistance

The fatigue resistance test was carried out in accordance with the proprietary methodology developed for the assessment on the device shown in Figure 2.

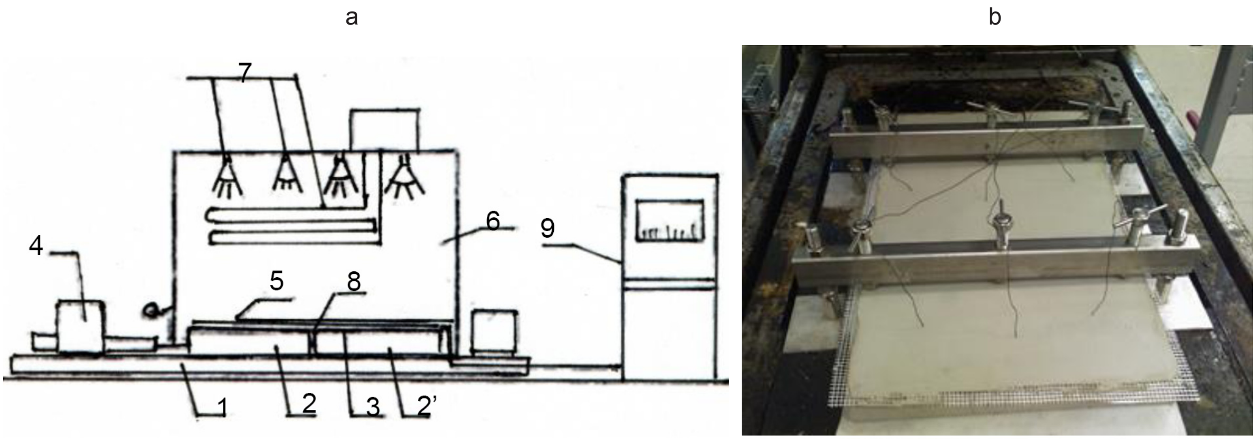

Fig. 2. Device for testing resistance to fatigue: (a) block diagram of the device: 1 – base, 2 – concrete slab of the substrate with the possibility of horizontal movement, 2’ – immobilised concrete slab, 3 – tested waterproofing layer, 4 – electric actuator, 5 – thermocouples, 6 – temperature chamber, 7 – heating lamps / variable cooling device, 7 – temperature recorder, 8 – gap between two concrete substrates, 9 – temperature recorder; (b) view of the sample surface during testing

Repetitive cycles of opening and closing the gap formed between the slabs of the concrete substrate on the surface of which waterproofing layers are laid were simulated at variable temperatures: –15°C and +70°C. The adopted range of horizontal plate movements was from 0 to 2 mm.

RESULTS AND DISCUSSION

Figure 3 shows graphically the tensile properties of selected systems of waterproofing solutions for flexible sheets in comparison with their resistance to fatigue.

In the case of flexible sheets, the resistance to fatigue caused by the movement of the substrate plates increases with increasing elongation of the product. Bitumen sheet with woven glass reinforcement, despite high mechanical strength, shows a low elongation value, which translates into a negative result of fatigue resistance. This observation is confirmed for the EPDM-type flexible sheet. It exhibits the lowest mechanical strength compared to the other three tested flexible sheets, but due to the highest elongation value, it is also resistant to the effects of substrate slab movements in the terrace cross-section. Advantageous properties in the field of fatigue resistance are also exhibited by the PVC sheet, which, despite the internal reinforcement insert, is characterized by a relatively high elongation, exceeding 20%.

