Waterproofing geomembranes life expectancy: effect of a pigmented coating

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ABSTRACT: In a waterproofing system, the geomembrane provides the barrier function, so, its durability is very important in the performance of the complete system. It is known that plasticized polyvinyl chloride (PVC-P), as other thermoplastic materials, is affected by the weathering conditions, especially when it is exposed to the environment. This is the case in most of the hydraulic works. Sun radiation and mainly the UV part of the spectrum are the principal responsible of the PVC-P degradation. The addition of a pigmented coating on the geomembrane acts as a protective layer against UV radiation and reduces plasticizer loss. As such, the coating increases the durability of the PVC-P geomembrane.

This paper explains and documents how the pigmented coating provides that protection and increases the expectancy of life. Weathering tests like EMMAQUA or studies in the Weather-O-meter were used in order to evaluate the performance of the coating. Microscopic examination provides the information to confirm coating durability and, by extension, the increase of geomembrane life.

Keywords: Waterproofing, geomembrane, life expectancy, coating.

1 INTRODUCTION

Throughout history, human beings have searched for the way to ‘manage’ the water in function of their necessities and to protect themselves from it. Nevertheless, water is very difficult to control. On one side, it is necessary to collect and accumulate it and on the other side, to isolate us from it.
Therefore, since long ago, waterproofing materials have been used for these purposes. Firstly, the ones that were found in nature, like bitumen, and lately, with the science development, the synthetic materials.
However, synthetic materials are organic too and they are affected by the exposition to the environment (Crespo, 2011). They will suffer ageing processes in function of the weathering conditions. Such degradation determinates the durability of the material (Hsuan et al. 2008). PVC-P, as others of the materials known as thermoplastics, is used widely as a waterproofing geomembrane in various applications like roofing, reservoirs, dams, canals, etc.
In a waterproofing system, the geomembrane provides the barrier function, so, its durability is very important in the performance of the complete system. In exposed applications, sun radiation and mainly the UV part of the spectrum is the principal responsible of the PVC-P degradation. So, adding to the geomembrane something that could delay that process, will help to increase its service life.
The complete electromagnetic spectrum in function of frequency and wavelength is shown in Figure 1.

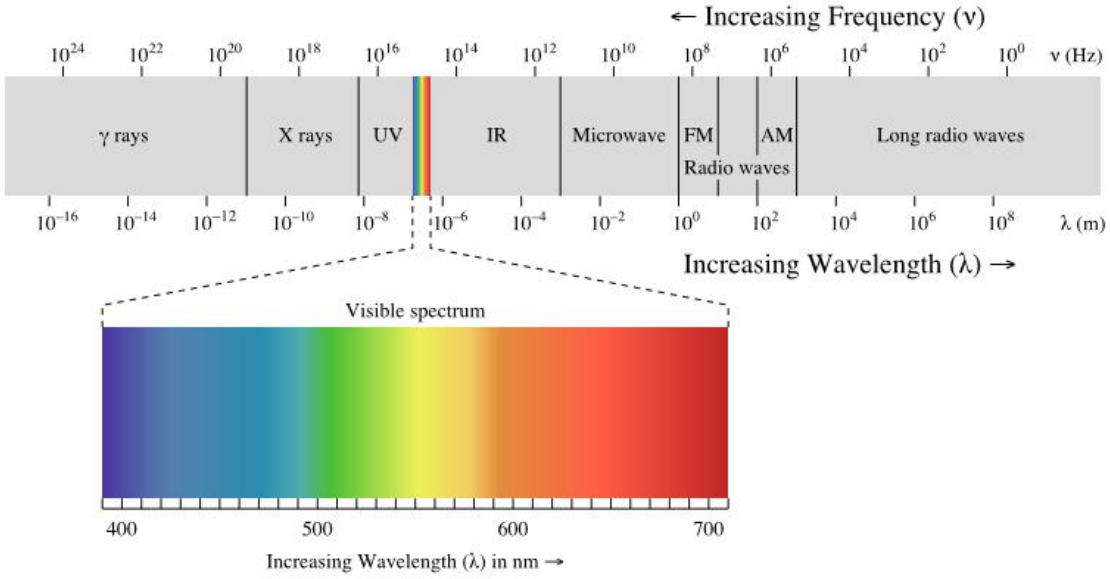

Figure 1. Electromagnetic spectrum in function of frequency and wavelength.

Sun's energy is divided in three regions in function of their decreasing wavelengths, Infrared (1mm -760 nm), Visible (760-380 nm) and Ultraviolet (380-100 nm). Due to the absorption by the atmosphere of mainly all UV radiation, UV- C (280-100 nm) and UV-B (315-280 nm) ranges; only the UV-A (380-315 nm) radiation reaches the earth's surface. However, the damage caused by it in organic materials is significant.
The amount of solar energy present near the surface is affected by factors such as time variation, cloud cover, and of course, geography; we all know that areas that are closer to the equator have a greater amount of solar radiation (Liley & McKenzie 2006). That is the reason why we consider some differentiated regions when we study the materials' ageing.

