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CEMENTITIOUS ADHESIVES PERFORMANCE DURING SERVICE LIFE

V. P. de Freitas, A.Vaz Sá
Laboratório de Física das Construções (LFC) – Faculdade de Engenharia da Universidade do Porto (FEUP)
Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
vpfreita@fe.up.pt vaz.sa@fe.up.pt

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ABSTRACT

Ceramic tiles have been extensively used on external walls in Portugal for many years. These tiles are often bedded into mortar or into a cement-based adhesive. In the last few years, however, there have been many mistakes, such as adhesion failure, in the use of ceramic wall tiles. A fundamental cause of these failures is an inadequate selection of the cementitious adhesive.

Adhesive performance is usually evaluated upon the bases of early age behaviour. The knowledge of this behaviour is essential for classification and labelling, however it gives no indication of long term service life performance. Objective test methods that can evaluate the building system and its components' performance throughout its service life are lacking.

At Faculdade de Engenharia da Universidade do Porto's (FEUP) Building Physics Laboratory - LFC, about 40 samples were submitted to more than one hundred accelerated aging cycles. This study's main goal was to evaluate the durability of the tile/cementitious adhesives system. This was done in terms of relating the decreasing performance (the influence of types and classes of cementitious adhesives and the tiles absorption coefficients) to the tensile adhesion strength and establish criterion of long-term performance; i.e. the selection of the most adequate adhesive for an external ceramic wall tileing systems.

KEYWORDS

Cementitious adhesives, Ceramic tile coating, Service life, Accelerated aging tests, Pathology.

1 INTRODUCTION

Since the 16th century Portugal has been Europe's leading user of ceramic tile coatings for building façades. Nowadays this type of coating is still greatly used due to its high durability, large functionality and aesthetic performance.

Despite significant developments in the ceramic and adhesives industries, there are still frequent and serious problems related to detachment. Materials' performance, especially as far as the cementitious adhesives are concerned, is usually evaluated at the early stages of the application. Knowing its initial characteristics is essential to its CE marking and classification. Although this classification is essential when selecting the material that best suits the desired application, it does not cover performance over long periods of time. Objective methods that can evaluate the tileing system throughout its service life are lacking.

Ceramic tile coating systems are basically made of substrate, rendering grout, adhesive mortar and ceramic tile. These materials are subjected to temperature and humidity variation, to sun radiation and rain, especially when applied on exterior walls. The materials' response to these degradation factors can be seen with the loss of its functionality. To evaluate the influence of the aging process in the cementitious adhesives' performance we performed tests in the accelerated ageing chamber at FEUP's LFC. The chamber simulated some of the most significant climatic conditions and actions (irradiation, rain, freezing and thawing), to which the chosen building elements are generally exposed. The threshold temperature and humidity values were established in order to slightly overcome the most adverse weather conditions that exterior walls in Portugal could possibly experience. Extreme conditions of hygrothermal movement were thus established.

The samples were subject to a cycle range that varied from 1 to 112 cycles. Material response to the degradation agents can be seen by the deterioration of certain performance-related characteristics. This study's main goal is to evaluate the durability of the cementitious adhesives in relation to their decreasing performance in tensile adhesion strength.

2 THE PROBLEM

Ceramic tile detachment [Fig.1] is a severe and common pathology. Moreover, ceramic tile detachment from façades also poses a serious threat to human safety.

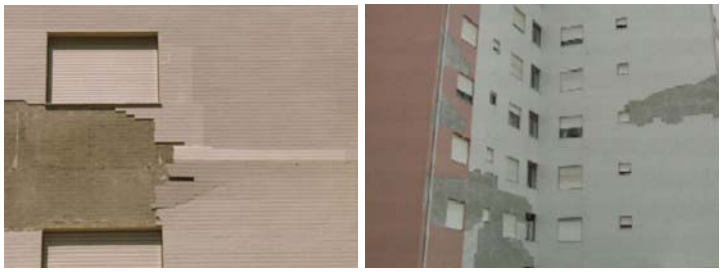


Figure 1. Pathologies on the ceramic tile coating of façades.

The main causes of ceramic tile coating detachment are: structural deformability, instability of the support, rendering grout characteristics, joint dimensions and inadequate selection of the cementitious adhesive. Although CE markings are very helpful, they don't cover material performance through time. There is an urgent need to develop service life evaluation testing methods.

3 SERVICE LIFE PREDICTION

Service life prediction of ceramic tile coatings can be estimated both by experimental or numerical analysis. On the development of a methodology for the prediction of ceramic tile coating working life and on the modelling of the degradation mechanisms it should be considered those that mostly feats its nature and its use in service.