Figures 4–6 graphically show the tensile properties of selected systems of waterproofing solutions of coating products in comparison with their resistance to fatigue. In the case of coatings, the diagrams show

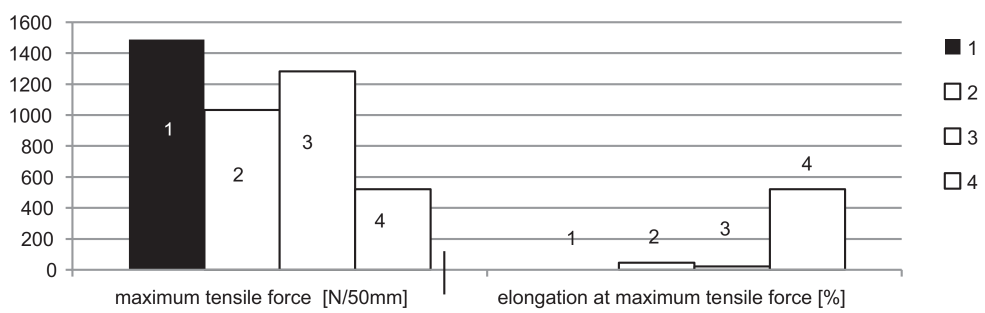

Fig. 3. Comparison of tensile properties for waterproofing layers made of flexible sheets vs. their resistance to fatigue. The black colour indicates no fatigue resistance, white colour indicates that this requirement is met: 1 – bitumen sheet with woven glass reinforcement, 2 – bitumen sheet with non-woven polyester fabric reinforcement, 3 – PVC sheet, 1.2 mm thick, 4 – EPDM sheet, 1.7 mm thick

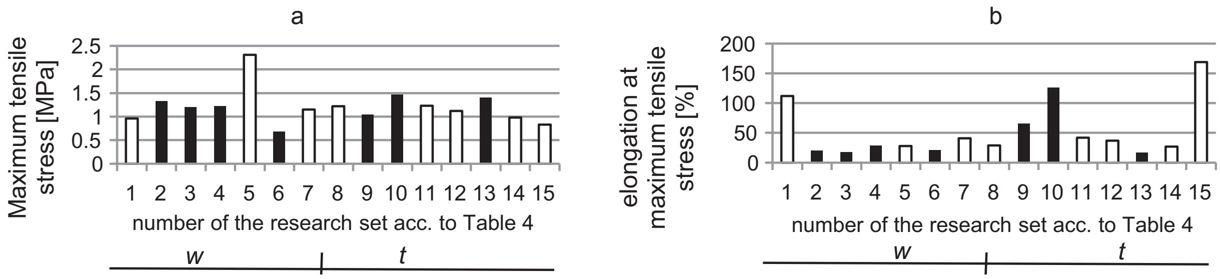

Fig. 4. Comparison of tensile properties and fatigue resistance for waterproofing layers made of two-components polymer-cement coating products: with the reinforcement on the whole entire surface (marked *w*) and with the plastic tape only over the thermal expansion joint (marked *t*). The black colour indicates no fatigue resistance, white colour indicates that this requirement is met (Francke, 2011, 2022)

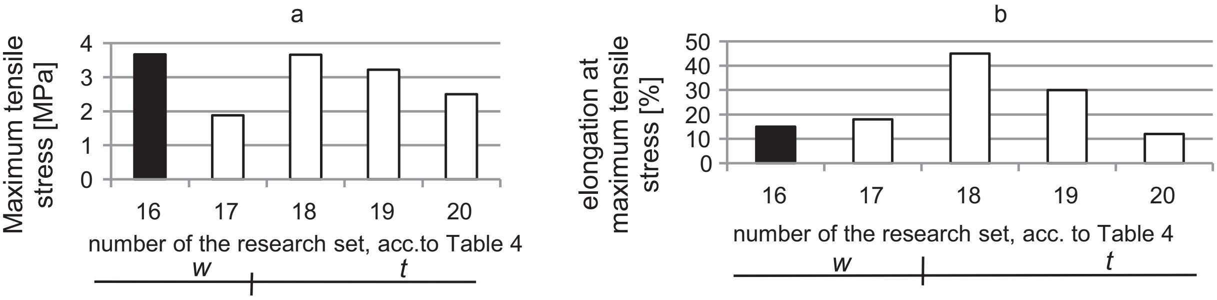

Fig. 5. Comparison of tensile properties and fatigue resistance for waterproofing layers made of one-component polymer modified cement coating products: with the reinforcement on the whole entire surface (marked *w*) and with the plastic tape only over the thermal expansion joint (marked *t*). The black colour indicates no fatigue resistance, white colour indicates that this requirement is met (Francke, 2011, 2022)