2 DURABILITY. EFFECT OF THE THICKNESS

Organic materials' degradation with time is a fact that cannot be avoided completely, but we can work on the materials' composition to increase their lifetime delaying their ageing.
Through the years, durability studies are focused on knowing which degradation processes affect more the materials' ageing.
The principal responsible of plasticized polyvinyl chloride (PVC-P) degradation are UV radiation and plasticizer loss. Furthermore, oxidation and temperature can affect the degradation too.
For this reason the main point of the actual durability studies are focused to find the improvements in the geomembrane composition what could delay that ageing processes.
A Natural Ageing study has been performed during 10 years (2004-2014), where 100 samples, in different groups, were studied. The test was carried out in the experimental fields that ATLAS Company has in the locations of Arizona (AR) and Florida (FL), which are the reference environments due to their special weathering conditions in respect to solar irradiance, temperature and moisture, which are the most critical weathering variables for materials' ageing.
Specific conditions, presented below, were provided by ATLAS Company after the 10 years of exposure test.
NATURAL AGEING IN FLORIDA:
Test Type: INLAND WEATHERING
Test Location: Miami, Florida (26°N)
Test Method: ASTM G147 – 2009, ASTM G7 – 2013
Exposure Type: Exposure testing is performed in Miami, FL (26°N) in accordance with Governing Standards at a tilt angle of 45° from the horizontal, facing south. The specimens are mounted unbacked on a continuous exposure rack, with grass ground cover, and the uncoded side facing the sun.

Exposure Type: DIRECT 45 DEG SOUTH, OPEN BACKING
Radiant Energy: 62,606 MJ/m² (Total); 1,496,319 Langleys, UV: 2,955 MJ/m² (295-385 nm)
Exposure Period: 6/17/2004 - 6/17/2014
Observations, Deviations and Waivers:
Exposure for this test was extended for an 3 additional years on 05/11/11.
Radiation reported for this test is adjusted to compensate for hurricane preparations performed in September 2004. All specimens were moved to our new AWSG Miami, Florida exposure site on 02/24/07.
NATURAL AGEING IN ARIZONA:
Test Type: DESERT WEATHERING
Test Location: New River, Arizona
Test Method: ASTM G147 – 2009, ASTM G7 - 2013
Exposure Type: Exposure testing is performed in New River, AZ (34°N) in accordance with Governing Standards at a tilt angle of 45° from the horizontal, facing south. The specimens are mounted unbacked on a 1643 x 3586 mm aluminium exposure rack, with gravel ground cover, and the uncoded side facing the sun.
Exposure Type: DIRECT 45 DEG SOUTH, OPEN BACKING
Radiant Energy: 82,280 MJ/m² (Total); 1,966,539 Langleys, UV: 3,474 MJ/m² (295-385 nm)
Exposure Period: 6/13/2004 - 6/17/2014
One particular group samples was sent to know the effect of increase of the thickness of the geomembrane on the durability:
Studied samples are light grey geomembranes (code 71004) with Central Europe formulation (code 35176) in four different thickness: 1.2 mm, 1.5 mm, 1.8 mm and 2.0 mm (Identification, increasing thickness: PVA705, PVA774, PVA707, PVA708)
Samples were sent to Arizona and Florida mounted on aluminium plates, 5 of each type, and returned, without cleaning or evaluation, at 3, 4, 5, 6 and 10 years of exposure, respectively. Evaluations were made in the Renolit laboratories of Oudenaarde, Belgium and Sant Celoni (Barcelona), Spain.
Soiling, weight loss, surface cracking and cold foldability are the evaluation criteria.

- *Soiling*

After 10 years of exposure, Florida samples presented a big amount of dirt, with dark sand and grey stains in top and central areas. Arizona samples were covered by a red sand.
These differences in soiling before cleaning the samples can be appreciated in the left image of Figure 2, while in right image one can observe the samples after cleaning with a sponge and demineralized water.

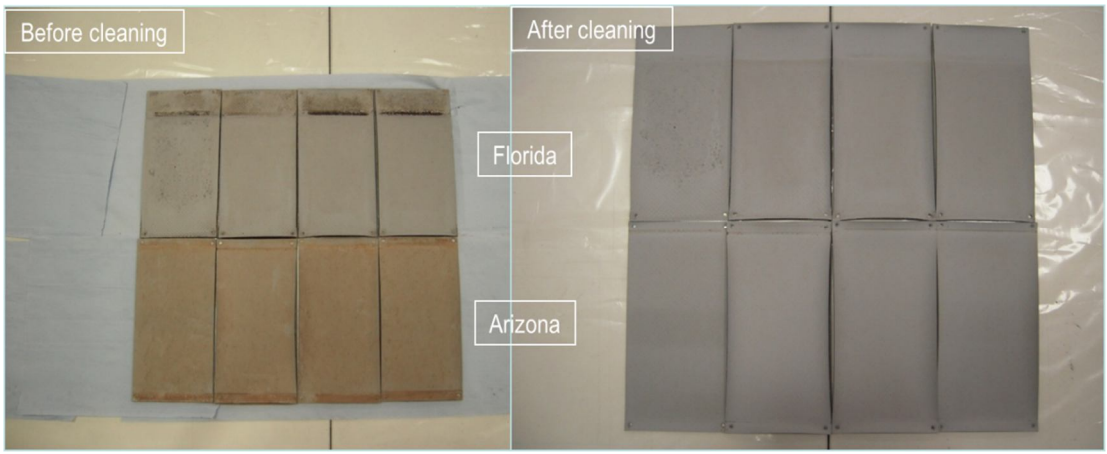

Figure 2. Florida and Arizona samples after 10 years of exposure, before and after cleaning.

- *Weight loss*

Weight loss of all samples was collected in table 1. It can be seen how Florida samples lost almost the double of weight than Arizona ones lost. This fact indicates that moisture present in Florida is an important variable to take into account for the geomembranes ageing in these types of locations.