Guidance Document 003 of the European Organization for Technical Approvals – GD003, EOTA, December 1999 – proposes a systematic methodology for assessing and/or predicting the working life of products. Based on that proposed methodology, we established the followed steps to evaluate the durability of ceramic tile coating:

1. Definition – User needs, building context, performance requirements and criteria and product characterisation are established.
2. Performance evaluation – After knowing the product characteristics we evaluate its initial performance by laboratory experimental tests.
3. Preparation – Possible degradation mechanisms, degradation factors, degradation indicators and suggest ageing tests.
4. Testing – Ageing tests both in short term and for longer periods are proposed.
5. Performance evaluation – Determine the performance of the aged product on the same characteristics evaluated before (3).
6. Predict service life – Verify that the degradation achieved is similar in both short term and for longer periods testing. If the behaviour under the effects of short term testing is similar to that observed in the longer term the results of the short term testing may be used to predict the service life.

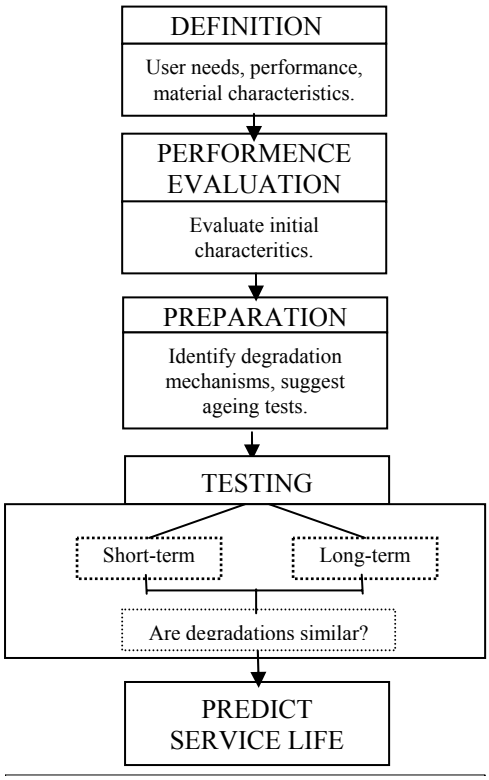


Figure 2. Systematic methodology for predicting the service life of ceramic tile coatings.

4 EXPERIMENTAL STUDY

4.1 Characteristics of the materials

Three different types of ceramic tiles were used in this experimental study. All three types are commonly used for external façade coatings in Portugal. With very distinct absorption coefficients, the ceramic tiles were called L0, L1 and L2. Table 1 and 2 summarises the main characteristics of the ceramic tiles in question.

Designation	*Group*[1]	*With x length* [mm^2]	*Thickness* [mm]
L0	BIa	50 x 50	5
L1	AI	50 x 50	5
L2	BIIa	50 x 50	10

Table 1. Dimensional characteristics of the ceramic tiles.

Designation	*Group*[1]	*Water absorption* [%]	*Flexural strength* [MPa]	*Abrasion resistance* [Mohs]	*Thermal expansion coefficient* [K^{-1}]
L0	BIa	0,02	≥ 27	≥ 6	$\leq 9x10^{-6}$
L1	AI	2,74	≥ 27	≥ 5	$\leq 9x10^{-6}$
L2	BIIa	5	≥ 18	≥ 6	$\leq 12x10^{-6}$

Table 2. Physical characteristics of the ceramic tiles.

The cementitious adhesives used in the study belong to the C2 and C2S classes, the only ones recommended for external application. Table 3 lists the main characteristics of cementitious adhesives.

Characteristics	*C2* [2] [MPa]	*C2S* [2] [MPa]
High initial tensile adhesion strength (after 3 days)	1	-
High initial tensile adhesion strength (after 28 days)	1,5	2
High tensile adhesion strength after heat ageing	1,0	1,5
High tensile adhesion strength after water immersion	0,5	1,0
High tensile adhesion strength after freeze-thaw cycles	-	1,0

Table 3. Characteristics of the cementitious adhesives used.

4.2 Samples Characterization

The tests were performed using 35 concrete slabs measuring 300x200x40mm. Three ceramic tiles were placed on each concrete slab according to the scheme in Figure 3. The 40mm-thick concrete slab, cementitious adhesive, class C2 or C2S, and three ceramic tiles, type L0, L1 or L2, comprise the sample [Fig.3].