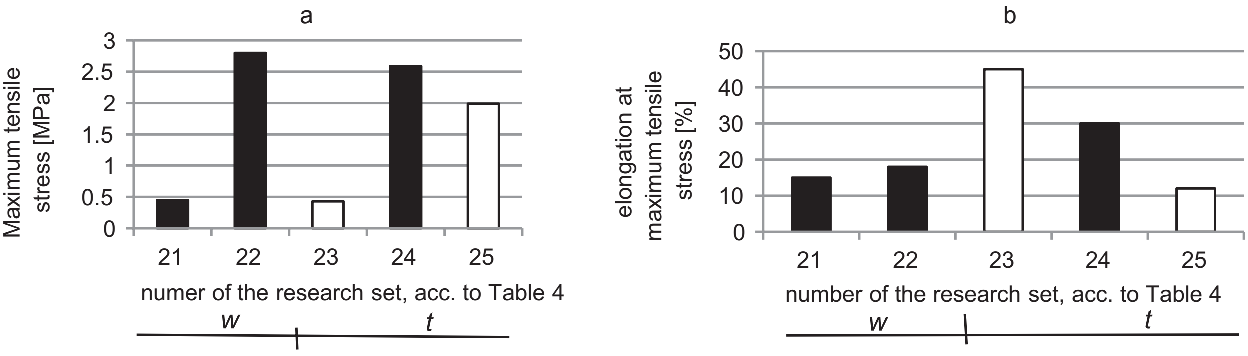

Fig. 6. Comparison of tensile properties and fatigue resistance for waterproofing layers made of one-component (polymer) coating products: with the reinforcement on the whole entire surface (marked *w*) and with the plastic tape only over the thermal expansion joint (marked *t*). The black colour indicates no fatigue resistance, white colour indicates that this requirement is met (Francke, 2011, 2022)

all measurement results obtained for various products, not only average values for a specific material group, to indicate the possibility of large dispersions in the values of tensile properties for products from different production batches. In general, it was found that in the case of coating products, no clear regularity between the fatigue resistance of the coating and the values of the tensile properties can be determined.

In the case of cement-polymer coatings reinforced on the entire surface, the increase in the mechanical strength of the coating does not clearly correlate with its fatigue resistance. The elongation value is more important in this case. Tensile stresses are mainly transmitted through the reinforcement. This statement is confirmed by the observations of the nature of the sample damage as a result of the fatigue resistance test. This damage is visible in the form of cracking only of the coating layer above the test gap, simulating the work of the thermal expansion joints of the substrate plates, without damaging the insert itself. In the present case, positive values of fatigue resistance were obtained for polymer-cement coatings for which the value of elongation at maximum stress was above 30%. These coatings also exhibited maximum tensile stress values above 0.4 MPa.

In the case of polymer-cement coatings reinforced with tapes only over thermal expansion joints, no regularity was found between the mechanical strength of the coating and its resistance to fatigue. The comparison of the test results for eight coating products shows that, based on the properties of the coating product, it is not possible to pre-define a model of cooperation between the coating and a specific type of tape over the thermal gaps. The discussed solution is also very complicated. The cement screed, which is the substrate for the waterproofing layer, should be dilated in areas 2.0 × 2.0 m, which in practice requires laying a reinforcing tape in the same areas while applying subsequent layers of the coating.

