Characterization of ETICS surface properties with graffiti aerosol paint and its cleaning

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1 Introduction and objetives

ETICS (External Thermal Insulation Composite Systems) are innovative systems, initially developed to improve buildings thermal insulation, minimize thermal bridges and condensation problems, and increase building lifetime. This solution has been used in new construction as well as in the retrofitting of existing buildings, with the aim of solving problems such as lack of thermal insulation, water leakage on walls or facades aesthetic degradation (Amaro et al. 2013).

Buildings are currently often vandalized by graffiti, especially in urban environments with densely populations zones. Besides being an aesthetic anomaly and affecting the properties of the claddings systems (e.g. water vapour diffusion, wettability), graffiti are also associated to social housing decline and insecurity. In the last few years, cleaning methods have been used with new methods, based on mechanical and chemical new approaches, or even laser cleaning. However, these cleaning methods are still expensive and may induce chemical and physical damages to the surface properties (Moura et al. 2016).

In Portugal, in cities like Porto and Lisbon, ETICS were mostly applied in Social Housing, where bombing graffiti is commonly found. Therefore, the evaluation of the performance of ETICS applied in social housing and localized in urban environment is an interesting point to explore. New protective solutions and cleaning methods can be systematically studied and eventually validated.

This dissertation's objectives are: (i) to evaluate the effect of common graffiti paint sprays (ultramarine blue and silver) on the surface characteristics of 12 commercial ETICS; (ii) to evaluate and compare graffiti cleaning efficiency, through different cleaning methods, and the harmfulness in those ETICS, by analyzing their surface properties.

2 Materials and methods

2.1 Materials

Twelve different commercially available ETICS systems, supplied by different manufacturers, were tested. The identification and the composition of each system is presented in Table 1. The selected ETICS present three insulation materials: expanded polystyrene (EPS), insulation cork board (ICB) and mineral wool (MW). In what concerns the rendering system and more specifically the base coat, cement mortar or hydraulic lime with mineral fillers, resins and synthetic fibers were used. A key-coat composed of an acrylic paint (composed of acrylic co-polymer, mineral aggregate, organic additives and pigments) was preferentially used. Each specimen has a 5 cm x 5 cm surface area.

Table 1 – Identification and composition of ETICS' systems and their components

Systems					
1G	**2G**	**3G**	**4G**	**5G**	**6G**
Insulation					
EPS	EPS	EPS	ICB	ICB	EPS
Base Coat					
a) Mortar with glass fibre mesh b) Sanded mortar	Mortar with glass fibre mesh	Mortar with glass fibre mesh	Hydraulic lime	Hydraulic lime	Cement mortar
Key-Coat					
Primer					
Waterborne white paint	Waterborne textured paint	Waterborne textured paint	Aerial lime with a hydraulic binder	Acrylic aqueous dispersion	Acrylic aqueous dispersion
Acrylic Paint	a) Waterborne coating b) Acrylic Paint	Waterborne coating		Acrylic Paint	Acrylic Paint

The colours chosen for the application of the spray paint were Ultramarine Blue (RAL 5002) and Silver (RAL 7001), both from Montana Colours S.L. This choice was based on previous studies (Pozo-Antonio et al. 2018) (Rivas et al. 2012), reporting that these two colours present different response to cleaning processes. The cleaning methods used in this study were water cleaning with a nylon brush and cold water, water cleaning with a nylon brush and warm water, appliance of a chemical gel and hot water pressure jet.

Table 2 – Identification and composition of ETICS' systems and their components (cont.)

Systems					
7G	**8G**	**9G**	**10G**	**11G**	**12G**
Insulation					
EPS	MW	ICB	ICB	EPS	MW
Base Coat					
Cement mortar	Cement mortar	Mortar with aggregates of cork and hydraulic lime	Mortar with aggregates of cork and hydraulic lime	Cement mortar	Cement mortar
Key Coat					
Primer					
Acrylic aqueous dispersion	Acrylic aqueous dispersion	Acrylic aqueous primer	Anti-alkaline primer	Anti-alkaline primer	Anti-alkaline primer
Finishing					
Acrylic Paint	Acrylic Paint	Acrylic aqueous paint	Acrylic paint	Acrylic paint	Acrylic paint