[1] Ceramic tile' groups according to European standard EN 14441, *Ceramic tiles – Definitions, classification, characteristics and marketing*, 2003.
[2] Cementitious adhesives for tiles' classification – *Cahier du CSTB 3264*. October, 2000.

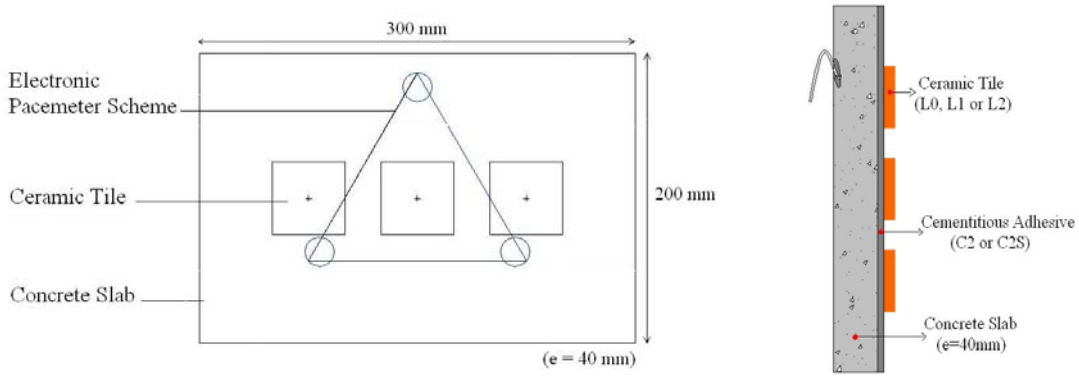


Figure 3. Ceramic tiles placement on the concrete slab.

Table 4 identifies the components comprising the samples prepared for this study.

Samples		*Cementitious adhesives*	
		C2	*C2S*
Tile	*L0*	PE0	-
	L1	PE1	PE2
	L2	PE3	PE4

Table 4. Characteristics of the cementitious adhesives used.

Seven samples were prepared for each type: PE0, PE1, PE2, PE3 and PE4. Each sample was subject to a different number of ageing cycles, varying from 1 to 112. Since one complete cycle lasts 12 hours, the conditioned time limit in the test chamber was of 2 months. Each sample consisted of three ceramic tiles. A total of 105 tiles were tested with a direct pull tensile force.

All samples were prepared under the supervision of a chemical engineer from the cimentitous adhesive manufacturer. We believe to have complied with the most adequate application process which, therefore, did not affect the service life.

4.3 Laboratory accelerated aging program

The accelerated aging program, conducted within an environmental test chamber, was established based on international standards: DS 1127, ASTM D 4798, ASTM E 632, ASTM G 26 and ASTM C481 and the following EOTA documents: Guidance Document GD 003 and Technical Report TR 010.

The established aging test has a total duration of 12 hours (720 minutes) and consists of the 9 steps summarised in Table 5.

Step	*Humidity* [%]	*Temperature* [ºC]	*Time* [min]	*Accumuleted Time* [min]	*Radiation/Rain*
1	95	20	1	1	
2	95	20	139	140	Rain – ON
3	95	20	30	170	Rain – OFF
4	60	-10	140	310	
5	60	-10	60	370	
6	95	50	180	550	
7	95	50	20	570	
8	40	30	140	710	Radiation – ON
9	40	30	10	720	Radiation – OFF

Table 5. Accelerated aging programme. Steps of a complete cycle.

4.4 Tensile adhesion strength tests

Tensile adhesion strength is the characteristic evaluated in this study that affects the performance of ceramic tile coating systems under investigation. To determine functional changes, each specimen type (PE0, PE1, PE2, PE3 e PE4) was analyzed before entering the environmental test chamber and at the end of the planned exposure times inside the chamber. The tensile adhesion strength tests were performed according to the test method described in European Standard EN 1348 (CEN, 1997).

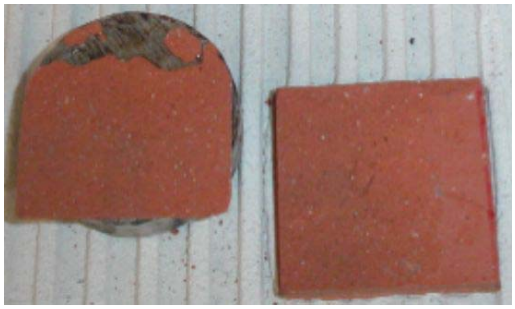
5 RESULTS

The tensile adhesion strength tests performed for type PE0 samples determined an adhesive failure in the interface between the ceramic tile and the cementitious adhesive [Fig. 4].