One-component cement-based products are rarely used as the main waterproofing layer for terraces. Usually, they are recommended for use beneath a ceramic tiling, in a system with appropriate waterproofing. For this reason, the tests were performed only for two sets with the reinforcement placed on the entire surface of the coating, which did not allow to establish a correlation between the mechanical properties of the product and its resistance to fatigue. In sets with reinforcing tapes, due to the considerable stiffness of one-component cementitious products, the entire surface of the tapes was not covered with them, but an uncoated area was left above the gap. In this way, only the tape fully transferred the tensile loads, which also did not allow to determine the correlation between the mechanical properties of the coating itself and its resistance to fatigue resulting from thermal movements of the substrate plates.

In the case of coatings made of polymer products, only in two out of the five assessed cases the coating's resistance to fatigue caused by thermal movements of the substrate plates was obtained. In both cases, these loads were transferred by tapes pasted over the test gap. The obtained results confirm the observations resulting from the market analysis, where such products are offered by manufacturers mainly for use in "wet" rooms not exposed to such high mechanical loads as waterproofing of terraces. In the present case, the correlation between the mechanical properties of the coatings and their resistance to fatigue cannot be determined, as a positive result.

CONCLUSIONS

The research results presented in this article allow the following conclusions regarding the influence of tensile properties of waterproofing products on their fatigue resistance caused by working breaks as a result of thermal operational impacts.

Thermal deformations of the substrate plates occurring within the terrace / balcony covering are most effectively transferred by flexibility sheets with a high relative elongation value that is: bitumen sheets with polyester reinforcement, PVC sheets and EPDM sheets. From the point of view of the above-mentioned impacts the method of modification of the bitumen does not have a significant importance.

In the group of coating products, the most favourable properties in the discussed range of loads are shown by two-component (polymer-cement) liquid applied water impermeable products reinforced on the entire surface or reinforced with special tapes over the thermal expansion joints of the substrate plates.

Authors' contributions

Conceptualisation: B.F. and L.R.; methodology: B.F. and L.R.; formal analysis: B.F.; investigation: B.F.; writing – original draft preparation: B.F.; visualisation: B.F.; supervision: L.R.

All authors have read and agreed to the published version of the manuscript.

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WPŁYW TRWAŁOŚCI WARSTW HYDROIZOLACYJNYCH NA ZABEZPIECZENIE TARASÓW PRZED DZIAŁANIEM WODY I WILGOCI

STRESZCZENIE

W artykule przeanalizowano trwałość rozwiązań hydroizolacyjnych tarasów, ze szczególnym uwzględnieniem zmian właściwości materiałów hydroizolacyjnych w efekcie działania czynników użytkowych. Określono wpływ wytrzymałości na rozciąganie tych materiałów na ich odporność na zmęczenie, wynikające z ruchów płyt podłoży powstających w efekcie działania zmiennej temperatury na powierzchni przekryć tarasowych. Przyjęty zakres badawczy ruchów poziomych płyt wynosił od 0 do 2 mm, w zmiennej temperaturze od –15°C do +70°C. Oceniono trwałość warstw hydroizolacyjnych wykonanych z pap, folii z PVC i wyrobów rolowych na bazie kauczuku, a także z wyrobów powłokowych. Największą odporność na odkształcenia termiczne płyt podłoża w obrębie przekrycia tarasowego wykazują wyroby rolowe o wysokim wydłużeniu względnym, takie jak: papy na osnowie poliestrowej, folie PVC i folie EPDM. Nie stwierdzono korelacji właściwości mechanicznych przy rozciąganiu w odniesieniu do wyrobów powłokowych. Najkorzystniejsze właściwości w zakresie odporności na zmęczenie w tej grupie wyrobów wykazują dwuskładnikowe wyroby polimerowo-cementowe wzmocnione wkładką wewnętrzną na całej powierzchni lub jedynie nad przerwami termicznymi płyt podłoża.

Słowa kluczowe: hydroizolacja tarasów, trwałość hydroizolacji, odporność na zmęczenie