2.2 Experimental methodology

ETICS samples were firstly referenced: in the identification, the first number indicated the type of ETICS (from 1 to 12 according to the different typologies), following a letter (G, that means graffiti) and the last number (from 1 to 18) is related to the specimen number in each ETICS. The last number starts at 10 because the specimen 1-9 are related to another master dissertation that is ongoing and approaches other surface features of the ETICS. Specimens from 10 to 12 correspond to the reference specimens, 13 to 15 the blue painted specimens and 16 to 18 the silver painted specimens

The graffiti spray paints were applied in agreement with the standard procedure from ASTM D7089 (ASTM 2014), i.e., spray paint was applied with a constant speed and at 15 cm distance from the specimen, with a 45º angle from the surface. After some preliminary tests, it was concluded that it was necessary to spray all the surface for 1 second to cover all the surface of the specimens and repeat this process 3 times and in 2 different directions. Following the recommendations of ASTM D6578 (ASTM 2018), after the application of the spray the specimens were left to dry at least 24 hours at room temperature, in order to ensure the polymerization and drying of the paint, before moving forward to new test. The specimens were stored in a climatic chamber with air temperature (~20ºC) and constant relative humidity (~65%), for 7 days.

After the application of the spray paint on the specimen and as presented in Figure 1, different tests were carried out to have an initial characterization of the surfaces: quantification of colour parameters, measurement of specular gloss, image analyses of the surface and surface roughness (surface texture and surface roughness with a profilometer). Cleaning procedures with a specific sequence were then carried out, based on the standard procedure from ASTM D7089 (ASTM 2014), information in the technical specifications of the products (cleaning products) and a previous study (Moura 2014), composed of a maximum of 5 cleaning steps (Figure 1):

1- Water cleaning, with a nylon brush in cold water;
2- Water cleaning, with a nylon brush in warm water (40ºC);
3- Chemical removal cleaning, followed by a warm water cleaning (40ºC) with nylon brush;
4- A further chemical removal cleaning followed by a warm water cleaning (40ºC) with nylon brush or a warm water (40ºC) jet cleaning.

It is important to mention that a further cleaning option was only used if the result in a current phase was considered unsatisfactory. Between each cleaning phase, colour, gloss and digital surface image acquisition were performed. After the last cleaning phase, the five initial tests were measured again (colour, specular gloss, digital surface image, surface texture and surface roughness with profilometer).