Table 1. Florida and Arizona samples after 10 years of exposure, before and after cleaning.

Weight Loss, %	ARIZONA				FLORIDA			
YEARS	T35176 71004 **1.2mm** (PVA705)	T35176 71004 **1.5mm** (PVA774)	T35176 71004 **1.8mm** (PVA707)	T35176 71004 **2.0mm** (PVA708)	T35176 71004 **1.2mm** (PVA705)	T35176 71004 **1.5mm** (PVA774)	T35176 71004 **1.8mm** (PVA707)	T35176 71004 **2.0mm** (PVA708)
0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	-1,40	-1,23	-0,90	-0,93	-4,82	-3,33	-3,37	-3,44
4	-2,00	-1,67	-1,28	-1,18	-6,23	-4,50	-4,24	-4,48
5	-2,67	-2,11	-1,57	-1,63	-7,46	-5,57	-5,34	-5,36
6	-3,22	-3,62	-2,15	-2,04	-8,20	-6,58	-6,31	-6,09
10	-5,84	-4,69	-4,38	-3,87	-10,20	-8,07	-7,72	-7,20

- *Surface cracking*

When exposed, PVC-P samples suffer cracks in their surface as effect of the sun radiation and plasticizers loss. In table 2 surface cracking of Arizona and Florida samples was expressed in a numerical classification, being number 1 the case of a geomembrane with no cracks and number 10 a membrane that is completely degraded. Can be observed how Arizona samples suffer a higher surface degradation than Florida ones, especially 1.2 mm thickness sample, so Arizona dry climate is more aggressive with the geomembrane surface.

Table 2. Surface cracking of Arizona and Florida samples at 10 years of exposure.

Cracks	ARIZONA				FLORIDA			
YEARS	T35176 71004 **1.2mm** (PVA705)	T35176 71004 **1.5mm** (PVA774)	T35176 71004 **1.8mm** (PVA707)	T35176 71004 **2.0mm** (PVA708)	T35176 71004 **1.2mm** (PVA705)	T35176 71004 **1.5mm** (PVA774)	T35176 71004 **1.8mm** (PVA707)	T35176 71004 **2.0mm** (PVA708)
10	6	5	5	5	4	4	4	4

- *Cold foldability*

The cold foldability test (UNE-EN 495-5. 2013) is a good measure for the material's fragility and indicates the state of material's degradation (Blanco et al. 2012). It shows too that thicker geomembranes maintain their properties in a better state than the thinner ones after 10 years of exposure. Samples of 2,0 mm have passed the cold foldability test at only 5 ºC less than in the test before the exposure, while 1,2 mm samples have passed the test at 15-20 ºC less of the initial test. Moreover, the temperature difference in Arizona samples is bigger in most cases. Therefore, this test result indicates that surface cracking has a higher influence in the material's ageing than weight loss. Table 3 collect all the results.

Table 3. Cold foldability Arizona and Florida samples after 10 years of exposure.

Cold foldability, ºC	ARIZONA				FLORIDA			
YEARS	T35176 71004 **1.2mm** (PVA705)	T35176 71004 **1.5mm** (PVA774)	T35176 71004 **1.8mm** (PVA707)	T35176 71004 **2.0mm** (PVA708)	T35176 71004 **1.2mm** (PVA705)	T35176 71004 **1.5mm** (PVA774)	T35176 71004 **1.8mm** (PVA707)	T35176 71004 **2.0mm** (PVA708)
0	-30,00	-30,00	-25,00	-25,00	-30,00	-30,00	-25,00	-25,00
3	-20,00	-15,00	-20,00	-25,00	-20,00	-20,00	-20,00	-25,00
4	-15,00	-10,00	-15,00	-20,00	-15,00	-15,00	-20,00	-25,00
5	-10,00	-15,00	-15,00	-20,00	-10,00	-15,00	-20,00	-20,00
6	-15,00	-15,00	-15,00	-20,00	-15,00	-15,00	-20,00	-20,00
10	-10,00	-15,00	-15,00	-20,00	-15,00	-15,00	-20,00	-20,00
DCF ºC	**20**	**15**	**10**	**5**	**15**	**15**	**5**	**5**

The combination of these groups of test results that evaluate the state of the samples after the natural exposure in Arizona and Florida, indicates that a higher thickness provides a better performance with time to the geo membrane.
Nevertheless, it is not possible to increase the thickness without taking in account some other considerations. One of the most important characteristics or requirements for the use of these synthetic geomembranes is to have a low weight. A very thick membranes could have an excessive weight that makes the geomembrane more difficult to manufacture, transport, install and being supported during its service life (Cazzuffi 2014). Increasing the thickness to several millimetres is possible but must be well studied by technicians in every particular case.

3 COATING: BARRIER EFFECT

A coating (acrylic based coating) acts as a barrier between PVC-P geomembrane and the exterior environment, against UV radiation, against plasticizer loss and against microorganisms.
Various studies were made to confirm the favorable effect of the coating to the geomembrane:
Humid/dry sand burial test, active soil burial test and accelerated UV ageing with xenon lamp.

