XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Behavior of Waterproofing Systems Exposed to Environmental Agents

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Abstract. *The service life of buildings can be associated with the durability of enveloping the elements, e.g., the flat roofs that are constantly exposed to environmental agents. Waterproof membranes, produced with bituminous or polymeric materials, usually protect these elements. This paper presents an experimental study of waterproofing systems subjected to environmental agents of degradation. Four types of membranes were tested: bituminous, polyurethane, acrylic and acrylic with polyester mesh. All membranes were applied to concrete substrates and exposed to cycles of 48 hours in 70°C oven and 24 hours in immersion vats with 23°C water. The specimens were subjected to 0, 4, or 8 cycles and submitted to pull-off tests. The results demonstrated that the waterproof system behavior change when subjected to cycles of the temperature gradient. The tests show that the different thermal deformation between the membranes and the concrete substrate results in loss of adhesion.*

Keywords: *Waterproofing System, Durability, Environmental Agent, Adhesion.*

1 Introduction

The waterproofing layer of the roof system can be considered as a building protection system since it prevents damaging actions of water as well as aggressive elements of the atmosphere (Gonçalves *et al.*, 2019). It is related to the building service life and it is the first principle of their durability (Henshell, 2000). The loss of properties of its materials can cause premature degradation in other building systems (Navratilova Rovenska, Jiránek, and Kačmaříková, 2015).

The roof is one of the building envelope part that requires the design of a system to predict the service life. The durability of the roofing system depends on several parameters (Cash, 2003) because it involves choosing proper design and materials considering the detrimental effects of natural agents (Henshell and Griffin, 2000).

The materials used in waterproofing systems, mainly those for flat roofs, are exposed to environmental agents like ultraviolet radiation, mechanical actions, contact of the organic solvents, moisture, and cycles of the oxygen, carbon and temperature (Bertolini, 2014; Marques, Lopes, and Correia, 2011; Pirondi, 1988). Due to these factors, the waterproofing systems are subject to natural and accelerated degradation processes of their mechanical water-tightness characteristics (Walter, De Brito, and Lopes, 2005).

The main factor for material degradation is temperature according to Patterson and Mehta (2001), the heat transference by radiation occurs because every object produces electromagnetic waves by virtual temperature. The membranes and sheets of the weatherproof system are polymeric materials like polyurethane, polyvinyl chloride, bituminous, acrylic, polypropylene (Cash, 2003; Marques *et al*., 2011). This class of material is known for its temperature instability due to its thermoplastic characteristics. The internal energy of polymers rises with the increase in temperatures, reducing weak bonds between macromolecules (Callister and Rethwisch, 2001). It leads to lower elastic modulus and higher flexibility (Bertolini, 2014). However, at high temperatures, covalent bonds are broken, leading to irreversible chemical degradation of the material. With this regard, it is important to understand the behavior of these materials when working together with building as a system, not just as a material.

In this work, the main objective is to analyze the behavior of four waterproofing materials applied in a concrete substrate submitted to weathering actions by temperature, air and wetting.

2 Methodology

This work evaluated the behavior of waterproofing systems when submitted to wetting and drying cycles. In the experimental study, four waterproofing systems adhered to the substrate were evaluated: acrylic with and without polyester mesh, polyurethane, and bituminous. The substrate used was concrete with steel mesh, produced according to the Brazilian standard ABNT NBR 14081-2: 2015.

The specimens were submitted to the aging process by wetting and drying cycles, placed in a forced air circulation oven at a constant temperature of (70 ± 1) ºC for 48 hours and moved to a water vat at (23 ± 1) °C for 24 hours. So, each cycle corresponds to 72 hours. Four substrates were tested for each waterproofing system, varying the number of cycles: 0, 4, 8 and 16.

Visual analyses were performed at each cycle stage. After finishing the cycles, the membranes were submitted to pull-off tests, using 10 samples for each substrate.

2.1 Materials

The selection of the waterproofing materials for the experiment was based on their relevance and application in the Brazilian market, their adhesion to the substrate and their distinct chemical composition and mechanical behavior. Table 1 presents the Brazilian standard and manufactures characteristics of the materials to compose the waterproofing systems: acrylic membrane, polyurethane membrane and bituminous sheet adhered with heated asphalt.