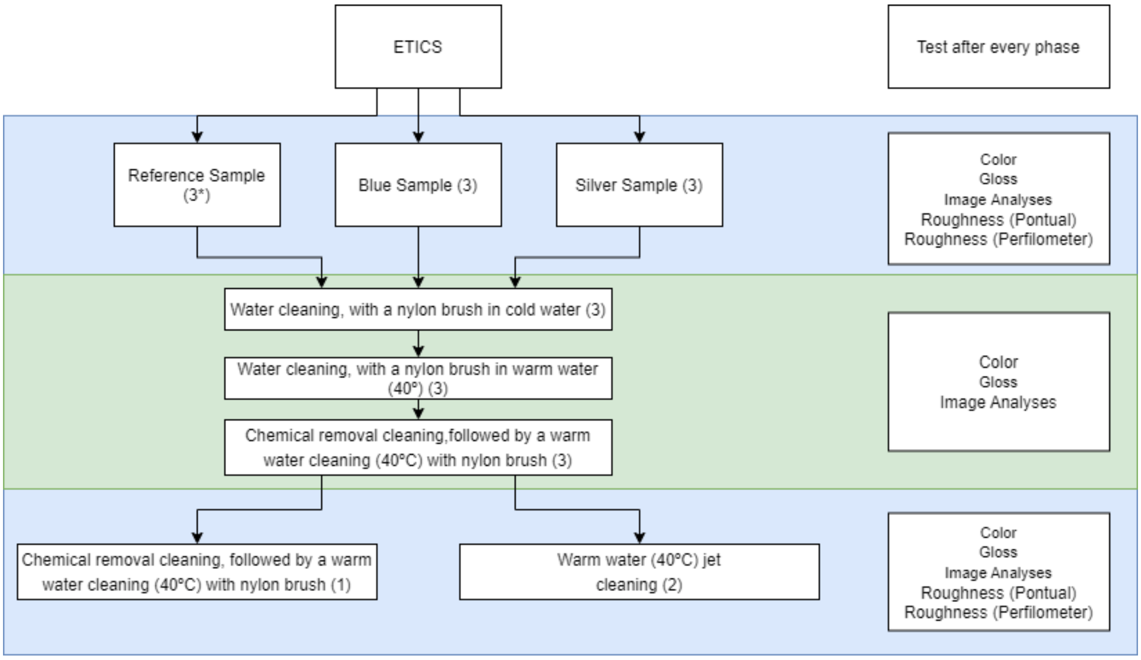

Figure 1 – Experimental design.

A colorimeter MINOLTA CR-410 Chroma Meter was used to evaluate colour, adopting the 3 coordinates (L*, a*, b*) of the CIELAB system. The L* gives the Luminosity value, that can range 0 (black) to 100 (white); the a* and b* values represent the chromatic coordinates of red-green (+a* is red and -a* green); and of yellow-blue (+b* is yellow and -b* blue). The Chroma or colour saturation (C*) can be calculated from the a* and b* values on equation 3.1:

$$C = \sqrt{a^2 + b^2} \tag{3.1}$$

To calculate de total variation of colour (ΔE_{ab}*), equation 3.2 was used (Mokrzycki and Tatol 2011), with four measures for each specimen, one in each quadrant:

$$\Delta E_{ab}{}^{*} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{3.2}$$

This method is more trustworthy than the visual observation, which is subjective and, therefore, not measurable in absolute terms. The colorimeter was already used in other studies of construction material, as in the case of stone or mortar (Carmona-Quiroga 2010; Gomes 2017; Moura et al. 2016).

The specular gloss measurement was made following the ASTM D6578 (ASTM 2018), i.e., measuring and recording initial 60° gloss on coated test specimen, which is, the beam angle emitted by the equipment with vertical axis. Three measures for each specimen were carried out.

The acquisition of the surface image test had two phases: the first is the surface digitalization, followed by the image processing, using digital tools. To determinate the cleaning area after every cleaning phase, the software GIMP® on the images was used to image processing and analysis.

An Elcometer 223 roughness meter was used to evaluate the surface texture. This equipment measures the surface roughness with a 2mm resolution and a graduated scale of 0.001 mm. In every specimen 9 measures (using a 3x3 holes mask, with 5 mm diameter holes) were carried out. These measures were registered when the pointer stabilized. The mean value and the standard deviation of the nine measure values of the specimen were calculated.

The roughness test with the profilometer was done with the Surfecoder SE 1200, composed by a pointer with a diamond coupled directly to a linear variable differential transformer. This test returns several parameters, and it was chosen to work with Ra and Rz, following the methodology of other authors (Carvalhão and Dionísio 2015). Ra is the arithmetic mean deviation of the roughness profile and Rz is the mean value of roughness depth of five consecutive sampling lengths. A scan length (le) of 25 mm was used and the parameters were measured in duplicated for each specimen at two different specimen points.

3 Results and discussion

3.1 Initial characterization

In the reference samples (without spray paint application), samples 4G and 9G significantly differ from the other samples, with different values of gloss, texture and roughness. These samples have higher values of gloss and lower values of roughness and texture.

After the application of the blue spray paint, all ETICS surfaces present similar colour, i.e., no system that has a $\Delta E_{ab}^*>5$ in comparison with the other systems. After application of the silver spray paint, 3 systems, 1G, 2G and 9G, differentiate from the other, with more luminosity ($\Delta L^*>7$). The systems 1G and 2G have a very similar composition, with the same finishing paint coat (acrylic paint) and 9G is the only system with silicate paint. These 3 systems have similar colour values.

Evaluating the specular gloss results before the application of the aerosol graffiti paints, it was observed that samples 1G and 2G have the same mean gloss values and standard deviation values. Samples 6G, 7G and 8G, that have the same composition, also have the same gloss and standard deviation values. There are two systems with gloss values higher than the others: 4G and 9G, both presenting different finishing coats when compared to other systems. The finishing coat of 4G is composed of aerial lime and in the 9G of a silicate paint.