3.1 *Humid/dry sand burial test*

Burial test in sand show the barrier effect of a coating against plasticizer loss when the geomembrane is in contact with humid and dry sand.
The study evaluates the weight loss of 6 samples with different formulation with and without coating, buried alternatively each 50 days in dry and humid sand (cycle 100 days) during 3 years.
Samples are placed vertically and fully buried in the sand.
Formulations:
Sample 1 = Light grey, plasticizer A, formulation without coating
Sample 2 = Light grey, plasticizer B, formulation without coating
Sample 3 = Light grey, plasticizer C, formulation without coating
Sample 4 = Light grey, plasticizer A, formulation + Double sided coating 5µm
Sample 5 = Light grey, plasticizer A, formulation + Double sided coating 15µm
Sample 6 = Light grey, plasticizer C, formulation + Double sided coating 15µm

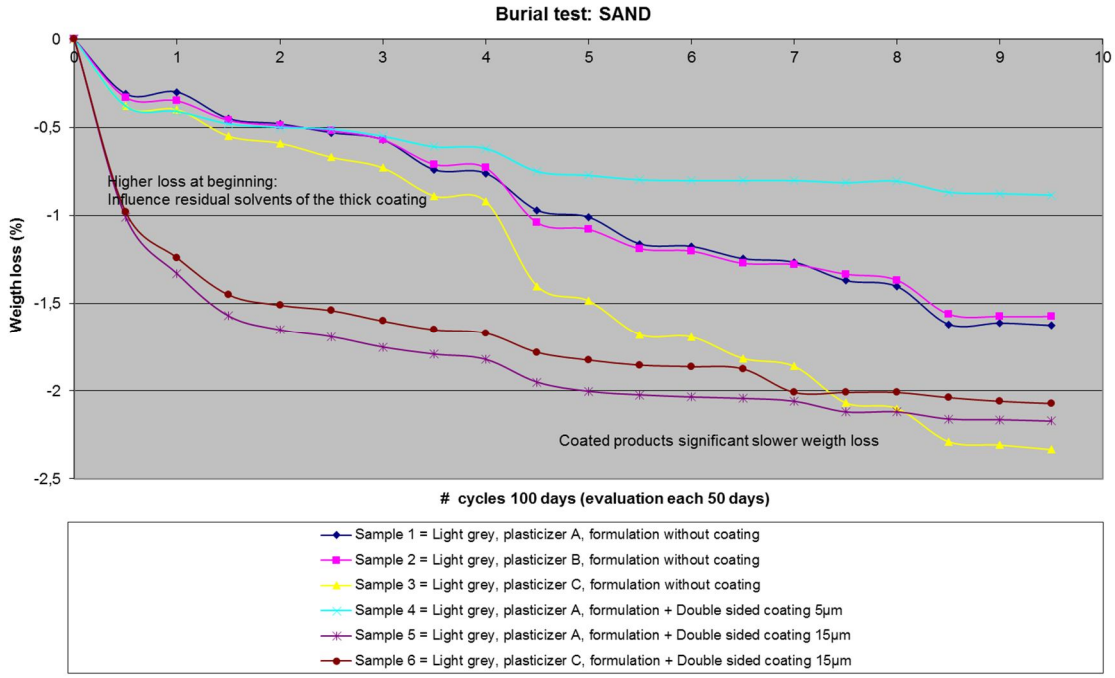

Figure 3. Humid/dry sand burial test.

In Figure 3, it is important to analyse the slope of the lines because that slope indicates the speed of the plasticizer loss. It can be appreciated how formulations without coating present a higher slope in the weight loss line, that means, that these samples lose in the same time more weight and more quickly than formulations with coating. Samples 5 and 6 show a steep slope at the beginning as consequence of the high and quick loss of residual solvents of the thick coating. After that period, these lines show the same gentle slope as the sample with the thinner coating (sample 4). One notices how the coating especially improves the performance of the sample with the least permanent plasticizer (plasticizer C).

3.2 *Active Soil burial test*

Active Soil burial test is an indicative of the geomembrane resistance against microorganisms. The test was carried out during 1 year with evaluations of the weight loss of the samples at 2, 4, 6 and 12 months. The composition of the active earth is 1/3 sand, 1/3 potting compost and 1/3 dried cow manure. Samples are vertically and fully buried in active earth (UNE-EN 12225:2001).
Formulations:
Sample 1 = fungicide, without coating
Sample 2 = fungicide + 5µm coating
Sample 3 = no fungicide, without coating
Sample 4 = no fungicide + 5µm coating