Figure 4 – Adhesive failure in the interface between the ceramic tile and the cementitious adhesive Sample PE0.

Cohesive failure was detected in the other tests, especially within the cementitious adhesive. However, in the tests of samples with cementitious adhesive type C2S and after 1 aging cycle, a cohesive failure was detected within the substrate [Fig.5 - PE4.1], and there was only one case where cohesive failure took place in the ceramic tile [Fig.5 - PE4.2].

Sample PE4 .1



Sample PE4.2

Figure 5 – Picture showing two different cohesive failure. Sample PE4.1 - Cohesive failure within the substrate; Sample PE4.2 - Cohesive failure within the ceramic tile.

The graphics in the next two figures show tensile adhesion strength according to the number of aging cycles. The results obtained so far show significant deterioration in tensile adhesion strength, although the critical level of tensile adhesion strength indicated as 0.3 MPa was not reached. Based on the average results, we can compute a tendency indicating the critical value under which the service life can be considered to have terminated.

The graphic in Figure 6 shows the tensile adhesion strength variation under the aging tests according to the number of cycles on specimen types PE0, PE1 and PE3. The tests results from these samples reveal three essential aspects:

1. Regardless of the cementitious adhesive type, about 140 cycles will lead to the end of ceramic tile coating's service life.

2. The failure type was greatly influenced by the type of ceramic tile used. Thus, the failure in the PE0 sample, consisting of ceramic tile with a low absorption coefficient (0.02%), belonged to the adhesive type. Consequently, the indicated values represent the cementitious adhesive adhesion. Nevertheless, the failure in the PE1 and PE3 samples (absorption coefficient > 0.5%) belonged to the cohesive type within the cementitious adhesive, and thus the attained values represent their tensile adhesion strength.
3. After 112 aging cycles we measured about 30% of the tensile adhesion strength's initial value.

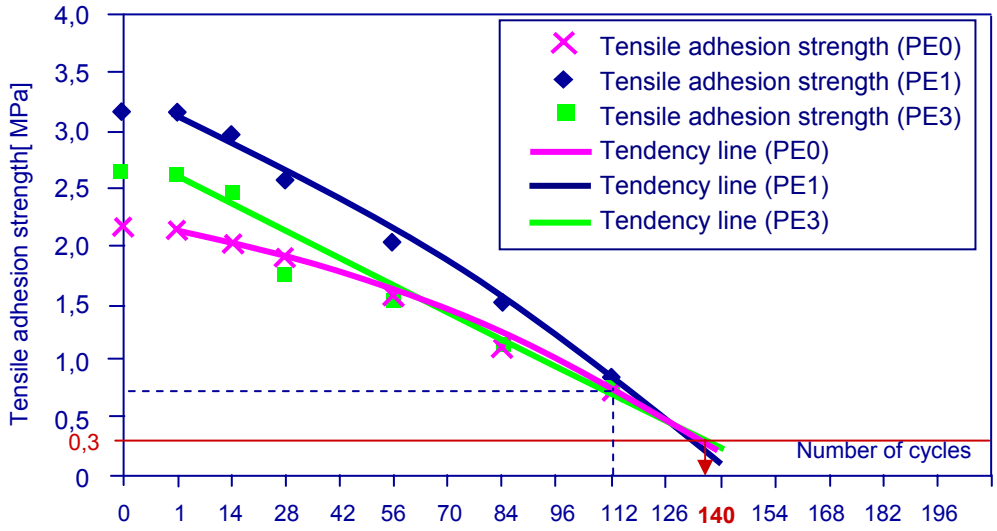


Figure 6 – Change in tensile adhesion strength during aging cycles – Samples PE0, PE1 and PE3 – Cementitious adhesive C2.

The graphic in Figure 7 shows the tensile adhesion strength variation caused by aging cycles according to the number of cycles imposed on specimen types PE2 and PE4. The graphic data reveals three different aspects about the samples consisting of cementitious adhesive type C2S that are worth noting:

1. The critical level was reached at the end of 210 aging cycles, thereby determining the end of the system's service life.
2. The tensile adhesion values of aging cycles 0 and 1 are very similar to the values of aging cycle 14. This can be explained by the observation, in the first case, of a cohesive-type failure within the substrate, whereas in the other situations the failure belonged to the cohesive type within the cementitious adhesive. Whereas cohesive failure within the substrate represents its tensile adhesion strength, the cohesive failure within the substrate indicates only that the cementitious adhesive's tensile adhesion strength is superior to the obtained value but does not indicate its exact value, which may be much higher.
3. After 112 aging cycles, measurements revealed about 50% of the initial tensile adhesion strength.