After the application of the blue paint, samples 1G, 4G and 9G drastically increased their gloss values (1G and 2G with an increase of 130% and 9G with 530%). This increase can be associated to the lowest texture of these systems or it can be related to the interaction of the paint with the coat. In silver painted samples, a similar behavior was registered: samples 1G and 9G drastically increased their gloss values. Sample 2G, with same finishing coat as 1G, had an increase of 12GU, a very different variation compared with the other systems.

Analyzing the surface texture, it can be highlighted that samples 1G, 4G and 9G presented lower values than the rest of the systems (0.500 mm compared to 0.850 mm). Samples 5G, 6G, 7G and

8G, which have a similar finishing coat, have similar surface texture values (0.873mm ± 10%). After the paint application, all ETICS samples decreased their surface roughness values. Similar trend was observed when evaluating the roughness with the profilometer: systems 1G, 4G and 9G presented the lowest Ra and Rz values lower. Moreover, the application of the blue paint resulted in a general decrease of the Ra and Rz values (an average decrease of 10% in Ra and 27% in Rz) for the sample 6G, this also happens in the silver paint with an average decrease of 14,7% in Ra and 17,2% in Rz.

3.2 Efficiency and harmfulness of the cleaning processes

The first phase of cleaning, cold water and nylon brush, did not promote significant macroscopically changes in the surface properties (either the reference, either the painted ones). Nevertheless, some total colour variations were registered. In the reference and silver samples, those variations are mainly caused by a decrease of the luminosity. In terms of specular gloss, the only significant variation of value was registered in 1G and 9G silver samples.

After warm water and nylon brush application, the samples with the biggest colour variation were the silver paint samples, and this variation was also associated to luminosity (Table 2). Systems 4G and 9G can be highlighted by their average ΔE_{ab}* of 9 and 12.54, respectively. In what concerns reference samples, a luminosity increase was registered and is reflected on a ΔE_{ab}*>5 in every ETICS sample studied. The other proprieties (specular gloss, texture and roughness) did not have a significant variation.

Table 2 – Colour variation (L*, a*, b* and Chroma) and total colour variation (**ΔE_{ab}***) after cleaning with chemical removal, comparing with the reference samples (initial characterization).

	Reference					**Blue**					**Silver**				
	ΔL*	**Δa***	**Δb***	**ΔE_{ab}***	**C***	**ΔL***	**Δa***	**Δb***	**ΔE_{ab}***	**C***	**ΔL***	**Δa***	**Δb***	**ΔE_{ab}***	**C***
1G	7,18	-0,08	-1,23	**7,28**	0,91	-41,38	4,63	-19,90	**46,15**	19,27	-11,96	-0,35	-3,02	**12,34**	1,31
2G	4,19	-0,23	1,77	**4,56**	3,08	-21,90	0,70	-5,78	**22,66**	5,11	-14,47	-0,25	-1,45	**14,54**	0,85
3G	7,57	-0,24	0,02	**7,57**	4,27	-22,50	0,89	-9,85	**24,58**	5,88	-12,03	-0,29	-4,07	**12,70**	0,96
4G	6,87	-0,05	0,62	**6,89**	4,26	-25,16	1,06	-15,58	**29,61**	11,76	-4,09	-0,74	2,68	**4,95**	6,32
5G	9,70	-0,32	0,61	**9,72**	4,57	-21,15	0,60	-12,42	**24,54**	8,72	-6,45	-1,09	-3,17	**7,27**	1,21
6G	1,64	0,04	0,52	**1,72**	4,29	-25,33	0,62	-10,43	**27,40**	7,06	-14,49	-0,57	-3,22	**14,86**	1,10
7G	3,34	0,10	-0,51	**3,38**	3,25	-33,07	2,37	-16,44	**37,01**	13,55	-15,66	-0,49	-4,27	**16,24**	1,08
8G	4,90	0,18	-0,67	**4,95**	4,17	-24,47	0,84	-11,07	**26,87**	7,68	-8,92	-0,24	-3,63	**9,64**	1,26
9G	0,05	0,21	0,71	**0,74**	2,44	-25,85	1,94	-12,48	**28,77**	10,98	-7,42	-0,07	-0,65	**7,45**	1,62
10G	2,53	0,03	0,83	**2,66**	4,91	-31,14	1,82	-16,96	**35,50**	13,23	-13,41	-0,88	-3,84	**13,98**	0,66
11G	1,75	0,05	0,93	**1,98**	5,09	-35,40	2,27	-17,17	**39,41**	13,45	-18,39	-0,58	-4,82	**19,02**	0,73
12G	3,02	0,18	0,58	**3,08**	5,54	-31,73	1,18	-13,76	**34,60**	9,72	-17,11	-0,46	-4,12	**17,60**	1,05