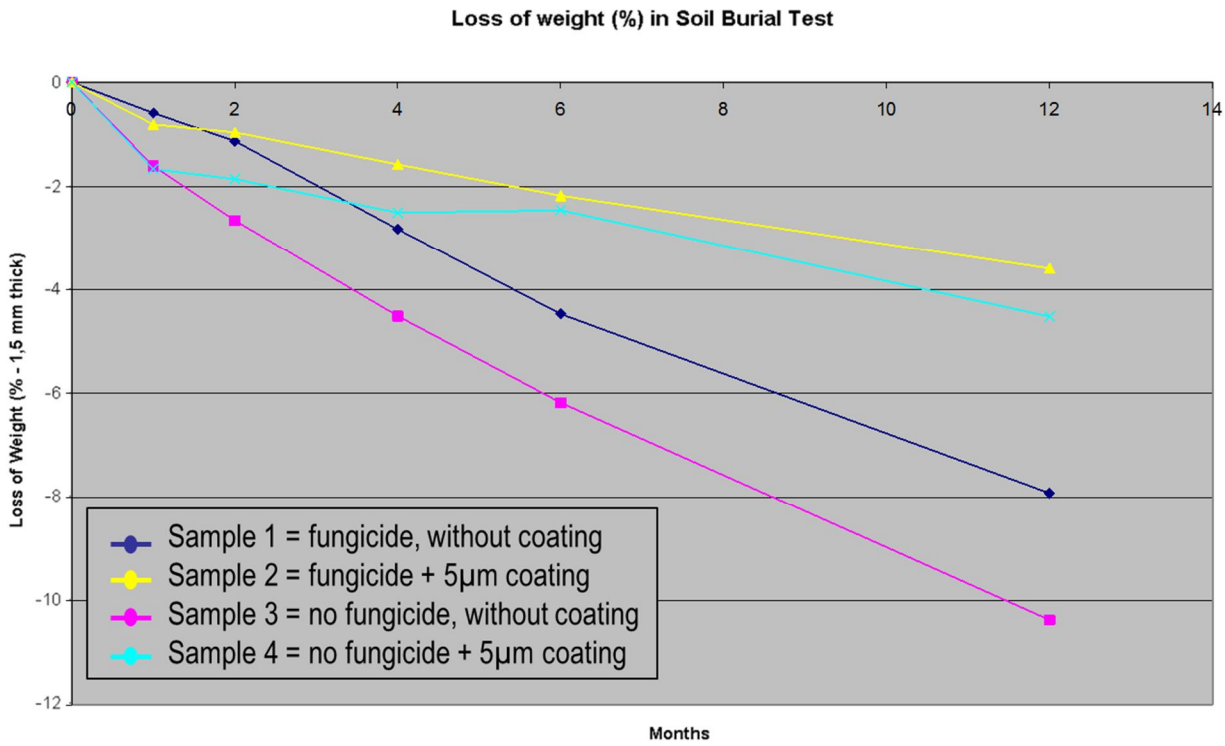

Figure 4. Active soil burial test.

In Figure 4, it can be observed how samples with coating have a higher resistance against microorganisms, their weight loss is significantly lower than samples without coating even with fungicide in their formulation (sample 3).

3.3 *Accelerated UV ageing test: 2SUN programme*

Accelerated UV ageing tests were developed to evaluate the deterioration caused by UV radiation in a shorter time and under controlled conditions (ISO 4892-2: 2013). 2SUN programme was developed to accelerate more the samples ageing.
The test were carried out in an Xenon arc device ATLAS ci 5000, with Borosilicate "S" type lamp filters inside & outside, and under an irradiance of 340 nm (1 W/m².nm (115 W/m² 300-400 nm)). Room Temperature is 45°C, Black Standard temperature 88° and Relative Humidity 40% in the dry period. Exposure cycle consist in 102 minutes 'dry' follow by 18 minutes cycle of deionized water spray (high humidity).
Rough correlation of this acceleration is that 1000 hours in 2SUN are equivalent to 2 years in Central Europe climate and 1.4 years in South Europe.
Samples (145 mm length x 35 mm width) are evaluated at 500, 1000, 2000, 3000… hours,
That evaluation consist in the measure of the weight loss (%), the colour change (DE*) and the observation of surface cracking.
Next study shows the favourable effect of a coating in the UV aging test after 7000 hours of exposure. Studied samples were light grey and dark grey formulation for Central Europe with and without coating. The comparison has been made for each colour:
Renolit Light grey without coating, 2,7 mm
Renolit Light grey + coating 5µm, 2,1 mm
Renolit Dark grey without coating, 2,5 mm
Renolit Dark grey + coating 5µm, 2,2 mm

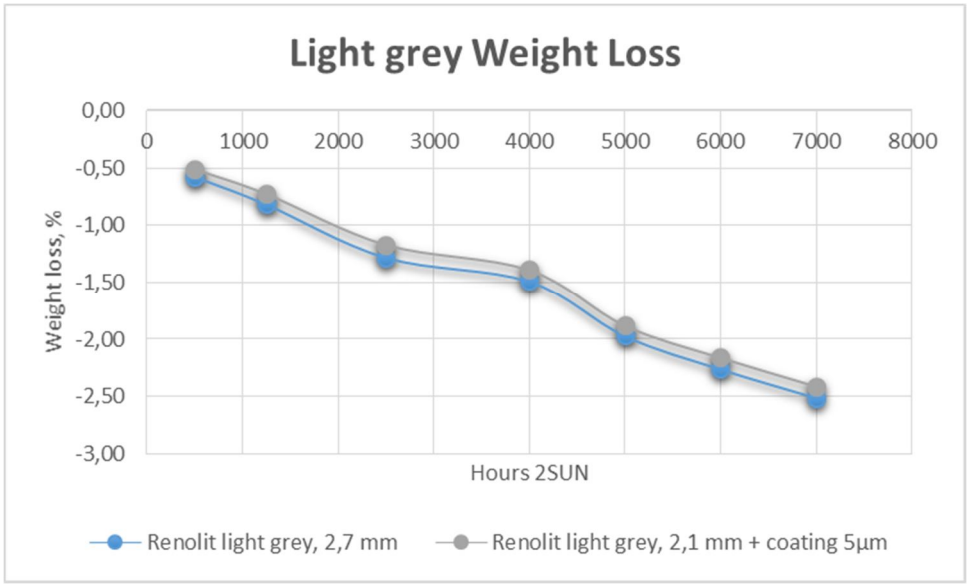

Figure 5. Light grey samples weight loss at 7000h of 2SUN exposure.