Table 1. Characteristic of waterproofing materials tested.

Characteristics	Acrylic Membrane	Polyurethane	Bituminous sheet
Color	White	Green	Black
Density (g/cm³)	1.40	1.4-1.6	Undeclared
Elongation (%)	200	70	30
Touch drying (h)	4	6	-
Consumption (kg/m²)	1.2	1.7	1.15m²/m²
Thickness (mm)	0.50-1.00	Undeclared	4.00
Application state	One-component liquid	Two-component viscous	Solid

The Systems composed of acrylic membrane received structural reinforcement with polyester mesh, table 2 present its physical and mechanical properties.

Table 2. Physical and mechanical properties of polyester mesh.

Physical and mechanical properties	Unit	Standard	Specifications
Longitudinal tensile strength	kgf	EN-ISO 1421	25±5
Transverse tensile strength	kgf	EN-ISO 1421	25 ± 5
Stretching	%	EN-ISO 1421	Max. 25
Resistance to longitudinal tear	kgf	DIN 53.363	15 ± 5
Tear Resistance	kgf	DIN 53.363	15 ± 5
Grimace	g/m²	EN-ISO 2286	15 ± 5
Thickness	mm	EN-ISO 2286	0.25 ± 0.05

The structural reinforcing mesh has the function of resisting the tensile forces when it is requested from the system (Pirondi, 1988). The bituminous sheet is prefabricated, modified with SBS (styrene-butadiene-styrene), structured with nonwoven continuous filament and sand-finished on both sides, with a thickness of 4 mm.

2.2.2 Specimens Preparation

The waterproofing systems were applied to the previously prepared substrate. The application process differs when the material is prefabricated or molded on-site. The membranes were applied using a brush and the material quantity is controlled by weighing it on a precision scale (0.01 g). For thickness control, a measurement was performed using a wet layer thickness gauge (25 to 3000 µm). Figures 1 to 4 demonstrate the procedure for specimens preparation.

Figure 1. Preparation of Bituminous sheet.

Figure 2. Application of the Bituminous sheet adhered with heated cement asphalt.

Figure 3. Application of Polyurethane membrane and inspection the thickness.

Figure 4. Application of the Acrylic membrane with polyester mesh.

The wetting and drying cycle started with the specimens in an air circulation oven at (70 ± 1) ºC. After 48 hours at a constant temperature, the specimens were removed and submerged in a water vat at (23 ± 1) ºC.

3 Results and Analysis

The test results were analyzed qualitatively and quantitatively. The first was performed by visual observations of changes in the systems during each cycle and the second by pull-off tests. The analysis of variance method (ANOVA) was used to evaluate if differences between the cycles are statistically significant.

3.1 Visual Analysis

Figures 5 to 10 illustrate the visual observations made in the test specimens throughout the 16 cycles. The visual inspection shows the occurrence of microbubbles, air bubbles, apparent pores, melting and debonding.

Figure 5. Air bubble disrupted and microporous in the Acrylic membrane with mesh.

Figure 6. Microbubbles and microporous in the Acrylic membrane.

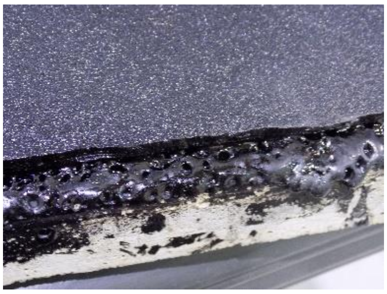

Figure 7. Increase in viscosity (melting) and microbubbles in the asphalt cement between the bituminous sheet and substrate.

Figure 8. Debonding of the bituminous sheet of the substrate with increase the temperature.

Figure 9. Air bubble in the Polyurethane system.

Figure 10. Microbubbles and apparent porous in the Polyurethane system.

3.2 Pull-off Analysis

The adhesion strength was measured using pull-off tests that were performed at the end of each wetting and drying cycle. Figures 11 to 12 demonstrate the preparation and performance of the test.

Figure 11. Preparation of the samples to the pull-off test.

Figure 12. Pull-off test in the polyurethane membrane.

The adhesion strength is given by the following equation:

$$Ra = \frac{F}{A} \tag{1}$$

Where Ra is the adhesion strength, expressed in Megapascal (MPa), F is the force, expressed in Newton (N), and A is the tested area, expressed in square millimeters (mm²).