Nevertheless, after macroscopically analyzes, it seems that the chemical agent can be very harmful for the insulation layer, mainly in the ETICS with EPS thermal insulation. In fact, if the product enters in contact with the EPS, it chemically reacts (possibly due to its high pH) and could even destroy the structure of the expanded polystyrene (Figure 2 a). This result can be relevant in a real situation, when an applied ETICS with some microcracks/fissures is cleaned with this chemical removal; a damage of the insulation system can occur and compromise the performance of this type of ETICS.

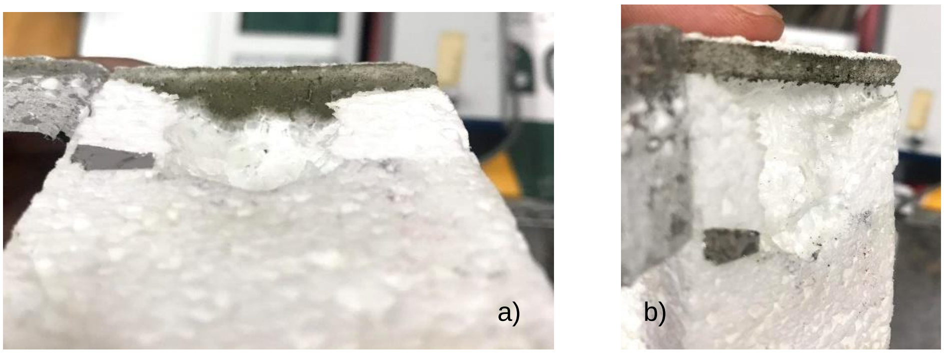

Figure 2 – Damage in th EPS caused by the chemical cleaning of the system 6G.

In general, the chemical removal had a better result than the warm jet removal (Table 3). The blue sample had a noticeably different colour variation, when compared to the reference sample (the mean of ΔE_{ab}^* is 32.20 units). The silver samples had a better result than the blue one, however, all the samples did not have an acceptable result, except for 4G, 5G 8G and 9G systems.

Table 3 – Colour variation (L*, a*, b* and Chroma) and total colour variation (**ΔE_{ab}^***) after cleaning with warm water jet cleaning, comparing with the reference samples in the initial characterization.