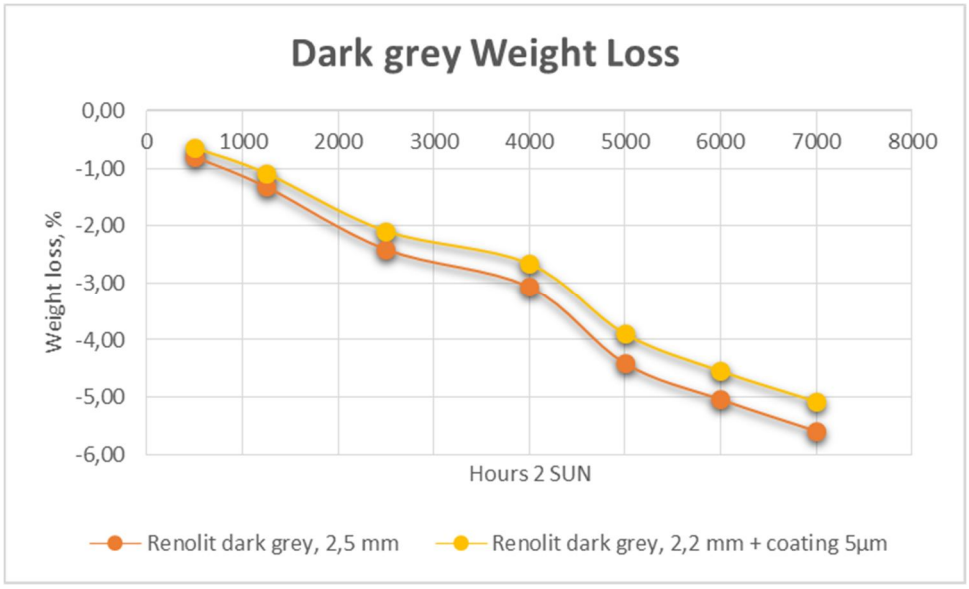

Figure 6. Dark grey samples weight loss at 7000h of 2SUN exposure.

In this case, samples with and without coating have the same bulk formulation, but thickness is different, so, it will be necessary to take into account this issue. After 7000h of exposure, there are no superficial cracks in any of the samples and colour change is not significant.
In Figures 5 and 6 it can be observed how a coating acts as a protection against UV radiation, in both cases weight loss of coated samples is lower than weight loss of samples without coating. Besides, thickness is fewer in the coated samples, with 0.6 mm of difference in light grey samples, and 0.3 in dark grey samples, therefore, the difference on the performance would be much higher with same thickness in all samples.

4 PIGMENTED COATING

In a geomembrane composition, there are some additives whose function is to avoid the degradation. UV absorbers and antioxidants are the most important. Some pigments are between the best UV absorbers we can find. It is well know that carbon black and TiO2 are used as UV protection of geomembranes long ago. The amount of TiO2 in a geomembrane has a noticeable effect in the geomembrane ageing, and higher quantities increase the durability.

However, these pigments are inorganic substances and they act like filler inside the plastic matrix too, so, big quantities affect negatively the mechanical properties of the final material. Therefore, the amount of these additives in the bulk must be limited.
The geomembrane surface receives directly the UV radiation and it has been proved that a coating provides the geomembrane with a better protection, so, if pigments can be added to the coating, the geomembrane will be even more protected.

4.1 *Transparent coating vs pigmented coating*

A pigmented coating would provide the best protection to the geomembrane, reducing plasticizers loss and giving a high UV protection.
The next study presents the improvement of a pigmented white coating with respect to a transparent coating.
Test performed is EMMAQUA (Equatorial Mount with Mirrors for Acceleration with Water), a Natural Ageing test but accelerated by the action of mirrors that reflect the sunlight over the samples, increasing the levels of irradiance and temperature. A controlled amount of moisture is provided by spraying water over the samples. The test was carried out in the ATLAS experimental field located in New River, Arizona. (ASTM G90-10, ASTM D4364-13).
Tested samples were two white PVC-P roofing geomembranes 2.5 mm thick, one with a 5µ of transparent coating and the other with 5µ of a white coating (TiO_2).
Samples were sent to Arizona mounted on aluminium plates, and returned without evaluation, at 6, 12, 18 and 24 months of exposure, respectively. Evaluations were made in Renolit laboratory. As rough correlation, 6 months EMMAQUA are equivalent to 6.5 years in Central Europe and 4.5 years in South Europe climates.
Figures 7 and 8 show the photographs obtained by TEM microscopy of the geomembranes' surface before exposure and after 12, 18 and 24 months of exposure.
The transparent coating (Figure 7), is degraded after 18 months in EMMAQUA exposure. After that time zones without the coating layer and zones with deep cracks in the coating can be observed. After 24 months cracks are observed on the foil too. So, durability of the transparent coating is maximum 18 months in EMMAQUA.
However, white coating starts the degradation after 24 months of exposure. It is after that time when zones without coating, or with deep crack in it and in the foil, appear. Therefore, the durability of the white coating is minimum 24 month of exposure in EMMAQUA.