In Figures 13 to 16 should be noticed that all waterproofing systems presented a decrease in adhesion strength when at least 4 wet-dry cycles were applied.

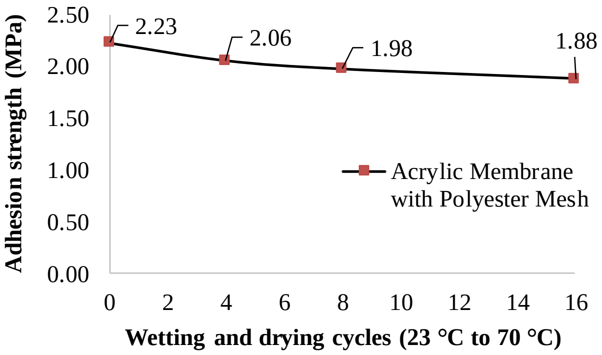

Figure 13. Adhesion Strength of Acrylic membrane with Polyester mesh.

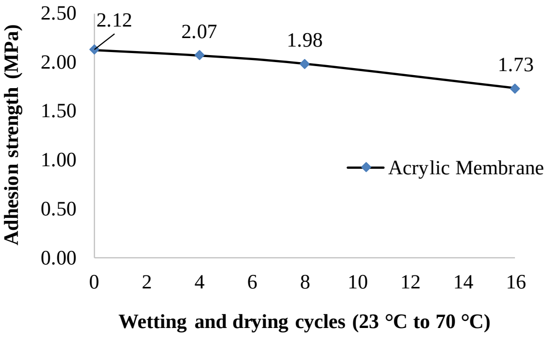

Figure 14. Adhesion Strength of Acrylic membrane.

Comparing Figures 13 and 14, it is can be seen that the reinforcement has no influence at the adhesion strength of acrylic membranes. Also, a decline of adherence with number of cycles is presented in both systems. Figures 15 and 16 indicates that the bituminous sheet and the polyurethane membrane show no significant decrease in adhesion strength after 4 cycles.

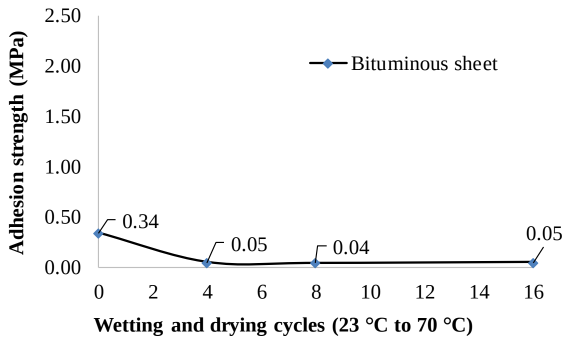

Figure 15. Adhesion Strength of Bituminous sheet.

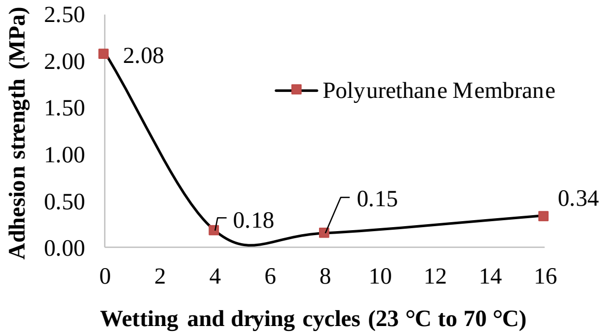

Figure 16. Adhesion Strength of Polyurethane membrane.

In Figure 17, the variability of the adhesion strength results is presented. Each result is an average of 10 specimens tested in each substrate plate. It is observed that polyurethane systems presented a larger deviation. It was observed that specimens located in points where air bubble formation results adhesion next to zero. Also, in the case of bituminous system, the penetration of fluids in the polymer-modified asphalt pores causes a debonding process.