	Reference					**Blue**					**Silver**				
	ΔL*	**Δa***	**Δb***	**ΔE_{ab}^***	**C***	**ΔL***	**Δa***	**Δb***	**ΔE_{ab}^***	**C***	**ΔL***	**Δa***	**Δb***	**ΔE_{ab}^***	**C***
1G	6,25	-0,05	-0,87	**6,31**	1,26	-16,31	1,76	-13,48	**21,24**	11,61	-15,08	-0,09	-3,41	**15,47**	1,33
2G	3,92	-0,36	1,79	**4,32**	3,13	-28,73	3,32	-11,92	**31,28***	11,07	-11,22	-0,32	0,59	**11,24***	1,97
3G	6,62	-0,32	-0,90	**6,69**	3,38	-16,89	1,52	-9,69	**19,53***	5,60	-9,94	-0,25	-3,51	**10,54***	0,95
4G	5,07	-0,26	3,65	**6,25**	7,28	-3,29	0,17	-1,48	**3,61***	3,01	3,26	-0,64	6,62	**7,41***	10,25
5G	8,80	-0,31	0,68	**8,84**	4,64	-13,79	0,67	-10,16	**17,14**	6,39	-9,94	-1,08	-4,18	**10,84**	0,42
6G	5,79	-0,03	0,89	**5,86**	4,66	-23,10	1,69	-12,25	**26,21**	8,73	-16,46	-0,58	-4,36	**17,03**	0,67
7G	6,66	-0,12	-0,34	**6,66**	3,41	-32,35	3,08	-18,36	**37,32**	14,95	-15,37	-0,46	-4,88	**16,13**	1,19
8G	6,11	0,22	-0,05	**6,12**	4,79	-24,37	1,90	-13,57	**27,96**	8,96	-15,96	-0,37	-5,40	**16,85**	0,66
9G	6,10	-0,22	-0,35	**6,12**	1,36	-32,06	3,54	-13,89	**35,12***	12,74	-17,74	-0,39	-2,73	**17,95***	1,08
10G	5,72	-0,16	0,92	**5,79**	4,98	-25,71	1,69	-12,52	**28,65**	8,77	-14,67	-0,82	-4,63	**15,40**	0,63
11G	4,04	0,01	0,92	**4,14**	5,08	-30,07	2,12	-13,48	**33,02**	9,64	-13,00	-0,50	-3,10	**13,38**	1,11
12G	4,44	0,23	0,55	**4,48**	5,51	-28,07	1,86	-13,86	**31,36**	9,18	-15,18	-0,57	-4,43	**15,83**	0,66

In terms of specular gloss, all samples (reference, blue and silver) had an acceptable result, after chemical cleaning, i.e., gloss variations are lower than 3GU when compared to those of the reference samples (before cleaning). Based on an estimation of the cleaning area through digital image analysis, it was possible to verify that for blue samples a value higher than 50% was achieved; however, these values are far from what can be considered as acceptable. In the silver samples the only systems that had an acceptable result are 4G and 9G systems, with a 95% cleaning area (Figure 3 a) and b)).

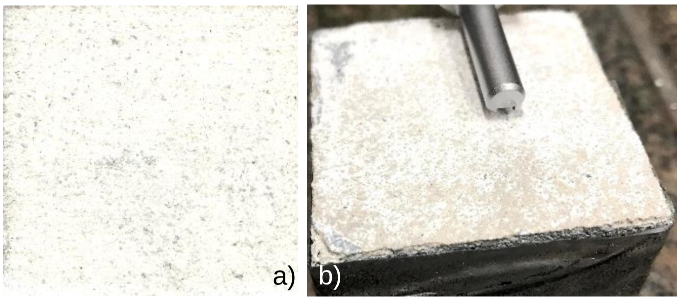

Figure 3 – Images showing the result of the 4G (a)) and 9G (b)) silver samples after cleaning with the chemical removal.

After chemical removal, only samples 5G, 6G and 9G changed their values in terms of surface texture. The only system that had a similar result as in the blue samples is the 5G. Systems 1G, 2G, 3G (systems with a very similar constitution) also have a variation in the blue samples, as well as 7G, that has a similar constitution as the 5G. Furthermore, in the silver samples, 1G, 2G, 4G, 7G and 9G samples also had a variation. Concerning, the measurement of the surface roughness with profilometer, only the reference systems 2G and 9G restored their (pre-cleaning) initial values. In the blue sample, samples 3G, 4G and 9G restored the initial Ra and Rz values. Finally, in the silver samples, the systems that restored the values were 3G, 6G, 8G and 12G.

Cleaning with warm water jet induce a relevant damage the surface of this type of ETICS. In fact, this cleaning method, although allowing the graffiti spray paint to be removed, also damage part of the ETICS key coat, as can be observed in Figure 4 a) and b).

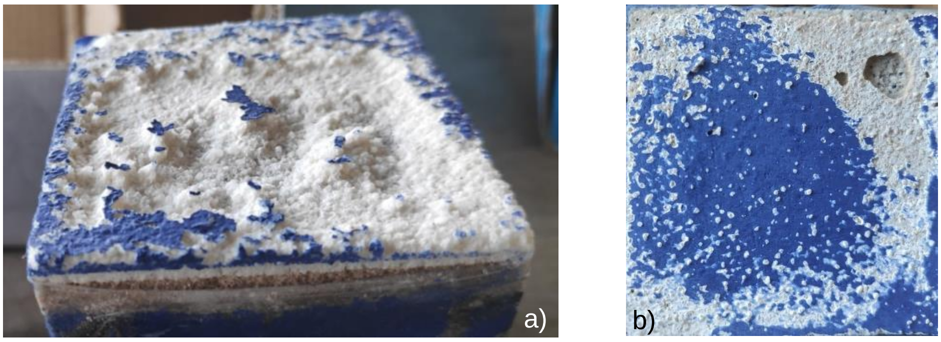

Figure 4 – Damage on the surfaces after graffiti cleaning with warm water jet: a) surface in the 4G and b) 9G blue samples.