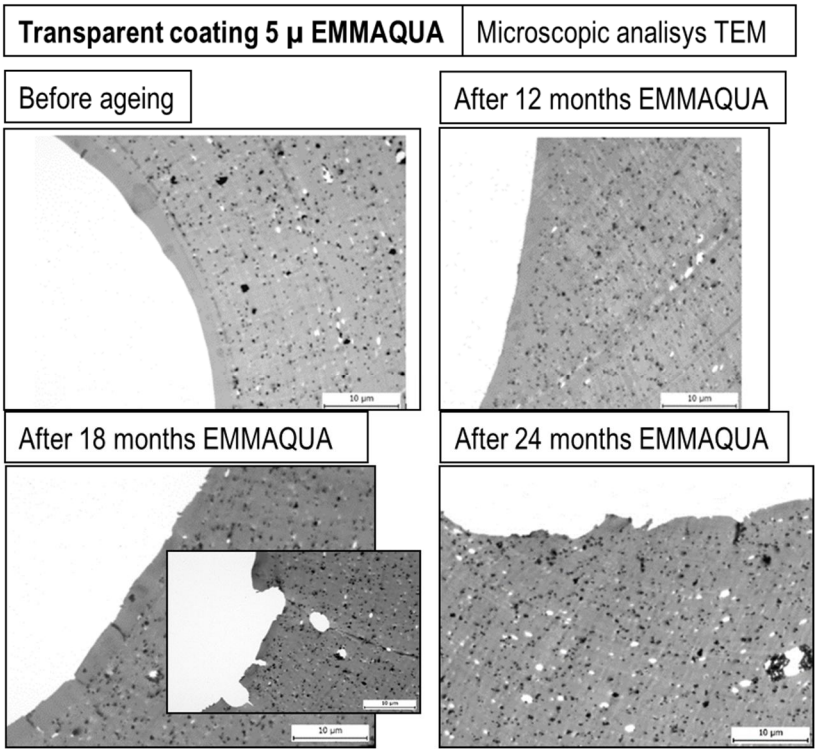

Figure 7. TEM photographs of transparent coating sample. EMMAQUA exposure.

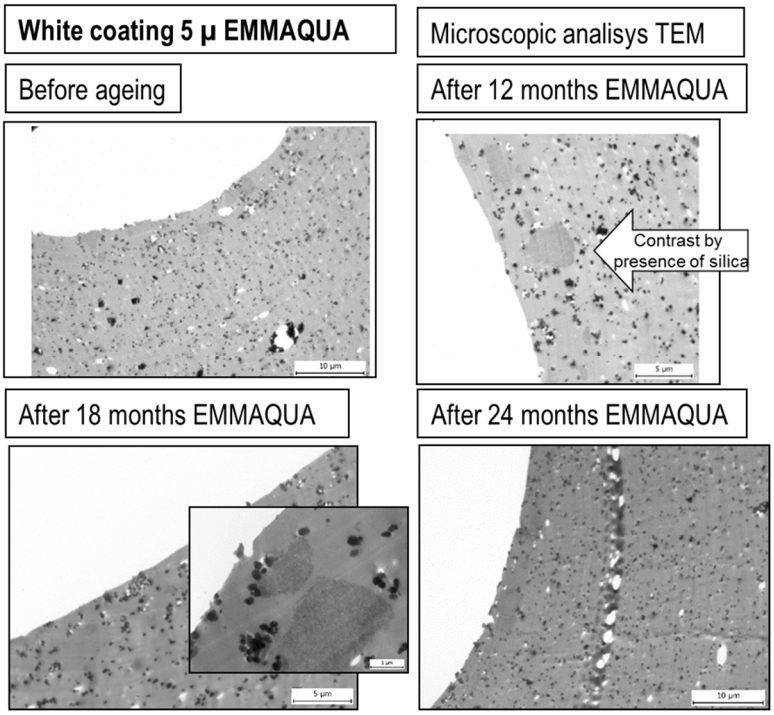

Figure 8. TEM photographs of white coating sample. EMMAQUA exposure.

4.2 *Pigments in the coating*

In the last study, samples with the same formulation and same thickness, blue swimming pool samples 1.5 mm thick, were coated with a white coating with different quantity of TiO_2 pigment each and exposed in 2SUN programme, at present time for 6000 hours. Test keeps running.
Figures 9 and 10 present the weight loss and the colour change of the samples. In both cases, the favourable effect of the pigment in function of its increasing quantity can be observed.