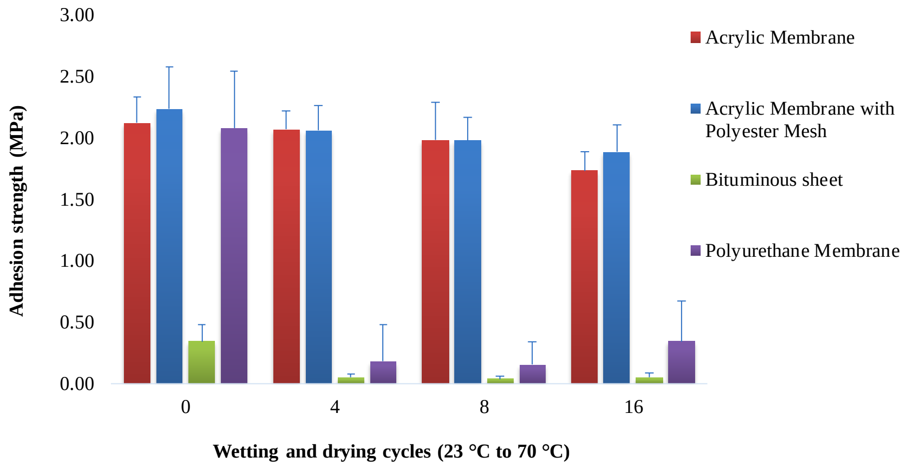

Figure 17. The Standard deviation of each waterproofing system.

It is noted that the behavior of the bituminous and polyurethane systems proved to be highly sensitive to temperature actions and wetting cycles. Additionally, it is noticeable that the adhesion strength of the bituminous sheet is the lowest, even in cycle 0. This factor is related to the adhesion shape, thickness, and type of material used to adhere the layers. The system consists of 3 layers: primer, polymer-modified asphalt cement and the bituminous sheet itself, resulting a 6 mm thickness. So, there is a larger area for energy dispersion when the system is stressed. In cycle 0, the adhesion strength of the polyurethane system was considerably high comparing to the other systems. However, the cycles of weathering result a loss of this initial behavior. As shown in Figure 9, during the wetting and drying cycle, air bubbles were formed between the substrate and the polyurethane system. In this process, the system had a loss of adhesion in some parts of the substrate.

Table 3 presents the comparison of adhesion strength of the tested systems using the analysis of variance (ANOVA), the level of significance considered is 5%.

Table 3. Analysis of variance and Tukey's paired comparisons of adherence strength.

System	Cycle	Value-P	Media	Group	
Acrylic Membrane	0	0.002	2.12	A	
	4		2.07	A	
	8		1.98	A	B
	16		1.73		B
Acrylic Membrane with Polyester Mesh	0	0.024	2.23	A	
	4		2.06	A	B
	8		1.98	A	B
	16		1.88		B
Bituminous sheet	0	0.000	0.34	A	
	4		0.05		B
	8		0.04		B
	16		0.05		B
Polyurethane Membrane	0	0.000	2.08	A	
	4		0.18		B
	8		0.15		B
	16		0.34		B

It can be seen that for all the systems the weathering cycle is significant for the decrease in adherence (value-P is less than 5%). Also, a Tukey's method is used to compare all possible pairs of results for each system. With this, it is possible to observe in the bituminous sheet and polyurethane membrane the cycle 0 and the others are significant different. Bur, the acrylic membranes do not show a significant difference in the adhesion strength up to the cycle 8.

4 Conclusions

Waterproofing systems as an integral part of the building need to provide weathering resistance. Through tests on wetting and drying cycles, it was possible to understand the behavior of waterproofing systems when adhered to the substrate. From the tests performed and materials used the following conclusions are drawn:

- The adherence of the acrylic membranes to the substrate is less influenced by weathering cycles than other systems. In addition, the use of reinforcement mesh does not influence significantly in this pattern.
- Despite the high adhesion strength of acrylic membranes, it was observed over the cycles the manifestation of air bubble disrupted and microporous. This may compromise the system in terms of watertightness.
- The polyurethane membrane system and the bituminous sheet system lost their bonding characteristic to the substrate after 4 cycles. In view of this behavior, it is necessary to evaluate previously the place where it will be applied; therefore, it is not indicated for regions susceptible to severe weather conditions, such as cycles of intensive rain and extremely high temperature.
- The results demonstrate the importance of the thermal protection layer in waterproofing systems that will be exposed to weather cycles. Moreover, a special attention should be taken in the design and execution of this layer.

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