Evaluating results after warm water jet, it can be concluded that most of the samples are far from acceptable in term of colour (Table 3), with the only exception in the 4G silver sample (which, however, presents a severely damaged surface). This type of removal damaged the surface of several samples: in the blue ones, only samples 2G, 3G, 4G e 9G; in the silver sample, 2G, 3G, 4G, 8G and 11G.

Analyzing the specular gloss, a similar result was achieved as with the chemical removal, i.e., samples restore their initial gloss. In terms of cleaning area percentage, in what concerns blue samples, in 11 systems a cleaning percentage higher than 55% was achieved. Analyzing the result of the silver sample more unsatisfactory results were attained, with values lower than 20%, for most of the systems. For silver samples, the 4G system had a 100% cleaning area but the sample had been severely damaged.

Evaluating the texture, only system 1G changed his value in every sample (reference, blue and silver) and does not have damages in its surface. In the blue samples, the other systems that had a variation in its texture were 2G and 3G (both considered damaged samples). In the silver samples, apart from 1G, only system 9G changed their texture and did not have a damaged surface.

Finally, concerning the roughness with profilometer, in the blue samples, 5G sample restore its initial Ra and Rz values. In the silver samples, system 5G also restore its initial values as well as 1G sample.

4 Conclusions

After the initial characterization, one can concludes that graffiti changes some of the surface properties, namely surface roughness, beside colour and specular gloss. Analyzing the reference samples, two groups of systems can be identified. The first group includes the samples (1G, 4G and 9G) with less surface roughness and glossier than the others. Systems 4G and 9G also have a finishing coat (aerial lime for 4G, silicate paint for 9G) which differs from the other systems. The application of the graffiti aerosol paint induced a decrease of ETICS surface roughness, and an increase in the specular gloss was observed in all silver paint samples.

Concerning the cleaning procedures, it can be concluded the first two steps (brushing with cold water and brushing with warm water) were ineffective and did not removed the graffiti paint. Also, it is worth noting that the warm jet cleaning is a significantly harmful method to the ETICS surface. In general, ETICS are systems extremely susceptible to the action of the cleaning agents. Chemical cleaning is not compatible and thus not recommended in the case of ETICS with EPS thermal insulation, since it can heavily degrade the EPS.

The cleaning method with warm water jet also damages the ETICS surfaces. Hence, one can conclude that the warm water jet is not appropriate to remove the graffiti from the ETICS. With that been said, the type of graffiti that had the better cleaning percentage is the 4G silver sample, however, presenting also severe damages in the surface. Excluding the damaged samples, the only type of ETICS that had a variation in its texture is the sample 1G, however, at the same time its initial Ra and Rz roughness values are restored at the end of the cleaning actions.

The cleaning with a chemical removal had a better result in the cleaning percentage than the warm water jet (either way, far from desired values). Only 4G and 9G silver samples had an acceptable result. Analyzing the colour variation, it can be seen the same results, the only two samples that had a $\Delta E<5$, comparing with the reference samples before painting, are the 4G and 9G silver samples. Also, in the colour variation analysis, the reference samples prove that the chemical product will modify the colour of the adjacent walls.

Additionally, all the systems restore their initial gloss and the texture (in this case, no significant change of their initial values along the cleaning methodology).

9G silver present also a variation of texture, however, opposite results were obtained in the roughness with a profilometer, being was one of the very few samples to restore the Ra and Rz values.

It can be concluded that only 4G and 9G silver samples, although having different finishing coats, provide satisfactory results, with a reasonably efficient graffiti removal and respect of their surface properties.

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