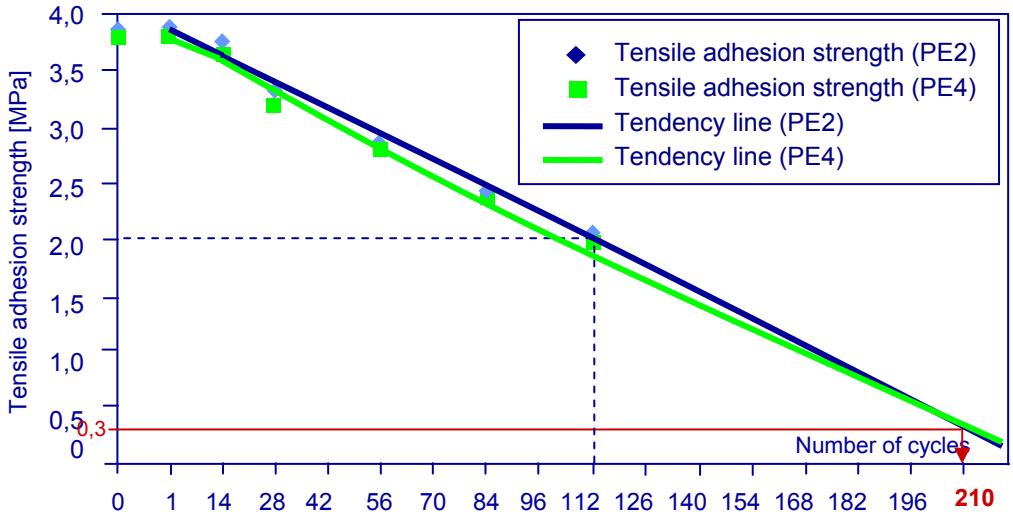


Figure 7 – Change in tensile adhesion strength during aging cycles – Samples PE2 and PE4 – Cementitious adhesive C2S.

6 CONCLUSIONS

The main conclusions are as follows:

1. The results show a substantial loss in tensile adhesion strength.
2. For the established critical value of 0.3 MPa, cementitious adhesives types C2 and C2S terminated their service life at 140 and 210 aging cycles, respectively.
3. The type of failure observed is strongly influenced by the type of ceramic tile used.
4. After 112 aging cycles, measurements indicated about 30% and 50% of the initial tensile adhesion strength for cementitious adhesive types C2 and C2S, respectively.
5. The accelerated aging test values will be compared, in the future, with values obtained from natural outdoor aging tests. The correlation between the results obtained from the two different methods will be necessary to determine the time re-scaling applied to determine the real service life of the ceramic tile coating.
6. The experimental data obtained so far will be very useful to establish an evaluation method to predict durability of cementitious adhesives in relation to the decreasing performance of the tensile adhesion strength and service life of all the coating systems.

7 REFERENCES

Freitas, Vasco Peixoto de; Sousa, Augusto Vaz Serra & Silva, J. A. Raimundo Mendes da; 2003, *Manual de Aplicação de Revestimentos Cerâmicos*, Coimbra.

Maggi, P.N.; Rejna, M.G.; Daniotti, B.; Cecconi, F. Re; Poli, T.; Rigamonti, G.; Jornet, A. & Teruzzi, T. 1999, 'Experimental program to evaluate building components service life: first results on brickwork', Eighth International Conference on Durability of Building Materials and Components 8 dbmc, Vancouver, Canada, May 30 – June 3, 1999, vol. 1, pp. 571-580.

Silva, D.A.; Roman, L.M.F.; Fredel, M.C. & Roman, H.R. 1999, 'Theoretical analysis of thermal stresses of ceramic tile coating systems', Eighth International Conference on Durability of Building Materials and Components 8 dbmc, Vancouver, Canada, May 30 – June 3, 1999, vol. 1, pp. 603-612.

Lucas, José A. Carvalho; 2001, *Anomalias em revestimentos cerâmicos colados*, ICT – ITMC 28. LNEC, Lisboa.

Sá, Ana Vaz; 2005, *Durabilidade de cimentos-cola em revestimentos cerâmicos aderentes a fachadas*, Dissertação de Mestrado em Construção de Edifícios. FEUP, Porto.