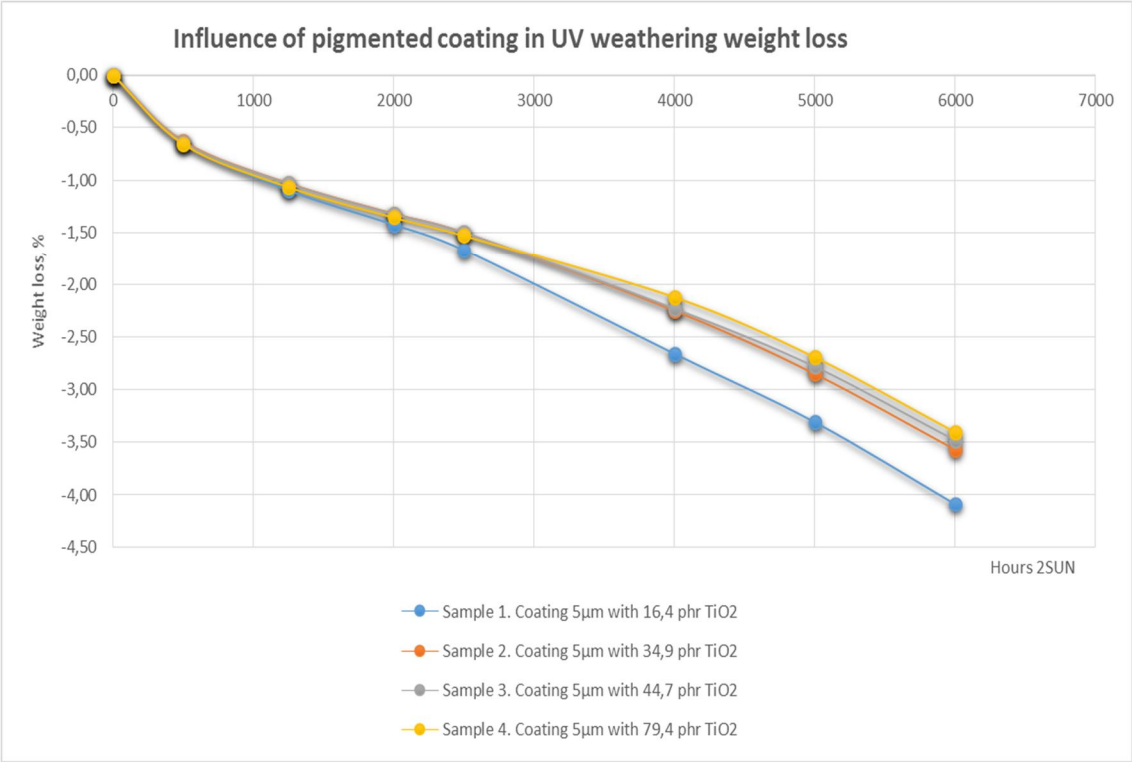

Figure 9. Weight loss at 6000h of 2SUN exposure.

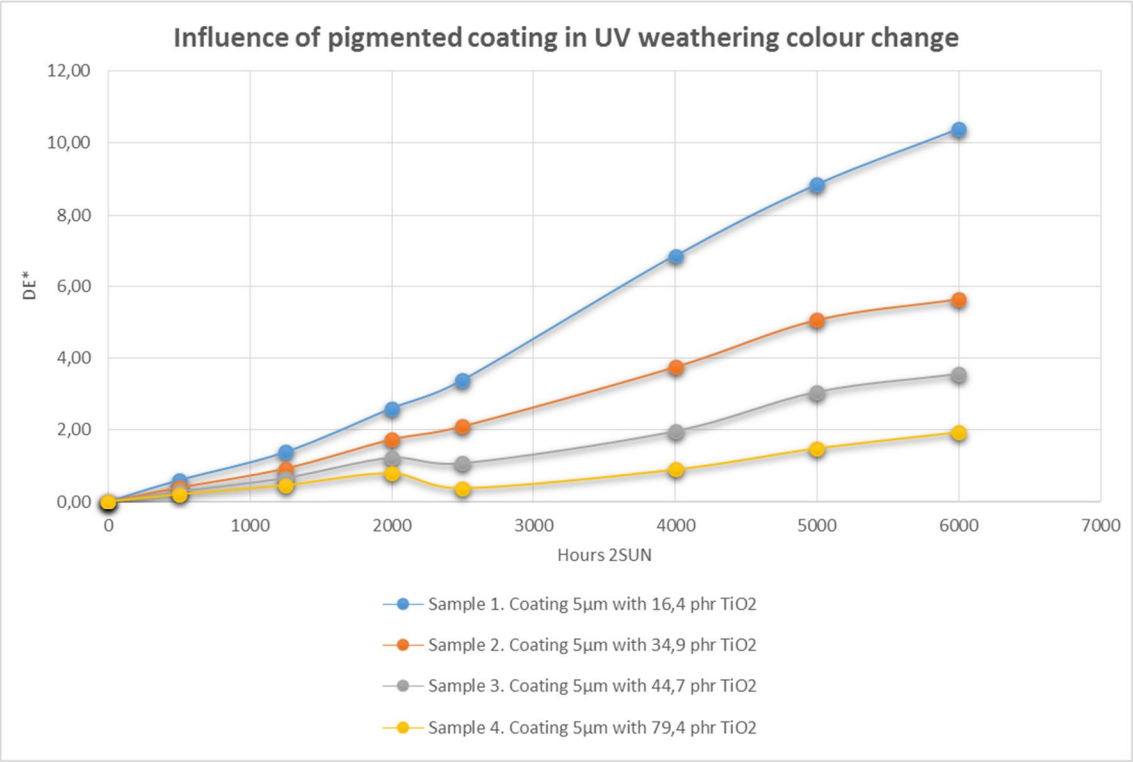

Figure 10. Colour change at 6000h of 2SUN exposure.

5 CONCLUSIONS

In this paper have been presented several durability studies; from their results it can be concluded that:

1. It is confirmed that the thickness has a decisive influence in the geomembrane durability. A thicker geomembrane will have a higher durability respect to a thinner one with the same formulation.
2. A coating acts as a barrier against plasticizer loss and microorganisms, so the loss of weight with the time due to these effects is slower by the protection given for that coating.
3. A coating increase the UV resistance of the geomembrane surface, so, a thinner geomembrane with a coating has a better performance than a thicker geomembrane without coating.
4. Pigments are UV absorbers that delay the action of the radiation over the geomembrane.
5. A pigmented coating can concentrate a big quantity of these additives on the geomembrane surface increasing noticeably the UV protection as well as having the benefits of the barrier effect.

In conclusion, durability of exposed PVC-P geomembranes can be increased by adding a pigmented coating. The barrier effect against plasticizer loss and microorganisms together with the high UV protection, thanks to the elevated content of pigments that coating provide to the geomembrane surface, maintain the good properties of the geomembrane for more time, delaying the ageing process. Specific conditions of each project determinate the selection of the geomembrane thickness, but, whatever it was, the addition of a pigmented coating will provide a better protection against PVC-P degradation. Durability will be increased, and therefore the service life of the geomembrane will be increased.

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